IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

AI POWERED 6G NETWORK: USE CASES AND TECHNOLOGIES

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Abstract: For the digital age that is becoming increasingly automated, intelligent, and ubiquitous, reliable data connectivity is essential. Mobile networks are the data highways. Everything will need to be connected in a thoughtful, connected digital world. Although fifth-generation (5G) wireless networks are currently being deployed, they offer significant advancements beyond LTE. Still, they may need help to meet all the connectivity requirements of the future digital society. This article will discuss technologies that will enable wireless networks to evolve towards a sixth-generation (6G), which we consider enablers for potential 6G uses. We give a system-level view of 6G scenarios and requirements. Then, we select 6G technologies to satisfy these requirements by either improving 5G's design or creating utterly new communication paradigms.

Index Terms **– 5G, 6G, artificial intelligence, Communication, network.**

I. INTRODUCTION

As shown in Fig. 1. Today's society is becoming increasingly data-centric, data-dependent, and automated. The future of productivity will be driven by radical automation in industrial manufacturing. Autonomous systems will soon be on our roads, oceans, and airspace. Installing millions of sensors in cities, homes, and production areas will allow for many new applications.

New systems that operate on artificial intelligence, which resides in the local cloud and fog environments, will also enable the integration of many more sensors. Communication networks will support these new intelligent system paradigms. However, the demands will be overwhelming.

The need for networks to transmit more data at higher speeds will be greater. The sixth generation (6G), continuing a trend already evident in 4G/5G, will allow personalized communication to be realized. It will connect people, computers, devices, wearables and sensors, and robotic agents. 5G was a significant step in developing a low-latency tactile network. It provided additional wireless nerve tracts via:

1. A new frequency band (e.g. the millimetre wave spectrum).
2. Advanced spectrum usage management in licensed as well as unlicensed bands.
3. And a complete redesign of the core network.

The rapid development of data-centric, automated processes that require a data rate of hundreds of terabits/second, a latency of hundreds of microseconds, and 107 connections/km2, may make it difficult to use the 5G systems.

Researchers have recently been inspired by the above discussion to investigate a sixth-generation (6G) wireless network to meet the needs of an intelligent, connected digital world. This paper aims to identify the technologies that can locate 6G networks and offer more efficient and vertically-specific wireless networking solutions. The report examines various scenarios that can be used to connect future systems and attempts to determine their requirements regarding latency, throughput and connectivity. We identify many use cases that go well beyond the current 5G system performance and show why we must consider future evolutions beyond 5G. We will need to develop new communication technologies, network architectures, deployment models, and other networking technologies to meet these requirements. We envision:

- **New disruptive communication technologies:** Although 5G networks are already designed to operate at very high frequencies (e.g. in the mmWave band in NR), 6G could benefit from higher spectrum technologies such as Terahertz or optical communications.

- **Innovative network architectures:** Although 5G advances have led to more efficient network setups, future applications are heterogeneous and require 3D coverage. This necessitates new cell-less architectural paradigms that rely on the tight integration of various communication technologies for access and backhaul and the disaggregation of and virtualization of networking equipment.

- **Integration Intelligence into the Network:** We expect 6G will bring intelligence from central computing facilities to end terminals. This will provide a concrete implementation of distributed learning models that were theoretically studied in a 5G context. Unsupervised learning and knowledge sharing are essential to real-time network decisions via prediction.

Previous publications, most notably [2],[3], have covered 6G communications. This article is unique in that it systematically analyses the challenges associated with 6G networks. It provides a full-stack view, including considerations related to spectrum usage, physical, medium and higher access, network architectures, and intelligence.

