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Automation of the Protocol Selection Process for IoT Systems

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ABSTRACT The Internet of Things is designed to eliminate or minimize human participation in functioning intelligent devices connected to a network for improving human living conditions and their comfort in different spheres. The rapid expansion of the Internet of Things leads to a steady increase in the number of signaling protocols and data structure protocols being developed and used in the IoT, and thus, it complicates their selection when designing the IoT system. In addition, when designing a wireless IoT network, the problem of selecting an energy-efficient protocol arises, as the constant exchange of data depletes the power supply that IoT devices are equipped with. Thus, human intervention for regular battery maintenance is required. A set of rules and criteria for the selection of optimal combination of protocols when designing the IoT system is proposed. The assessment of distributed protocols according to selected criteria based on the Boolean functions has been conducted. The developed program that enables choosing the optimal combination of protocols has been presented. Automation of the protocol selection process at the initial stage will make it possible to reduce the time for designing the IoT system.

KEYWORDS Internet of Things; protocols; software; process automation; data exchange; network.

I. INTRODUCTION

THE development of technologies has led to the emergence of smart home systems that have an Internet connection. The components of such systems are called IoT devices or Internet of Things devices. They have the facilities for interaction with each other and the external environment and are connected by a data network. Appropriate data exchange protocols are used for transmitting information in the Internet of Things systems.

The main concept of IoT systems is the ability to work automatically without human intervention. The system receives data from IoT devices, processes them, and sends commands to the device to maintain a comfortable existence for the user.

Such networks use a wired or wireless connection. When using a wireless connection, you can use energy-efficient devices having their power supply. These can be batteries or disposable batteries.

Constant data exchange depletes the power supply, which leads to the need for regular recharging of batteries or their replacement. Such human intervention negates the benefits of the autonomous operation of the system and its independence from the user.

Therefore, the problem with IoT devices is the time it takes for the power supply to be depleted. It imposes restrictions on the communication protocols that will be used in the system.

The selection of protocols for data exchange in the system is one of the mandatory requirements when designing IoT systems. The process of making this selection is quite complex. One way of its simplification is the automation of the optimal protocol selection for the system under design.

II. RELATED LITERATURE

Traditional approaches to building IoT systems involve selecting equipment that already uses proper protocols for transmitting commands and data. This process is time-consuming because the number of offers on the market is growing exponentially day by day. The invalid selection at the initial stage can lead to significant problems in the final implementation of the system.

Many publications in recent years have been devoted to the analysis of traffic and data transmission methods in IoT systems. In [1], the performance of different messages in the IoT is compared. Different network conditions with payloads of different sizes were emulated, and the method of dynamic selection of data transmission protocol was proposed. The authors of [2] proposed a synchronized distributed protocol for direct communication between D2D devices, which indicates the regular emergence of new protocols for data transmission in IoT systems. In [3], the protocols used for data transmission in the IoT were unified, and it was justified that the widespread deployment of the Internet of Things requires simpler communication protocols. A comparison between HTTP performance in the legacy protocol category and MQTT in the protocol category based on the ICN architecture was made.

The authors of [4] compared IoT communication protocols focusing on the main characteristics and behavior of different energy efficiency indicators, security, data transfer rate, and others. This research is aimed at the development of guidelines for the developers selecting the optimal protocol [5-9]. At present, the research on communication protocols used between embedded IoT systems and the cloud is also conducted [10]. The implementation of the protocol via TCP sockets using the JSON packet is proposed.

Thus, automating the selection of optimal protocols for the IoT systems while designing is relevant today. It should reduce the time of protocol selection, provided that there are criteria and requirements for the system.

III. MATERIALS AND METHODS

The Internet of Things (IoT) is a computer system that integrates physical objects with embedded sensors and software through computer networks.

The main purpose of such a system is to automate processes for ensuring the comfort of human existence, without human intervention in the system.

The system has its own data center to verify the information received from the data collection nodes to send control commands to the execution nodes. Fig. 1 shows the scheme of interaction in the Internet of Things system.

