Quantum Computing Technologies to Accelerate 6G and CONASENSE Integration Beyond 2030 *

*Note: Proposed Seminar on 6G and CONASENSE integration beyond 2030

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***Abstract*—This article underscores the pivotal role of quantum computing and related technologies in advancing Communication, Navigation, Sensing, and Services Integration (CONASENSE) in the 6G realm. The study provides a methodical journey through the chronological development of computing paradigms, starting from foundational computational frameworks like Turing Machines and Von Neumann's architecture, culminating in a sophisticated understanding of Quantum Turing Machines. Tracing computing's evolution from Turing Machines to Quantum Turing Machines, it acknowledges contributions from scientists like Bohr, Einstein, Feynman, and Benioff to quantum theory. The convergence of Quantum Computing and AI offers solutions to complex, NP-hard challenges, heralding a new era of optimization. This includes Quantum Computing, Quantum Algorithms, Quantum Machine Learning (QML), Quantum Communications, Quantum Sensing & Metrology, Quantum Simulation, and Quantum Imaging within the emerging CONASENSE and 6G paradigms, projecting their sustained relevance and impact beyond 2030.**

***Index Terms*—6G, B5G, CONASENSE, Turing Machines, Von Neumann's architecture, Quantum Turing Machine, Quantum Computing, Quantum Machine Learning**

I. Introduction

In this paper, the focal point is the elucidation of the role quantum computing plays in catalyzing advancements in Communication, Navigation, Sensing, and Services Integration (CONASENSE), pivotal elements in the evolving landscape of 6G technology. As humanity evaluates the unprecedented capacities beyond 2030, leveraging the transformative potentialities of quantum technologies becomes imperative. These technologies, encompassing quantum computing and quantum machine learning, are the linchpins in realizing a paradigm characterized by enhanced connectivity, optimized computational prowess, and unparalleled integration services.

Quantum Mechanics is a scholarly discipline that delineates the behaviors of particles at sub-atomic scales, with a particular emphasis on the interactions between photons and electrons. Luminaries such as Niels Bohr and Albert Einstein have significantly contributed to the foundational concepts of quantum theory, which subsequently laid the groundwork for the development of quantum technologies.

Professors Richard Feynman and Paul Benioff improved the theory and proposed the first quantum computers (QC) **[1]**. Quantum computation is designed to architect computer systems based on quantum mechanics, which can handle quantum logical gates and bits (qubits) depending on the quantum architecture strategy adopted. The merge of QC with Artificial Intelligence (AI) will make it possible to create a new generation of powerful Quantum Technologies that can resolve complex tasks and enable the resolution of scientific challenges that lie in a computer's complexity of class, such as nondeterministic polynomial (NP) and above.

This study strives to elucidate the crucial role anticipated for quantum computing technologies in advancing Communication, Navigation, Sensing, and Services Integration (CONASENSE) within the unfolding domain of 6G communications. Starting with a historical exploration of computing paradigms, this work meticulously traverses the intricacies of integrating CONASENSE within contemporary mobile networks. A systematic progression from foundational Turing Machines through to Von Neumann's architecture paves the way for a nuanced understanding of Quantum Turing Machines. By intricately unraveling the complexities of such integration, this exploration offers insights into the transformative potentials of quantum computing in shaping the future frameworks of future wireless communication networks.

The groundbreaking proposition by Albert Einstein, Nathan Rosen, and Boris Podolsky, positing the incompleteness of Quantum Mechanics—based on the historic paper **[2]** known as EPR —ushered in the era of Quantum Entanglement. Subsequent advancements by luminaries such as Richard Feynman and Paul Benioff refined the theoretical underpinnings of quantum mechanics and quantum computing. The convergence of quantum computing and Artificial Intelligence is foreseen to be a catalyst, driving the evolution of next-generation Quantum Machine Learning models, endowed with the capability to solve highly complex, notably NP-hard complexity class problems and beyond.

This synergy has given rise to a novel suite of quantum technologies, including Quantum Communications, Quantum Sensing & Metrology, Quantum Simulation, and Quantum Imaging, each poised to make significant contributions to fully realized CONASENSE and 6G ecosystems post-2030. These emerging technologies represent not only the integration of advanced quantum principles but also herald the commencement of unprecedented technological landscapes, offering innovative solutions and applications in the realm of 6G communications and beyond. These advancements are poised to enrich the holistic integration within the CONASENSE and 6G paradigms, looking ahead and beyond 2030.

