забезпечити збереження та захист інформації, а також безперебійний доступ до неї, уможливити спільну роботу над матеріалом дослідників з різних країн.

Отже, проаналізовані фактори є визначальними для впровадження хмарних технологій у практику діяльності сучасної бібліотеки, врахування їх на підставі аналізу ситуації дозволить підвищити ефективність українських бібліотек у контексті світового досвіду.

O. Borysov

INTERNET OF THINGS NETWORK PROTOCOLS AT TCP/IP MODEL LAYERS: TRENDS AND IMPLEMENTATION PERSPECTIVES IN LIBRARIES

О. Борисов

МЕРЕЖЕВІ ПРОТОКОЛИ ІНТЕРНЕТУ РЕЧЕЙ НА РІВНЯХ МОДЕЛІ TCP/IP: ТРЕНДИ ТА ПЕРСПЕКТИВИ ВПРОВАДЖЕННЯ В БІБЛІОТЕКАХ

Development of the Internet of Things (IoT) has become a significant factor in supporting economic growth, transforming buildings and cities into autonomous, self-regulating systems that operate independently of human intervention. These systems interact with the physical world by means of sensors, actuators, and control mechanisms, utilizing the existing internet protocols for data transmission, analytics, and decision-making. Today, it's almost impossible to imagine any area of life where IoT technology is not applied, as it relies on the development of "smart" systems supported by a wide range of wireless technologies like Wi-Fi, Zigbee, and Bluetooth, along with the integrated sensors and actuators. This leads to the generation of vast amounts of data that require processing, storage, and display in an efficient, simple, and continuous manner. Consequently, choosing the appropriate communication protocol becomes crucial, necessitating the evaluation of next-generation networks with the enhanced characteristics. This study highlights the significance of both wireless and wired IoT technologies, their applications, and provides a thorough analysis of IoT communication protocols with technical information about their stacks, limitations, and applications.

The creation of various network models aims to generalize and standardize the principles governing network devices and protocols in these systems. This simplifies the process of developing and implementing network technologies, structures the system's topology, and facilitates interaction among various network components.

The OSI (Open Systems Interconnection) model was developed by the International Organization for Standardization (ISO) in the late 1970s. The program for developing common standards and methods for network communication was launched by ISO in the late 1970s. In 1984, the OSI architecture was officially adopted by ISO as an international standard.

The TCP/IP (Transmission Control Protocol/Internet Protocol) model was developed in the 1970s as a part of the ARPANET project, an enterprise of the U.S. Department of Defense. In 1974, Vint Cerf and Bob Kahn published a paper titled "Protocol for Packet Network Intercommunication", which described the TCP/IP model. On January 1, 1983, ARPAnet switched to TCP/IP, and ARPAnet ceased to exist in 1990. The Internet emerged from the roots of ARPAnet, with TCP/IP evolving to meet the changing needs of the Internet.

The development of protocols for IoT began with the advancement of wireless technologies and embedded systems. Throughout the 2000s, specific protocols and technologies were developed and implemented to facilitate communication in large IoT networks. Modern IoT protocols and architectures have developed considering the needs for minimizing energy consumption, supporting a large number of devices, and ensuring security. Currently, there are several IoT stack models with different levels of abstraction.

The OSI, TCP/IP, and IoT stack models each have distinct features reflecting their uniqueness and specific application in network communications. The OSI model comprises seven layers, each with the defined functions, interfaces, and protocols. The TCP/IP model consists of four layers, focusing on providing connectivity over the Internet, utilizing TCP and IP protocols for reliable data transmission. The layers in TCP/IP are less distinct compared to OSI, and the model lacks clear separation of functions, interfaces, and protocols.

In the context of the Internet of Things, the IoT stack model is tailored to the specifics of IoT devices, often characterized by limited computational capabilities and energy consumption. This model includes varying numbers of layers depending on the specific implementation and focuses on energy efficiency, security, and scalability to support a large number of devices.

Each of these models plays a key role in the development of network technologies and has unique features making it suitable for certain applications and usage scenarios. The structural features of each model are depicted in Figure 1.

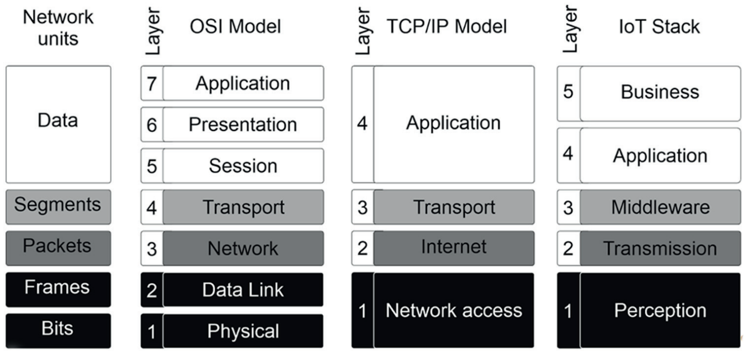

Fig. 1. Structural features of network models

In this study, the choice of the specific TCP/IP network model is determined by its suitability for the required level of abstraction in the development of system architecture for hardware solutions, particularly in the context of the Internet of Things and data exchange protocols. Each layer of the studied network model can utilize corresponding protocols. Table 1 presents a ranking of the most common protocols used in IoT solutions, according to their layers in the TCP/IP model. This facilitates the identification of hardware, software, and comprehensive tools for the purpose of optimizing the processes of developing architecture for end systems.

