CONCEPTUAL FOUNDATIONS, ARCHITECTURAL MODELS, AND INNOVATIVE DEVELOPMENT DIRECTIONS OF IOT TECHNOLOGY

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ABSTRACT- This study analyzes the conceptual foundations, architectural structure, and innovative development directions of Internet of Things (IoT) technology. The IoT concept is aimed at integrating physical objects into the digital environment through hardware and software tools, as well as ensuring automated control based on information exchange between them. The IoT architecture consists of the sensing (sensor), network (data transmission), and application layers, and the close interconnection among these layers enhances the efficiency of data collection, transmission, and processing processes [1]. Furthermore, according to the research findings, the innovative development of IoT technologies is characterized by the widespread adoption of wireless communication technologies such as RFID, NFC, Bluetooth Low Energy, ZigBee, and LoRaWAN, as well as their deep integration with artificial intelligence (AI), fog computing, and edge computing solutions. As a result, IoT technologies are emerging as a key factor in forming an energy-efficient digital infrastructure that improves efficiency and ensures security in smart cities, healthcare, transportation, agriculture, and industrial systems

KEYWORDS- RFID, NFC, Bluetooth Low Energy, ZigBee, LoRaWAN and IoT

I. INTRODUCTION

Information and communication technologies (ICT) are currently recognized as one of the main driving forces of global economic and social development. ICT not only contribute to improving the efficiency of enterprises and organizations, but also play a key role in accelerating digital transformation processes. According to statistical data, the global ICT market reached a value of 5 trillion US dollars in 2023, and steady growth of this indicator is forecast for the next decade.

One of the key structural components of ICT is cloud computing technologies, which provide capabilities for storing, processing, and analyzing large volumes of data. As of 2024, the global adoption of cloud services has increased by 25 percent, and this upward trend is expected to continue in the coming years [2–3].

Another promising direction of ICT development is Internet of Things (IoT) technologies. The IoT concept is based on integrating household appliances, vehicles, and other technical objects into a unified information network to enable mutual data exchange. According to reports, the number of IoT devices worldwide reached 14 billion in 2024, with this figure continuing to grow annually. IoT technologies play a significant role in the implementation of the “smart city” concept, substantially increasing efficiency in transportation, energy, water supply, and waste management sectors. According to forecasts, more than 60 smart cities are expected to be established worldwide by 2030

II. RELATED STUDIES:

The analysis of the aforementioned scientific sources indicates that the concept, architecture, and innovative development directions of IoT technologies play a crucial role in contemporary digital transformation processes.

Liu et al. (2018) proposed the concept of an AI- and IoT-based "unmanned store." As a result, a system was developed in which customer movements are monitored through cameras, sensors, RFID, and intelligent networks, while payments are processed automatically.

Jayaram (2017) suggested the "Retail 4.0" model, which enables the management of interactions between consumers and producers in retail through an IoT network. In this approach, product placement, pricing, and marketing strategies are optimized based on data analysis.

Munirathinam (2017) identified the key components of Industrial Internet of Things (IIoT) technologies in manufacturing, including sensors, networks, data analytics, and cloud platforms. These components enable real-time monitoring, predictive maintenance, and improved energy efficiency in industrial processes.

Zhou et al. (2017) reported the development of a system for underground coal mines that monitors safety, ventilation, gas concentrations, and worker locations using IoT sensors. Consequently, real-time monitoring significantly reduced the number of emergency incidents.

Javaid et al. (2021) emphasized that IIoT technologies enhance efficiency, flexibility, and real-time control in manufacturing processes. Using sensor networks, data analytics, and automated decision-making systems, the digital maturity of production is significantly improved.

Thus, it can be concluded that IoT technologies facilitate the formation of intelligent management systems, real-time data analysis, and autonomous decision-making capabilities across manufacturing, industrial, transportation, energy, and retail sectors. Their architectures are deeply integrated with networked sensor systems, cloud computing infrastructures, and artificial intelligence modules.

III. THE CONCEPT OF IoT TECHNOLOGY:

The core essence of the IoT concept lies in the ability of devices to connect with each other and exchange information autonomously, without human intervention. As a result, the Internet is no longer solely a medium for communication between people, but also becomes an environment for independent interaction and coordination among technical objects. For this reason, this paradigm is referred to as the "Internet of Things" (IoT) [7].

IoT systems are built on a complex, multi-layered architecture, with each layer performing functions such as data collection, transmission, processing, and delivery to the end-user in a step-by-step manner. The IoT architecture defines the specific role of each component within the system, ensuring interoperability and continuous operation of the devices. This approach enables modular management of networked systems and enhances the scalability and extensibility of the technology.

