A Theoretical Framework for the 6G Wireless Communication Standard Vision, Applications and Challenges

Faizan Nazir*, Dr Neetu Sood*

Department of Electronics and Communication, Dr B R Ambedkar National Institute of Technology, Jalandhar, Punjab, India

*Corresponding author
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Abstract

With the 5G standard being completely solidified and currently being rolled out in multiple countries with total commercial deployment being expected by 2022, focus has now shifted towards conceptualization and standardisation of Beyond 5G (B5G) and 6G wireless systems. Research has already begun in various countries on what to expect from the next generation of wireless communication which is being expected to be deployed early in the next decade. In this article a vision for the next generation of wireless communication is presented based on the trend in usage scenarios around the globe. Some of the promising technologies in 6G such as Reconfigurable Intelligent Surfaces, Smart terminals etc. are explained and the major challenges the next generation of wireless communication faces are also defined. The emergence of Artificial Intelligence (AI) as an inherent part of the 6G intelligent networks and the increased Virtualization of the system is also discussed.

Keywords: wireless, beyond 5G, 6G, RIS, artificial intelligence, virtualization

1 Background

To get a better understanding of the theoretical framework for the 6G communication system, it's necessary to get a basic understanding of the evolution of wireless communication standards; 1G to 4G and the 5G standard in current deployment phase. As 6G is expected to borrow a number of core technologies from the previous generation itself, a clear understanding of the fundamentals of 5G as well as the standards before 5G becomes essential to provide a clear overview of what to expect from the networks beyond fifth generation and the sixth generation of wireless communication.

Table 1. List of abbreviations and acronyms

1G	First Generation
2G	Second Generation
3G	Third Generation
3GPP	Third Generation Partnership Project
4G	Fourth Generation
5G	Fifth Generation
6G	Sixth Generation
AI	Artificial Intelligence
AR	Augmented Reality
B5G	Beyond Fifth Generation
BSN	Body of Sensor Networks
CDMA	Code Division Multiple Access
eMBB	Enhanced Mobile Broadband
IoNT	Internet of Nano Things

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IoT	Internet of Things
IRS	Intelligent Reflective Surface
LoS	Line of Sight
LTE	Long Term Evolution
M2M	Machine to Machine
MIMO	Massive Input Massive Output
mMTC	Massive Machine Type Communication
mmWAVE	Millimetre Wave
NFV	Network Function Virtualization
OFDM	Orthogonal Frequency Division Multiplexing
QoE	Quality of Experience
RIS	Reconfigurable Intelligent Surface
SDN	Software Defined Network
TDMA	Time Division Multiple Access
THz	Terra-Hertz
UAV	Unmanned Aerial Vehicle
URLLC	Ultra Reliable Low Latency Communication
VR	Virtual Reality
WiMAX	Wide Interoperability for Microwave Access

2 1G to 4G progress

Since the development of wireless communication, pioneered by people such as Marconi, Tesla etc. and its theoretical integration with the information theory in the last century by Claude Shannon, wireless communication was standardised in early 1980's. There have been 3 major updates in the wireless communication standard viz 2G, 3G and 4G since then. The fifth generation of wireless communication standard is currently being tested and deployed in various markets. The 1G standard was introduced back in 1980's. This standard was analogue in nature and was exclusively developed for voice communication. With the advent of 2G, digital cellular networks came into existence back in 1990's. The digital nature of communication provided data services such as short messaging service in addition to voice services and also enabled initial encryption of data. The third generation of wireless communications or 3G, introduced in early 2000's, was a turning point in the wireless communication arena with advancements in multiple access techniques as well as a huge leap in bandwidth. The introduction of technologies such as *Code Division Multiple Access (CDMA) and Time Division Multiple Access as (TDMA)* as well as the introduction *World-Wide Interoperability for Microwave Access (WiMAX)* led to seamless integration of voice and data services with even video calling becoming possible due to the increased bandwidth and data rate. The 4G standard also referred to as Long Term Evolution (LTE) was standardized late in the first decade of the 21'st century introduced Orthogonal Frequency Division Multiplexing (OFDM) along with the integrated Internet Protocol helped in enabling high data rates as well as high throughput in 4G communication networks which in turn paved the way for large scale implementation of new technologies such as Internet of Things (IoT) and Machine to Machine communication (M2M).