II. Challenges for 6G Autonomous Intelligent Network and CONASENSE beyond 2030 - Problem Statement

Numerous social and environmental dilemmas necessitate immediate action from humankind to rectify the prevailing global disparities and menaces to our civilization and planet. In this context, there's a pressing need for cognitive, omnipresent, and human-centered wireless technology capable of functioning across varied settings. As a result, the forthcoming wireless network generation, 6G, should bolster vital interventions across all societal sectors, anchored in robust frameworks such as the United Nations' Sustainable Development Goals (SDGs) and newly created Society 5.0.

The SDGs combined with Society 5.0 encompass a broad spectrum of objectives, addressing situations that span diverse geoeconomic and environmental contexts, from bustling urban centers to isolated rural and distant terrains. These frameworks also venture into novel territories, including underwater communications and the outernet **[3]**. The latter notably emphasizes advancing space exploration and interstellar communications, echoing innovative endeavors like NASA's Artemis project **[4]**.

Furthermore, it is imperative to contemplate solutions for essential medical scenarios and design networks that can cater to these. This encompasses remote surgical procedures with immediate mechanical responses, non-invasive surgical interventions, and nanotechnological advancements. These applications require wireless accuracy to the scale of centimeters and, in certain cases, even millimeters, taking into account personal area networks (PAN) and body area networks (BAN). Consequently, 6G will necessitate the formulation of a novel key performance indicator (KPI) termed as the Quality of Physical Experience (QoPE) to gauge the efficacy of such pivotal services.

Thus, accelerating CONASENSE integration is vital to the aforementioned use cases. Therefore, 6G and CONASENSE topics are walking hand in hand **[5]** as a cornerstone for enabling an advanced society well-equipped to overcome such challenges and create innovation.

Numerous overlapping themes emerge after evaluating the present-day hurdles obstructing the seamless assimilation of CONASENSE and 6G. **Table I** delineates the existing challenges within CONASENSE, while **Table II** details the prospective obstacles in developing 6G as an intelligent wireless network.

TABLE I
CONASENSE Integration Challenges

Challenges	**Description**
Computational Complexity	*Resource Efficiency: time, space, memory.*
Network Complexity	*Network entropy*
Interoperability	*Secure Diverse Networking*
Data Accuracy and Precision	*Geolocation precision.*
Dependency Risks	*Prevent Hyperconnectivity Failure.*
Integration Challenges	*HW, SW and devices integration*
Unified theoretical frameworks	*Open standardization and standardized frameworks.*
Angular resolution	*High angular resolution.*

Tables I and II illustrate the inherent challenges and commonalities between CONASENSE and 6G. The primary overlapping obstacles include *Computational Complexity, Network Complexity,* and *Interoperability*. A detailed analysis of these issues underscores the necessity for a novel engineering approach, specifically in developing robust artificial intelligence and machine learning solutions, to complete CONASENSE integration and realize the vision of a 6G autonomous, ubiquitous, human-centered network.

TABLE II
6G Integration Challenges

Challenges	**Description**
Network Complexity	*Network entropy.*
Computational Complexity	*Resource Efficiency: time, space, memory.*
Latency	*Data transmission delay.*
Scalability	*Efficient network scaling..*
Power Consumption	*Energy efficiency..*
Security	*Data Security and Protection.*
Resource Constraints	*Ecosystem constraints..*
Bandwidth Demands	*User and Mobility count.*
Interoperability	*Secure Network Diversification.*

Computational Complexity belongs to the computer science field, and it is responsible for studying the amount of *computer resources* like space, time, memory, and processing power required in solving mathematical problems. A Computational Complexity can also be described in terms of:

- **Problem size**: which describes the size input of a problem. Which is denoted by the letter n.
- **Time complexity:** It is related to the size of memory required for an algorithm to run a function. This measurement is expressed in the *Big O* notation.
- **Space complexity:** This measurement is related to how much memory an algorithm consumes to run a function based on the problem input size.

Computational complexity is also related to the mathematical problem someone wants to resolve. The problem type can be *deterministic*. A deterministic problem is one in which the algorithm can clearly define an outcome. For instance, a Deterministic Touring Machine (DTM) will constantly follow the same state and provide a predictable output for a given input in the initial state. For instance, a problem that follows the same series of steps to be resolved or a problem that can be defined by YES or NOT. *"Nondeterministic"* problems are the ones in which one can guess the response and try to check its veracity. The nature of the problem, also known as a "decision problem," can be deterministic or nondeterministic, influencing and dictating the best optimal Touring Machine to use. Finally, computer complexity can be classified into classes that vary from less complexity, such as Polinomyal Time (P), which stands for a class of deterministic problems that can be easily resolved in a Polinomyal time, passing to more complex classes like Bounded-error Probabilistic Polynomial Time (BPP).

