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The Case of 6G and Beyond

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Abstract-Following the commercialization of 5G technologies, both academia and industry are initiating research activities to shape the next-generation communication system, namely 6G. Considering the general trend of successive generations of communication systems introducing new services with more stringent requirements, it is reasonable to expect 6G to satisfy unprecedented requirements and expectations that 5G cannot meet.

We expect that 6G will provide ultimate experience for all through hyper-connectivity involving humans and everything. In this research, we aim to provide readers with a comprehensive overview of various aspects related to 6G, including technical and societal trends, services, requirements, and candidate technologies.

Keywords- *6G, Bandwidth, Satellite Communications, Frequency, Satellite Bands*

I. SUMMARY

For 6G, it should be pointed out that many frequency bands spanning from 28GHz to 90GHz (and beyond) are also under consideration.

This spectrum has already been extensively used for decades, mostly for satellite communications in the figure below:

TABLE I. SATELLITE BANDS: THESE BANDS ARE WITH THE RADIO AND MICROWAVE FREQUENCY BANDS

Frequency	Low GHz	High GHz
C	3.7	4.2
Ku	12	18
K	18	26
Ka	26	40
V	40	75
W	75	110

TABLE II. LOW, MID AND HIGH BAND AT A GLANCE

Nomenclature	Frequency Range	Available Band
Low-Band	600 – 705MHz	20MHz
Mid-Band	3.7 – 4.2 GHz or share the 500MHz spectrum with intelligent resource sharing	20MHz
High-Band	24.26 – 24.45GHz 24.75 – 25.25GHz 27.5 – 28.35GHz	200MHz 500MHz 850MhZ

In this case, the issue is not feasibility but how to apportion some specific shivers of this spectrum for 6G specific applications.

It seems beneficial to assume that the need for larger allocations of Bandwidth will be necessary in the future as new applications (like holographic communications) will require a huge amount of bandwidth to carry the necessary volume of information required.

It is therefore useful to keep this concept in mind so that construction of the next network could be done in the near future in such a way that it could conveniently accommodate for new capabilities in the more distant future without having to completely tear down one network to build the next one.

A. Megatrends toward 6G

Applications that take advantage of wireless communications are expanding from connecting humans to connecting various things. Wireless communication is becoming an important part of social infrastructure and people's daily lives. In addition, today's exponential growth of advanced technologies such as artificial intelligence (AI), robotics, and automation will usher in unprecedented paradigm shifts in the wireless communication. These circumstances lead to four major megatrends advancing toward 6G: connected machines, use of AI for the wireless communication, openness of mobile communications, and increased contribution for achieving social goals. The rest of this section discusses details of these four megatrends [1].

B. AI

1) New Tool for Wireless Communications

In recent years, the rise of AI has pervaded various areas such as finance, health care, manufacturing, industry, and wireless communication systems. Application of AI in wireless communications holds the potential to improve performance and reduce capital expenditure (CAPEX) and operational expenditure (OPEX)[2]. For example, AI can

- Improve performance of handover operation taking into account network deployments and geographical environments
- Optimize network planning involving base station (BS) location determination
- Reduce network energy consumption
- Predict, detect, and enable self-healing of network anomalies

The potential benefits of AI applied to wireless communications are promising. On the other hand, there is a limit to what is achievable today, as use of AI in communication networks was not considered when developing existing communication systems such as 5G. In the case of 6G, knowing that AI technologies are available for practical applications, we can develop a system that takes into account the possibility of embedding AI in various entities comprising wireless networks and services. A tremendous amount of data associated with hundreds of billions of connected machines and humans needs to be collected and utilized in 6G systems[3].

Considering AI from the initial phase of developing concepts and technologies for 6G will give us more opportunities to take advantage of AI for improvement of overall network operation in terms of performance, cost, and ability to provide various services.

II. 6G SERVICES

Representative categories of 5G services, i.e., enhanced mobile broadband (eMBB), ultra-reliable and low latency communications (URLLC), and massive machine-type communications (mMTC) will continue to improve moving towards 6G. In this section, we focus on new 6G services that will emerge due to advances in communications as well as other technologies such as sensing, imaging, displaying, and AI. Those new services will be introduced through hyper-connectivity involving humans and everything and provide ultimate multimedia experience. In the rest of this section, we highlight three key 6G services, namely, truly immersive extended reality (XR), high-fidelity mobile hologram, and digital replica [4].

