Key Technologies for the Advent of the 6G

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***Abstract*—True, the scientific community still has a lot to investigate on how to get 5G to have a satisfactory journey in the development of standards. However, it is now that we must begin to glimpse the future of mobile technology, it is time to imagine what 6G will be. This paper offers a realistic view of what this technology might be. In this case, the experience of one of the most important groups in Europe dedicated to the mobile communication systems design, the iTEAM research institute, is combined with the one of the world's leading manufacturers of femtocells, Casa Systems. From the belief that the deployment of 5G will come from homes, this paper analyzes the new use cases of the 6G, as well as the three technological pillars of this future technology.**

***Index Terms*—6G, Beyond 5G, Federated Deep Learning, Cell-less deployment**

I. Introduction

For more than forty years, engineers and researchers have been developing new technologies and standards of the different generations of mobile communications not only to accommodate the always increasing demand of traffic, but also to improve human and machine communications [1]. Nowadays, we are seeing that the brand new 5G is rolling out in small scale in the form of a campus-style or even private networks. However, taking into consideration that the main scenarios of 5G were defined as three, namely enhanced mobile broadband (eMBB), massive machine-type communications (mMTC), and ultra-reliable low-latency communications (URLLC) [2], in Release 15 the only scenario receiving attention from the 3rd generation partnership project (3GPP) standards was eMBB.

That is, 5G has just been born, and we will still see in the coming years an important evolution of its characteristics, an evolution that will allow it to reach the three desired services. However, from the point of view of research, it is time to start talking about the sixth generation mobile, that is, the technologies that will change the way we see the world in 2030. This is the advent of the 6G.

Although it seems surprising, it was in September 2018 when the first rigorous article dealing with the topic of 6G was published [3]. Klaus David was the first one to wonder if a new generation mobile was really needed. Soon, other researchers came to the discussion reinforcing the idea that yes, on their view there will be a new paradigm that supposes the sixth generation mobile. In fact, the first ideas regarding the 6G revolution came from the hand of quantum technologies. In April 2019, Nawaz *et al.* [4] defended the idea that the 6G should be the union of greater transmission capabilities and artificial intelligence (AI) enabled by quantum processors. They would not be the only ones, since from this point on, any contribution on the 6G vision includes a fact: the 6G will bring the incorporation of AI into mobile communications systems [5]–[8].

Some more recent articles go one step further, and come to define the key performance indicators (KPIs) that will characterize it [5], [7]. Others focus more on use cases [8], or even to investigate unconventional communications, such as underwater [5]. As with AI, everyone agrees that the 6G will be a Terahertz technology, likely using visible light communications (VLC) too.

This article carries out a conceptualization exercise of the 6G from the conviction that the network will be articulated from indoor plus aerial deployment and, therefore, conventional base stations will be removed. For this, we have gathered the vision of one of the leading groups in mobile system design in Europe, the iTEAM, and the North American company Casa Systems, manufacturer of femtocells. Firstly, this paper will present the main use cases that, from our point of view, will require the design of a new mobile generation. Next, the three technological pillars of this 6G will be described in detail, that is, the cell-less deployment, in Section III, the extension of the access point up to a few meters distant from the user, in Section IV, and the configuration of a federated network of shared intelligence, in Section V. The concluding section gathers some final questions, as well as suggestions on how to arrange the process that comes in the near future.

II. Vision on the Use Cases

The definition of a new mobile generation always begins by imagining, in the first place, the most characteristic applications of the society making use of that technology. In this case, we have to project our imagination to 2030 and figure out how our society will look like in 10 years.

Figure 1 shows an exercise of this speculative projection, where the main services are distributed in space according to three axes. These axes correspond to a group of services as proposed in this article, depending on the main characteristics that define them. Specifically, three types of services have been contemplated and are described in the following sections.