Table 1

IoT Protocols mapped to the TCP/IP Model

TCP/IP layer	IoT Protocols
Application layer	HTTPS, XMPP, CoAP, MQTT, AMQP
Transport layer	UDP, TCP
Internet layer	IPv4, IPv6, 6LoWPAN, RPL
Network access layer	IEEE 802.15.4, IEEE 802.11, IEEE 802.3, LPWAN, BLE, LTE, NFC, PLC, RFID, Z-Wave, Zigbee

To identify the influence of protocols on the development of Internet of Things (IoT) technologies in the library environment, overall trends, and the most promising among them, a bibliometric analysis was conducted using the capabilities of the Scopus scientometric database. In this research, covering the period from 2018 to 2022, IoT protocols were grouped according to the layers of the TCP/IP model and sorted by the number of publications in descending order. The data obtained is presented in Table 2.

Table 2

Number of publications on IoT protocols keywords at the layers of the TCP/IP Model from 2018 to 2022 (According to Scopus data)

Protocol	Number of Publications from 2018 to 2022					
	2018	2019	2020	2021	2022	Total
TCP/IP Network access layer						
RFID	512	567	566	611	625	2881
IEEE 802.11	266	318	335	356	372	1647
LPWAN	186	245	261	270	280	1242
Zigbee	217	230	242	223	261	1173
LTE	242	253	195	175	173	1038
BLE	188	165	156	208	192	909
IEEE 802.15.4	145	143	121	116	83	608
IEEE 802.3	84	84	68	75	64	375
NFC	54	49	50	49	53	255
PLC	22	29	17	21	27	116
Z-Wave	12	9	14	11	17	63
TCP/IP Internet layer						
RPL	123	138	191	179	183	814
IPv6	149	161	169	125	126	730
6LoWPAN	107	111	100	73	73	464
IPv4	18	31	24	17	16	106

TCP/IP Transport layer						
TCP	118	151	112	139	129	649
UDP	40	44	46	50	40	220
TCP/IP Application layer						
MQTT	301	371	345	437	442	1896
CoAP	166	152	146	116	115	695
HTTPS	20	31	42	58	70	221
AMQP	18	20	22	27	20	107
XMPP	21	17	16	20	10	84

The research identifies several protocols that are particularly actively researched. At the Network access layer, RFID, IEEE 802.11, LPWAN, and Zigbee protocols stand out, each with its unique application features. In library environments, RFID and Wi-Fi (IEEE 802.11) technologies are most prevalent. At the Internet layer, IPv6 and RPL protocols dominate, the latter being designed for energy-efficient networks with unstable communication channels. Interest in IPv6-based protocols is driven by their ability to address $3.4x10^{38}$ network devices, compared to IPv4's limitation of 2^{32} unique addresses, which is already insufficient globally.

At the Transport layer, TCP is preferred for guaranteed data delivery, while UDP is used for time synchronization, broadcast messages, and streaming data not critical to information loss. At the Application layer, MQTT and CoAP protocols are favored due to their low resource demand and implementation cost. MQTT supports encryption, guaranteed delivery, and data storage on brokers, enabling efficient data exchange without high-speed network requirements. CoAP, differing from MQTT, has a client-server architecture, using UDP for data transmission and is mainly used for non-critical information exchange.

The application of these protocols in implementing IoT solutions allows for effective solutions, partly based on the existing institutional resources like RFID systems for library collections, Wi-Fi networks, and NFC or Bluetooth for identification and authorization.

Лю Іцюнь

ПОПУЛЯРИЗАЦІЯ КУЛЬТУРНОЇ СПАДЩИНИ КИТАЙСЬКОЇ НАРОДНОЇ РЕСПУБЛІКИ: ДІАЛОГ ІЗ CHATGPT

Liu Yiqun

PROMOTING THE CULTURAL HERITAGE OF THE PEOPLE'S REPUBLIC OF CHINA: A DIALOGUE WITH CHATGPT

У цифрову епоху пошук нових шляхів та методів популяризації культурної спадщини Китайської народної республіки значно спрощує потужний інструментарій ChatGPT. Цей надзвичайно популярний останнім часом сервіс дозволяє упорядкувати і всебічно розглянути тисячі тематичних публікацій та визначити найбільш ефективні рішення в стислому, але достатньо вичерпному вигляді.