Integrated AI and 6G Driven e-Health: Enabling Design, Challenges, and Future Prospects

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***Abstract*—The next generation of wireless networks is set to leverage artificial intelligence (AI) algorithms for enhanced application support, which is currently intensifying through the fusion of modern learning techniques (e.g., symbolic AI and neural networks). Further, the fusion of these AI tools offers immense potential, addressing critical wireless use cases with a focus on driving advancements in the communication and healthcare industry. Observing these potentials, this paper explores the integration of AI with 6G networks to develop an advanced e-health system. Firstly, we provide an overview of how the fusion of symbolic AI, i.e., an advanced AI tool, enhances decision-making and cognitive modeling in e-healthcare in conjunction with the 6G network. Further, we propose an integrated 6G-neuro-symbolic AI healthcare architecture that leverages several enabling features of AI-assisted computing and 6G transmission support. Moreover, the performance of the proposed architecture has been evaluated, presenting prediction accuracy and latency. Finally, we discuss industrial and standardization challenges, offering recommendations for addressing infrastructure, scalability, and ethical concerns in AI-driven healthcare systems.**

***Index Terms*—AI for Healthcare, Internet of Medical-things (IoMT), 6G for e-Health.**

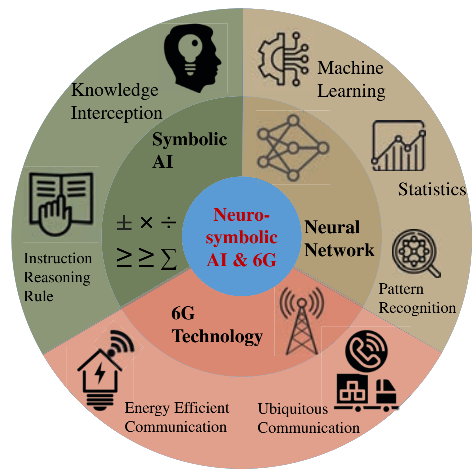

Fig. 1. An integration of symbolic AI, neural network, and 6G wireless communication technology with stunning parameters.

I. Introduction

Advancements in artificial intelligence (AI) and wireless communication technologies are progressing in parallel, opening numerous possibilities for the transformative innovations across multiple sectors. Specifically, the technology integration of AI with sixth-generation (6G) wireless networks is expected to play a pivotal role in revolutionizing future use cases [1], [2]. Indeed, the wireless network expansion and evolving features in AI models complement each other. For instance, the integration of AI aims to meet various wireless requisites, including intelligent decision-making, cognitive modeling, and real-time analysis. On the other hand, the notion of ubiquitous connectivity and massive machine-type communication (mMTC) communication fuel AI learning modeling, creating a strong backbone for the upcoming framework [3]. One such prominent use case includes healthcare, where the increasing complexity of medical data, together with the focus on personalized patient care, demands a faster, reliable, and scalable solution. In healthcare, decision-making is often complex and multi-faceted, requiring a blend of quantitative data analysis, pattern recognition, and contextual understanding. Thereby, the fusion of modern learning techniques, e.g., neuro-symbolic AI, integrated with 6G networks, appears as the most effective solution to these challenges.

The global AI healthcare market, valued at USD 10.4 billion in 2021 [17], is expected to grow further at more considerable pace. International efforts in this direction include platforms designed for medical-grade AI applications, which leverage tools, e.g., NVIDIA, to enable real-time edge computing for healthcare. Also, AI-powered software provides real-time imaging guidance during surgeries, enhancing accuracy and efficiency. However, a projected shortage of 10 million healthcare workers by 2030 highlights the growing need for AI-driven solutions to address global healthcare challenges [18]. Indeed, new verticals like AI-driven mental health solutions utilize wearables and remote platforms for real-time monitoring and intervention. Thus, emerging business models, like Healthcare as a Service (HaaS), rely on AI-powered platforms and real-time health data to monetize healthcare delivery.