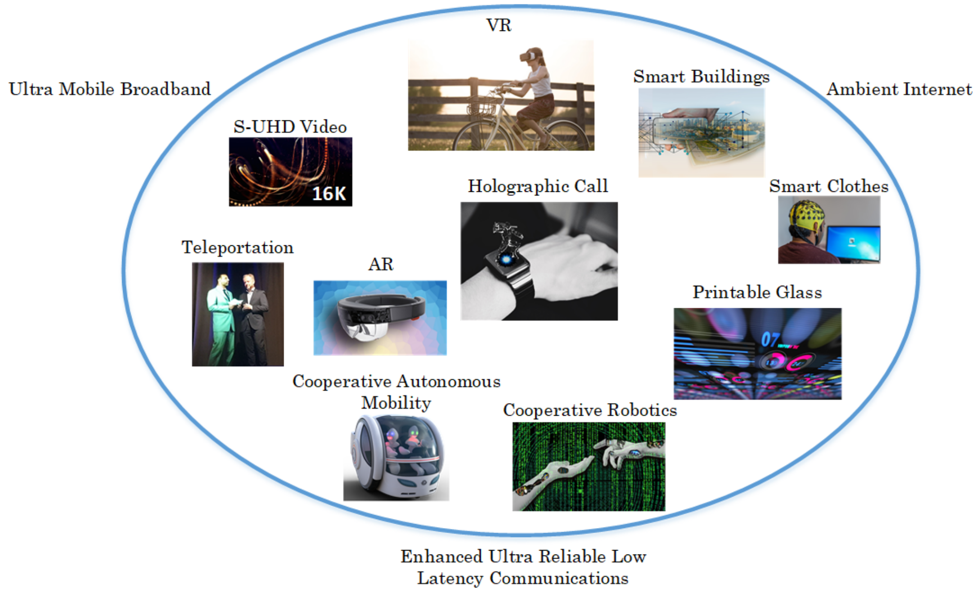

Fig. 1. Use cases envisioned for 6G organized according to dimensions of UMBB, Ambient Internet and eURLLC.

Special attention is paid to the holographic call service, since this is, in the authors' view, the killer application of the 6G.

A. Ultra Mobile Broadband

The type of Ultra Mobile Broadband (UMBB) service is characterized by the fact that is the capacity of the link which determines the quality of experience of the end user. Typically, it can be assimilated with the services that are executed in the user's terminal, although it is not clear if this terminal will be a handheld device, a watch, a wearable or some kind of glass or headset.

One aspect in which all researchers agree upon is that this type of service will continue to exist, and it is likely that with capacity requirements not much higher than those offered by 5G, but in any case, providing a transmission experience in the terminal between 10 and 100 Gbps. Some applications under this category could be the following:

- Super-Ultra High Definition (S-UHD) Video: current devices support 2K+ pixels and a refresh frequency of 60 Hz. For dimensions of around 6 inches, this resolution seems sufficient and our retina would not be able to identify a higher resolution, except for the refreshment, that raising it to 100 Hz would show greater fluidity in the videos. The inclusion of higher resolutions on phone screens are justified by the development of virtual reality technology. When the phone is situated so close to the eyes, pixels are an issue. 16K resolution with a refresh rate of 240 Hz is deemed to be the resolution able to make us have a full immersive virtual experience, or project the image in a larger screen, e.g. in the wall of the dinning room. S-UHD refers to a display resolution of 15360 horizontal pixels by 8640 vertical pixels, resulting in a total of 132.7 megapixels per frame. With a refresh rate of 240 Hz, and plain RGB coding, this results in about 750 Gbps data rate. This is UMBB, indeed.
- Virtual Reality (VR) on the move: when this S-UHD video gets moving, problems grow. Mainly in two dimensions, the accuracy in the necessary location and the feedback obtained from the environment. The VR gets closer to the Ambient Internet concept discussed in Section II.C since the virtual world has to adapt to the real world and vice versa in order to allow the user to move along without physically crushing with the real objects around that are hidden to his/her eyes. Here the problem lies in the ability to compute and sense in real time that allows adapting the virtual world to the client's desire and to the underlying reality. The interaction with the surrounding objects will be fundamental, and the connection will be of proximity. The architecture requirements from the new 6G network are based on the flexibility and the local interaction of connected devices and sensors.
- Teleportation: 3D holographic projectors already exist. They are based on two perpendicular LED lines that, hanging from the ceiling or on the floor, allow projecting a 3D image in space. The object to be teleported must be characterized as an Avatar, that is, creating a kind of fictional object –like an object of a game– that characterizes said person or thing. For this, a set of cameras have to record in real time the object to teleport and build the avatar in real time, to later transmit it and be projected. To sum up, what is projected is a 3D reconstruction of a real object or person. In the case of a person, it could even be transported virtually to the new location just by placing a 360 camera at that point and using a VR glass reproducing what is being recorded by the camera. Humanity has finally managed to teleport, but

