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Explore the Technological Advancements that will Shape the Future of 6G Networks

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Abstract: ***The fifth generation, or 5G, mobile communication has been increasing steadily in most countries which mean that their market share is already very large. Thus, it is time for academia and industry to start thinking about the sixth generation (6G) of phones. The next world-changing technology will certainly be a topic of interest so an overview of what current technology is like and what future developments might occur would be very interesting.***
This research paper tries to provide a comprehensive understanding of what 6G might look like, what would be its technology requirements, what would be its use case scenarios, and what development has been made so far in this field. We will begin by trying to answer the question, "Do we really want 6G. To answer this question, we'll look at the reasons why we're looking forward to 6G. Next, we'll look at the potential use cases of 6G, and all the new features that it will bring to the table. And lastly, we'll look at its technological requirements.
Keywords: Internet of Things, Quality of Service, International Mobile Telecommunications, Integrated access and backhaul, enhanced mobile intelligence.

I. INTRODUCTION

The mobile telecommunication started with 1G or first generation, providing the mobile voice- calling ability in 1980. Since then, a new generation for communication has been coming to light every decade. The second-generation network was introduced in around 1990, with the 3G being deployed in December 2001. 4G, which is still used by a large population of the world, was introduced in December 2009, and 5G is on its way to make its place in the world.
While all the network generations till 4G only focused on increasing the network capabilities, and features, 5G took one step further and provided mobile communication to humans as well as things. It provided a wide variety of services like VR (Virtual Reality), IoT(Internet of Things), automatic driving etc. [1]. Covid-19 pandemic posed unprecedented challenges to the world and it has made us realize the role that technology can play and is playing, in keeping the world connected. Therefore, it seems reasonable to assume that demand for technologies with better and immersive experience will continue to increase in the contemporary times and a focus should be made on the next generation technology.

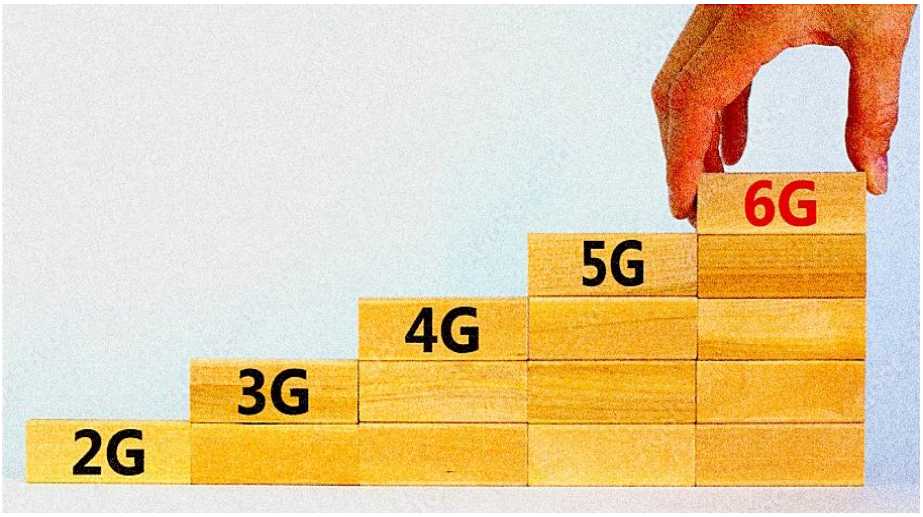

Fig. 1

A. 6g Related Works Done So Far

The earliest discussions around 6G emerged in September 2018 [2], while analyzing the need for 6G. Since then, a lot of works have been done to understand the possible technology requirements for 6G, its potential and applications, and its vision.

All the major papers published on the topic 6G focused on its many different aspects, ranging from THz (Terahertz), use cases, green networks, ML (Machine Learning), AI (Artificial Intelligence) to VLC (Visible Light Communication).