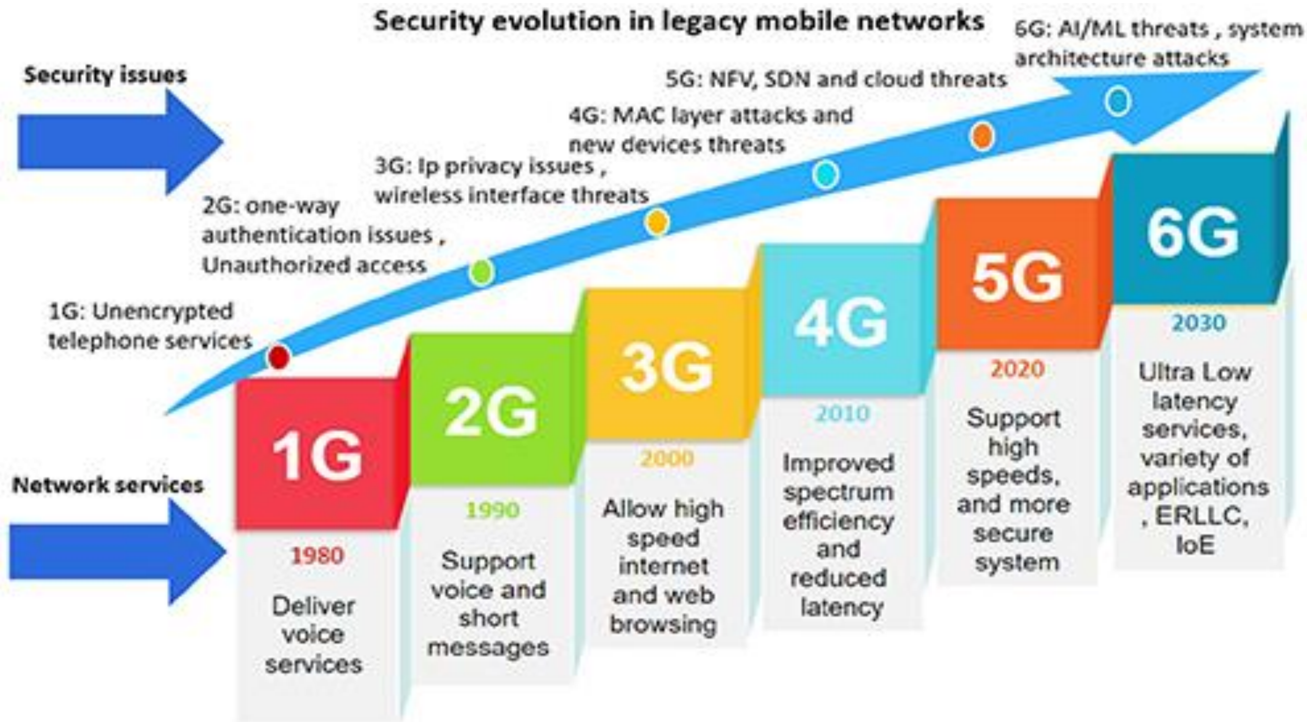

Fig. 1: Evolution of internet from 1G to 6G, with a representative application for each generation.

A multifaceted critical approach informs our work. We have selected the best solutions from various possible innovations that will be most useful for future 6G systems. Although some of these technologies may seem incremental, the combination of breakthrough technologies with the evolutions of existing networks should be recognized as a new generation of mobile networks. These solutions still need to be fully addressed in current 5G standards development and, therefore, will not be included in commercial 5G deployments. Our investigation will encourage research efforts to develop new communication and networking technologies to meet the most demanding 6G use cases.

II. 6G Use Cases

5G involves latency, energy costs, hardware complexity, throughput, and reliability trade-offs. Different configurations of 5G networks can address other requirements, such as mobile broadband and ultra-reliable low-latency communications. In contrast, 6G will be designed to meet the stringent network requirements (e.g., high reliability, capacity and efficiency as well as low latency) in a holistic manner, taking into account the economic, technological and environmental contexts of the 2030 era. This section examined the characteristics and expected requirements of future 6G services. Fig. 2 gives a complete view of the scenario in terms of different Key Performance Indicators.