TABLE I
ARTIFICIAL INTELLIGENCE-DRIVEN HEALTHCARE SYSTEMS AND SERVICES

Category	Application	Benefits	Challenges
Medical Imaging and its Diagnostics [4]	AI-powered image analysis (X-rays, MRIs, and CT scans) can detect diseases like cancer and heart conditions	Quicker and more precise diagnosis is possible	Quality of the Data, interpretability of AI results, integration of symbolic AI with neural network
Wearables Sensors and Remote Monitoring [5], [6]	Real-time data from wearables, such as heart rate and glucose levels, etc., is processed by AI	Early identification of medical conditions and Regular monitoring	Resource allocation, device integration, and Data privacy
Predictive Analytics [7]	AI forecasts patient readmission risks, illness progression, and outcomes	Early disease detection, prevention, and individualized and customized treatment are possible	Requires massive, high-quality datasets, and a risk of data bias
Personalized Treatments and Medicine [8]	Customized medical interventions based on genetic data	Decreased side effects and increased therapeutic efficacy	Integration of data and privacy issues
NLP [9] **in EHRs** [10] **Telemedicine, centralized data center** [11]	Clinical data is extracted from unstructured electronic health records (EHRs) using natural language processing (NLP)	Automates documentation, enhances clinical decision-making	Handling unstructured data, ensuring accuracy
Remote Robotic Surgery [12]	AI-powered remote surgical platforms that enable minimally invasive procedures	Increased precision, shorter surgery and recovery time	Technology is too expensive and requires substantial training for medical professionals
Virtual Reality (Holographic) Telepresence Health Assistants (consultants)	AI-driven chatbots and holographic telepresence offer schedules, symptom checks, and medical advice	24/7 patient assistance and a lighter workload for medical staff	Limited to simple interactions, patient trust, and must be ethical
Drug Discovery, Development & Recommendation [13]	AI models simulate molecular interactions and forecast medication efficacy	Accelerates the production of new drugs and lowers the cost of research and development	Regulatory constraints and AI prediction validation
Intelligent Clinical Decision Support [14]	AI helps doctors by recommending treatment plans and offering diagnostic support	Increases decision-making accuracy, Minimizes the number of diagnostic errors	Trust in AI and the explainability of recommendations
Population Health Management and Handling Pandemic Situations [15]	AI recognizes at-risk populations and recommends preventive actions	Enhances public health outcomes and aids in the administration of extensive healthcare initiatives	Data complexity, the possibility of ignoring rare scenarios
Integration of Medical and non-medical Services Framework [16]	AI with 6G incorporates health insurance, government health schemes, charitable and public funds, organ donors, etc.	Stakeholders can avail services at a place and save time	Stakeholder's involvement and integration in the system

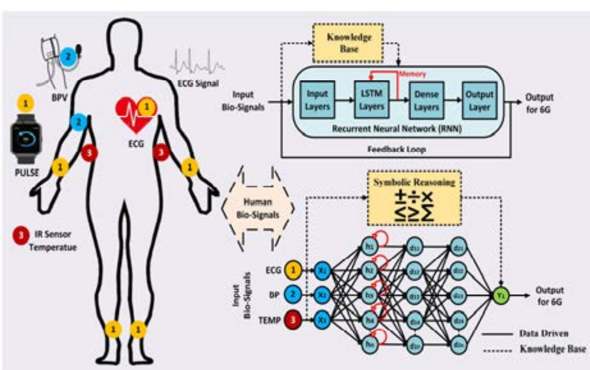

Fig. 2. An illustration of patient health monitoring using bio-sensor network and *neuro-symbolic AI*.

Indeed, the integrated framework holds great potential from the healthcare perspective; however, it also possesses several implementation barriers, raising several industrial and standardization considerations. As depicted in Fig. 1, this work explores several innovative aspects of the integrated framework towards an enhanced e-healthcare from both implementation and industrial perspective that includes the following: *a)* a comprehensive overview of the synergy between neural networks and symbolic AI, highlighting how this integration enhances the decision-making, and cognitive modeling capabilities in healthcare applications, *b)* the role of 6G as the next frontier for real-time data processing and intelligent healthcare that has a great influence on the communication industry, *c)* introducing an architecture for the seamless next-generation e-health, offering a framework designed to leverage the strengths of both neuro-symbolic AI and 6G, *d)* the architecture has been evaluated to demonstrate improvements in latency, throughput, and real-time data handling, *e)* examining key industrial barriers such as infrastructure, scalability, and interoperability, alongside the pressing need for standardization in AI-driven healthcare systems, concluding with future recommendations, addressing industrial and ethical considerations.

