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OPINION

An overview of quantum computing and quantum communication systems

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1 | INTRODUCTION

While the commercial deployment of 5G networks and beyond is a reality, the first work for the definition and study of 6G networks has started. The scientific community agrees that these networks will be characterised by a very high spatial density of access points, heterogeneity of access technologies, an increased number of users per access point, and demand for ubiquitous connectivity that must combine ultra-low latency, very high bandwidth, and high energy efficiency [1, 2].

Among the emerging challenges, holographic communications, high-precision manufacturing, the ubiquitous introduction of intelligence, and the incorporation of new technologies based on sub-terahertz (THz) or Visible Light Communications (VLC) are real issues. These are taking place in a truly three-dimensional coverage framework, integrating terrestrial and aerial radio to meet the needs with cloud-based capabilities where and when needed (on-demand). Radio frequencies are used in wireless telecommunications, but the need for very high throughput requires wider bandwidths, hence very high frequencies, in particular THz bands.

Moving to a higher frequency range—from 100 GHz to 10 THz—is expected to significantly increase the bandwidth of the radio channel, which will make it possible to serve a significant number of users. In this case, we are not talking about the connection of cell phones, tablets, or computers (and even smart cars)—we are considering the use of Internet of Things (IoT) devices, which within one base station can be quite a lot. Therefore, the technologies for beamforming, device location, etc., developed for the 5G generation that is just being implemented now should also remain but will be used at higher frequencies [3].

For which 6G is primarily intended, IoT solutions have been given a particular name: 'human-machine-things'. They involve three elements in the system: a person as a physical carrier; an intelligent device with which the person interacts; collects data and executes commands from an application running on the person's device [4].

The 6G radio networks will provide the means of communication and data gathering necessary to accumulate information. Still, a system's approach will be required for the 6G technology market as a whole involving data analytics, artificial intelligence (AI), and next-generation computation capabilities via HPC and quantum computing [3, 5].

This tremendous amount of data may be harnessed, with strong processing and learning capabilities, to manage the network at different levels. To this end, quantum computing methods can play a significant enabling role and can provide a guaranteed security platform.

Towards provisioning this massive connectivity and efficiently processing the voluminous data available at the user and network sides, quantum-powered computing methods have a strong potential in realising the ambitions of a service-driven, fully intelligent 6G communication network.

2 | RESEARCH CHALLENGES IN QUANTUM TECHNOLOGY

There is every reason to believe that the integration of quantum technology can improve the throughput, efficiency, and security of 6G networks. In addition to the advantages mentioned above, this technology also has benefits in computing speed, guaranteed security, and minimal storage requirements. This makes it ideally suited for various future quantum communication network applications. Research is needed on many fronts to evaluate the potential opportunities of quantum computing in 6G applications.

2.1 | Quantum-resilience for 6G

In 5G, a functional division is operated in both the RAN and core networks to meet the ultra-low latency and ultra-high efficiency requirements of 5G verticals. Notably, RAN functions are split into cloud-deployed services with interfacing capabilities. This new architecture has a significant impact on the efficient implementation of security processes [6]. One of the key challenges in deploying secure 5G networks is analysing how current cryptographic algorithms for secure authentication and data transmission can adapt to provide secure authentication between services and secure data encryption while ensuring that stringent efficiency requirements are met [7].

2.2 | Quantum-assisted design of wireless systems

The powerful parallel processing capability of quantum search algorithms can be leveraged to solve large-scale wireless optimisation problems. (1) Is this 'beyond 5G?' This topic is highly exploratory and undoubtedly beyond the boundaries of core 5G R&D. (2) What are the new features and key challenges? Classically, the mutual information between the channel input and output must be maximised. For quantum channels, the capacity must be redefined. Quantum channels can increase the achievable capacity. As a result, error correction without redundancy is possible on noisy channels. Quantum computers can enable exponentially complex combinatorial ML decoding in classical systems [5, 6].

2.3 | Ultra-low-power circuits with high-performance processing capabilities

To cope with latency-critical scenarios such as automated cars and medical applications, communication must be accomplished in a concise time. Achieving latency of only a few milliseconds is a real challenge. To achieve low latency and ultra-high reliability, it is essential to develop powerful high-end processors that consume little power. Quantum computing seems to be a reliable solution to this issue [8].

2.4 | Variable radio resource allocation

With variable quality of service (QoS) requirements, a variable radio resource must be allocated to the user. This can be of variable bandwidth, variable power, or both. Another challenging aspect of 6G is that with the propagation frequency, the signal can attenuate quickly and have a high penetration loss at high frequencies [9]. The signal is also automatically attenuated when accessing homes, residences, or workplaces. As the frequency increases, radio waves attenuate and may have difficulty penetrating the walls of buildings and homes while affecting users' QoS requirements. Therefore, it is very important to develop stable, fast and accurate quantum algorithms to handle 6G communication requirements by dynamically allocating variable resources [10].