Figure 1 below describes the intrinsic relationship between the required computational resources to run an algorithm and solve a problem based on Von Neumann's architecture versus the main existing computational complexity classes. The higher the complexity class, the more computational resources will be required. *Network Complexity* is the study of the nature and structures of the network. The network can be artificial or of a natural structure. In this particular case,

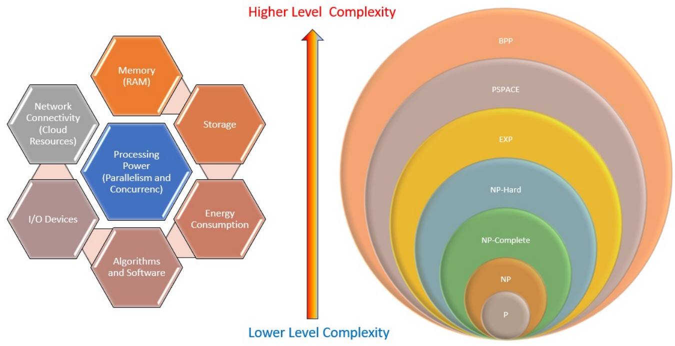


Fig. 1. Computational Resources vs Complexity Classes

we are studying artificial networks created by humans to use as a telecommunication means. Even in this specific case, network complexity is measured by:

- **Network Size:** is related to the number of devices, links, and nodes in a network structure.
- **Networks Topology:** It is related to the physical and logical design of the network that directly impacts its complexity level. For this, a star shape, ring, end, etc exists.
- **Scalability:** it is related to the behavior of growing the network and its impact on the level of complexity for managing the performance of the network resources during such an increase.
- **Dynamic Nature:** It describes the dynamics of the network to deal with unexpected or expected changes, such as self-configured, self-healing, redundant path, failover mechanisms, etc. For this example, there are the Self-Defined Networks (SDNs) or Cognitive Networks (CNs).
- **Network Entropy:** It is related to the level of stochasticity in the network. The more randomly connected the network's node, the higher the network entropy, and the opposite results in lower entropy. The concept of network entropy is based on Shannon's entropy theory.

Additionally, network complexity challenges such as network's functionality, protocols and standards, and security can be included.

Finally, it is equally important to consider *interoperability*. Interoperability refers to the ability of diverse systems, devices, and protocols to operate seamlessly or in a standardized mode that can guarantee self-adjustment, self-healing, and a high level of cognition. It also raises the need to investigate the challenges of hyperconnectivity, as a failure of a node or computer resource can lead to the mild to severe degradation of services and ultimately compromise QoE and QoPE. This is necessary to complete the integration of both CONASENSE and 6G, allowing the sharing of network and computer resources.

III. Classical Computing vs. Quantum Computing

Classical Computers are based on Turing Machine models, and Van Neumman's computer architecture drives its latest architecture. Classical computers are successfully applied to resolve the deterministic P class of problems. Its nature is based on classical bits defined by zero (0) or one (1) logically manipulated in an arrangement of classical logical gates created by transistors and electrical pulses. Based on this model, one can argue that quantum physics phenomena also control classical computers. Indeed, they are, but the computation is totally based on classical physics. In other words, there is no superposition of classical bits. Therefore, the results are one or zero and never both simultaneously. Classical computers are based on quantum physics theory because of the manipulation of electrons in the classical computer circuits. Electrons behave under the rules of quantum physics as they belong to the subatomic level of nature's structure.

Classical computers, especially personal computers (PC), the Internet, and cellular networks, were responsible for the Third Industrial Revolution. The fourth industrial revolution (4IR) continues with the synergy of those three entities computers, the Internet, and wireless networks associated with artificial intelligence (AI) and machine learning (ML). 4IR symbolizes the complete automation of most industrial sectors, which will mark this new era. However, due to the deterministic nature of classical computers and limitations experienced in the more complex computational problems beyond Non-Deterministic Polinomyal Time (NP) and beyond classical computers, they are limited to catching up. Even with the miniaturization techniques of transistors, it seems that Moore's Law is apparently coming to an end **[6]**. Therefore, classical computation associated with cloud computing architectures and AI and ML require more and more powerful computer resources.

