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OPTIMIZING SMART HOME NETWORK PROTOCOL SELECTION BY HIERARCHY ANALYSIS METHOD

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Abstract. The article analyzes four protocols of the Internet of Things smart home network with corresponding characteristics. The process of choosing the best protocol depending on the expert requirements for the IoT SH network is considered. An example of choosing a protocol based on four indicators based on the hierarchy analysis method is given.

Keywords: IoT network, protocols, smart home, hierarchy analysis method.

Introduction

The Internet of things (IoT) is a set of embedded systems, networks of wireless sensors, control systems and automation tools for processing information received from sensors. An important point in the development of IoT is the analysis of the types of protocols for collecting information from sensors used to transmit data between components of IoT network on short distance [1]. However, finding the best match between the protocol and the IoT network is an optimization task, since it is difficult to understand the influence of parameters when choosing a protocol. In this paper, we consider the choice of the appropriate protocol of the IoT smart home (SH) network using the hierarchy analysis method (HAM).

Algorithm of hierarchy analysis method

The hierarchy analysis method was developed in the early 1970s by T.L. Saati, an operations researcher at the University of Pittsburgh, USA [2]. It is based on a deep analysis of the nature, influencing factors and internal relationships of complex decision-making problems, using less quantitative information to algorithmize the decision-making process. The HAM algorithm includes steps [3].

Step 1. Identification of the problem and formulation of the goal.

Step 2. Definition of the main criteria and alternatives.

Step 3. Building a hierarchy: from goals through criteria to alternatives.

Step 4. Construction of a matrix of pairwise comparisons of criteria in order to select alternatives by criteria.

Step 5. Application of the method of analysis of the obtained matrices.

Step 6. Determination of alternative weights according to the hierarchy system.

The importance of different system options and different quality indicators are compared in pairs. The results of paired comparisons of elements are reduced to a matrix form:

$$\mathbf{A} = \left\| a_{ij} \right\|, \tag{1}$$

where $a_{ij} = w_i / w_j$ are estimates of paired comparisons of w_i and w_j selection elements. The diagonal of this matrix is filled with single values, and the matrix elements lying below the diagonal are filled with inverse values, for example, for the value 2 will be 1/2, for the value 3 – 1/3, etc.

The expert matrix formed by the pairwise comparison results is called the judgment matrix.

The scaling method of the judgment matrix element a_{ij} is based on comparison from Table 1. Experts form matrices of paired comparisons in relation to all quality indicators.

Table 1. **Element scale table**

Factor *i* is better than factor *j*	Value
Two elements of comparison are equally important	1
Moderate advantage of one element over another	3
Significant advantages of one element over another	5
The greater advantage of one element over another	7
The very strong superiority of one element over another	9
Intermediate decision between two decisions	2, 4, 6, 8

Next, the generated matrices of pairwise comparisons of the elements of quality indicators are processed. From a mathematical point of view, this processing problem is reduced to the calculation of the main eigenvector corresponding to the maximum eigenvalue of the matrix. As a result of processing the obtained matrixes, the components of the eigenvector V_j of the global priority vector P_j are obtained

$$V_j = \sqrt[n]{\sum_{i=1}^{n} a_{ij}}, j \in (1,n), \tag{2}$$

$$P_j = \frac{V_j}{S}, j \in (1,n), S = \sum_{j=1}^{n} V_j, \tag{3}$$

where n is the number of variants of self-organization algorithms, is compared.

Using the obtained data, the values of the components of the vector of global priorities C_j are calculated according to formula

$$C_j = \sum_{j=1}^{n} P_j Q_{ij}, i \in (1,n), Q_{ij} = V_i / \sum V_i. \tag{4}$$

Data transmission standards

Currently, there are several standards for data transmission in the IoT networks. Let's consider some of them [4].

1. The Wireless USB standard is a wireless data transmission standard developed by the Wireless USB Promoter Group. During the development, much attention was paid to improving energy efficiency. Devices manufactured in accordance with Specification 1.1 consume less power in idle mode. Wireless USB 1.1 supports NFC technology, which simplifies the setup and operation of wireless USB devices.

2. The Narrowband Internet of Things (NB-IoT) standard is a mobile communication standard for telemetry devices with low data exchange volumes. It was developed by the 3GPP consortium as part of the work on new generation mobile network standards. It was intended to connect a wide range of autonomous devices to the digital communication network, for example, medical sensors, resource consumption meters, smart home devices, etc. NB-IoT is one of three IoT standards developed by 3GPP for mobile communications: eMTC (enhanced machine-type communication), NB-IoT and EC-GSM-IoT [2]. The standard eMTC has the highest bandwidth and is built on the basis of LTE standard equipment. The EC-GSM-IoT standard provides the lowest bandwidth and goes beyond the GSM network.

There are many different communication protocols in the IoT SH network [4]. Taking a smart home as an example, a suitable communication protocol can optimize the network environment and reduce the energy consumption of the entire system.

Optimization the selection of the IoT network protocol

We optimize the smart home network by using the HAM to choose data transmission protocols. The first is the choice of data transmission standards with parameters [4] (Table 2).