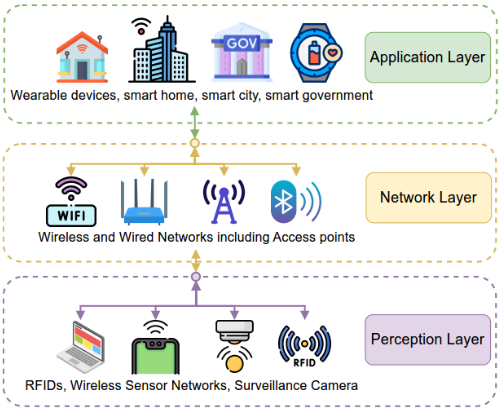

Figure 1. IoT three-tier architecture model

The three-tier architecture of IoT systems is recognized as the most fundamental and widely adopted model. This architecture consists of the following layers:

1. Perception Layer (Sensing Layer) – This layer directly interacts with the physical environment, collecting data from the real world and converting it into a digital format. It employs sensors, RFID tags, actuators, and various measurement devices. The primary function of the perception layer is to detect parameters such as an object's status, location, temperature, pressure, illumination, and movement, and to transmit this information to the next layer. The efficiency of the perception layer is one of the key factors determining the overall reliability of the system, as it serves as the initial source of data.

2. Network Layer (Transmission Layer) – This layer transmits data obtained from the perception layer to higher-level processing centers via various communication protocols. It functions as the "nervous system" of the IoT system. The network layer employs wired and wireless technologies such as Wi-Fi, ZigBee, LTE, 5G, LoRaWAN, and Bluetooth Low Energy (BLE). In addition to data transmission, it performs routing, secure transmission, and data aggregation. The stability and throughput of the network layer directly affect the overall performance of the IoT system.

3. Application Layer (Application or Control Layer) – This layer serves as the interface between the system and the end-user. Data transmitted through the network layer is processed, analyzed, and transformed into actionable control decisions at this stage. For example, in smart home systems, temperature data from sensors can automatically trigger air conditioning. The application layer also provides data visualization, monitoring, and real-time control, offering tailored services across various domains such as healthcare, transportation, manufacturing, and energy [8–10].

Despite its simplicity, the three-layer model forms the fundamental structural foundation for complex IoT systems. However, modern requirements—particularly real-time computing, low latency, and processing of large volumes of data (big data)—have led to the adoption of a four-layer architecture. This extended model incorporates an additional Edge or Fog Computing layer, which performs computation and analysis close to the data source at the network edge.

Thus, this conceptual model of IoT architecture goes beyond merely defining the technical framework of the system; it encapsulates the scientific, operational, and even philosophical foundations underlying modern digital ecosystems. By integrating sensing, communication, and application layers, the model allows each individual device or object within the network to autonomously perceive its own state, continuously monitor its environment, process and analyze collected data, and make independent decisions based on contextual and real-time information.

This capability transforms the traditional notion of the Internet from a platform solely for human-to-human communication into a dynamic, interconnected environment where devices and systems actively interact, coordinate, and optimize processes without direct human intervention. Consequently, IoT systems drastically reduce the need for manual oversight, enhance operational efficiency, and enable predictive and adaptive responses across a wide range of applications, including smart cities, industrial automation, healthcare, energy management, and transportation.

Moreover, by providing a foundation for intelligent decision-making and autonomous coordination, this architecture fosters the creation of a globally integrated, scalable, and resilient management environment. It not only supports high levels of automation and real-time control but also establishes the conditions for continuous learning, self-optimization, and the development of next-generation digital ecosystems that can evolve in response to changing environmental, operational, and user requirements

IV.SCIENTIFIC CLASSIFICATION OF IOT TECHNOLOGIES:

The scientific classification of Internet of Things (IoT) technologies reflects their differences in architecture, communication range, energy efficiency, and application. IoT networks are usually divided into short-range and long-range communication technologies.[11].

Table 1

IoT networks are connected to communication technologies

Technology type	Technology name	Key features	Advantages	Scope of application
Short-range communication technologies	ZigBee	Based on the IEEE 802.15.4 standard, low power consumption, stable connection	Energy efficiency, multi-node network support	Smart home systems, industrial automation
	Bluetooth Low Energy (BLE)	Transmits data in real time with low power consumption	Convenient, small-sized modules for personal devices	Medical devices, smart gadgets, monitoring
	Wi-Fi	High bandwidth, fast transmission capability	Widespread infrastructure, high speed	Office networks, smart buildings
	NFC (Near Field Communication)	Works at a very short distance (up to 10 cm)	Secure and fast communication, identification capability	Payment systems, access control, identification

Long-distance communication technologies	LoRaWAN	Low speed, but long-distance transmission capability	Energy-saving, long-lasting battery life	Agriculture, environmental monitoring
	LTE-M (LTE for Machines)	A simplified version of the 4G network	Stable communication in moving objects	Transportation systems, mobile IoT devices
	NB-IoT (NarrowBand IoT)	Low bandwidth, wide coverage	Ability to connect thousands of devices to a single network	Smart cities, public utilities
Cloud service platforms	ThingSpeak	MATLAB integration, open cloud system	Real-time analysis, graphical visualization	Data collection and analysis systems
	Carriots	Works based on the REST API	Centralized device management, monitoring	IoT applications, industrial systems
	Exosite	Designed for large industries	Secure data transfer, working with large amounts of data	Industrial production, automation
	Nimbits	Open source, local operation capability	Adapted analysis models, working in cloud and local environments	Local IoT networks, scientific research
Integration technologies	RFID (Radio Frequency Identification)	Object identification via radio waves	Remote monitoring and control capability	Logistics, transport, security systems
	NFC (takroriy)	Used in mobile communications and payment systems	Secure data exchange	Banking systems, access cards
	V2V (Vehicle-to-Vehicle)	Communication between vehicles	Increase autonomous	Automobile networks, intelligent