Data collection nodes and execution nodes are the basic units of the network, each of which is a device designed to perform its specific task.

According to the coverage area, the IoT system can be divided into three categories:

- Personal networks. Their coverage area is with a radius of up to 10 meters. They enable the integration of IoT devices within a room.

- Wireless networks. Their coverage area is up to 100 meters. They connect devices within the house.

- Large-scale networks. They enable data transmission over a distance of several kilometers, which can cover part or all of the city.

Due to the presence of territorial distribution and the possibility of integration of a wide variety of devices, it is necessary to analyze the data which will be transmitted over the network and the area where the system will operate during the formation of the system. Based on the obtained analysis results, the protocols according to which the project will work are selected with the optimal energy consumption of IoT devices.

Typically, large-scale networks require using devices that must operate in power-saving mode due to the difficulty of maintaining power systems. Therefore, it is necessary to use protocols that can support the operation of the device only for the time of data collection and transmission. At all other times, the device should be in sleep mode.

Protocols used in IoT systems can be divided into two categories:

– signal transmission protocols.
– data structure protocols.

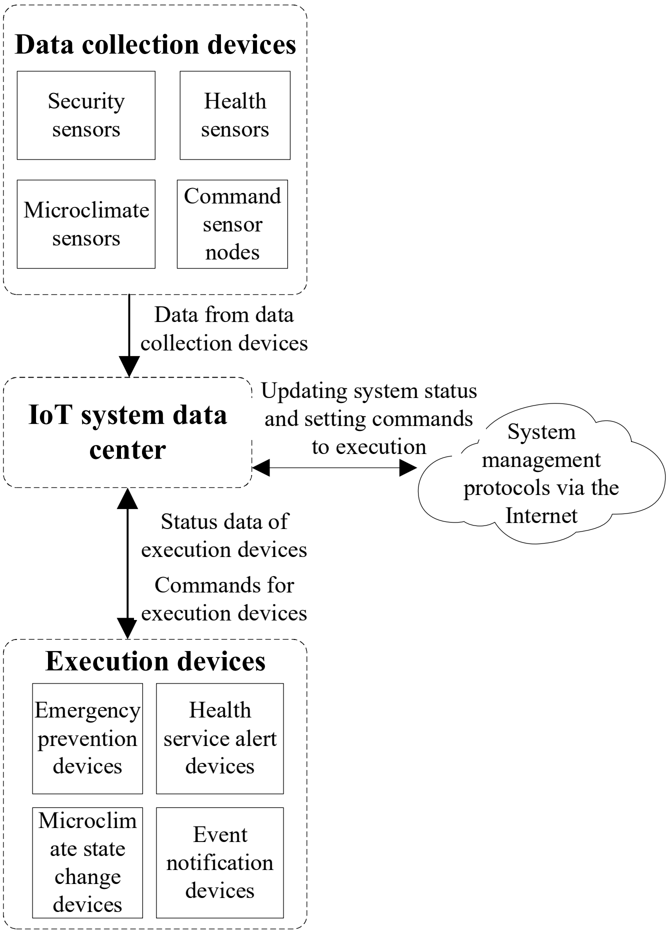

Figure 1. Interaction in the Internet of Things system

Both categories must be used when developing the system. Signal transmission protocols determine the data transmission medium, frequency characteristics of the signals, data encoding methods, the structure of data packets.

Data structure protocols define the data description method for quick separation of some data from others during processing.

Signal transmission protocols include [11-25]:

– Wi-Fi;
– Bluetooth;
– NB-IoT (Narrow Band Internet of Things);
– ZigBee;
– MeshLogic;
– 6LoWPAN (IPv6 over Low power Wireless Personal Area Networks);

– WirelessHART (Wireless Highway Addressable Remote Transducer Protocol).

Each of the protocols has a description of the connection method among devices for data transmission, speed characteristics, transmission distance.

The data structure protocols include:

– HTTP (HyperText Transfer Protocol);
– SOAP (Simple Object Access Protocol);
– XMPP (eXtensible Messaging and Presence Protocol);
– STOMP (Streaming Text Oriented Messaging Protocol);
– CoAP (Constrained Application Protocol);
– MQTT (Message Queue Telemetry Transport);
– MQTT-SN (Message Queue Telemetry Transport for Sensor Networks);
– Self-developed protocols.

