

Principle of 6G Wireless Networks: Vision, Challenges and Applications

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Abstract

The 5G mobile communication has now become commercially available. Furthermore, research across the globe has begun to improve the system beyond 5G and it is anticipated that 6G will deliver higher quality services and energy efficiency than 5G. The mobile network architecture needs to be redesigned to meet the requirements of the future. In the wake of the commercial rollout of the 5G model, both users and developers have realized the limitations of the system when compared to the system's original premise of being able to support the vast applications of connected devices. The article discusses the related technologies that can contribute to a robust and seamless network service. An upheaval in the use of vast mobile applications, especially those powered and managed by AI, has opened the doors to discussion on how mobile communication will evolve in the future. 6G is expected to go beyond being merely a mobile internet service provider to support the omnipresent AI services that will form the rock bed of end-to-end connected network-based devices. Moreover, the technologies that support 6G services and comprehensive research that enables this level of technical prowess have also been identified here. This paper presents a collective wide-angle vision that will facilitate a better understanding of the features of the 6G system.

Keywords: 5G, 6G, Antenna, Handover, Internet of Things (IoT), URLLC, Mobile Communication, terahertz (THz), Radio Frequency (RF), massive connectivity, Internet of Everything (IoE)

1. Introduction

Having standardized 5G, commercial user programs for deploying 5G wireless networks have been underway since 2019. 5G wireless networks represent a new digital society that has achieved substantial advancements in quantifiable terms, such as latency, data rates,

mobility at various speeds, and smart connected devices, in comparison to its predecessor generations. Based on available historical data of the evolution in mobile communications, it can be inferred that it takes roughly a decade from the conception of the idea to its commercial availability; moreover, its relevant use typically extends for another ten years. Now that 5G has reached the stage of commercial availability, it is appropriate for its successor, i.e., 6G, to be released at this time.

Finland has launched its 6Genesis Flagship program, an eight-year comprehensive program with an estimated cost of \$290 million to build an advanced 6G ecosystem. Mobile communication has become a major part of our lives and the world is beginning to realize its importance. The user experience has been significantly improved with every successive generation from 2G, 3G, 4G, and now 5G. So far, the evolution of wireless networks has mainly been driven by demands for higher data rates, which is translated into higher network capacities. As the market is expected to grow exponentially, the new age applications of the connected devices, bridging millions of users and devices, result in the astounding shift from traditional enhanced Mobile Broadband services (eMBB) to Ultra-Reliable Low Latency Communications (URLLC). 5G's primary objective to become the actual carrier of connected devices for end-user services was not realized during the development of the 5G system as a key contributor to IoE through the standardization of 5G, which eventually led to 5G New Radio (5G NR).

Over the developmental years, eMBB services have seen significant improvements in their ability to sustain high demand. However, the actual goal of 5G is yet to reach the point where it can support a wide range of wireless devices capable of operating at high-frequency millimeter-wave frequencies (mmWave).

2. Understanding Trends in 5G

Compared to previous mobile communication generations 5G is expected to become an improved version. One of the primary objectives that 5G was supposed to attain was the interconnection of everything (IoE). IoE may only be the primitive niche of 5G technologies; hence lot of issues are not being calculated at the moment. Large scale adoption and integration of IoE devices and peripherals is complex to implement and there is a need to consider that these are difficult to implement in short-term and takes long time to build robust system. IoE integration could be an early idea for 5G mobile communication application but could be a

resolved and implemented better in 6G mobile communication applications. This could be another motivation for research to move from 5G to 6G [9].

2.1 Wireless Technologies for 5G

2.1.1. Adaptive Modulation and Coding

In the Adaptive Modulation and Coding system, the modulation order, method for coding and rate of coding of symbols to enhance the summation of transmission is dynamically calibrated. This is done since the through-put of the OFDM system is associated with the modulation system, bit error rate and the coding method. Usually, the target error rate can be manually set [8, 13].

2.1.2. mm-Wave communication

With such a growth in mobile traffic requirement, the congestion around the spectrum limitations and capabilities has become progressively obvious. The border of wireless bandwidth has become a concern for fifth generation telecom services. As a conservative estimation, the mmWave with large wavelengths ranging from 30GHz to 300GHz are being advised for multi-gigabit communication systems. This is expected to contribute towards the general adoption of applications of HDTV and UHD TV [9, 14].