Augmented Reality (AR) and Virtual Reality (VR): 4G systems have unlocked the potential for video-over-wireless (VoW), one of the most data-hungry of all time. To guarantee 5G capacity, the increasing popularity of streaming and multimedia services justifies the adoption mmWaves (new spectrum). This multi-Gbps opportunity attracts new applications that are heavier than bi-dimensional multimedia content. 5G will be the catalyst for the early adoption of AR/VR. As with video-over wireless saturated 4G networks (see below), AR/VR applications will eat up the 5G spectrum and demand a system capable of at least 1 Tbps. This contrasts with the 20 Gbps 5G target [1]. AR/VR can't be compressed to meet the latency requirements for real-time user interaction within the immersive environment. This is in contrast to the 100 Mbps 5G target.

Holographic Telepresence: 6G networks will face severe communication problems due to the human tendency to communicate remotely with greater fidelity. [4] outlines the data requirements for a 3D Holographic Display: A raw hologram without compression with colours, full parallax and 30 fps would require 4.32 Tbps. As VR/AR requires only a few view angles, the latency requirement will exceed the sub-ms. To fully experience a remote immersive experience, all five senses must be digitalized and transferred to future networks. This will increase the overall target data rate.

eHealth: 6G is a revolution in the healthcare industry, eliminating space and time barriers via remote surgery and optimizing workflows. Aside from the high price, the current limitation is the inability to receive tactile feedback in real-time [5]. The proliferation of eHealth services will also challenge our ability to meet their strict Quality of Service (QoS), i.e. continuous connection availability (99.99999% reliability), sub-ms latency (sub-1ms), and mobility support. These KPIs will be guaranteed by the increased spectrum availability and advanced intelligence of 6G networks.

Pervasive connectivity: Mobile traffic is predicted to increase 3-fold between 2016 and 2021. This will push the number of mobile devices to their extreme, with 107 machines per square kilometre in dense areas (up to 106 in 5G) [1]and more than 125 million devices worldwide by 2030. 6G will connect personal devices and sensors to implement the smart-city paradigm, vehicles, and other objects. This will make connecting devices and sensors in already congested networks more challenging. 2. To allow for scalable and low-cost deployments with minimal environmental impact and better coverage, 6G networks will need a higher overall energy efficiency (between 10 to 100x in comparison to 5G). In comparison, 6G networks will require a higher overall energy efficiency (10-100x concerning 5G) to enable scalable, low-cost deployments with low environmental impact and better coverage.

Fig 2. Representation of multiple KPIs of 6G use cases, together with the improvements with respect to 5G networks, using data from

80% of the mobile traffic is generated indoors; 5 G cellular networks, which are being mainly deployed outdoors and may be operating in the mmWave spectrum, will hardly provide indoor connectivity as high-frequency radio signals cannot easily penetrate dielectric materials (e.g., concrete). 6G networks will instead provide seamless and pervasive connectivity in a variety of different contexts, matching stringent QoS requirements in outdoor and indoor scenarios with a cost-aware and resilient infrastructure

Industry 4.0 and Robotics: 6G can fully implement the Industrial 4.0 revolution initiated by 5G, i.e. an industrial revolution digitalized with cyber-physical technology and IoT services. The ability to bridge the gap between the existing manufacturing facility and the cyber-computing space will allow internet-based diagnostics, maintenance operations and direct machine communication in a low-cost, flexible and efficient way [66. Automation has specific needs in terms of reliable and reliable communication [7which 6G can tackle through the revolutionary technology we'll be discussing in Sec. III.

For instance, industrial control demands real-time operations that are guaranteed to us delay jitter and Gbps maximum rates of data for industrial AR/VR applications (e.g. for training or inspection, etc.).

Unmanned mobility: advancement towards completely autonomous transport systems provides safe travel, better traffic management and support for entertainment, which has 7 trillion dollars [8]. Connecting autonomous vehicles to the internet requires unimaginable levels of reliability and very low latency (i.e. above 99.99999 per cent and less than one millisecond, for instance), even in ultra-high-speed scenarios (up to 1,000 km/h), to ensure security for passengers. Current technologies need to be able to meet this requirement. Furthermore, the growing amount of sensors on a vehicle will result in higher speeds for data (with Terabytes of data generated per driving hour [99]) over and above what the current network can handle. In addition, flying vehicles (e.g., drones) represent a huge potential for various scenarios (e.g., construction, first responders). A swarm of drones will require increased capacity to expand Internet connectivity. From this perspective, 6G will pave the way for connected cars through technological advances in hardware, software and connectivity solutions that we'll discuss in the Section. III.