In some cases, a specialized data description during transmission may be required when developing the system. It can reduce transmission time and improve energy efficiency.

Some protocols require constant support of the connection for IoT devices to the system. If the system does not have to respond immediately to changes in status, then permanently connected protocols will only deplete the power supply.

The algorithm of the protocol selection process is shown in Fig. 2.

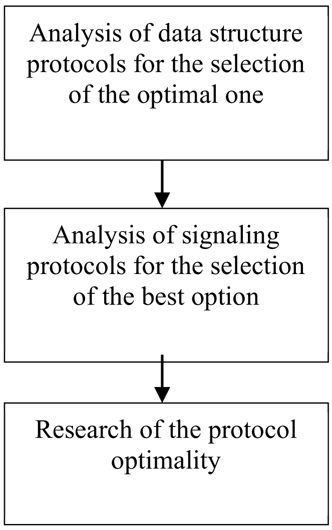

Figure 2. The process of protocol selection

The situations in which several protocols can give the same results will occur. In this case, the system developers have to decide which of the alternative protocols to use.

Table 1 provides information on signal transmission protocols as to transmission distance, power supply depletion time, transmission rate, and data packet size.

Table 1. Characteristics of IoT-protocols [7-10]

Protocol	Transmission distance	Power supply depletion time	Transmission rate	Data packet size
Wi-Fi	< 100 m.	several months	2 Gbps.	32 byte
Bluetooth	< 50 m.	several months	24 Mbps	7 byte
NB-IoT	< 50 km.	1-2 years	250 Kbps	7 byte
ZigBee	< 100 m.	5-10 years	250 Kbps	31 byte
MeshLogic	< 100 m.	4-7 years	250 Kbps.	31 byte
6LoWPAN	< 800 m.	several months	250 Kbps	31 byte
WirelessHART	< 255 m.	4-10 years	250 Kbps	31 byte

The presented data are based only on the theoretical calculation of operating time when designing the protocols.

To simplify the selection of protocols, a set of rules was formed, according to which one can choose the optimal combination of protocols [16-25]:

- The transmission of video/audio data on a network requires high speed, so a Wi-Fi signaling protocol is recommended for such networks.
- For long transmission distances, the optimal signal transmission protocol is NB-IoT.
- For simplified integration of the system into the Internet, the 6LoWPAN signaling protocol and the HTTP data structure protocol are recommended.
- If a distributed data network is required, the XMPP data structure protocol is recommended, which enables an inter-server transmission without additional modules.
- If remote device management is required, the MQTT protocol is recommended, which enables maintaining device activity in standby mode with a command to execute.
- If you need simplified integration into the system, the SOAP data structure protocol is recommended for third-party developers, as it uses the XML markup language, which facilitates the formation and analysis of the data packet.
- Devices in personal networks can transmit data at a distance of up to 10 meters, in local networks at a distance of up to 200 m. In large-scale systems, the transmission can be performed at a distance of up to 50 km.

We decided to use several indicators to formalize the protocol selection process based on the above rules.

The following selection criteria were chosen:

- Transmission distance: depending on the transmission distance, one of the signal transmission protocols is determined.

- A distributed network of processing servers: if distributed computing is required, one of the data structure protocols will be selected.

- Simplified integration for the third-party developers: if the third-party developers work with the already developed system, one of the data structure protocols will be selected, using a simple method of describing information.

- Video/audio data: this type of data transmission requires protocols that have a high transmission rate and are capable of simple binary data transmission.

- Rapid response of devices in the system to commands from the server: if it is necessary to control Internet of Things devices in the system remotely, the situation when devices have to receive a command as soon as possible may occur, that will require selecting the protocol capable of sending a command to the device at once.