Thus, a new type of computer architecture is required to operate in the upper layers of computer complexity to advance humanity to solve intrinsic challenges related to social, environmental, economic, and scientific goals. Several computational architectures are being proposed, from supercomputers to neuromorphic computation. However, quantum computation is the higher candidate to assume the protagonism of human history until the end of this century.

The reason for this assumption is based on the limitation of Moore's Law, as previously announced, followed by the limitations of classical computation to deal with complex classes of problems that go above and beyond NP and are from the domain of nondeterministic nature and problem-solving. For instance, AI and Machine learning are leaning towards trying to solve and emulate complex biological structures like the human brain via neural networks and deep learning. For example, during the recent COVID-19 pandemic, biotech company Moderna rapidly developed the messenger ribonucleic acid (mRNA) vaccine using AI **[7]**. However, there are still challenges to emulate clinical trials. In this case, a more powerful computation model can be applied to it. It can revolutionize medicine to beat now incurable diseases or to prevent them.

The other example is the creation of the generative AI platform for the large language model (LLMs) AI based on the foundation models architecture **[8]** complemented with Reinforcement Learning from Human Feedback (RLHF), the Generative Pre-trained Transformer (GPT), commercially known as ChatGPT, created by the company Open AI. Such generative AI required approximately 175 billion parameters to be engineered. The disadvantage of the foundation models approach, which led to the generative AI success, is that it requires a huge computational cost, which is a hurdle for a small company to train the millions and billions of data, followed by the trustworthiness of these models without considering to avoid bias and misinformation as most of the data relies on the internet data.

Another great example of computational power that requires a large amount of feature space to complete a simulation is the successful scientific research called the THESAN project **[9]** envisioned in 2019. The THESAN project was collective scientific research in astronomy focused on emulating the universe's evolution in a life space of the first billion years of the universe after the beginning of the Big Bang in an area coverage of 300 million years of light years. The project rendered astonishing image and video simulations with high-resolution physical fidelity, thanks to the scientific efforts combined with the astrophysics and cosmological algorithm created for this simulation, the Arepo Code, and the supercomputer SuperMUC-NG. SuperMUC-NG is located in the Leibniz Supercomputing Centre (LRZ), Germany, and it has embedded 60,000 processors working in parallel processing architecture.

The entire Thesan Project took 30 million hours of continuous calculation, which gives interrupts 500 hours of constant processing time for each one of the central processing units (CPU). The final results were the unique controlled and synthetic version of the universe's genesis, thanks to the numerical simulation employed. Thesan Project was concluded in 2021, and its results are available for the general public to consult, including the simulation code.

Utilizing supercomputers brings several technical advantages, enabling complex simulations with large data processing and huge parallel computing power.

However, the supercomputer architecture also posed a challenge in computation due to the complex arrangements to engineer a parallel configuration of thousands of CPUs, the size of supercomputers, and the infrastructure required to implement them, which requires special energy consumption planning, in which some cases can consume electrical power of an entire city, without mentioning the costs of implementing it, capital expenditure (CAPEX) and during the operational expenditure (OPEX).

In summary, supercomputers are not energy efficient and cost-effective yet, despite the SuperMUC-NG an advanced cooling system.

Table III shows the challenges of employing supercomputers.

TABLE III
SUPERCOMPUTERS CHALLENGES

Challenges	**Description**
Complexity of System Management	*Managing Ops and Computer resources*
Data Management and Storage	*Data volume generated and data solutions*
High Costs	*Requires high financial investments*
Training	*Requires skilled personnel.*
High Energy Consumption	*Requires an enormous power.*
Security	*Data protection, data security*
Cooling Requirements	*Requires efficient cooling processes*

Such computational challenges require a novel topological nature to overcome the hurdles of the feature spaces. *Feature space* in ML is considered any data variables of n-dimension that will be considered to extract and optimize data. The problem with feature space, also known as variables or characteristics that define the data that needs to be observed or extracted to allow AI or ML to find an optimized solution, can vary to an immeasurable scale. Such growth directly influences the performance of machine learning operating over the classical computer and classical algorithm. In many cases, it becomes infeasible to solve it.

Thus, to conclude, a quantum computer is a must, as when the engineering process is completely mastered, it will offer exponential computer power and parallel computation based on a nondeterministic Touring Machine that can solve computation problems of classes NP, NP-Hard and Bound Error Quantum Polynomial Time (BQP).