As detailed in the following Section, the variety of usage instances is an outstanding feature of the 6G technology, which can be fully realized only through technological breakthroughs and innovative network designs.

III. 6G ENABLING TECHNOLOGIES

This Section will discuss the technology rapidly developing as enablers for the KPIs to be used in the 6G scenarios outlined in the Section. II. Particularly Table I summarises the potential and challenges associated with each technological innovation proposed and suggests which applications discussed in Sec. II, they can help. While some of these advances were previously discussed within their context in 5G, they were excluded from the initial 5G standards development (i.e. threeGPP's NR release 15 and 16). They won't be utilized for commercial 5G deployments due to technology limitations or because markets need to be sufficiently mature enough to support them. The physical layer is the most critical component in Sec. III-A, as well as new protocols and architectural solutions in Sec. III-B, and then disruptive application of artificial intelligence within Sec. III-C

A. Disruptive Communication Technologies

The modern mobile network is usually defined as a collection of innovative communication technology that offers unprecedented performance (e.g. in terms of latency and data rate) in addition to capabilities. For instance, massive Multiple Input and Multiple Output (MIMO) and mmWave communications enable 5G networks. To put it in perspective, To satisfy the requirements we discussed in the section. II 6G networks are required to utilize traditional spectrum (i.e. the sub-6-GHz band and mmWaves) and frequencies that haven't yet been considered for standards for cell phones to meet the requirements, such as the Terahertz band as well as Visible Light Communications (VLC). Fig. 3 shows the path loss of each of these bands in the typical deployment scenarios to highlight the differentiators and opportunities each segment of the spectrum has to offer. In the following paragraphs, we will concentrate on the two unique spectrum band bands utilized in 6G.

- **Terahertz** communications are available in the range of 100 GHz and 10 THz. Compared to mmWaves, they offer the maximum possibilities of high-frequency connectivity providing data speeds of hundreds of Gbps to meet the most extreme 6G specifications. On the other hand, the primary obstacles that have hindered the use of Terahertz connections in commercial systems are the loss of molecular propagation absorption, penetration losses, and the engineering challenges of antennas and radio Frequency (RF) technology. For mmWaves, propagation loss can be offset with directional antenna arrays, enabling spatial multiplexing with minimal interference. Additionally, Terahertz communication performance can be enhanced by operating in frequencies that aren't significantly affected by the effect of molecular absorption, as shown in Figure. 3. Furthermore, when confined to indoor-to-indoor situations, these frequency bands can enable the development of new ultra-small-scale electronic packaging solutions for antenna and RF circuits.

- **VLC** has been suggested to complement RF communications by piggybacking the growing use of inexpensive Light Emitting Diode (LED) luminaries. They can switch between various light intensities to alter a signal that can be sent to a suitable receiver [1111. The research in VLC is much more advanced than research on Terahertz communications due to the lower price of testing platforms. As shown in Fig. 3, VLCs have a limited coverage area, need an illuminated source, are susceptible to noise from other light sources (e.g. the sun), and are typically employed indoors [1111. Furthermore, they require to be supported by RF to uplink. However, VLC could provide coverage for cellular in indoor environments that, as described in Sec. II. a situation that cellular standards need to address adequately.

While standardization bodies are encouraging studies that are directed towards research into VLC and THz solutions for future wireless networks (i.e. IEEE 802.15.3d and 802.15.7 and 802.15.7, respectively) However, these technologies haven't yet been added to a mobile network standard, and they will be focusing on other 5G scenarios. Additionally, further research is needed to enable mobile phones with 6G to work within the THz and VLC spectrums, including software and algorithms that allow for multi-beam flexibility and tracking within Non-Line-ofSight (NLOS) conditions.