The selection process can be reduced to answering "yes" or "no" to six questions:

- Does the transmission distance in the protocol meet the system requirements?
- Is a distributed network of processing servers required?
- Is simplified integration for the third-party developers required?
- Is the transmission of video/audio data available?
- Is the quick response of devices to commands from the server required?
- Is the integration into the Internet simple?

Having only two options for answering the questions enables the creation of Boolean functions from n-variables.

We decided to divide the questions into two groups according to the groups of protocols.

Based on the input questions, tables of Boolean functions are constructed for each of the protocols (Table 2 and Table 3), where, for Table 2, a is the answer to the question "Does the transmission distance in the protocol meet the system requirements?", b – "Is the transmission of video/audio data available?", c – "Is the integration into the Internet simple?".

For Table 3, the variables answer the following questions: a – "Is a distributed network of processing servers required?", b – "Is simplified integration for the third-party developers required?", c – "Is the quick response of devices to commands from the server required?", d – "Is the integration into the Internet simple?".

The result is the values of the Boolean functions F (abc) and F (abcd) for each of the available protocols. If the function for the protocol is "1", it can be used in this system.

Table 2. Table of values of Boolean functions of the first group

a	b	c	$F_{Wi\text{-}Fi}(abc)$	$F_{Bluetooth}(abc)$	$F_{NB\text{-}IoT}(abc)$	$F_{ZigBee}(abc)$	$F_{MeshLogic}(abc)$	$F_{6LoWPAN}(abc)$	$F_{WirelessHART}(abc)$
0	0	0	0	0	0	0	0	0	0
0	0	1	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	0	0
0	1	1	0	0	0	0	0	0	0
1	0	0	1	1	1	1	1	1	1
1	0	1	0	0	0	0	0	1	0
1	1	0	1	0	0	0	0	0	0
1	1	1	1	0	0	0	0	0	0

Table 3. Table of values of Boolean functions of the second group

a	b	c	d	$F_{HTTP}(abcd)$	$F_{SOAP}(abcd)$	$F_{XMPP}(abcd)$	$F_{STOMP}(abcd)$	$F_{CoAP}(abcd)$	$F_{MQTT}(abcd)$
0	0	0	0	0	0	0	1	1	0
0	0	0	1	1	0	0	0	0	0
0	0	1	0	0	0	0	0	0	1
0	0	1	1	0	0	0	0	0	0
0	1	0	0	0	1	0	0	0	0
0	1	0	1	0	0	0	0	0	0
0	1	1	0	0	0	0	0	0	0
0	1	1	1	0	0	0	0	0	0
1	0	0	0	0	0	1	0	0	0
1	0	0	1	0	0	0	0	0	0
1	0	1	0	0	0	0	0	0	0
1	0	1	1	0	0	0	0	0	0
1	1	0	0	0	0	0	0	0	0
1	1	0	1	0	0	0	0	0	0
1	1	1	0	0	0	0	0	0	0
1	1	1	1	0	0	0	0	0	0

Table 2 makes it possible to come to the functions of 3 variables for the first group of protocols:

$$F_{Wi-Fi}(abc) = a\bar{b}\bar{c} + ab\bar{c} + abc = a\bar{c} + ab$$
$$F_{Bluetooth}(abc) = a\bar{b}\bar{c}$$
$$F_{NB-}\quad(abc) = a\bar{b}\bar{c}$$
$$F_{ZigBee}(abc) = a\bar{b}\bar{c}$$
$$F_{MeshLogic}(abc) = a\bar{b}\bar{c}$$
$$F_{6LoWPAN}(abc) = a\bar{b}\bar{c} + a\bar{b}c = a\bar{b}$$
$$F_{WirelessHART}(abc) = a\bar{b}\bar{c}.$$

Table 3 shows the functions of 4 variables for the second group of protocols:

$$F_{HTTP}(abcd) = \bar{a}\bar{b}\bar{c}d$$
$$F_{SOAP}(abcd) = \bar{a}b\bar{c}\bar{d}$$
$$F_{XMPP}(abcd) = a\bar{b}\bar{c}\bar{d}$$
$$F_{STOMP}(abcd) = \bar{a}\bar{b}\bar{c}\bar{d}$$
$$F_{CoAP}(abcd) = \bar{a}\bar{b}\bar{c}\bar{d}$$
$$F_{MQTT}(abcd) = \bar{a}\bar{b}c\bar{d}.$$

IV. RESULTS

Since the values of Boolean functions can be represented in the program code using the basic operators "AND" and "OR", then using obtained functions, software for selecting protocols "LProtocols Selector" was developed, which enables the formation of a list of protocols requirements during the preparation of a new system immediately.