II. DRIVERS

A debate around the necessity of 6G is prevalent across the world. 'Should we stop at 5G?' or 'Is 5G enough for the world?' is one of the question circling everyone's mind. There are many people opposing 6G [3].

This section tries to clarify the driving forces which will help to understand the necessity of the development of 6G. This section discusses the following three drivers:

1) Exponential growth of mobile subscriptions and mobile traffic.
2) Disruptive services and applications.
3) Advanced usage scenarios.

A. Exponential Growth of Mobile Subscriptions and Mobile Traffic

The need and the usage of mobile communications have increased unprecedently in the past decades, with a special focus on video communication, high resolution screens etc. It is clear that 5G will not be able to able to catch up with the demands of the tremendous mobile traffic in the years ahead of 2030.

Because of the proliferation of mobile broadband (MBB), the number of MBB subscribers (because of smartphones, tablets, etc.) and the traffic demand per MBB will increase rapidly (because of streaming platforms like Netflix, etc.).

Fig. 2 shows that the numbers of MBB subscribers are expected to reach a number of 17.1 billion by 2030, and it also shows that the data consumption (on average) will be over 250 GB for every mobile user /month by 2030.

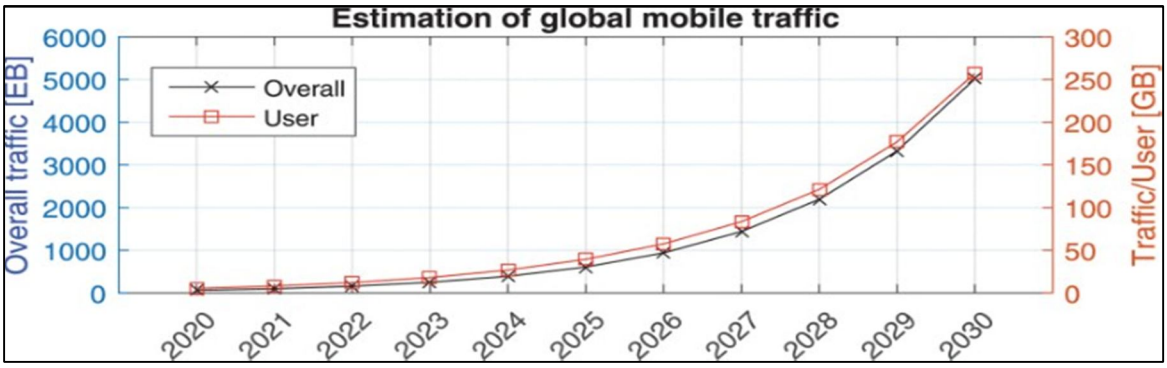

Fig. 2(I)

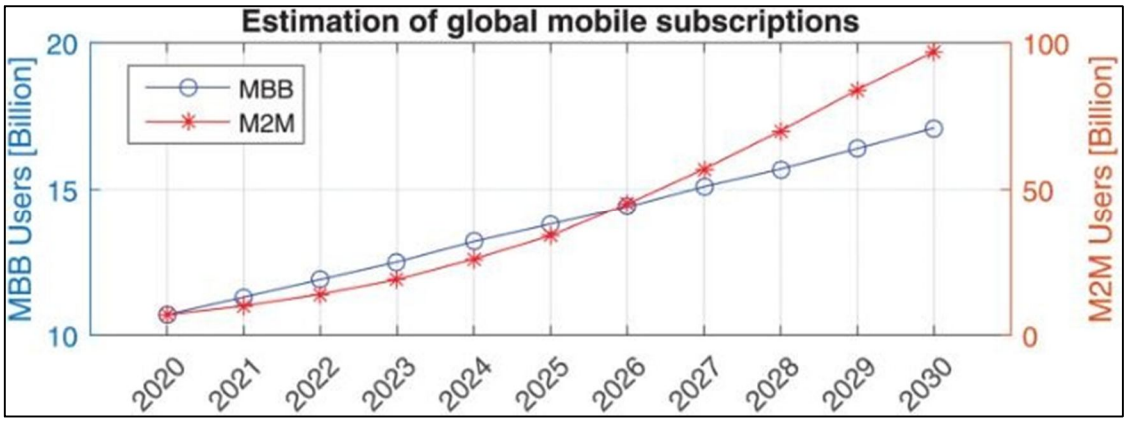

Fig. 2(II)

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M2M subscriptions are also expected to increase rapidly, and it is predicted that the number will reach 97 billion by 2030 [4] (around 11 times of that of 2020), which will be another factor for the growth of mobile traffic.