II. SYNERGIZING NEURO-SYMBOLIC AI WITH 6G: A DRIVING FORCE FOR E-HEALTH

Symbolic AI traditionally represents knowledge through logic-based reasoning and rule-based systems in a format that is both human-readable and interpretable [19]. On the other hand, neural networks excel at identifying patterns and relationships within large datasets, performing tasks such as pattern recognition, image and speech recognition, natural language processing, and complex decision-making. Despite their strengths, each of them possesses several limitations, presented in Table I. Neuro-symbolic AI bridges these gaps by merging the capabilities of both approaches, resulting in a

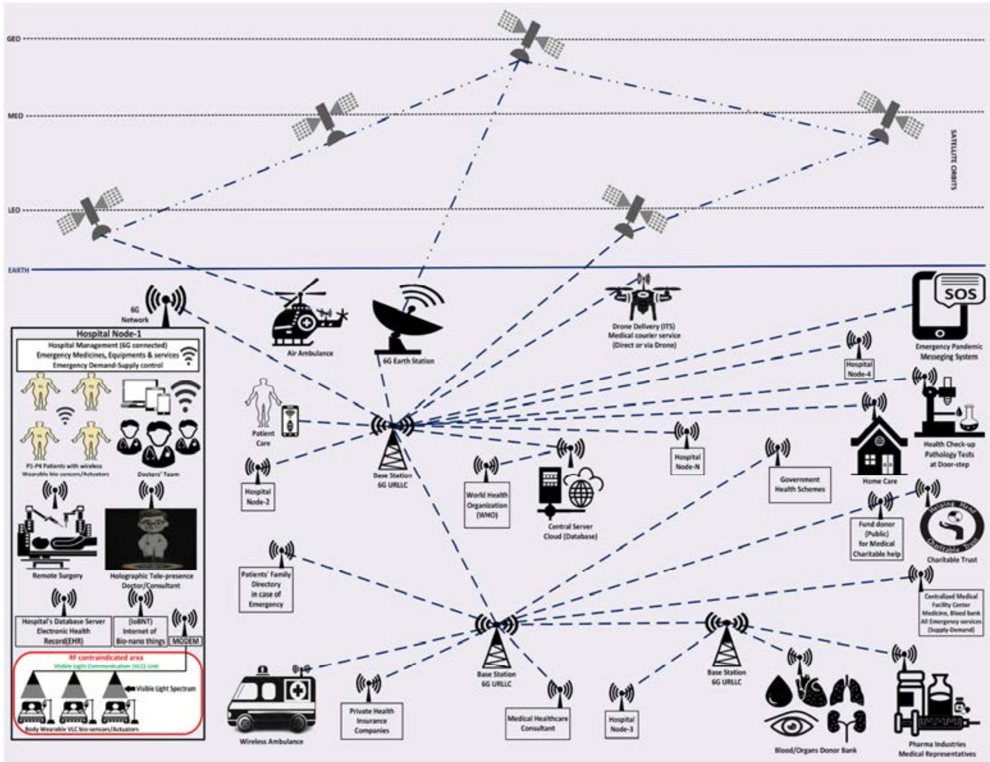

Fig. 3. Smart healthcare system using neuro-symbolic AI Integrated with 6G wireless technology provides tactile, ubiquitous, optical wireless communication, heterogeneous network, 3D global low latency connectivity for various healthcare services

more powerful AI that can reason, learn, and model cognition effectively.

A. Neuro-symbolic AI Integration: An Overview

Current research in neuro-symbolic AI covers diverse applications such as robotics, healthcare, sentiment analysis, hierarchical classification models, etc. Specifically from healthcare perspective, notable work includes advancements in sentiment analysis, protein function prediction, and logical reasoning [20]. Despite its wide-ranging impact, there is limited research on integrating neuro-symbolic AI with 6G technology in smart healthcare systems [21]. As depicted in Fig. 2, patient health is continuously monitored through a biosensor network. The collected data is processed using long short-term memory (LSTM) networks, a specialized form recurrent neural network (RNN), capable of handling sequential information, which further enhances the interpretation of signals from the biosensors, combining neural and symbolic reasoning for more accurate health assessments.

B. Integration with 6G Networks: The Next Frontier

Next-generation wireless networks, such as given in Fig. 3, are expected to be driven by AI functions to analyze the Internet of everything (IoE) behavior, providing the service management functions of a wireless IoE zero-touch network. Further, research efforts are being made to jointly utilize AI, presenting emergent semantic communications with an emphasis on the semantic layer to send useful/functional information to the receiver [22]. By combining symbolic reasoning with the learning capabilities of neural networks, 6G can enhance its ability to interpret, filter, and transmit only the most meaningful information, significantly reducing bandwidth consumption and improving latency. In Section III, we propose an architecture that combines the strengths of modern tools. Further, Section IV covers the experimental setup and the evaluation of the proposed framework.