not by displacing the body, but by bringing the world to us. Along 2019, teleportation experiences have already been done over a 5G network, although those experiences to date are very static and of poor quality. By 2030 teleportation will be a daily-use application, a mobile reality that will require transmission capacities at least higher than 1 Gbps everywhere.

- Augmented Reality (AR) on the move: in this case the idea is to superimpose to reality some context information that allows interacting with this reality in a rich way. A kind of glass or helmet shall be used with a light projection over the crystal. From the point of view of data connection, requirements are low –below 100 Mbps in the worse case–, since the information is minor, although accuracy in location must be in the order of few centimetres and response to the movements of the head must be fast to avoid dizziness, more specifically, below 20 ms [9].

B. Enhanced Ultra Reliable Low Latency Communications

Enhanced Ultra Reliable and Low Latency Communications (eURLLC) refers to the evolution of concepts already present in the definition of 5G and which are related to the speed in which objects are able to communicate with a guaranteed transmission that in many cases will be necessary for safety reasons. Two main applications are clear examples of this:

- Cooperative Autonomous Mobility: the means of transportation as we know them today are about to change. The recent advances in wireless communication networks and the technological development of the automotive industry have paved the way for a safer transportation of passengers and goods. Multiple technologies can be integrated in one autonomous and intelligent vehicle that shall take care of their passengers. In this context, the term Intelligent Transportation Systems (ITS) refers to a new set of information and communications technologies that allow vehicles to exchange information among them and with the infrastructure to improve road safety and travel comfort. Services like auto-activation of the vehicle brakes, and the identification and communication to the driver of road hazard warnings are planned to be feasible in 5 years. At that time, the transportation industry will begin to wonder how to continue evolving, and for this question, there is a clear answer: efficient transportation. However, several things are missing to get a real efficient transport system, mainly because of the current low vehicle-to-vehicle (V2V) communication channel capacity and reliability. Free-Space Optical (FSO) communication and the extension of conventional wireless technologies to multi-hop communications are clear technology trends that will make this service be ultra reliable and ultra low latency. Target values refer to a hundred of microseconds and full reliability of the transmission via multiple paths of communication. Without any doubt, safety is a must when the AI will take control of our vehicles.
- Cooperative Robotics: just like autonomous cars, autonomous robots are a technological reality. The use case of cooperative robotics refers to the future of the industry, what is called Industry 4.0, in which the production processes are flexible and necessarily wireless to exactly match the product-to-product demand. In this scenario, the robots will carry out cooperative production functions, manipulating two robots the same piece and requiring in this case precision levels not known so far to ensure maximum accuracy. The required latency is unknown yet, but should go below the current 1 ms of the 5G.

C. Ambient Internet

Ambient Internet refers to the last conceptual evolution of the Internet, in which historical information coming from all devices in the network is combined with contextual data from the ambient coming from nearby sensors and, then, AI is applied to produce at the end new user experiences that can be executed into the devices of the network. Home assistants, such as Amazon Alexa or Google Home, are preluding this concept that we are starting to look at today. Some voices call this concept Ambient Internet, others call it Internet of Bodies. In the authors' view, this is the 6G.