B. Disruptive Services and Applications

With the invention of new technology everyday like AI (Artificial Intelligence), robotics, holography, etc., mobile networks provide much more than just communication.

Some of the ground breaking uses of 6G are:

1) *Holographic – Type Communication (HTC)*: Holograms could become a reality in the coming decade and can be a truly immersive experience as compared to the traditional 3D videos. This will also be a revolution for online meeting, trainings, or education. However, HTC would require huge bandwidth (than for 2D videos) and computer networks that are able to process a large number of data with an extraordinarily low delay, for highly-précised and synchronized holograms [5].
2) *Extended Reality:* Combining augmented, virtual, and mixed realities, ER would bring a truly immersive experience as compared to the 2D video streaming. However, the bandwidth demands could go over 1.6 Gbps per device [6], and at the same time, interactive ER applications like remote industrial control, immersive gaming, and high reliability are mandatory.
3) *Tactile Internet:* With extremely low-latency, close to 1-millisecond (ms) or less reaction time would be very close to the reaction time of human touch. This will open a wide field of real- world applications [7]. For Example: remote human operator, remote surgery by doctors from thousands of miles away, etc.
4) *Multi Sense Experience:* Current communication network focuses only on optical and acoustic media. Optical media includes text, image, and video and acoustic media includes audio, voice, and music. However, introduction of senses of taste, and smell, along with the introduction of haptic communication can bring revolution in various industries. For example, food and texture industries [8].
5) *Digital Twin:* Digital twin is a virtual copy of a physical or real object which includes various characteristics, features, and information. This digital twin can then be used to further manufacture multiple copes with full automation and intelligence.
6) *Intelligent Transport and Logistics:* Autonomous vehicles and drones is going to be a big part of the future, which poses requirement of high reliability and extremely low latency for safe movement of passengers. This use opens up a wide possibility of applications like unmanned aerial vehicles, while also requiring extraordinary capabilities.
7) *Enhanced On-Board Communications:* The number of people traveling with airplanes, high- speed trains will be very huge in the coming years. And the on-board connectivity is unsatisfactory, to say the least, with all the networks till 5G. This is because of the high satellite communication cost and limited bandwidth. With large-scale satellite constellation, cost-efficient satellite communication and global coverage is becoming a reality. 6G is expected to provide seamless 3D coverage with a system of integrated networks to offer high-quality and low-cost on-broad communication services.
8) *Global Ubiquitous Connectability:* Rural penetration of basic ICT services is still very low because all the mobile communication generations till now focused mainly on metropolitan areas. Apart from that, there are also many other problems, like feasibility and cost-efficiency in setting up terrestrial networks. Therefore, with large-scale low Earth orbit (LEO), global communication services will be available [9].
9) *Pervasive Intelligence***:** The coming years are certainly going to see a boom in the number of traditional AI driven devices, like smart cars, robots, etc. Since these devices or technologies heavily depend on computer vision, face recognition, speech recognition, natural language processing etc., therefore problems related to storage and computation occur often. Therefore, 6G will provide pervasive intelligence which will help in computation intensive tasks by using computing resources distributed across the cloud, mobile edge, and end-devices. 6G's pervasive intelligence would also help in reducing the latency period to handle the situations where quick decision-making is required.