2.2.3. Massive MIMO

The fifth-generation new radio (5G NR) has taken it to a whole new paradigm. This includes the notion of massive MIMO which by definition has involvement of MIMO system on a bigger magnitude for wider network coverage and capability. The massive MIMO is made up of several more transmitter and receiver antennas to further intensify the transmission gain and spectral effectiveness. In order to attain massive MIMO like capacity gain, UEs with higher manifold is needed to generate downlink passage concurrently [1, 15].

2.2 Network Technologies for 5G

2.2.1. 5G Network Slicing

This method of networking can be understood as a configuration that means, which puts multiple networks which are virtually independent, realized on an upper layer of traditionally available infrastructure. This means that configuration alone has the competence to become so

vital in realization of a 5G landscape. Individual portion of the network can be distributed to the specific requirement of the subscriber [1, 16].

2.2.2. Mobile Edge-Computation (MEC)

Edge computing alone has the capability to revolutionize the entire performance of the applications and mediate extensive loads of data which require accurate real-time processing. Given the scenario; 5G and edge computing are mutually entangled. 5G has improved the existing speeds of 4G by ten times whereas, edge computing has facilitated the reduction in latency and making computation capabilities available into the network which is local to the user [3, 17].

2.3 Challenging Technical indicators of 5G

There are certain challenges which are required to be addressed. These include issues related to the GBPS data-rate of Enhanced Mobile Broadband (eMBB), interference in atmosphere, time lag in Ultra – Reliable Low Latency Communication (URLLC), one million connections per square kilometer ($1M/km^2$) of Massive Machine Type Communication (mMTC). Queries to be addressed are: What are the actual demands of the future? What kind of concerns will the industries face? What will the industrial ecology actually look like? [8, 18]

3. Emergence of 6G

Higher data rate for mobile broadband is important in the case where there is a situational demand to transmit data at higher volumes. In such instances the concern shifts towards reliability over higher speed because the required signals could be retransmitted in small packets even if data is lost. In examples such as High-Definition video streaming, user can wait to deal with buffering in mobile devices.

However, if the connectivity is in between critical devices, there will be a requirement of system with high reliability and low latency. For example, in applications such as autonomous driving, robotic surgery, autonomous space vehicles etc.

Furthermore, if a network was built with capability of delivering high data rates, manufacturer/user can chose not to be efficient and still get required decent data rate. And if higher reliability is needed, then data rate could be traded away, and hence, the message could be repeated multiple times. Therefore, the resultant was a redundancy, lower data rate but

increased reliability. A lot of IoT devices that do not transmit high volumes of data, involves in just measuring small data points from sensors/computers. In such devices, higher battery life is required. Hence, transmission efficiency can be traded off to improve energy efficiency [1].

Table 1. Comparison between parameters [3]

Parameter	5G	6G
Traffic density	10 Tb/sec/sq-km	> 100 Tb/sec/sq-km
User Experience data rate	>1Gb/s	>10Gb/s
Connection Density	1 million/km ²	10 million/km ²
Delay	ms level	<1ms
Positioning precision	Meter level	Centimeter level
Receiver Sensitivity	About -120dBm	<-130dBm

3.1 Need of 6G

As discussed above, 5G technology has its own sets of applications with limitations. The successor 6G is expected to solve these limitations. One major issue with 5G communication network is network coverage among the devices; 6G will be vital in addressing this specific problem.

User perception of different generations of communications network:

- i) 1G and 2G: voice and text.
- ii) 3G and 4G: picture and video became common place.
- iii) 5G: Live ultra-HD 3D data can be employed.
- iv) 6G: It is expected that the user would have ubiquitous (widely available) virtual existence.

At present, due to cost and technological limitations there exists coverage of only 20% of global land surface area and lesser than 6% the entire earth's total surface area under the available mobile communication network. User volumes of 2G, 3G, 4G terrestrial mobile

communication network is expected to be nearly 70% of the global population. In order to look towards future, to make an infrastructure of connected devices, there is an increase in urgency to cover and connect every corner accessible [2, 19].