2.5 | Post-quantum cryptography and security architecture for 6G

The current 5G standard does not address the issue of quantum computing but relies on traditional cryptography. The development towards cloud and edge native infrastructures is expected to continue in 6G networks. While large-scale quantum computing can be expected to take a longer duration, it is time to prepare for the shift to cryptography that is secure in the post-quantum world. According to current knowledge, contemporary symmetric cryptography remains secure for the most part, even after the advent of quantum computing. Furthermore, authentication by a physical layer signature, such as RF fingerprinting, and some other technologies, such as randomisation of MIMO transmission coefficients, coding, etc., could potentially be used in 6G [5, 11].

2.6 | Optimisation of communication systems in 6G

Whether it is for the optimisation of heterogeneous resources in 6G networks that result in the solution of 'NP-complete' combinatorial problems, for the compensation of non-linear effects of a communication chain or the optimisation of MIMO transmitter pre-coding matrix, future network nodes and devices will have to be equipped with learning and decision-making capabilities through AI and machine learning, so that they autonomously optimise their operation in response to changes in the environment [5].

In this context, the use of optimisation techniques based on quantum computing and AI applied to the field of 6G networks could be of considerable interest. Besides, quantum computing allows NP-hard optimisation problems to be solved in linear time, making it possible to solve and execute network optimisation problems in a much faster time, even in real-time [12].

2.7 | Standardisation and Regulatory Aspects

Regulatory and standardisation work will impact our future technology solutions in 5G networks and beyond. Protecting individual privacy and identity has long been a challenge for standards bodies, as countries have very different perspectives and regulations in this area. International standards bodies such as JTC 1 have committees working on privacy frameworks and are making progress, but there is still much to be done [13].

To conclude, we believe that our readers will find this opinion piece useful in giving an overview of the importance of Quantum Computing/communications in shaping the next communication systems and its security platforms. This is a technology in its infancy and a lot of research remains to be carried out to achieve sustainable solutions and overcome the current challenges. The use of intelligent systems (AI, ML and other techniques) will be essential in achieving solutions faster and providing sustainable outcomes. But IoT devices as well as cloud and edges nodes must be AI-ready and be able to support the use of intelligent algorithms.

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REFERENCES

1. Dogra, A., Jha, R.K., Jain, S.: A survey on beyond 5G network with the advent of 6G: architecture and emerging technologies. IEEE Access. 9, 67512–67547 (2020). https://doi.org/10.1109/ACCESS.2020.3031234
2. Akyildiz, I.F., Kak, A., Nie, S.: 6G and beyond: the future of wireless communications systems. IEEE Access. 8, 133995–134030 (2020). https://doi.org/10.1109/ACCESS.2020.3010896
3. Tankimanova, A., et al.: Colloidal PbS quantum dots for visible-to-near-infrared optical-internet-of-things. IEEE Photonics J. 13, 1–11 (2021). https://doi.org/10.1109/JPHOT.2021.3066521
4. Yang, H., et al.: Artificial-intelligence-enabled intelligent 6G networks. IEEE Netw. 34(6), 272–280 (2020). https://doi.org/10.1109/MNET.011.2000195
5. Nawaz, S.J., et al.: Quantum machine learning for 6G communication networks: state-of-the-art and vision for the future. IEEE Access. 7, 46317–46350 (2019). https://doi.org/10.1109/ACCESS.2019.2909490
6. Yang, P., et al.: 6G wireless communications: vision and potential techniques. IEEE Netw. 33(4), 70–75 (2019). https://doi.org/10.1109/MNET.2019.1800418
7. Ylianttila, J., et al.: 6G white paper: research challenges for trust, security and privacy. arXiv Prepr. arXiv2004 11665 (2020)
8. Nawaz, S.J., et al.: Non-coherent and backscatter communications: enabling ultra-massive connectivity in 6G wireless networks. IEEE Access. 9, 38144–38186 (2021). https://doi.org/10.1109/ACCESS.2021.3061499
9. Saad, W., Bennis, M., Chen, M.: A vision of 6G wireless systems: applications, trends, technologies, and open research problems. IEEE Netw. 34(3), 134–142 (2020). https://doi.org/10.1109/MNET.001.1900287
10. Chen, H., et al.: 6G wireless communications: security technologies and research challenges In: 2020 international conference on urban engineering and management science (ICUEMS), pp. 592–595. (2020). https://doi.org/10.1109/ICUEMS50872.2020.00130
11. Akhtar, M.W., et al.: The shift to 6G communications: vision and requirements. Human-centric Comput. Inf. Sci. 10(1), 53 (2020). https://doi.org/10.1186/s13673-020-00258-2
12. Tataria, H., et al.: 6G wireless systems: vision, requirements, challenges, insights, and opportunities. Proc IEEE. 109, 1166–1199 (2021). https://doi.org/10.1109/JPROC.2021.3061701
13. Jiang, W., et al.: The road towards 6G: a comprehensive survey. IEEE Open J. Commun. Soc. 2, 334–366 (2021). https://doi.org/10.1109/OJCOMS.2021.3057679

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