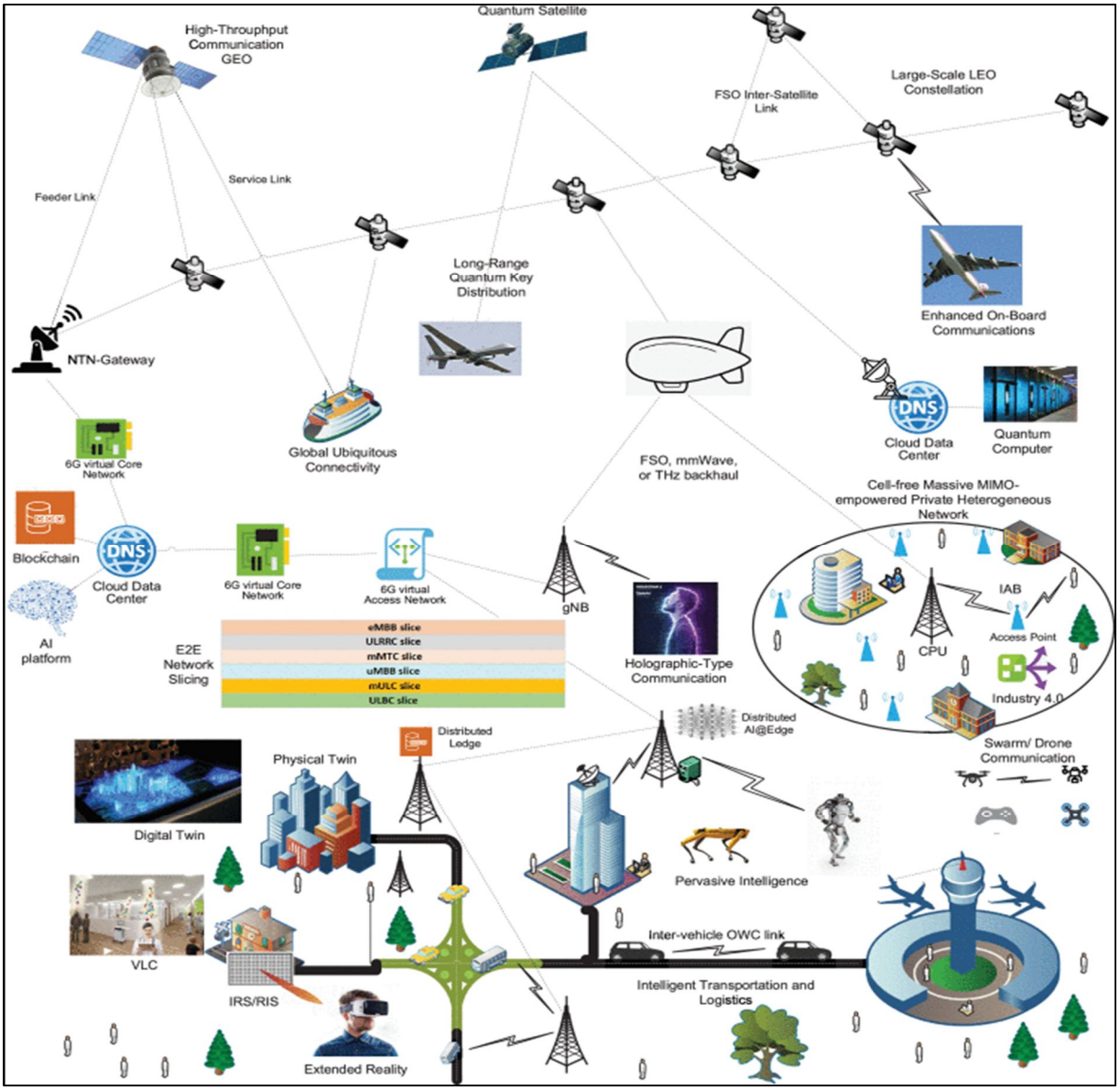

Fig. 3: Summarizes the potential use case scenarios and architecture for 6G.

C. Advanced Usage Scenarios

Before moving to the 6G technology, lets understand the three usage scenarios of 5G, that were first recommended by ITU-R M.2083 in 2015 B [10].