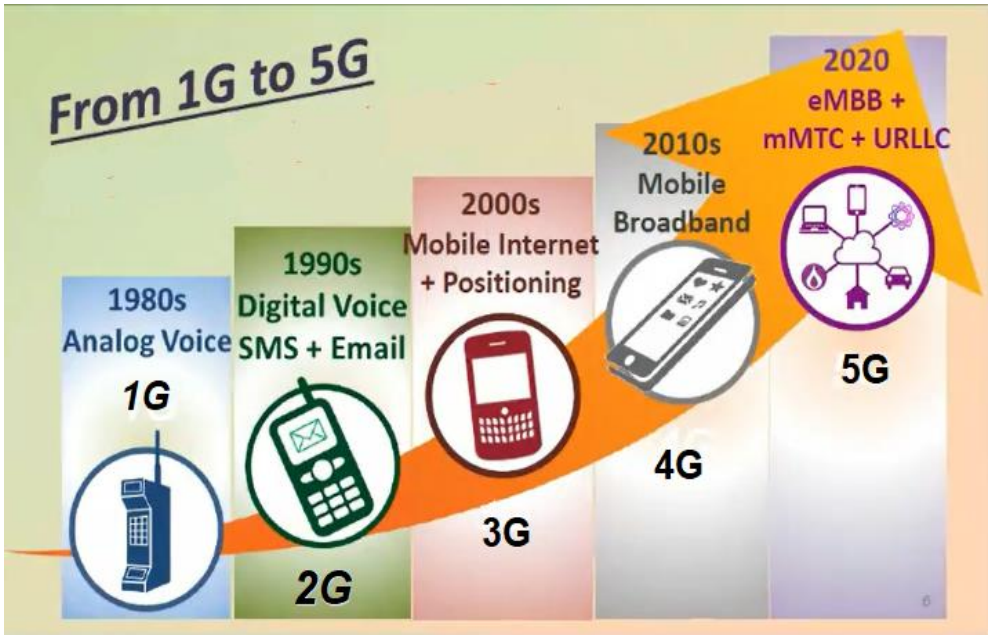

Fig.1 The Evolution of the wireless standard from analogue 1G to 5G.

3 The 5G status quo

The 5G concept started to take shape in mid-2014 with conceptualization of technologies such as millimetre-wave transmission and use of a higher number of transmitter and receiver antennas in what was called *Massive Multiple-Input Multiple-Output* (massive MIMO) configuration. The commercial deployment was estimated for the year 2020. While some developed countries have deployed functioning 5G networks, large-scale deployment has been pushed to 2022. The 3rd Generation Partnership Project (3GPP) was agreed upon by various operators for the 5G New Radio standard which operated in the *2 GHz–6 GHz* spectrum. Some new technologies such as *densification and network slicing* have been delayed and reserved for critical applications. Commercial stress has been put on High-Definition video streaming, Virtual Reality (VR) and Augmented Reality (AR) applications on top of providing high speed internet services on a global scale. A fully finished 5G network is aimed to provide three courses for communication as:

i. Enhanced Mobile Broadband (eMBB)
ii. Ultra-Reliable Low-Latency Communications (URLLC)
iii. Massive Machine-Type Communications (mMTC)

Even though 5G standard aims to provide fast and reliable communication standard for the next decade, it doesn't include any revolutionary new technology but borrows most of its fundamentals from the 4G standard while all the advances are attributed towards higher spectrum bandwidth and efficient hardware solutions.

4 Vision

The number of connected devices by 2030 is estimated to triple from their current 8.5 billion to over 25 billion devices. Such a data driven information society will need extremely low latency, high bandwidth and high data rate in its communication framework. 6G is said to be the main facilitator for such a digitized communication on a world-wide scale. The primary expectations from the sixth generation of wireless communication standard are as:

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4.1 Ubiquitous Connectivity

A 6G communication framework will provide universal connectivity in all the basic geographic and non-geographic areas such as land or terrestrial, under-water, air and space communication. The land based communication network will still be the primary focus of the framework Data rates of the order of hundreds of Gb/s or even Tb/s are expected. In order to achieve such a high data rate mm-wave and cm-wave bands will be exploited to provide with the bandwidth for the communication network. The main problem that persists with the mm-wave band is the high path loss suffered by signals in such a high frequency. This will be mitigated by providing an increased number of base stations in a compactly dense environment. The main driver space communication will be primarily through satellites where mm-wave communication will be reserved for those areas where land based communication will be difficult to achieve while laser communication will be reserved for satellite to satellite communication. The goal of universal connectivity will be brought to life by the use of *Unmanned Aerial Vehicles* (UAVs) acting as floating base stations to access areas that are in difficult terrain. The UAVs will be of two types viz. tethered or connected and untethered or free-flying. The untethered UAVs act as simple drones and are used to provide Line of Sight communication to areas where providing so is difficult given LoS is paramount to a reliable communication in mm-wave band. Untethered UAVs are also used to deploy temporary base stations in areas where network or user density is too much to handle by specified number of base stations that are already provided.