With respect to some relevant applications related to this kind of service, the following two can be highlighted:

- Smart clothing and environment: all the things and objects we have around will be sending information, even our clothes, which will in turn make our context rich-full and therefore useful for the network. Multiple touchpoints will exist, like cars, speakers, chatbots, cameras, etc. Sensors will be everywhere, and they will make AI agents guess what you most likely need at any moment. As an example, publicity could be adapted to the people that is around, or lighting can be following you, like also doors or air conditioning.
- Printable glass and projected objects: augmented projection interfaces are needed in the form of glasses, clocks, windshields, etc. Heads Up Displays (HUD) used in cars are the technology more mature now. An inherited concept from gaming, with HUDs it is possible to superimpose relevant status information on the windshield of the car, so that the driver can see the road through an image projected on the window of, for example, the odometer. In order to achieve that, what is done is to install a projector on the dashboard of the car, and modify the characteristics of the windshield glass to be more reflective, and therefore the driver can see a reflected image of the projection on the glass. A similar technology could be developed for car windows, house windows, shop windows or, why not, our glass bottle, which reminds us our water consumption.

D. The holographic call

From the point of view of the authors of this article, the holographic call represents everything that 6G will be. Imagine that someone calls you and when answering the hologram of this person appears on your wrist device (see central figure inside Figure 1). The question is how to get the recording of your avatar to be projected in mobility, anywhere and without having a specialized recording studio around. The answer lies in the collective intelligence of the network. Any camera seeing you will record images of you and configure another piece of information about your avatar, your virtualized self. Therefore, it may be e.g. the traffic camera that detects your clothing, and the camera of your neighbor in the elevator that detects the shoes you are wearing today. At the end, the details of your face can be captured in live with your front camera, making your avatar created with collective intelligence get alive. UMBB, eURLLC and Ambient Internet, all together in a single application.

Fig. 2. Cell-less deployment concept.

III. Cell-less Deployment

To date, the cellular concept has been a key element of the mobile and wireless communication networks. It enables an efficient use of the scarce spectrum resources by allowing its reuse in different locations. In this context, cell densification has been a common means to increase the total capacity of a system, and hence we have seen macrocells being complemented by microcells, then picocells and, eventually, femtocells, each one covering shorter ranges. With the advent of the 6G, even smaller cells, namely attocells and zeptocells, will be deployed, with ranges lower than 10 meters and 5 meters, respectively, to satisfy the higher capacity needs. These kind of cells are already foreseen in the context of VLC communications, where attocells are meant to cover rooms, while zeptocells would cover a part of a room, e.g. a desktop. Additionally, this smaller-than-femto cells are also the currently assumption when talking about cells operating in the THz band of spectrum.

The extreme densification will be a reality, above all, in indoor scenarios, where VLC and THz communications characteristic short range is not a significant problem because of the smaller areas to be covered. These technologies come with a huge potential capacity that will be of great use to satisfy the needs of capacity-hungry applications such as S-UHD video, VR, teleportation, etc., which will be commonly indoors. However, we foresee that the huge increase of capacity will exceed the needs of indoors communication allowing the use of part of this capacity to serve the outdoor surrounding environment. Indoor coverage would not be anymore just a problem but a solution that would allow the network operators to reduce the number of long-range cells. In fact, we foresee a more general trend in which the higher density of short-range stations will lead to less and less long-range stations being active, eventually leading to the end of the macro-stations.

An important problem of the cellular concept is the inter-cell interference, which has an impact on the quality of service experienced by the users in the border of the service areas of different cells. Cell coordination techniques have been proposed to mitigate this problem, but these proposals have not been implemented in reality. One reason is the high complexity of some proposals, whose real time implementation was not feasible. Another reason is that some proposals were useful basically in ultra-dense deployments, which have not been deployed in the real world. Nevertheless, these conditions will change in 6G. The outcome is that it will be feasible a higher degree of joint work between neighbour cells. Users could in this case be connected to multiple cells that would coordinate its resources as if they were part of a single pool of resources, the Radio Access Network (RAN) pool. Therefore, the user would no longer be connected to a specific cell, but to the RAN itself. In this regard, the higher number of transmission/reception points will not result in more cells, but in a cell-less deployment where the center is not the cell but the user, or the service, whose requirements are satisfied by the RAN as a whole.