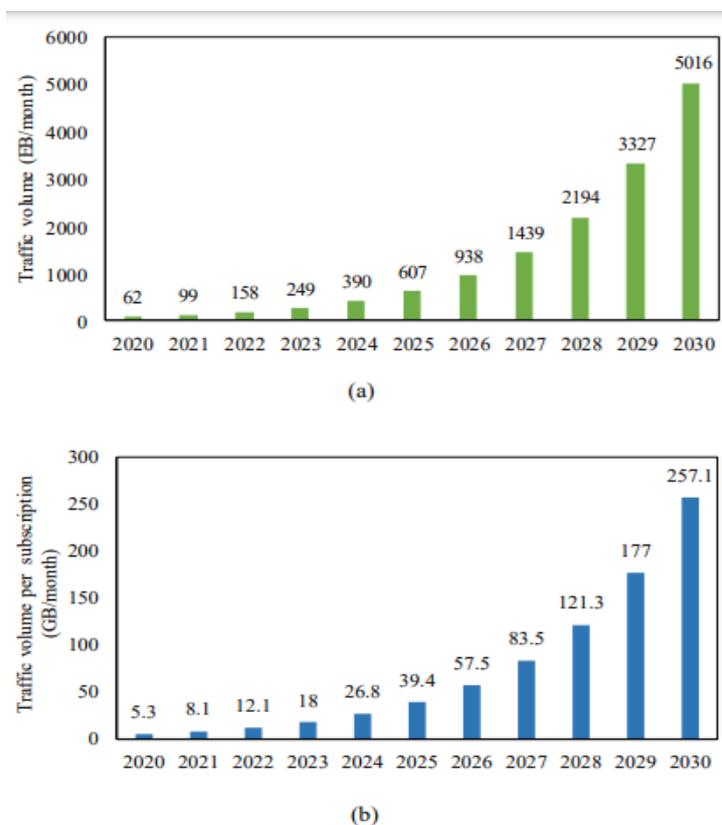


Figure 1. Global mobile connectivity is predicted to grow during the period 2020-2030 [1]

(a) Summation of global volume, (b) Traffic volume per user subscription

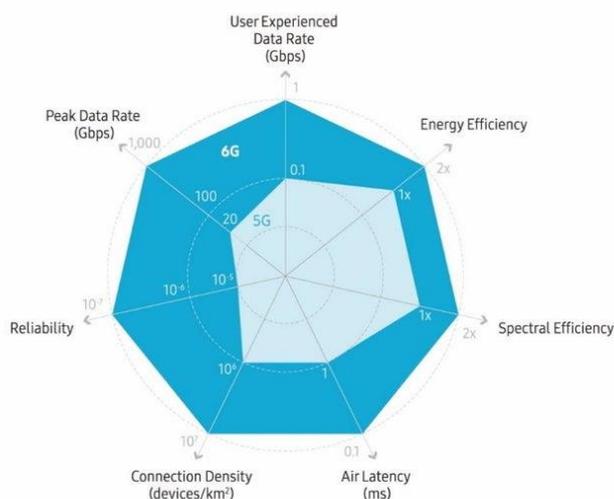


Figure 2. Spider diagram showing user requirement for 6G [2]

3.2 Proposed architecture for 6G

- (a) sCELL - AP: Small Cell Access Points
- (b) BCI: Brain Computer Interface
- (c) UAV: Unmanned Ariel Vehicle
- (d) M-UE: Macro-cellular User Equipment
- (e) sCELL - UE: Small Cell Use Equipment
- (f) M2H: Machine to Human
- (g) VLC: Visible Light Communication
- (h) M2M: Machine to Machine
- (i) M-UE: Macro-cellular User Equipment
- (j) VLC: Visible Light Communication
- (k) SDN: Software Defined Networking
- (l) UM-MIMO BS: Ultra Massive MIMO Base Station

It is difficult when there has been a need to process such a vast and diverse nature of data sets under human intervention. Therefore, a robust system of Artificial Intelligence and Machine Learning is required to make machines self-dependent. First major step would be that the devices need to be automated and on further iterative developments, the devices would be able to think for themselves unsupervised [6].

3.3 Expectations and Applications of 6G

At present 5G has shown promising capabilities. However the research has begun to look beyond 2030, i.e., 6G. 6G would support Ubiquitous Intelligent Mobile Society (UIMS) accommodating intelligent life and industrial applications, support speedy moving devices and cater as interconnection among the peripheral devices, and capable of handling data rates of TBPS and GBPS. The system would have upgraded and expanded spectrum capable of achieving 10x to 100x higher data rate, higher system capacity, higher spectrum efficiency, lower latency, with wider and deeper coverage.

Ubiquitous and Integrated Network (UIN) will enable wider and comprehensive coverage including satellite communication, terrestrial communication and device to device communication in short-range. Intelligent Mobility Management Technology (IMMT) would be able to provide in wide arena of environment such as aero-space, terrestrial and sea/oceans, realizing global Ubiquitous Mobile Broadband Communication-systems.