A. Truly Immersive XR

XR is a new term that combines VR, AR, and mixed reality (MR). It has attracted great attention and opened new horizons in various fields including entertainment, medicine, science, education, and manufacturing industries. Technical development to realize XR is still in progress, and new 14 innovative technologies are constantly appearing. The critical obstacle between the potential and reality of XR is hardware. In particular, these technologies require advanced device form-factors, such as hand-held components, to support mobile and active software content. Current mobile devices lack sufficient stand-alone computing capability. Unfortunately, progress in hardware performance, especially mobile computing power and battery capacity, cannot keep pace with what the boom of XR requires. This discrepancy could severely deter market expansion. In our view, these challenges can be overcome by offloading computing to more powerful devices or servers [5].

Another challenge is sufficient wireless capacity. Note that current AR technology requires 55.3 megabits per second (Mbps) to support 8K display (with one million points), which can provide enough user experience on a mobile display. However, in order to provide truly immersive AR, the density should be largely improved and it will require 0.44 gigabits per second (Gbps) throughput (with 16 million points). In addition, XR media streaming may have similar demands to 16K UHD (Ultra High Definition) quality video. For example, 16K VR requires 0.9 Gbps throughput (with compression ratio of 1/400). The current user experienced data rate of 5G is not sufficient for seamless streaming. It is expected that the market sizes for VR and AR will reach $44.7 billion [6] and $87 billion [7], respectively, by 2030.

B. High-Fidelity Mobile Hologram

With the unprecedented rate of advances in high-resolution rendering, wearable displays, and wireless networks, mobile devices will be able to render media for 3D hologram displays. Hologram is a next-generation media technology that can present gestures and facial expressions by means of a holographic display. The content to display can be obtained by means of real-time capture, transmission, and 3D rendering techniques. In order to provide hologram display as a part of real-time services, extremely high data rate transmission, hundreds of times greater than current 5G system, 15 will be essential. For example, 19.1 Gigapixel requires 1 terabits per second (Tbps) [8]. A hologram display over a mobile device (one micro meter pixel size on a 6.7 inch display, i.e., 11.1 Gigapixel) form-factor requires at least 0.58 Tbps. Moreover, support of a human-sized hologram requires a significantly large number of pixels (e.g., requiring several Tbps) [9]. The peak data rate of 5G is 20 Gbps. 5G cannot possibly support such an extremely large volume of data as required for hologram media in real-time. To reduce the magnitude of data communication required for hologram displays and realize it in the 6G era, AI can be leveraged to achieve efficient com-pression, extraction, and rendering of the hologram data. The market size for the hologram displays is expected to be $7.6 billion by year 2023 [10].

C. Digital Replica

With the help of advanced sensors, AI, and communication technologies, it will be possible to replicate physical entities, including people, devices, objects, systems, and even places, in a virtual world. This digital replica of a physical entity is called a digital twin. In a 6G environment, through digital twins, users will be able to explore and monitor the reality in a virtual world, without temporal or spatial constraints. Users will be

able to observe changes or detect problems remotely through the representation offered by digital twins [10].

Users will be even able to go beyond observation, and actually interact with the digital twins, using VR devices or holographic displays. A digital twin could be a representation of a remotely controlled set of sensors and actuators. In this manner, a user's interaction with a digital twin can result in actions in the physical world. For example, a user could physically move within a remote site by controlling a robot in that space entirely via real-time interactions with a digital twin representation of that remote site.

With the help of AI, digital replication, management of real world and problem detection and mitigation can be done efficiently without the presence or even detailed supervision by a human being.

III. CONCLUSION

The mobile industry has achieved great successes, from 2G to 4G. While it is still quite important to work to ensure commercial success of 5G in coming years, we believe it is the right time to start preparing for 6G. Shaping 6G will require many years, as we have seen with previous generations in the past. In this spirit, we have presented our initial view of various aspects of 6G including the megatrends, services, requirements, candidate technologies, and timeline for standardization and commercialization. Our view will naturally be updated as we proceed with our research for 6G in the future.

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