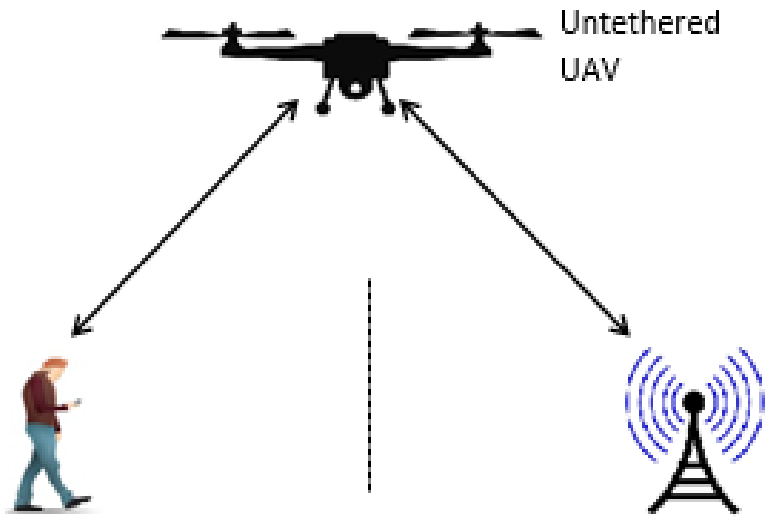

Fig.2 An Untethered UAV providing a Line of Sight

There are some obvious problems to free flying UAVs such as time limited flying capacity as well as a weight limit to the number of transmitting devices a UAV can carry. The quality of transmission will be dependent on the wireless link of the UAV with the base station. Also there is always a risk of the UAV breaking connection due to turbulent weather and being rendered useless. The second type of the UAVs is the connected UAV which is connected to the base station via a physical link such as a cable of defined length. The limitations of the untethered type are mitigated in tethered UAVs such as the cable can be used to provide power to the UAV which would solve the limited battery issue as the cable can also be used to act as a physical communication link to the base station thereby increasing the link transmission quality.

This also solves the issue of the UAV breaking connection and flying away. One limitation to this type of UAV is the limited altitude that the UAV can fly up to keeping the cable length that can be connected to it practically, in consideration for the link transmission. The integration of underwater communication is the factor that makes a 6G communication system a truly universal communication framework. While the previous three types of communication viz. land, air and space were integrated in the 5G standard, the inclusion of the underwater makes its way in the sixth generation. This is achieved by using acoustic sound and laser. This integration can be utilized for both commercial as well as military applications by floating buoys as well as submerged hubs.

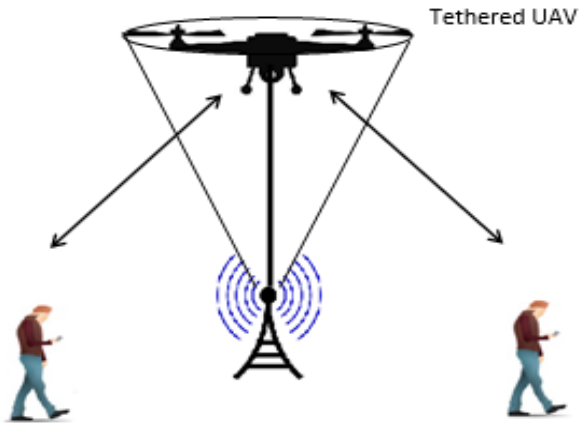

Fig. 3 A tethered UAV providing Line of Sight

5 Reconfigurable Intelligent Surfaces (RIS)

The use of Intelligent Reflecting Surfaces (IRS) in 6G tends to passively direct radio waves through reflection or scattering towards the destination in order to boost the signal quality. These intelligent surfaces employ a metal or any meta-material consisting of small, low cost passive or active elements that have tunable reflection and thus can be used to direct radio waves in the desired direction. These intelligent surfaces can easily be placed on the indoor or outdoor surfaces and can help in achieving a higher Quality of Service in the propagation channel. The advantages of using RIS lie in the fact that they can provide coverage to areas not reachable before while also absorbing any leakage and thus enhancing physical link security in the network system.