The program asks the system criteria that correspond to the values of variables in Boolean functions. Based on the input values of the variables with the help of conditional operators, each of the protocols is checked for the value of its Boolean function. When the value is "1", the protocol is considered suitable for the system.

The program is written in C#. To use the program, you need a computer with the Microsoft Windows family of operating systems, starting with Microsoft Windows XP [10]. Fig. 3 shows the main window of the LProtocols Selector program.

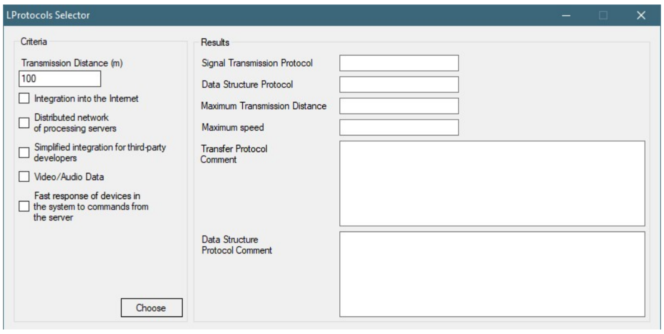

Figure 3. The main program window of LProtocols Selector

The program window is divided into 2 parts. On the left, there are the criteria that the Internet of Things has to comply with. The right part will display information about the selected protocols after analyzing the criteria based on the rules mentioned above.

The user inputs data and selects criteria, and after clicking the "Select" button, the program will choose a combination based on rules and criteria, consisting of a signal transmission protocol and a data structure protocol. The results will be displayed in the right part of the window. Fig. 4 shows the results of the program.

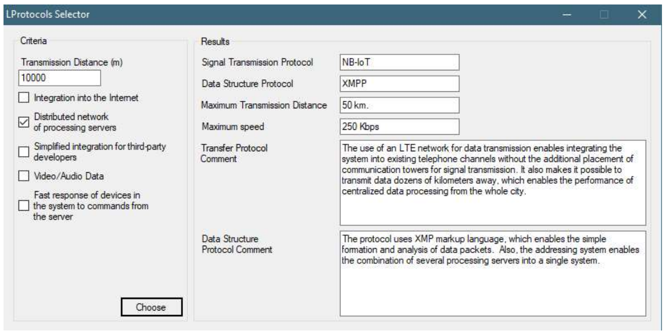

Figure 4. The main window of LProtocols Selector

The program displays the following additional data:

- The maximum distance that can be transmitted using the selected signaling protocol.
- The maximum speed at which data can be transmitted with the selected signaling protocol.
- The comment on the signal transmission protocol, where there is information about the protocol and the reason for its selection.
- The comment on the data structure protocol displays information about the protocol as well as the reason why the program has chosen it.

Protocols selected as a result of the program are optional. In some cases, the selected protocols may not be suitable due to the location or the need to use technologies that are not compatible with the protocols.

An example of a territorial location problem is the problem of placing intermediate routers for ZigBee or 6LoWPAN protocols. Therefore, it is necessary to change the signal transmission protocol to one that will have a cell topology in which the routers will be the devices themselves.

V. CONCLUSION

The distribution of IoT systems and the need for individual system design require the selection of data transmission protocols each time. To facilitate the process of protocol selection, the use of Boolean functions based on the requirements of the designed network is proposed. Existing Boolean functions enable the selection of protocols from the signaling group and the data structure group. Based on Boolean functions, the software for automation of the process of initial protocol selection has been developed. Further development of the software involves updating the list of Boolean functions, where new protocols and the input parameters of the resulting system will be added. Software testing based on test project data is currently performed.

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