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INTEGRATION ECOSYSTEM OF WIRELESS SENSOR NETWORKS AND THE INTERNET OF THINGS

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ІНТЕГРАЦІЙНА ЕКОСИСТЕМА БЕЗДРОТОВИХ СЕНСОРНИХ МЕРЕЖ ТА ІНТЕРНЕТУ РЕЧЕЙ

У статті наводиться опис концепції інтеграційної екосистеми бездротових сенсорних мереж та Інтернету речей, що базується на синергії сучасних технологій зв'язку, хмарних обчислень та інтелектуальних алгоритмів для забезпечення ефективного збору, передачі та обробки даних.

Окреслено ключові технічні та стратегічні межі розвитку даної екосистеми, зокрема впровадження технологій 5G/6G, субтерагерцових систем, штучного інтелекту та віртуальних середовищ, що сприяють формуванню нової цифрової економіки та створенню умов для розгортання інтерактивних систем майбутнього.

Wireless sensor networks (*WSN*) are of increasing interest for scientific research and play a major role in the deployment of the Internet of Things (*IoT*) and the formation of the Metaverse [1].

Symbiotic technologies such as artificial intelligence (*AI*), cloud computing, big data and wireless systems IMT -2020 (5G), combined with the power *of IoT*, opens up new possibilities for their use in telecommunications, information technology and other "smart" industries of metaverse. Significant progress has been observed in the development by the International Telecommunication Union (*ITU)* 5G technology and the implementation of generally accepted standards for the approval of sixth generation (6G) radio interface technology [2].

In the future, these technologies are aimed at creating densely distributed, interacting and self-organizing networks of international mobile communications (*IMT*) with the joint allocation of radio resources of different heterogeneous systems to improve resource utilization and enhance system performance. In turn, with the widespread deployment of base stations (BS), edge servers, and intelligent devices, mobile networks provide a new platform for ubiquitous data collection,

storage, exchange, and computation. These are potential factors of semantic communications of future mobile distributed/collaborative machine learning (ML).

Recent advances *in AI* in image, video and audio signal processing, data analysis, among other things, have allowed wireless communication to move towards an intelligent paradigm, in particular, architecture, protocols, and algorithms for IMT. The rapid growth of mobile data and traffic flow motivates the implementation of new technologies to improve the efficiency of radio spectrum use (*Spectrum Engineering, SE*), energy efficiency improvement (*Energy Efficiency, EE*) and sensor deployment density. Actually, *WSNs* refer to networks of spatially separated and dedicated sensors and devices interconnected by radio signals, which are capable of relay messages from one element to another.

In this context, research into subterahertz (THz) technologies is playing a significant role. It is predicted that in the future, these technologies will enable exceptional data rates for 5G and 6G wireless communication systems, especially for intelligent communication between devices falling under the category of *IoT*. The transition from the current 5G millimeter wave (mmW) technology to the THz spectrum will provide unprecedented solutions that will guarantee higher transmission speeds and channel capacity for any wireless communication system. One of the technologies that will contribute to achieving communication at frequencies up to THz, providing low path loss and power with reliable and fast data transmission, is the implementation of terahertz high-gain antennas. THz antennas are suitable for IoT applications that require fast data transmission, as they provide high-speed wireless connectivity for 5G and 6G. Compared to other wireless technologies, these applications include high-definition video streaming, virtual reality (VR), augmented reality (AR), mixed reality (MR), and waves for real-time sensor data collection. In this virtual space, the basic microparticle may not be a biological cell, but a binary code (0 and 1), or even a quantum bit (qubit). AI is able to construct a multi-level digital continuum, where elementary binary or quantum units form complex structures - from virtual organisms to entire ecosystems and societies.

The compatibility and growth of shared ecosystems on this basis is shaping a new digital world and unlocking its potential, fueling the next wave of recombinant

innovation and defining the next evolution of the Internet. It is built on decentralized blockchain technologies, a metaverse, and non-fungible tokens (NFTs).

According to the definition proposed by the International Telecommunication Union ITU-T FGMV-20 focus group, the metaverse is considered as “an integrated ecosystem of virtual worlds that offers immersive experiences that change existing ones and create new values” [3]. For example, three-dimensional (3D) virtual AI agents in virtual reality (VR) or holograms in augmented reality (AR) can establish new possible forms of interaction in the metaverse, in which traditional channels give way to interactive ones. In the metaverse, everyone can create their own avatar and freely explore the simulated environment. Similarly, in the metaverse, remote or hard-to-reach places can be recreated, processes can be simulated, etc. It is obvious that the increased level of interaction and immersion offered by the metaverse opens up unprecedented opportunities and challenges for scientific research *on WSNs* in the context of deployment *IoT*. Ukraine is part of this growing segment of the market for computing power, AI, cloud and edge capabilities, spatial content creation, software and specialized knowledge, as it leverages VR, AR and MR capabilities [4].

The metaverse already represents the integration of digital and real economies, which will define the next generation of digital economy involving immersive technologies (immersion in the virtual world), holographic principles (property of quantum gravity), tactile communications and new media beyond 8K image resolution, etc [5]. For the development and evolution of the metaverse, VR/AR/MR technologies in combination with the integration of information and communication technologies act as the main tool that will be crucial in the future [6]. According to expert forecasts, the metaverse market will reach $2.1 billion in 2025. The annual growth rate of this market (CAGR 2024-2030) is expected to be 40.03%, leading to a projected market size of US $16.1 billion by 2030. In this regard, there is a need to form a systemic approach to creating a new digital space that would be simultaneously effective, stable and socially significant based on a multi-level model of building a metaverse. One example of addressing these issues

is the “Development Plan for the Metaverse Industry in China”, which directly addresses VR as the foundation of the metaverse and defines strategic goals for the development of VR technologies in industry, education and entertainment, including the integration of AI and 5G [7] In addition, countries such as India, South Africa, and Vietnam are actively implementing augmented reality and AI in key industries by integrating physical objects with their connection to *WSNs.* IoT allows these objects to collect and share data, which has far-reaching implications for improving efficiency, resource allocation, and quality of life. *WSNs* are an effective-distributed data collection technology that will play a major role in IoT deployment, but issues related to reliability, autonomy, cost, and accessibility to application domain experts still limit their widespread use.

Conclusion. The integration of IoT with WSNs is a revolutionizing way of interacting with the world and offers significant potential for increasing efficiency, productivity, and connectivity across sectors of the economy. In addition, addressing strategic challenges requires long-term digitalization efforts and continuous data review, which are the basis for the network economy model. This requires further understanding of how to address the challenges and opportunities of the metaverse, and in what direction to further explore potentially new forms of interaction. *IoT* with *WSNs.*

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