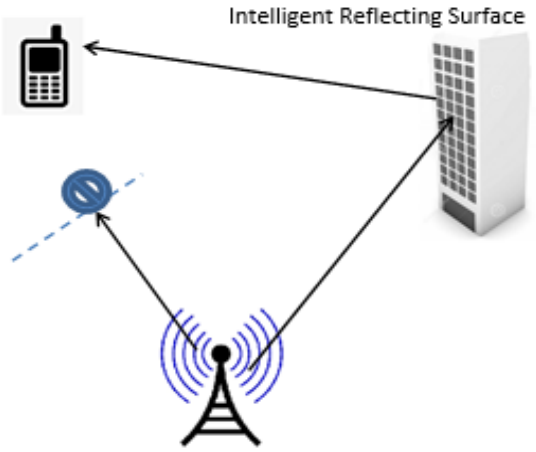

Fig. 4 An IRS providing a Line of Sight.

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6 AI Driven Autonomous Communication Paradigm

One of the most invasive enablers in the current technological scenario is artificial intelligence and machine learning algorithms and thus it's obvious that artificial intelligence will be at the centre of 6G communication system development. Due to the tremendous advancement in AI technology in recent years, especially deep learning in conjunction with availability of large scale training data, immense interest has developed in using AI for the design as well as optimization of wireless networks. The use of AI will be either localized to a particular domain or will be applied to the network as a whole. Nonetheless the increased use of AI in the 6G network will turn the communication system into a self-sustaining network. Now, even though one of the most promising areas of artificial intelligence is Deep learning, 6G is moving more towards a distributed cloud architecture of billions of devices which forces the network to undergo edge training in contrast to deep neural networks which rely on centralized training mechanisms. The successful integration of AI into 6G will be the inclusion of various other pure areas of theoretical improvements such as game theory and decision making optimization algorithms. In addition, the co-development of software and hardware solutions will add to ensure the seamless integration of AI with 6G.

7 Virtualization

The increased virtualization of the network protocols was already seen in active development in the 5G standard. The Softwarization and Virtualization of 5G network architecture as seen by techniques such as *Software Defined Radio* (SDN) and *Network Function Virtualization* (NFV) are passed on to the sixth generation along with slicing techniques, which help in paving the way for a truly autonomous network. The added feature in 6G networks will be the integration of artificial intelligence as stated in the previous paragraph with the virtualization techniques such as SDN and NFV etc. The optimization of the network based on AI enabled indicators will help in real time monitoring of some key primary indicators and thus provide a better Quality of Experience (QoE). The integration of AI in the 6G wireless network system will occur at two levels. One at the centralized core network where as another level will be distributed in nature, at the edge of the radio access network. The centralized network will handle the multi base-station issues such as mobility while as the distributed network will handle the single base station related issues such as physical layer communication.

One of the concerns of integrating AI in the 6G network will be that of privacy. As training an Artificial Neural Network will require access to personal data of users, process the data and then optimize the network based on findings which requires access to personal data of users.

For a better performing ANN, higher amount of data will be needed which in return will prove detrimental to the privacy of the users' data.

8 Use-Cases

8.1 Ultra High-Definition Streaming

6G wireless networks will be capable of handling throughput requirements for ultra-high definition (4K), super-high definition (8K) and extremely high definition video streaming. The huge amount of bandwidth requirements for streaming such high qualities videos over the air will be of primary focus and directed towards the ever growing entertainment industry.

8.2 Autonomous Transport

The automation level of a vehicle is tipped at level 3 or level 4 of automation where geofencing still has a huge involvement in the automation of the vehicle which means that automation is dependent on infrastructure as well as policy. Even though autonomous vehicles can operate on their own, their level of

automation is limited as available only in certain urban areas as well as limits on speed. A fully autonomous mode of transport will entirely exclude human involvement as well as manual takeover of the vehicle. Geofencing will be completely eliminated and the fully autonomous vehicle will be able to do everything that can be done by a human driver.