C. Global Efforts and New Verticals:

Global efforts are underway to seamlessly integrate wireless technology into the healthcare sector. Key examples include: a) the ITU/WHO Focus Group on “AI for Health” (FG-AI4H), established in 2018, which aims to develop standards for AI solutions in healthcare by incorporating various fields, such as statistics, and promoting a transparent benchmarking framework; b) the European Health Data Space (EHDS), which seeks to create a unified framework for utilizing health data across the European Union (EU), enabling research with broader datasets and addressing current limitations; and c) McGill University Health Centre (MUHC) in Montreal, where AI not only enhances medical procedures but also plays a crucial role in managerial decisions, such as patient scheduling, prioritization platforms, and capacity management.

III. Proposed Architecture: An Emerging Healthcare Design

Observing the above-mentioned gaps, this work proposes an architecture that combines the strengths of modern tools,

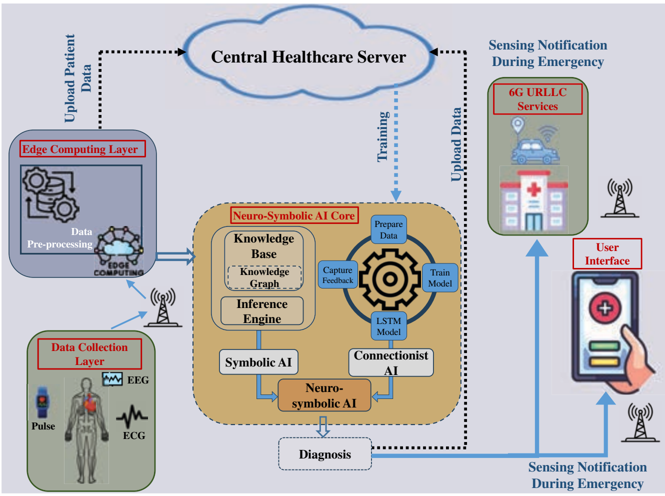

Fig. 4. Proposed integrated architecture shows patient's bio-signal data acquisition using implantable/wearable devices and their processing through *neuro-symbolic AI Model* for medical diagnosis and medical services using 6G HRLLC technology.

including neural networks, symbolic reasoning, and ultra-fast low-latency communications, aiming to enhance healthcare services. As shown in Fig. 4, the proposed architecture brings together several essential components described below:

a) Data Collection Layer: This layer is mainly responsible for feeding vital information to the computational unit. In healthcare applications, this layer is equipped with advanced sensors and communication devices to continuously gather, process, and transmit patient data in real-time. The communication between wearable devices and a nearby gateway relies on bluetooth low energy (BLE). Further, the communication between sensors and devices relies on low power network, enabling efficient data transfer over short distances within the patient's vicinity.

b) Edge Computing Layer: The proposed architecture utilizes the edge computing layer, enabling pre-processing near the source, reducing latency and offloads computational tasks from central servers for 6G hyper reliable low-latency communication (HRLLC) services. For sending real-time updates from edge devices to servers, message queuing telemetry transport (MQTT) are required for reliable communication between devices with minimal bandwidth usage.[1]

c) Neuro-Symbolic AI Core: Edge computing layer shares the data with the core run by neuro-symbolic AI Core layer, which combines symbolic AI (for reasoning) and connectionist AI (with LSTM for learning). To ensure smooth integration between the LSTM layer and knowledge-based systems, remote procedure call enables real-time data exchange between the symbolic and connectionist components. Further, protocol buffers ensures efficient serialization and de-serialization of large datasets, including patient health records, facilitated transmission between different AI components. To ensure secure communication between the symbolic and connectionist components, the secure sockets layer is used to protect sensitive data (e.g., patient health information) during model training, data transfers, safeguarding patient privacy and complying with healthcare regulations like health insurance portability and accountability act (HIPAA).

d) Central Healthcare System and Knowledge Management: The Central Healthcare System consolidates data from various sources, such as wearables and electronic health records (EHRs), to create a comprehensive and unified patient profile. It leverages symbolic AI to construct and manage knowledge graphs, that integrate medical expertise, patient-specific information, and treatment guidelines, facilitating more informed and holistic care.

e) User Interface: After the neuro-symbolic AI processes the data, it delivers real-time diagnostic updates directly to the patient's device. For real-time interaction with patients and healthcare providers, web-socket protocols enable continuous, bi-directional communication between the patient's mobile app and the cloud-based healthcare platform. In the event of an emergency, protocols like session initiation protocol can be used to initiate immediate notifications and establish a communication session between healthcare providers, ensuring that vital alerts are delivered promptly.