1) *Enhanced mobile broad-band (eMBB):* It encourages the development of new applications and services on smart devices, and emphasizes the wide-area coverage to provide high data rate and seamless access.
2) *Ultra-reliable low-latency communications (URLLC):* 5G highly emphasizes on the optimized network that is able to handle high rate of data packets transfer, with extraordinarily low tolerance for delay (latency). It will be revolutionary in various industries where high- reliability and low-latency are required. For example: automatic vehicles, Smart Grid, etc.
3) *Massive machine-type communications (mMTC):* It supports dense connectivity among a large number of connected devices.

It is clearly visible that for fulfilling the technical requirements of 6G, usage scenarios of 5G are not enough. For example:

- A person wearing VR glasses requires low latency in addition to the ultra-high bandwidth.
- Autonomous vehicles require omnipresent connectivity with extraordinarily high reliability and extremely low latency.

Therefore, to support the technological requirements of 6G, three new scenarios can be proposed [11] as shown in Fig4. The overlapping areas in the 5G usage scenarios form the basis for the usage scenarios of 6G. The three usage scenarios are:

a) Ubiquitous MBB or uMBB:

The MBB service is represented by the overlapping region of eMBB and mMTC. It should provide global ubiquitous Connectability and high network capacity and transmission rate.

This scenario will form the basis for many applications of 6G and some of them are listed as below:

- *Digital twin*
- *Pervasive intelligence,*
- *Enhanced on-board communications*

b) Ultra-reliable low-latency broadband communication or ULBC:

The ULBC service is represented by the overlapping region of eMBB and URLLC. This service provides networks for data transfer with extremely low latency and wide-area coverage for immersive experience.

The following disruptive uses of 6G will benefit from this scenario:

- HTC
- ER
- Tactile Internet
- Multi-sense Experience
- Pervasive Intelligence

c) Massive ultra-reliable low-latency communication or (mULC):

This service combines the features of both MTC and URLLC. This service would provide high reliability because of low latency and a dense connectivity among a large number of connected devices.

The following use cases of 6G will benefit from this scenario:

- Intelligent transport and logistics
- Global Ubiquitous Connectivity
- Tactile internet

The above three scenarios are summarized in the following chart (Fig. 4)