Generally, quantum computers utilize the foundational principles of quantum mechanics, encompassing three key characteristics: superposition, entanglement, parallelism, and interference. These quantum attributes provide a significant advantage over traditional computation.

Below there is a clear description of these three features:

Superposition is the natural description of the state of the quantum bits (Qubits), which is to be presented in the same state of zero (0) and one (1) simultaneously. The **equation I** describes the Superposition:

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle \quad (1)$$

The symbol Ψ represents the state of Qubits followed by $|\alpha|^2$ and $|\beta|^2$, which represent the probability of measuring the Qubits in the state $|0\rangle$ or $|1\rangle$.

Then, $|\alpha|^2 + |\beta|^2 = 1$. Consequently, the exponential prowess of quantum computing can be ascertained for any given number of qubits, n, as they can concurrently represent 2^n state possibilities due to superposition. Such superposition states can be described using the quantum bloch sphere model. **Figure 2** shows precisely this representation.

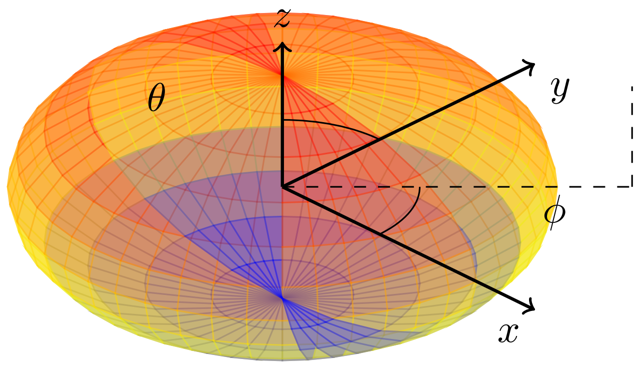


Fig. 2. Representation of a qubit's state on the Bloch sphere with angles θ and ϕ.

The Quantum Computing Bloch Sphere (QCBS) provides the graphic view of the qubit states. The QCBS has a spatial three-dimensional structure presented in the shape of a sphere and represents a single qubit. At the sphere poles, north and south represent the states $|0\rangle$ and $|1\rangle$, respectively. Thus, any point in the QCBS can represent a qubit state. The result of making a measurement in the qubits causes it to collapse to one of these poles, north or south. The superposition state can be described as shown in the **equation II**. The angle θ is the angle in the positive z-axis. The angle ϕ is the angle on the positive x-axis between the y-axis. In conclusion, the superposition coefficients are complex numbers.

$$|\psi\rangle = \cos\left(\frac{\theta}{2}\right)|0\rangle + e^{i\phi}\sin\left(\frac{\theta}{2}\right)|1\rangle \quad (2)$$

Entanglement is the phenomenon in which Qubits become entangled, and the result of one Qubits is correlated with the outcome of the other, no matter the distance they are separated. Thus, one qubit is entirely dependent on the other, which is entangled. Classical bits cannot have this state. **Equation III** describes the qubits entanglement.

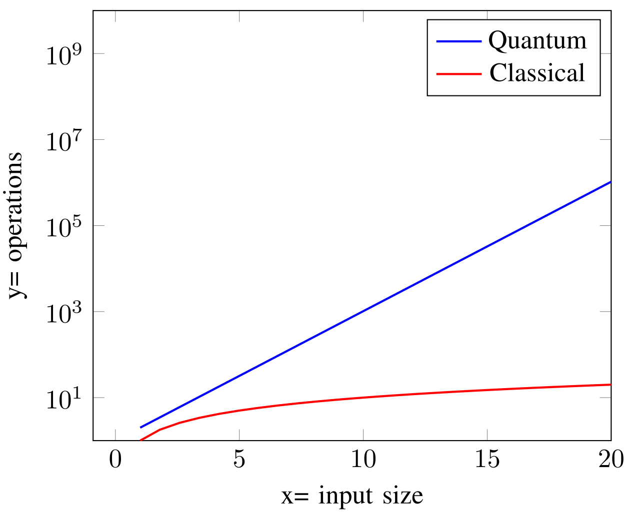
$$|\psi\rangle = \alpha|00\rangle + \beta|11\rangle \tag{3}$$

Quantum Parallelism is the ability of quantum computers to perform several parallel computations simultaneously. All of this is possible to achieve due to entanglement and superposition, as explained before. For instance, classical bits would require 2^n to determine all the outputs of all possible n-bits. In contrast, quantum computing can achieve such results in a single step defined by the following **function**.

$$f : \{0,1\}^n \rightarrow \{0,1\} \tag{4}$$

It is important to consider that quantum parallelism depends on the algorithm that is being used, which ultimately can apply such exponential computation. In short, not all cases can be used for exploiting the quantum computing exponential power.