Not only the network is expected to be denser in the context of 6G, also the user density will increase. In the Ambient Internet, a huge number of devices will require local or remote connectivity. A majority of these devices will have low cost and low energy communication equipment, which will benefit from dense network deployments in which the communication takes place in short ranges. But, another implication of this fact is that there will be a huge number of elements with communication equipment. These devices can be not only termination points, terminals of the communication. Instead, they can take an active role in the network being another node more of the radio network. Of course, this is a game-changing idea that has implications on the business models, data privacy issues, etc., but whose benefits would be undeniable. It is clear, for example, that this idea would increase significantly the density of the radio network with the above mentioned benefits. For this vision to be implemented in practice, we foresee that a feature neglected in previous generations has to be considered: multi-hoping. One clear application of multi-hoping is V2X communications. Although multi-hoping has been considered in vehicular ad-hoc networks for a long time, 5G standards have overlooked this feature. However, in the age of autonomous vehicles, we can no longer underestimate its usefulness to empower the vehicles with the higher level of connectivity that comes with multi-hoping.

The end of the cellular era is reinforced by the increasing importance of two types of connectivity nodes, namely unmanned aerial stations and high throughput satellites. Its privileged position in the air facilitates the provision of wide coverage by using them, what makes long-range terrestrial stations less important. Unmanned aerial stations provide an additional benefit which is the high dynamicity in the system configuration and its fast deployment for emergency situations. These concepts are not novel, but its increasingly maturity and the prospect of better regulation and deployment in the 6G time frame will make them a reality.

Figure 2 illustrates the cell-less deployment concept, where macro-stations have been ignored on purpose to highlight the key role of short-range stations, new roles of user devices, indoor-to-outdoor coverage, multi-hopping, high-throughput satellites, and unmanned aerial stations.

IV. Network Everywhere

With the 6G the Internet will move from being available anywhere and anytime in a device to being available everywhere at any time through most devices. Interactions will be different, and the mobile screen will no longer be the only possible interface for our interaction with the Internet. With 6G, in fact, the Internet will disappear from the users life, embedded in the system in a way that obfuscates it.

The most natural next step towards this vision is to distribute antennas everywhere, in such a way that the distance to the end user is reduced to few meters and hopefully with always line of sight conditions. The shorter the link length the better for propagation, interference confinement and feasibility of using higher frequency bands. Next sections are dedicated to describe how this hyper-dense network could work.

A. Radio-stripes

The concept of radio stripe arises from an idea of Ericsson published in 2018 [10]. In the concept of radio stripe, the antennas and their processing units are connected serially within the same cable, or cable roll, so that a shared bus offers the necessary information for synchronism, data transfer and power supply. In this continuous antenna cable, each access point includes all the required circuit-mounted chips within the same protection cover, so that a radio stripe actually includes multiple antenna elements, as much as the length of the cable.

The radio stripe concept allows flexible and very cheap deployment of a massive antenna system, regardless of the cell concept. From the point of view of what this entails, we would have to imagine how architecture could incorporate this type of radio stripes into any building element and thus make the antennas really be everywhere. Figure 3 shows an example of the ease with which the system could be incorporated in blinds, columns or cornices and ceilings, so that the 6G network could have direct vision from any point to the connected devices.

B. Focused and seamless wireless charging

Since we have antennas everywhere, the idea is to make the most of it and use use beamforming for contact-less battery

Fig. 3. Change in the architecture for the radio-stripe concept.

charge, this is typically referred to as power beaming [11]. If the network is less than 1 m away, all devices could be charged from the same network provided that the beampointing is good enough because a huge number of antennas is used. With the radio-stripe concept, we could go for hundreds of antennas and, therefore, reach the devices without any problem. In fact, the state of the art states that this way of wirelessly charging could reach even kilometers of distance with the appropriate signal processing [11].