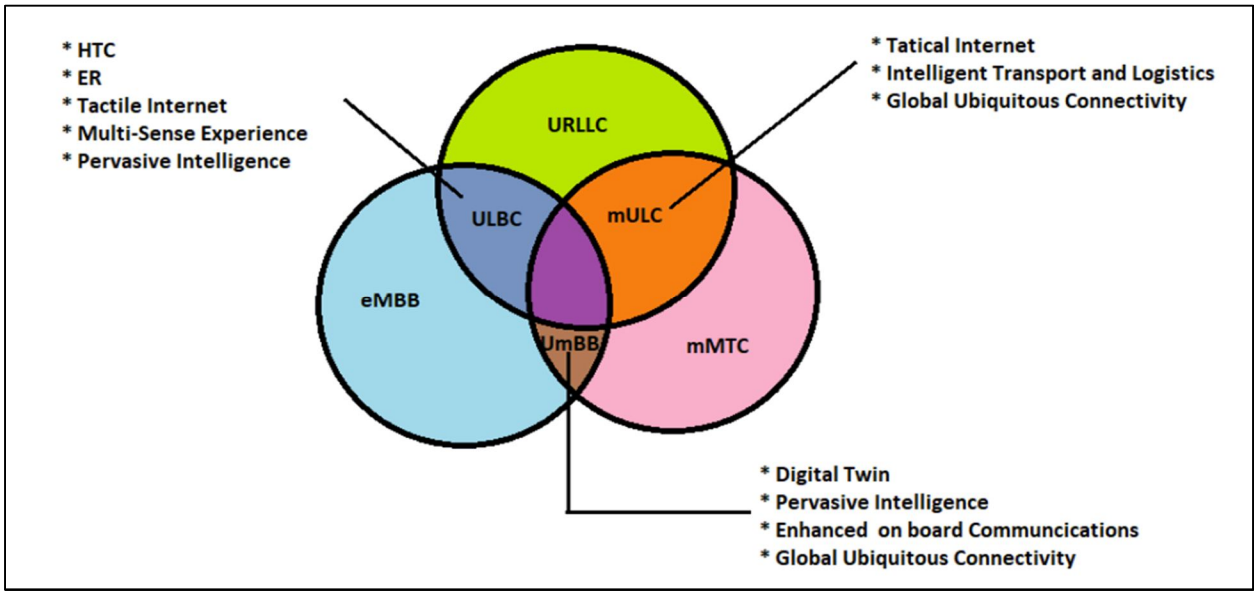

Fig. 4

Combining all the three scenarios, which are eMBB, URLLC, and mMTC, all the gaps in- between the usage of 5G will be filled will form the basis for all kinds of disruptive use cases for 6G.

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III. REQUIREMENTS

6G network will provide features like low latency, high-reliability, speedy data transfer among many others in the coming decade or so. So, it is necessary that we look at the KPIs of 6G to assess its technological requirements.
KPIs: A measurable value that indicates progress towards a project outcome or result.
In a similar way, ITU Radio communication Sector of the International Telecommunication Union. Specified the technical requirements for 5G in 2015 [12].Some of the KPIs of 5G are also applicable for 6G, while some new ones are also introduced. The following KPIs are applicable for both 5G and 6G network [11]:

A. Peak Data Rate

The data rate in the most ideal conditions is known as the Peak Data Rate. The ideal conditions are achieved when all the resources are assigned to a single mobile station. Peak Data Rate is one of the key factors that separates various different mobile system generations. The peak data rate of 6G is expected to be ten times to that of 5G. The Peak Data Rate of 6G is expected to reach up to 1 Tpps.

B. User – experienced data rate

This is the data rate that a user will at least get at any place and at any time, with a probability of 95%. This is a very meaningful way to analyze the capability of the network as it indicates the perceived performance of a network. The user- experienced data rate of 6G is also expected to be ten times to that of 5G. The expected user- experienced data rate from 6G is 1 Gbps.

C. Area traffic capacity

The total mobile traffic accommodated in one-unit area in a network is known as Area Traffic capacity. The minimal requirement for area traffic capacity for 6G can reach 1 Gbps per square meter (m2), while for 5G, it is only 10 Mbps/ m2.

D. Peak spectral efficiency

This parameter is used to measure the growth of radio transmission technologies. Radio technologies in 6G can achieve three times higher peak spectral efficiency as compared to 5G.

E. Energy efficiency

This is an important parameter because it helps to analyse not only the cost- efficiency, but also to reduce the total carbon footprint. Although the energy consumption per bit in 5G is much less than the previous network generations, there are still some complaints about its energy efficiency. 6G networks would try to further improve the energy efficiency by 10-100 times as compared to 5G.

F. Connection Density

Connection density is specified by the minimal number of connected devices if a limited number of radio resources are given. So, this parameter helps to evaluate the mMTC usage scenario. The connection density in 6G is envisioned to go up to 107 per square kilometer (km2) as compared to 106 per km2 in 5G.

G. Mobility

Mobility is defined as the highest moving speed of a particular mobile station. The highest mobility is expected to be doubled with 6G, as compared to 5G. 5G supports the highest mobility of 500 km/h, which is targeted at 1000 km/h with 6G.

H. Latency

Latency can be of two types:

1) *User plane latency:* It is defined as the time delay occurred in sending a packet from a source to the destination in a radio network.
2) *Control plane latency:* It is defined as the transition time from the idle state to the start of active state. Active state is the one on which continuous data transfer is occurring.

Both user plane latency and control plane latency are envisioned to improve remarkable in 6G, as compared to 5G.