Overall, this integrated architecture maximizes healthcare efficiency through continuous monitoring, rapid processing, and real-time intervention, ensuring a comprehensive and proactive healthcare system. Further, Section IV outlines the experimental setup, and critical performance metrics, including network latency and prediction accuracy, are also evaluated.

IV. Experimental Setup and Results

This section covers the experimental setup and further evaluates the proposed framework using patient data. The performance is evaluated on key metrics such as network latency and prediction accuracy.

A. Experimental Setup: A Guide to Commercial Rollout

We discuss the experimental setup and model, conducting experiments to evaluate the performance of the proposed framework. Specifically, the experiments have been conducted using patient data, initially processed at the edge computing layer. For model training and inference, we utilize a central server powered by an NVIDIA RTX 3080 GPU and 32GB RAM to ensure high computational efficiency. On the software side, Python-based frameworks such as TensorFlow and Keras are employed for LSTM modeling and are complemented by symbolic reasoning libraries. Data is gathered and monitored across parameters, including glucose levels, heart rate, and activity level. The processed data, utilizing LSTM and neuro-symbolic AI, is transmitted under a 6G-based scenario for further diagnosis.

B. Performance Evaluation

We first evaluate the performance of the proposed framework concerning network latency, depicted in Fig. 5(a). By maintaining low-latency across various components, the system ensures timely insights, and facilitate effective communication among healthcare providers. As illustrated in Fig.

[1]Further, IPv6/IPv4 ensures the communication between the edge devices and the healthcare server.

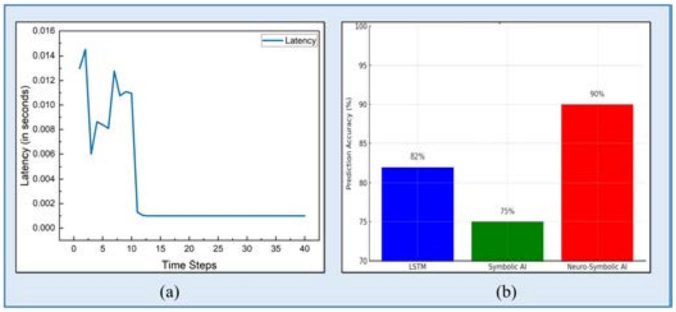

Fig. 5. Performance analysis of (a) latency under 6G HRLLC scenario and (b) accuracy obtained using *neuro-symbolic AI*.

5(a), the end-to-end latency achieved is approx 1 *ms*, which is essential to provide timely feedback. Delays in alerting healthcare providers leads to abnormal health metrics, due to high latency, could put patient safety at risk. In the event of an emergency, such as heart attack, the system needs to send alerts to healthcare providers immediately. The proposed architecture with 6G ultra-reliable low latency communication (URLLC) ensures minimal latency in sending notifications or receiving actionable responses. As depicted from result in Fig. 5(a), the initial fluctuation in latency results from setting up connections and establishing communication protocols. Once the system is fully set up, the latency drastically drops to a lower value, indicating that the system is running efficiently. Finally, the consistent low-latency signifies the ability of proposed architecture to maintain low-latency performance which is crucial for real-time monitoring.

Further, the performance is evaluated in terms of prediction accuracy as key performance metric. In healthcare, even minor prediction errors result into significant consequences. The proposed architecture with neuro-symbolic AI core integrates connectionist with LSTM models and symbolic AI with knowledge graphs for continual learning and reasoning. The comparison of prediction accuracy with neuro-symbolic AI, symbolic AI and LSTM architecture is illustrated in Fig. 5(b).

V. Challenges and Future Directions

The implementation of AI-driven 6G e-health faces significant industrial barriers, including high infrastructure costs, complex scalability, etc. Furthermore, data privacy and security concerns add layers of complexity to healthcare systems, while ensuring regulatory compliance. Moreover, standardization challenges in 6G and AI for healthcare also persist, with a lack of unified global standards and regulatory hurdles. This section summarises such industrial and standardization challenges, complemented by future recommendations.