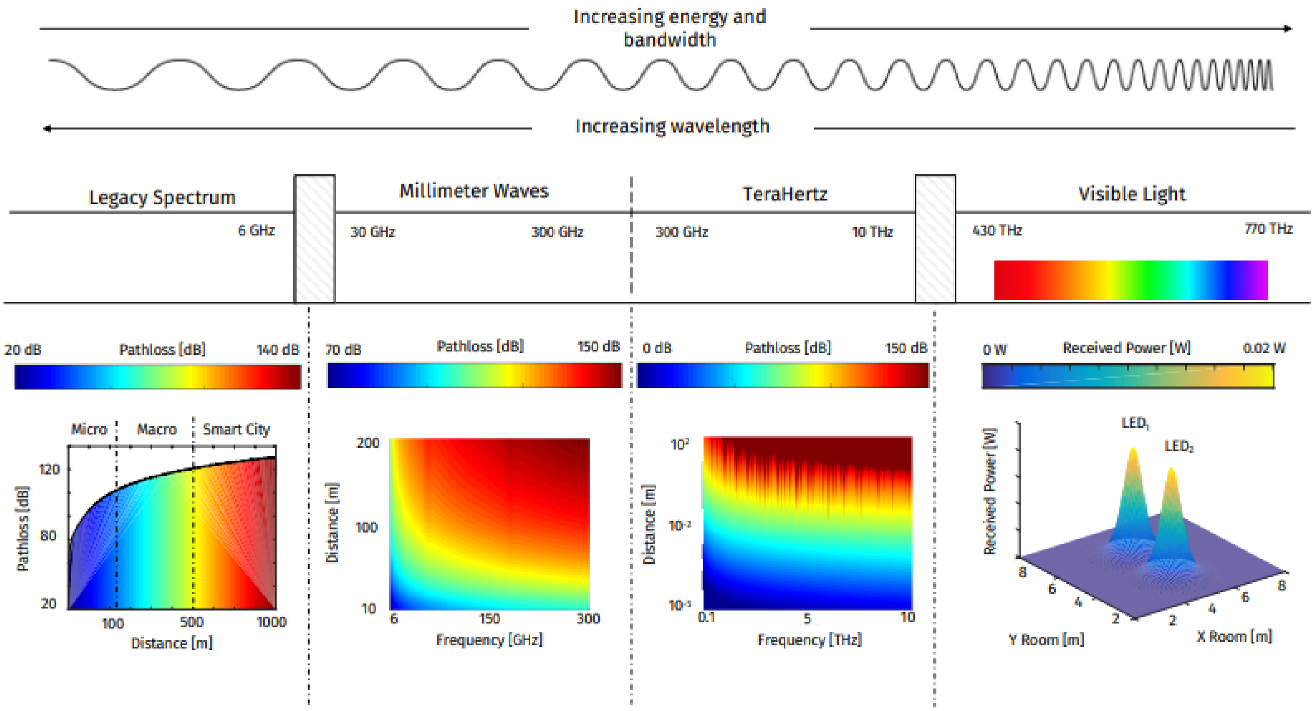

Fig. 3: Pathloss for sub-6 GHz, mmWave and Terahertz bands, and received power for VLC. The sub-6 GHz and mmWave pathloss follows the 3GPP models considering both Line-of-Sight (LOS) and NLOS conditions, while LOS-only is considered for Terahertz [10] and VLC [12].

Alongside the new spectrum, 6G will also revolutionize wireless networks, leveraging the latest technologies enabled by the latest research in the field of physical layers and circuits; however, they are not included in 5G. The following technologies will be the primary technology enablers for 6G:

- applications.
- **B. Innovative Network Architectures Full-duplex communications stack**. With full-duplex communications, the transceivers will be capable of receiving a signal while also transmitting, thanks to carefully designed self-interference-suppression circuits [13]. Practically, full-duplex deployments require changes in the antenna design and circuit design to minimize interference between the transmitter and receiver circuits of the wireless device. Therefore they have yet to be incorporated into the current specifications for cellular networks. Technology advancements in the future allow simultaneous transmission of uplink and downlink and will improve the capabilities of multiplexing and the overall system's capacity without requiring more bandwidth. But, the 6G networks will require careful planning of the full-duplex deployment and procedures to prevent interference and create a new resource scheduler design [13].
- **Innovative channel estimation methods (e.g. out-of-band estimation or compression sensing).** Channel estimation in directional communication will be essential in mmWaves and Terahertz frequencies. However, developing efficient strategies for directional communication takes time, considering several frequency bands and possibly a considerable bandwidth. Thus, 6G systems will require innovative channel estimation methods. For example, out-of-band estimation (e.g. to determine the angular direction for the signals) will improve beam management's responsiveness by mapping the all-directional propagation of sub-6GHz signals to channel analysis of frequencies in the mmWave band [14]. Also, considering the sparseness in terms of the angular direction of the mmWave and Terahertz channels, it is possible to utilize compressive sensing to determine the track with smaller samples.

Sensing and network-based location. The use of RF signals to allow simultaneous mapping and localization is extensively researched. However, these capabilities have yet to be fully integrated into the operations and protocols of cell networks. 6G networks will utilize the unified interface between communication and localization to (i) enhance control processes and depend on context data to determine patterns for beamforming to reduce interference and even predict handovers (ii) provide innovative user applications, e.g., for automobiles as well as eHealth

The change brought on by the technologies for communication described in Sec. III-A will allow a brand new architecture for the 6G network. However, it could also require structural modifications to the current models for mobile networking. For instance, the high density and the high-speed data speed of Terahertz communications will create more capacity for the transportation network that needs to provide more points of connectivity to fibre and a greater degree than the current backhaul networks. Furthermore, the range of communication technologies that are accessible will increase the heterogeneity that the networks will have and needs to be managed.

The significant architectural changes that 6G will bring to the table are detailed in Fig. 4. In this regard, we envisage the introduction or deployment of these models:

- **Tight integration of multiple frequencies and communication technologies and cell-less architecture**. 6G devices allow a range of radios that are heterogeneous in the devices. This will enable multi-connection methods that expand the existing limits of cell networks and connect users to the web in general (i.e. via several technology alternatives) rather than just one cell. The network-based cell-free procedures will ensure a seamless mobile experience, with no overhead caused by handovers (which can be frequent in systems operating at Terahertz frequencies) and also provide security guarantees for QoS that conform to the most complex mobility requirements that are anticipated for 6G, such for example, in vehicular scenarios. The devices can effortlessly switch between heterogeneous connections (e.g. sub-6 GHz, mmWave Terahertz, or VLC) without requiring manual intervention or setting up. In addition, based on the particular use case, users can also utilize multiple interfaces for network connectivity to benefit from their unique features, e.g., the sub-6 GHz layer to control and control or the Terahertz link to the information plane.

• **3D network architecture.** 5G networks (and earlier generations) were created to offer connectivity to most of a bi-dimensional space, i.e. network access points are used to provide connectivity to devices located on the ground. However, we imagine future 6G heterogeneous architectures that offer 3D (3D) network coverage, thus supplementing terrestrial infrastructures by using terrestrial platforms that are not terrestrial (e.g. drones, drones, balloons, satellites and so on). Additionally, these components can be deployed quickly to provide continuous service reliability and continuity, e.g., in remote locations or during events, thus avoiding the management and operational costs of fixed, always-on infrastructures. However, despite these exciting possibilities, numerous issues must be resolved before flying platforms can be utilized to create wireless networks. e.g. the air-to-ground channel model, trajectory and topology optimization, management of resources, and energy efficiency.

• **Virtualization and disaggregation of networking equipment**. While networks have begun to shift towards disaggregation and virtualization of previously monolithic networking equipment, the 3GPP needs to define how to implement virtualization concepts explicitly. In addition, the 5G studies currently in progress are not yet addressing the problems associated with the design of disaggregated structures that operate with the increased control latency that could be brought about through centralization, as well as the security of virtualized network functions that could be vulnerable to cyber-attacks. 6G networks will take disaggregation to a new level by virtualizing Medium Access Control (MAC) and Physical (PHY) layer components that currently require hardware-specific implementations and implementing low-cost distributed platforms using only antennas and minimal processing. This will reduce the price of networking hardware, making a pervasive deployment financially feasible.