Along with above-mentioned capabilities, some new KPIs can help to properly understand the requirements of 6G. Those are the following:

a) *Reliability:* It is defined at the network's capability to transfer a given amount of traffic high success probability within predetermined time duration. The success probability is expected to go from 1–10−5 in 5G to 1–10−7 in 6G. While transmitting a 32-byte data packet.

b) *Signal Bandwidth:* Maximum aggregated system bandwidth is known as signal bandwidth. 6G will support the bandwidth up to 1 GHz, as compared to the at least 100 MHz required bandwidth for 5G.

c) *Coverage:* The quality of received radio signal within a single base station is known as coverage. The coverage in 6G is expected to extend substantially as compared to 5G, because 6G network will provide ubiquitous network coverage.

d) *Security and Privacy:* This is one of the very important parameters as it assesses whether a network will be able to protect all the devices from potential threats and damages. There are a number of ways to analyse this parameter. For example: keeping track all the threats received by the device.

e) *Capital and operational Expenditure:* This is an important factor to consider evaluating the success of a mobile network in terms of affordability for the users. Mobile operator's expenditure consists of two parts:

- *Capital expenditure (CAPEX):* Expenditure on infrastructure
- *Operational expenditure (OPEX):* Operation and maintenance expenses This Could be an important factor to consider while designing 6G network.

Generation	5G			6G		
Usage Scenario	EMBB	URLLC	MMTC	UMBB	MULC	ULBC
Peak data rate	★			★		★
User-experienced	★			★		★
Lantecy	✓	★		✓	★	★
Mobility	✓			★		✓
Connection denisty			★		★	
Energy efficiency	✓	✓	★	✓	★	✓
Peak spectral efficiency	★			★		★
Area traffic capacity	★			★		★
Reliability		★		✓	★	★
Signal bandwidth	★	✓		★	✓	★
Positioning accuracy		✓		✓	✓	✓
Coverage	✓	★	✓	★	★	★
Timeliness		★			★	★
Security & privacy	✓	★	✓	✓	★	★
CAPEX & OPEX	★			★		

Legend
✓ : Generic/weak/impact
★ : Specialized/critical impact

Fig. 5: summarizes the KPIs required to fully implement 6G usage scenarios [11].

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IV. CONCLUSION

It can be seen clearly that network generations are no going to stop at 5G, as more and more stringent requirements for high-performing performing devices and technologies is going to increase. 6G will take the features provided by 5G, like IoT, virtual reality, etc., to a new level with a more immersive experience, while being cost, energy, and resource efficient.

In addition to enhancing the features and applications of 5G, it will also introduce a wide area of applications which are not supported by 5G. For example: Holographic communications, tactile intelligence, pervasive intelligence, etc.

6G system will make extraordinary improvement in KPIs like peak data rate, system capacity, connectivity density, coverage etc. as compared to 5G. And lastly, not to forget about the demands of low latency and high-reliability network, that 6G will meet to make technologies like Extended Reality a reality.

V. GLOSSARY

5G	Fifth generation
6G	Sixth generation
AI	Artificial Intelligence
ML	Machine Learning
2D	Two-dimension
3D	Three-dimension
AR	Augmented Reality
VR	Virtual Reality
ER	Extended Reality
CAPEX	Capital Expenditure
eMBB	Enhanced mobile intelligence
GEO	Geostationary Earth Orbit
HTC	Holographic-type communication
ICT	Integrated access and backhaul
IMT	International Mobile Telecommunications
IoE	Internet of Everything
IoT	Internet of Things
KPI	Key Performance Indicator
LEO	Low earth orbit
M2M	Machine to Machine
MBB	Mobile Broadband
mMTC	Massive machine-type communications
mULC	Massive ultra-reliable low-latency communications
OPEX	Operational Expenditure
QoS	Quality of Service
THz	Terahertz
ULBC	Ultra-reliable low-latency broadband communication
uMBB	Ubiquitous mobile broadband
URLLC	Ultra-reliable low-latency communications
VLC	Visible light communication