C. Terahertzs

With the network everywhere, where there is always direct vision and short distance between transmitter and receiver, propagation losses are no longer a problem and it is possible to rise more in frequency, beyond the millimeter wave bands proposed for the 5G. In the literature, Terahertzs communications refers to the use of spectrum from 0.1 to 10 THz. In this band we can actually have electromagnetic and light waves, with better propagation conditions than some bands in the mmW spectrum, due to the lack of zones where electromagnetic radiation is absorbed by water. Moreover, the spectrum chunks in Terahertz band can be of hundreds of gigahertzs, allowing potentially for the terabit communication objective. Finally, it is worth highlighting that the wavelength in the Terahertz band is by far much shorter than the millimeter wave band, and therefore antenna integration and packaging is supposed to be easier, which is of special relevance for the radio stripe realization.

V. Federated AI-based Network

Machine Learning (ML) is an application of AI, based on providing computers with programs that allow them to learn automatically using training data for prediction and classification. Moreover, the proficiency of ML depends on the the existence of an acceptable amount of data to analyze and process and has the dilemma of the large delay of data processing. This condition creates a limitation in the deployment of ML models. Thus, Deep Learning (DL) joined ML as a new family member [12], bringing vigorous algorithms based on structuring the available data using deep neural network. Those algorithms are used in wireless networks such as network traffic classification prediction and control, interference classification, wireless resource allocation, channel estimation, modulation recognition and more [12]. DL has proofed its capacity to reduce the processing time, by executing the algorithms on advanced graphics processing units and advanced tensor processing units.

The 6G will be able to feed the hunger of DL towards data. With the Ambient Internet, data will be continuously collected from a plethora of devices located everywhere around us. In AI nomenclature, the 6G will be a federated deep learning network, where the intelligence is distributed among a number of points. DL and massive amount of data comes with two big challenges, massive data classification and security.

A. Quantum computing for the federated DL process

Conventional computers are built from billions of transistors that are turned 'on' or 'off' to represent a value of either '1' or '0'. This allows classical computers to store data in form of bits. In contrast, quantum computers process information using quantum bits or 'qubits' that can be represented by superconducting electronic circuits. Due to laws of quantum mechanics, qubits can exist in more than one state at the same point in time. This makes a qubit assume a value of '1' or '0' or both simultaneously. In turn, this enables a quantum computer to process a far higher number of data possibilities than a classical computer. Thus, if we have n interacting qubits, they can simultaneously represent 2^n unique binary patterns, instead of a single binary pattern at-once in the case of classical computers. In addition, assuming superposition, qubits can become 'entangled', which means that the sate of a qubit can depend on the state of anothers. This is useful and powerful, as it means that observing one qubit can reveal the state of its unobserved pair.

Indeed, this is the era of quantum computing (QC). IBM, Intel and Google have already got advanced cloud-based quantum hardware as well as quantum processors. Besides, those big companies are targeting production-level quantum computers within ten years.

The combined framework of QC and DL will help develop powerful and efficient DL algorithm to satisfy the requirement of 6G. Taking into consideration that in 6G the data transmitted will be in the order of Tbps, using classical computer will not be enough. Therefore, the use of QC is a must to boost the computing capability of the 6G system.

DL in 6G will be used to manipulate and classify a large amount of data in the form of large-dimensional vectors. On the other hand, QC has the great potential to manipulate such large-dimensional data vectors. As a result, this combination will lead QC to accelerate the intelligent data analysis methods of DL [4].

Another advantage of using QC with DL is to provide strong security, which is based on the use of the quantum no-cloning theorem and uncertainty principle. Therefore, in a quantum communication, the qubit is disturbed whenever a wiretapper try to copy or listen to data. This allows the system to detect strange behaviors [13] and potential attacks.

The previous indications assert that the truly intelligence in communication networks will become a reality in 6G communications with QC-assisted DL in a federated AI-based network.

VI. Conclusion

It is not clear how society will be in the year 2030, but this paper is a projection exercise to foresee what will be necessary for the mobile network to support in the next generation. There are still doubts about whether there will really be a radical paradigm shift, but there should not be any doubt on the fact that there will be a sixth generation mobile, because the digital world is about to explore its maximum realization. From here, it will be a matter of the ITU-R to trigger the consultation process, a process that will begin to be discussed in 2023 and that will call the international community in 2026. Until then, science will continue inventing until the policy puts the industry to work.

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