• **They advanced backhaul-access integration.** The vast data speeds of the latest 6G access technology will require a significant expansion of the backhaul capacity. Furthermore, Terahertz and VLC deployments will boost the number of access points that need backhaul connectivity to their neighbours and the core network. The massive potential of the 6G technology can be utilized for self-backhauling solutions where radios within base stations offer access and backhaul. Similar options are already being explored in 5G technology; the size of deployments for 6G will present new challenges and possibilities, e.g. because the networks will require more capacity for autonomous configuration.

• **Energy-harvesting strategies for low power consumption network operations**. Integrating energy-harvesting techniques in 5G infrastructures is facing numerous issues, such as compatibility with communications and loss of efficiency when converting captured signals into electrical current. Due to the massive scale of the 6G network, it's essential to create systems in both the circuitry and communications stack designed with energy awareness in mind. One approach is to utilize energy harvesting circuits that allow devices to self-power, which could be crucial to enable, for instance, off-grid functions, long-lasting IoT sensors and devices, and long stand-by time for machines and equipment that are not used often.

C. Integrating Intelligence in the Network

Complexity of the 6G communications technology and network deployments will likely prevent closed-form and manual optimizations. Although intelligent methods in mobile networks are currently being explored in 5G, we anticipate the deployments of 6G to be larger (i.e. in terms of the number of users and access points) as well as more diverse (in regards to the interconnection of various applications and technologies) and have more strict requirements for performance in comparison to 5G. This means that intelligence will play an increasingly important role on the internet, far over the classifying and forecasting tasks being investigated for 5G networks. It is important to note that the standard does not provide the strategies and learning strategies to be employed in networks; however, data-driven strategies can be viewed as tools that network operators and vendors can use to meet 6G standards [1515. Mainly, research on 6G is geared towards these aspects:

• **Learning techniques for data selection and feature extraction**. The massive amount of data produced by the future technology that is connected (e.g. sensor systems in autonomous vehicles) will place a burden on communication technology, which will not be able to guarantee quality. Therefore, it is crucial to distinguish the worth of data to maximize its value for users who have (limited) network resources. Machine learning (ML) methods can assess how much correlation exists between the data, draw specific features from input vectors, and calculate the probabilities of an a-posteriori sequence based on its entire time. In 6G methods, reinforcement and unsupervised learning strategies, for instance, do not require labelling and can manage the network independently.

• **Information sharing among inter-users.** Sharing spectrum and infrastructure can be beneficial in cell networks, increasing the capabilities of multiplexing. With networks that learn, operators and users can also share their learned representations that describe specific deployments or applications, such as to speed up network set-up in new markets or to be better able to adapt to unpredictable operational scenarios. The trade-offs between power consumption, latency system overhead, and costs will be examined in 6G for both edge cloud-assisted and on-board solutions.

• **User-centric network architecture.** ML-driven networks are at an early stage. However, they will become integral to complex 6G systems that envisage distributed artificial intelligence to create a user-centric network design. As a result, the final terminals can take autonomous network decisions by analyzing the results of previous actions, with no communications overhead between and to central controllers. Distributed methods can process ML algorithms in real-time, i.e., with low latency required by a variety of 6G-related services, leading to better network management that is more responsive.

IV. CONCLUSIONS

In this article, we have reviewed the various use cases and technologies we believe will be the basis for 6G networks. Table 1 summarizes primary issues, possibilities and use instances of each enabling technology. Research in 6G wireless could disrupt the conventional cellular network concepts in 5G. It will introduce, for example, support for Terahertz as well as visible light spectrums, cell-less as well as aerial architectures, as well as enormous distributed intelligence for instance. However, these technologies still need to be ready for commercialization. This is an excellent opportunity for researchers in the field of wireless to create new technologies that could lead to unimaginable digital applications for the 2030 era and beyond.

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