Quantum Comput. Power vs. Classical Computing Power



The above chart contrasts the computational prowess of quantum systems against traditional classical computers. The blue curve exemplifies the exponential growth of quantum parallelism, governed by the function 2^n. In contrast, the red curve illustrates the linear progression typical of classical computational capabilities.

Quantum Interference represents a constructive or destructive interference that impacts a probability amplitude to achieve the desired outcome of Qubits based on the quantum gates operations.

Summarizing quantum computers offers an advantage based on the exploitation of quantum phenomena to operate the quantum logic gates that present reverse computing, superposition based on quantum entanglement phenomenon, in which this latter can enable to engineer Qubits with superposition values that can assume the simultaneous value of zero and one.

On the other hand, the primary challenges in quantum computing encompass mitigating quantum noise affecting qubit fidelity, maintaining temperatures near absolute zero, and the lack of a generic task-oriented quantum architecture akin to the classical Van Neumann architecture.

However, much progress has been made in quantum computers, and every year hiperscalers such as Google, IBM, and Microsoft are reporting the advancement of this technology with more and more qubits added to the technology. It is possible to notice that the Law of Accelerating Returns will definitely act upon the technogenesis progress of the science of quantum computing and quantum technologies in general.

In the commercial realm, several initiatives are underway. A notable example is the collaboration between pharmaceutical company Moderna and IBM, utilizing quantum computing to create innovative drugs and vaccines.

This research opens new avenues for invigorating discourse on the practical applications of quantum computing and general quantum technologies in integrating 6G and CONASENSE.

IV. Quantum Technologies Applied in CONASENSE and 6G

Quantum Technologies hold transformative potential across numerous facets of human existence. The preceding sections have explored the significance of quantum computers in depth. To build upon this research analysis focused on the deployment of quantum technologies, a high-level synopsis is provided to elucidate the prospective value derived from amalgamating these technologies within the realms of 6G architecture and CONASENSE.

Quantum Machine Learning blends quantum computing and machine learning to boost computational speed and data storage. It has potential applications in advancing 6G intelligent networks and supporting cognitive integration in CONASENSE frameworks.

Quantum Sensing & Metrology employ the fundamentals of quantum physics to counteract the noise generated by quantum fluctuations, thereby facilitating the development of innovative technologies characterized by unmatched accuracy and precision. Fundamentally, it enhances the precision of imaging, navigation, and communication services within the CONASENSE framework.

Quantum Simulation is a robust instrument for analyzing and emulating intricate systems, allowing researchers to acquire insights into the dynamics of many fields in science that prove challenging to simulate on classical computers. The benefits can reach advanced materials, chemistry, biology, medical sciences, and astronomy. Both 6G networks and CONASENSE stand to gain substantial advantages from these quantum simulation capabilities.

Quantum Imaging leverages quantum optics to capture high-precision imaging data unattainable by classical methods, even under constrained conditions like fog or smoke. This method is advantageous for enhancing the precision of CONASENSE services, including medical imaging.

Quantum Communication &Cryptography will enable creating a highly secure and robust communication system that will benefit 6G and CONASENSE.

V. Conclusions

Quantum computing heralds a transformative era poised to shape the upcoming decade. Building on classical computing's legacy, the fusion of quantum capabilities, AI, and ML signifies a monumental stride forward. Its reach extends from drug discovery, healthcare, clean energy, and advanced transport to security, data privacy, and space exploration, faster communications. Additionally, incorporating Quantum Technologies such as Quantum Sensing, Simulation, Imaging, Communication & Cryptography will create a new societal, economic, and environmental evolution. Prioritizing quantum access and fostering ethical quantum education is pivotal, especially for achieving the aspirations of 6G human-centric networks [10] in all socioeconomic levels, without forgetting the diversity and inclusion to prevent bias and discrimination. Harnessing quantum computing can refine networks linked to quantum neural networks, addressing dense network complications arising from 6G's demand for hyperconnectivity and CONASENSE across types of geographic regions. Together with quantum technology, this propels the progression of the UN SDGs and the fulfillment of Society 5.0. In unison, these initiatives are set to catalyze the 5th Industrial Revolution, rooted in a quantum-human-centric economy, accelerating our capacity to tackle obstacles in an era of swift technological advancement beyond 2030.

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