9 Internet of Nano-Things (IoNT)

IoNt requires a high speed network to connect a large number of devices to one another and collect critical data that can further be analysed to gain insights about various developments. This technology has a huge potential in various areas with some detailed below:

i. *Healthcare*— In healthcare a large number of nano-sized sensors can be deployed with a body to create a Body of Sensors (BSN). The data from BSN will be used to monitor a patient's health activity.

ii. *Environment* The degradation of Environment is being witnessed currently at a global scale. From melting of polar ice-caps to desertification to increased forest fires, effects of climate change are being felt everywhere. In order to better monitor the changes in environment, large number of nano sensors will be deployed to monitor changes at various places within an area and the data generated can be used for better policy making to mitigate the effects of global warming.

iii. *Agriculture*— Agriculture is one of the most promising areas for which IoNT will be applicable. A large number of nano sensors will be deployed to monitor the parameters that affect the crops such as soil, weather, humidity, insecticide and pesticide requirements, the data of which will be used to provide meaningful solutions to agricultural issues.

10 Deep Sea and Space Exploration

6G wireless networks will enable deep sea exploration far beyond current limits by providing submerged hubs to act as mid links for transmission of data o the desired destination. Space exploration can be done by providing a number of low and mid orbit as well as geosynchronous satellites to provide global connectivity as well as outer space.

11 Challenges

11.1 mm-Wave Band Path Loss

The path loss presented in mm-Wave band will be the central problem in 6G wireless communication systems. For successful communication in THz frequency, highly directive and sensitive transceivers as well as propagation models are to be constructed. New link models are to be constructed. New link layer and network protocols are be developed for the highly vying and uncertain nature of mm-Wave band.

12 Health Concerns

It is anticipated that the increased exposure to higher power and high frequency electro-magnetic radiation will be a matter of concern in 6G as it is in 5G. Even though no conclusive studies show any drastic effect of EMF radiation on a human body in the 5G arena but as we move higher in the frequency spectrum and increase the power at the same time, it will tend to have some effects on the human body. Therefore, research in this area becomes an important aspect in the development of 6G networks.

13 Power Considerations

The increase in hardware in 6G communication system in both the BS and UE domain will lead to higher power dissipation by the equipment which in turn will need higher power capacities to operate in the mm-Wave band. This is one of the biggest challenges faced by the 6G communication systems and

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effective and sustainable solution to the power issue will be one of the most researched areas in the drive for 6G standard deployment.

14 Literary Research

The 5G standard is already being implemented in various parts of the world and now active research is being done on B5G and 6G networks. The following table provides an insight into the studies that have been published to push the 6G standard forward:Reference	Year of Publication	Contribution Summary
M.Giordani et al [1]	2020	Requirements for 6G communication standard and some use cases are presented.
David K et al [4]	2018	The need based upgrades in the 6G standard have been presented.
Yastrebova et al [5]	2020	The development trends of wireless communication networks for the next decade has been discussed
R.Shafin et al [10]	2020	The integration of artificial intelligence into cellular networks in B5G and 6G standards has been discussed along with challenges in 6G development.
L. Zhang et al [19]	2019	Various characteristics such as super IoT and artificial intelligence have been discussed for 6G communication network. Their implementation has been presented.
Raghavan et al [21]	2019	The communication parameters for physical layer have been discussed keeping in mind the B5G and 6G communication standard.
T.Huang et al [24]	2020	The architectural aspects of 6G deployment as well as the framework for its universal coverage and inclusion of AI have been discussed.
Y. al-Eryani et al [33]	2019	Delta-orthogonal multiple access, a new multiple access method, has been proposed.
Y. Zeng et al [37]	2020	Features and key enabling technologies for the 6G communication standard have been presented. Usage of unmanned aerial vehicles gas been discussed.
Basar et al [42]	2019	A comprehensive study of reconfigurable intelligent surfaces has been presented along with their application in the 6G wireless communication standard.
Y.Zhang et al [48]	2020	A layer based heterogeneous mobile edge computing and a machine learning based approach to low latency communication is presented.
M.S Sim et al [50]	2020	Beam selection based on an artificial intelligence framework is presented backward compatible with 5G
This paper		Vision for the sixth generation of wireless communication standard has been presented along with the challenges faced in the implementation of the 6G standard. A few application scenarios have also been discussed

15 Conclusion

In this article the next generation of wireless communication standard was discussed. The evolution of a self-sustaining, intelligent network was shown which relies on modern technological trends such as Artificial Intelligence and Big Data was shown. The vision of the 6G standard on what to expect from the new generation was examined. The application areas of 6G from healthcare to agriculture to streaming are all discussed in brief detail. Finally the challenges faced by the 6G wireless networks from path loss to health concerns are looked at and the extensive research required to overcome such challenged for successful deployment of the 6G standard in the next decade is studied.

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