A. Industrial Barriers

- *AI-Driven 6G e-Health:* Despite numerous benefits, the joint implementation of AI-driven 6G e-health [23] possesses significant challenges. as the transition to 6G networks demands highly advanced infrastructure that calls for large-scale investment, innovative hardware, network densification, edge computing facilities, and the deployment of advanced AI processing capabilities at both the network core and edge. Achieving this demands interconnected healthcare environments, including the deployment of small cells, mMTC, etc. Healthcare providers must navigate integration challenges while maintaining compliance with stringent regulatory standards.

- *Data Privacy and Security in Healthcare:* Data privacy and security pose another industrial barrier in healthcare, especially under data-driven frameworks [24]. Besides, ensuring secure transmission becomes more complex as the integrated framework involves movement of data across different layers. Nonetheless, healthcare regulations like the general data protection regulation (GDPR) and the HIPAA impose strict compliance requirements for the handling of personal health information. Meeting these regulatory standards while implementing new AI-driven solutions adds another layer of complexity for healthcare providers and technology developers. These concerns opens new research directions for the robust encryption methods, secure network architectures, and continuous monitoring.

- *Cost and Investment Considerations:* Apart from the above-mentioned challenges, the implementation of the integrated framework faces significant cost and investment barriers. Besides, the high initial expenses for infrastructure, e.g., 6G-enabled devices, advanced communication networks, etc., are compounded by operational and maintenance costs. Moreover, the integration demands healthcare providers to invest in training staff and recruiting skilled IT professionals. Justifying these high costs is challenging, especially when immediate returns on investment are unclear.

B. Standarization Challenges

- *Lack of Unified Standards for AI in Healthcare:* To maximize the potential advantages and minimize the hazards of emerging technologies, it is important to address the absence of uniform standards for AI in healthcare. All the stakeholders, as shown in Fig. 3 (such as healthcare professionals, technical developers, regulators, patient advocacy groups, etc.), must work together and take the initiative to build a strong framework that guarantees the safe, efficient, and fair use of AI in healthcare.

- *6G Standardization for e-Health:* The standardization of 6G for e-Health faces challenges, like early stages of development and lack of global standards that have yet to be fully defined. This poses interoperability challenges between devices and systems in healthcare. Moreover, healthcare regulations like HIPAA or GDPR demand stringent requirements. Delays for global consensus and stringent requisites slow down the development of universal standards, especially for healthcare. Many legal obstacles must be addressed while implementing AI in healthcare. These challenges are data privacy and security, clinical validation and efficacy, algorithm transparency and explainability, bias and fairness interoperability standards, liability and accountability, patient awareness and consent process, rapid technological advancement/update, and ethical considerations.

C. Future Industrial and Ethical Recommendations

- Industry and Government Collaboration for AI-Driven 6G e-Health: Developing a roadmap for AI-powered 6G e-health requires strategic planning and setting clear objectives to enhance patient care and facilitate remote monitoring. Moreover, incentivizing research and development (R&D) in AI and 6G technology is crucial that may involve grants, tax breaks, or subsidies to encourage telecommunication firms to explore novel solutions for remote diagnostics.

Another critical area is the workforce development as there will be a growing demand for professionals with expertise in both domains. Possible solutions may include certifications and training initiatives to equip the healthcare workforce to accelerate the adoption of these transformative technologies.

- Research and Development Opportunities: The forthcoming world will enjoy several transformative use cases, most of which rely upon the data driven algorithms. Thus, the integration of AI offers plenty of research and development opportunities including *a)* the integration of AI also allows seamless combining with integrated sensing and communication, making it easier to diagnose patient disease and their recovery predictions, *b)* towards automotive applications, AI-based solutions possess the potential to manage device heterogeneity, energy-efficient communication, and self-healing networks, *c)* furthermore, AI-enhanced 6G will help to enable recent advancements, including immersive virtual reality experiences, with real-time interaction in virtual environments.

VI. Conclusion

Advancements in AI and 6G wireless technologies offer transformative potential, especially in healthcare. neuro-symbolic AI, combining the strengths of neural networks, supports intelligent decision-making, cognitive modeling, and real-time analysis. This paper explores the integration of AI with 6G networks to develop an advanced e-health system, providing an overview of symbolic AI fusion. Besides, an integrated 6G-AI healthcare architecture has been proposed. The performance of the network has been evaluated, presenting prediction accuracy and latency. Finally, industrial and standardization challenges have been discussed, offering recommendations for addressing concerns.

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