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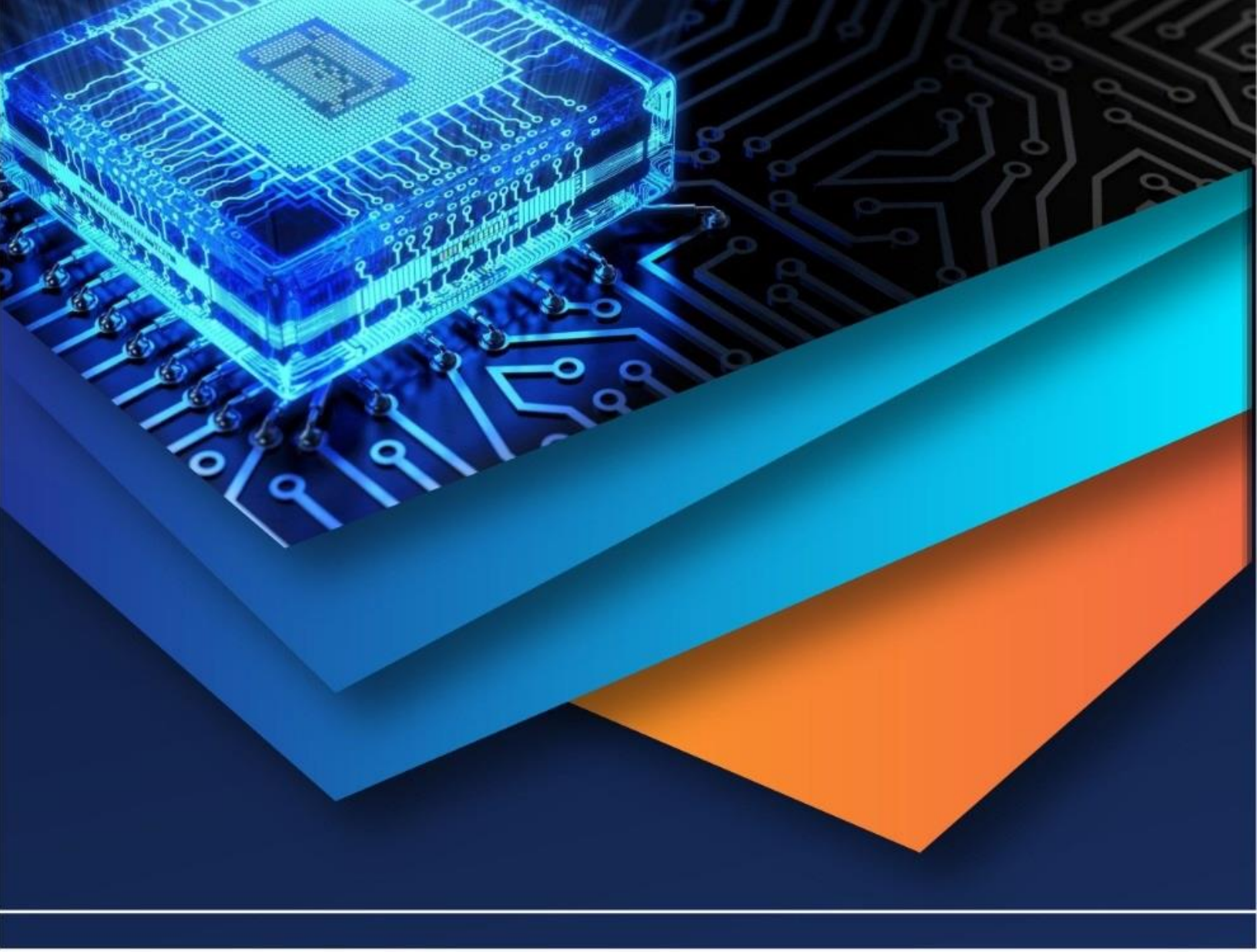

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