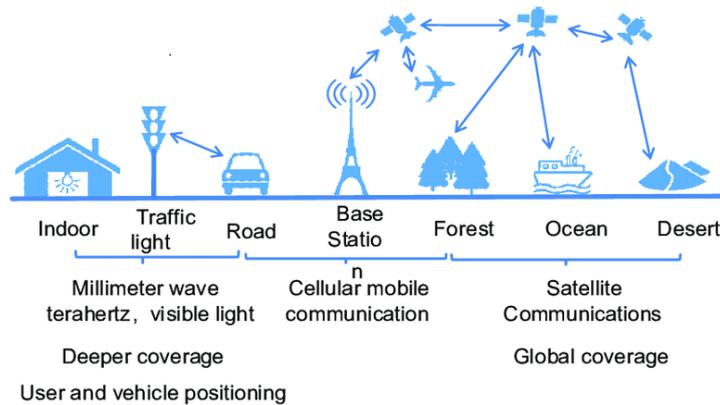


Figure 3. Representation of various methods to enhance network coverage [3]

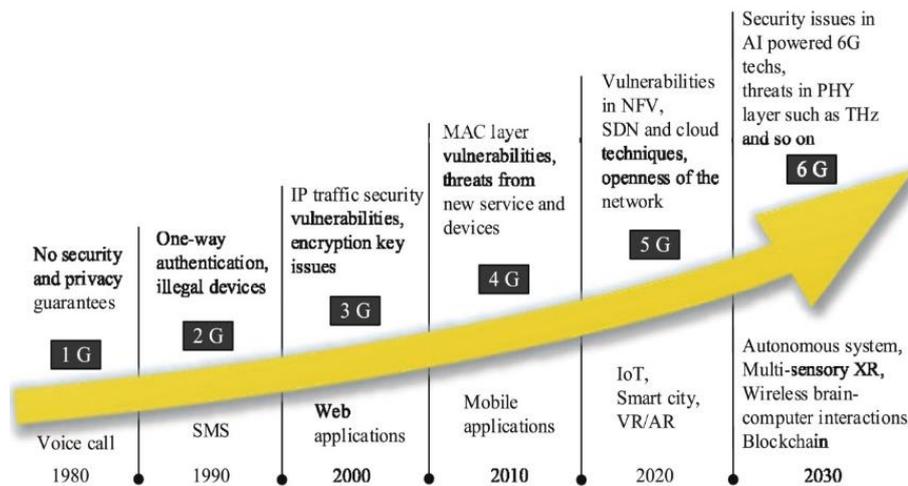


Figure 4. Evolution in wireless systems [4]

6G would work on a higher prescribed frequency to achieve a spacious bandwidth, i.e., mm-wave, THz and visible light. Utilizing the flexible frequency sharing method further boosts the efficiency of frequency-reuse capability. Personalized intelligent network powered by AI will make it possible to enable virtualized mobile communication.

This would translate into the competence like self-awareness, real-time dynamic analysis, adaptive risk and confidence evaluation; that would further help realize the cyber-space security target [1].

3.4 Applications of 6G:

One of the main reasons to develop infrastructure for high data rate and low latency system is extensive adoption and development of AR, VR and extended reality-based applications. Further, holographic communication which includes digital twins, 3D hologram over mobile devices, personnel monitoring, and drone-based delivery consignment system, internet of robots and wireless brain-computer interactions are more advanced applications [1].

- i) eMBB plus provides strong platform for high-quality conventional mobile commitment and the BigCom supports fundamental arena of communications for far reached-remote locations.
- ii) SUBLLC in 6G is a combination upgrade combining URLLC and mMTC of 5G with higher expectations of real feasibility.
- iii) 3D – inter-com raises the bar of the network optimization and planning dimension.
- iv) UCDC offers the possibility of incorporating new communication prototypes and standards.

4. TRENDS AND CHALLENGES OF 6G

Below are mentioned the key aspects for 6G communication:

- i) The new resource and utilization methods of the spectrum: THz and visible light frequency-band, intelligent-spectrum sharing and cognitive- radio systems.
- ii) New methods of resource for modulation: OAM (Orbital Angular Momentum).
- iii) New Core network: 3D architecture and intelligent-mobility management.
- iv) Expansion of coverage territory: the harmonious integration of terrestrial and satellite mobile communication.
- v) Increasing the system's capacity: de-cellular and user centric UDN
- vi) Adding capabilities: computing and integrated AI

With such requirement in the list, the existing system would not be enough and the implementation of 6G would require new modulation techniques. For example, Orbital Angular Momentum (OAM) and massive MIMO [6].