			management and security	transport systems

Internet of Things (IoT) technologies have a complex, multi-layered structure, and their effective operation depends on the harmonious combination of various communication protocols, platforms and integration technologies. The scientific classification of IoT technologies allows them to be grouped according to functional orientation, communication range and energy efficiency. Short-range technologies (ZigBee, BLE, Wi-Fi, NFC) provide information exchange in local and personal networks, while long-range technologies (LoRaWAN, LTE-M, NB-IoT) provide stable connectivity over large areas, in particular in smart cities and industrial networks.

V. INNOVATIVE DEVELOPMENT OF IOT TECHNOLOGIES:

The Internet of Things (IoT) concept refers to a complex technological system that connects physical objects in the real world to digital networks, enabling their mutual data exchange, automated control, and analysis. IoT systems not only collect and transmit data but also process and analyze this information in real time, allowing for the automatic execution of necessary decisions. Therefore, the IoT concept goes beyond being a mere communication channel between devices, transforming them into an intelligent, autonomous, and adaptable component of a digital Currently, IoT technologies are applied across numerous sectors, including manufacturing, services, transportation, healthcare, energy, and agriculture. They convert existing infrastructures into smart, networked systems, significantly accelerating the transition to a digital economy. For instance, Industrial IoT (IIoT) enables real-time monitoring, predictive maintenance, and improved energy efficiency in manufacturing processes. Similarly, the smart city concept enhances social and environmental sustainability by optimizing transportation, efficiently managing energy and water resources, and monitoring waste management. The innovative development and expansion of IoT technologies are expected to continue along several directions. Firstly, distributed architectures and edge/fog computing technologies allow computational and data analysis processes to be executed at the network edge, close to the data source. This approach significantly reduces latency and network load, enhancing the system’s overall efficiency.

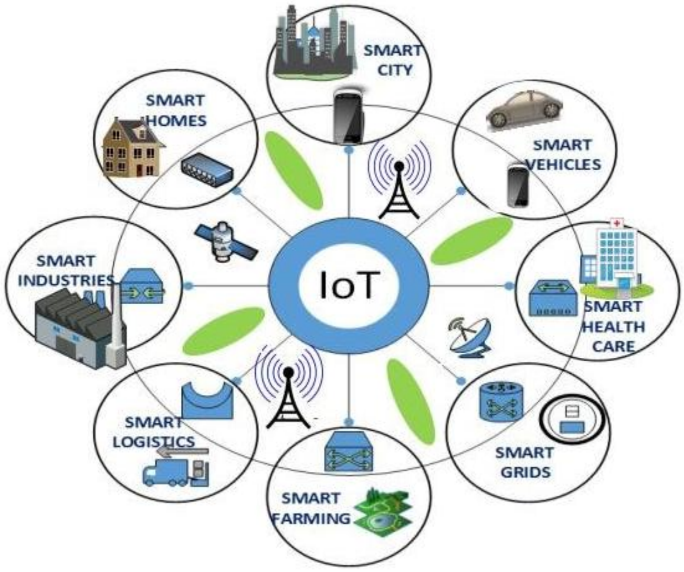

Figure 2. Trends in the innovative development of IoT

Also, standardization and interoperability are important for the effective operation of IoT systems. Ensuring compatibility between platforms created by different manufacturers, standardizing data exchange protocols in a single format, and ensuring semantic compatibility are among the main scientific tasks in this area. The innovative development of IoT technologies is bringing significant changes not only in technical, but also in social and economic spheres.

In particular, in areas such as smart cities (Smart City), digital health (e-Health), smart agriculture (Smart Farming), industrial automation systems (Industry 4.0), and energy management, IoT solutions are a factor that serves to improve the quality of human life, rational use of resources, and sustainable development[15-16].

VI. CONCLUSION:

Internet of Things (IoT) technologies are one of the main driving forces of digital transformation, bringing the interaction between people and devices to the level of automated, intelligent systems. The IoT concept simplifies the process of collecting, transmitting and analyzing data by integrating physical objects into digital networks, and creates the possibility of real-time management. The IoT architecture consists of three main layers, the seamless operation of which determines the efficiency of the system.According to the research results, the development of IoT technologies is based on the integration of wireless communication tools such as RFID, NFC, ZigBee, LoRaWAN, 5G, and artificial intelligence, fog and edge computing solutions. This approach reduces network latency, expands the capabilities of rapid data analysis and autonomous management.

IoT technologies serve to increase efficiency, energy efficiency and security in the fields of smart cities, transport, healthcare, industry and agriculture. Also, innovative solutions based on IoT play an important role in the rational use of resources and achieving sustainable development. Overall, the Internet of Things is creating the foundation of the economy of the future as an integral part of the global digital infrastructure.

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