4.1 Extending of Coverage: Integration of terrestrial and satellite mobile communication

As discussed earlier, wide area coverage in inaccessible areas is a major challenge. Therefore, adoption of Satellite Mobile Communication would help us achieve wide coverage at low cost. 6G would facilitate integration of surface-based wireless-communication Medium-Earth Orbit (MEO) and Low Earth Orbit (LEO) satellite mobile communication and short-range unbroken communication methodologies into the mobile system [3].

Major challenges would be challenges related to Doppler shift, Doppler variation and large transmission delay. A new challenge that would be encountered is designing new core-network architecture and mobility-management because, sometimes the system could be terrestrial bound and sometimes satellite bound. The challenges related to Inter-Satellite Link (ISL) also require proper attention. At present, there exists different communication protocols for terrestrial and satellite communication, and therefore need to find reliable methods to establish interoperability.

Major factors	Satellite mobile communication	Terrestrial mobile communication
Link type	Including service link and feeder link	Service link only
Transmission distance	Above 600km	About 1 km
Transmission delay	Tens to hundreds millisecond	us to ms level
Frequency	Usually high frequency band like Ku, Ka, Q, etc	Usually low frequency band below 6GHz
Path loss	Often above 180 dB	Usually within 140 dB
Doppler shift	Up to several hundred KHz	Usually within KHz level
Cell Radius	Often several hundred km	Usually 300–500 m
Mobility	Frequently happen, including inter-beams (inter-cells), inter-satellites, inter-gateways.	Inter-cells only
Requirements for PAPR	Strictly low PAPR to avoid power waste	Low PAPR
Frequency reuse	Different frequencies with reuse factor 4,8, etc.	Same frequency with reuse factor 1.

Figure 5. Comparison between terrestrial and satellite mobile communication systems [3]

In order to mitigate problem where line of sight does not exist, the manufacturers can make use of Reconfigurable Intelligent Surfaces (RIS). It can be done by building an array of small passive elements where each one of them would reflect the signal, depending upon the reflection coefficient, which is determined by physical properties like impedance of surface.

The material could be connected to a controlling switch that can change its impedance values. And hence the capability to control the direction of the transmitted signal could be attained. No additional radio energy would be required, rather only changing the physical properties of the reflecting surface [3].

4.2 Capability Enhancement

The use of high frequency band eliminates the scarcity of spectrum capacity constraints of the presently available wireless-communication systems. The recommended frequency range of Terahertz band is suggested as 0.1 THz to 10 THz; and that for visible-band of light is between 400 THz to 800 THz. There are two recommended THz system of communication:

- i) Solid-State Terahertz Communication System: It is built across the mechanism of mixing.
- ii) Spatial Direct-Modulation: The modulated baseband signals are readily linked into an ongoing terahertz carrier-wave.

The Terahertz communication can find its applications in the local indoor wireless mobile networks which can support holographic video-conferencing and virtual-reality, nano-scale communication network for systems responsible for health-monitoring with help from nano-mechanics, and space communication networks like the inner satellite-communication and near space-communication.

Since this is in its nascent phase, the challenges that one would face is design and manufacture of THz frequency hardware components, channel modeling and estimation, and bandwidth enhancement and estimation [1].

4.2.1 Cognitive Radio

Cognitive Radio (CR) allows multiple wireless systems to share portions with the identical spectrum which was achieved by making use of the spectrum sensing and systematic interference management methods. Intelligent Symbiotic Radio (SR) is a proven robust available means. SR's diverse sub-systems of a miscellaneous wireless communication system meticulously operate with each other to make a symbiosis of beneficiary transmission system and efficient enough sharing of the available resources. It shares goals to magnify the performance of the combined communication system with help from intelligent inter-subsystem management. And then allows various other wireless systems to share the one and

the same bandwidth of spectrum by employing spectrum detecting and interference handling methods [6].

AI could mitigate and restrict collision by previously predicting the spectrum-usage of the other subscribers within a limited amount of information exchanged. The system could learn and then predict how users can access the spectrum and distribute the spectrum among the service providers accordingly.

4.2.2 Orbital Angular Momentum (OAM)

The building blocks of current wireless communication are raised on a traditional plane. But the electromagnetic (PE) waves not only have linear momentum but also have angular momentum. Therefore, alternatives of EM waves are required. One of the promising methods would be Orbital Angular Momentum (OAM) multiplexing. Spacing of OAM has a greater number of topological changes. Various OAM modes are orthogonal with respect to each other; those can be multiplexed and demultiplexed with one another by all new ways for capacity enhancement management in 6G, the successive wireless communications network. With the OAM, higher order spatial multiplexing can be accommodated in the ecosystem where it is not feasible with the conventional design based on MIMO, i.e., LOS channel system [5].

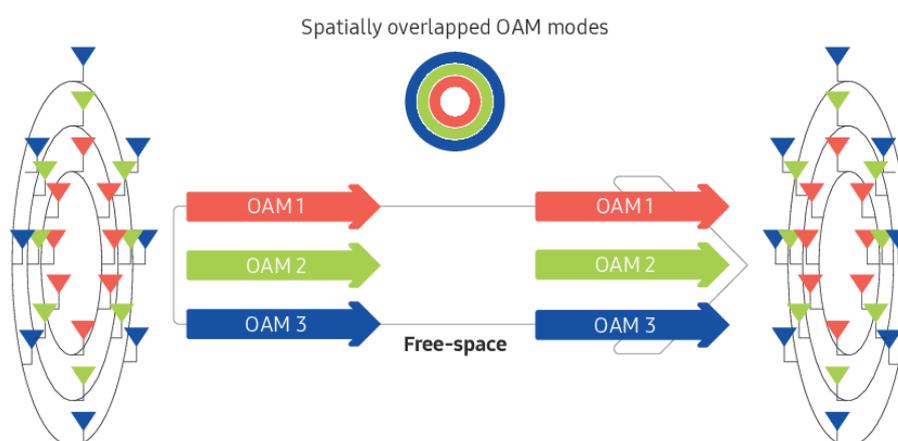


Figure 6. Spatially overlapped OAM modes [5]

The major challenges involved with the implementation of OAM are beam divergence and transceiver misalignment (OAM is phase sensitive).

4.2.3 DeCellular and UUDN

When compared with the previous fifth generation, the wireless coverage vicinity of 6G base station or access point is marginally smaller. It is practically not possible for a cell to

split so many times and hence this limitation of the system's capacity which needs further improvement. A User centric Ultra Dense Network (UUDN) could check for wireless network with density which is comparable with the access points and mean of users. Moreover, DeCellular and UUDN are feasible for greater frequency bands such as millimeter wave, THz and visible light band.

Some common challenges to this model are issues regarding network architecture, mobility management, interference management, and resource and security management [7].

4.2.4. Computation and Integration of AI

AI could help to build means for extending coverage, meet diverse requirement, process the acquired user's data, help to interconnect wide volumes of peripheral equipments from various theaters of atmosphere, upper-space, surface and sea/ocean, and provide unhindered service quality. However, challenges include collaboration of intelligence and computation power among different cloud service provider and hardware constraints.

While developing 5G, there was an increase in requirement to change computing capability location local to the mobile user devices. This could be done by re-positioning of multiple-access edge computing servers of 5G core systems or in the base station. By adopting the combined package of above-mentioned methods, the overall latency and other glitches experienced by the end user could be mitigated further [10, 11].

Further 6G technology should be engineered to achieve actual umbrella of coverage for communications and computations so that the end subscriber device can utilize computer power available in the network without any friction.

Via this method which allows Split Computing of mobile devices, can very efficiently achieve larger leaps in performance as well as extend their battery stamina. These devices would be able to shed the heavy loads of computation calculations to computation resources available in the network.

While there exists a feature to split the computation capability, there is also a need to develop an integrated system with compatible protocols. AI network nested with the network nodes of the branches of terrestrial system and network nodes of a satellite system would enable intelligent mobility management, better and reliable network resource utilization and protocol inter-operability [12].

5. Conclusion

New and exciting features are added to communications systems with each successive generation. There are many impressive features of 5G communication. Nonetheless, 5G will not be able to handle all the demands in the wireless communication industry by 2030. The adoption of 6G is therefore necessary. The paper presents a perspective on current and future research and development efforts aimed at enabling the next generation of wireless communication networks, and it outlines their key enabling techniques. The various technologies that can be used to communicate over 6G have also been clarified, as well as the vision and goal for 6G. Ultimately, 6G will be able to provide uber smart society with peripherals connected to the branched as well as single networks, with improved network performance, integration of different technologies, and improved QoS. Additionally, this paper presents the main challenges faced by 6G technologies.

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