Table 2. **Comparative analysis of the data transmission standard LTE Cat 0, eMTC, NB-IoT, EC-GSM-IoTs**

	LTE Cat 0	eMTC	NB-IoT	EC-GSM-IoT
Downlink speed	1 Mbit/s	1 Mbit/s	250 kbit/s	474 kbit/s or 2 Mbit/s
Delay	5 ms	10 ms–15 ms	1,6 s–10 s	700 ms–2 s
Device bandwidth	1,4–20 MHz	1,4 MHz	180 kHz	200 kHz
Device transmission power	23 dBm	20/23 dBm	20/23 dBm	23/33 dBm

We build the relevant hierarchy according to the Table 3. We create the structural model based on the four characteristics of download speed, delay, device bandwidth, and device transmission power consumption for the four protocols of LTE Cat 0, eMTC, NB-IoT, EC-GSM-IoT. The first level in this structure is the target of the preferred choice, the second level is the quality criteria, and the third level is the alternatives (Figure 1).

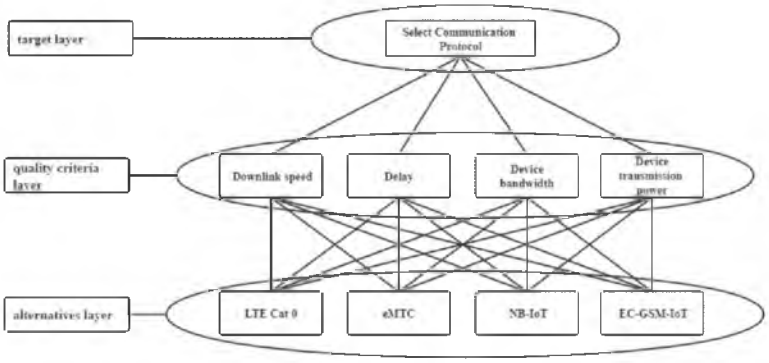

Figure 1. Decomposition of the choice problem

A pairwise comparison matrix was established by experts for this group of quality indicators according with HAM. In Table 3 experts, a pairwise comparison of the importance of selected quality metrics, in particular downlink speed, delay, device bandwidth and device transmission power builds. The diagonal of this matrix is filled with the value "1", and the matrix elements below the diagonal are filled with the inverse value.

Table 3. **Computational estimation of matrix and vector components for pairwise comparison of communication protocols**

	Downlink speed	Delay	Device bandwidth	Device transmission power	Eigenvector components V_j	Components of the priority vector P_j
Downlink speed	1	1/5	1/4	1	0,47	0,09
Delay	5	1	2	5	2,65	0,52
Device bandwidth	4	1/2	1	2	1,41	0,27
Device transmission power	1	1/5	1/2	1	0,56	0,11

Next, pairwise comparisons are made at step 3 in the form of the relative complexity of the alternatives in relation to each quality indicator. As a result of processing the obtained matrices, according to formula (2) and (3), the eigenvectors (V_{ij}) and priority vectors (Q_{ij}) are calculated, which are given in Tables 4–7.

Table 4. **Pairwise comparison matrix of download speed**

	LTE Cat 0	eMTC	NB-IoT	EC-GSM-IoT	V_{i1}	Q_{i1}
LTE Cat 0	1	1	4	2	1,68	0,36
eMTC	1	1	4	2	1,68	0,36
NB-IoT	1/4	1/4	1	1/2	0,42	0,09
EC-GSM-IoT	1/2	1/2	2	1	0,84	0,18

Table 5. **Pairwise comparison matrix of delay**

	LTE Cat 0	eMTC	NB-IoT	EC-GSM-IoT	V_{i2}	Q_{i2}
LTE Cat 0	1	3	9	7	3,70	0,58
eMTC	1/3	1	7	5	1,84	0,29
NB-IoT	1/9	1/7	1	1/2	0,29	0,04
EC-GSM-IoT	1/7	1/5	2	1	0,48	0,07

Table 6. **Pairwise comparison matrix of device bandwidth**

	LTE Cat 0	eMTC	NB-IoT	EC-GSM-IoT	V_{i3}	Q_{i3}
LTE Cat 0	1	3	9	7	3,70	0,59
eMTC	1/3	1	6	5	1,77	0,28
NB-IoT	1/9	1/6	1	2	0,43	0,06
EC-GSM-IoT	1/7	1/5	1/2	1	0,34	0,05

Table 7. **Pairwise comparison matrix of device transmission power**

	LTE Cat 0	eMTC	NB-IoT	EC-GSM-IoT	V_{i4}	Q_{i4}
LTE Cat 0	1	2	2	3	1,86	0,42
eMTC	1/2	1	1	2	1	0,22
NB-IoT	1/2	1	1	2	1	0,22
EC-GSM-IoT	1/3	1/2	1/2	1	0,53	0,12

Table 8 summarizes the component estimates of download speed, latency, bandwidth, and communication power consumption construct-related quality indicator priority vectors. Using these priority vectors, the values of each sub-vector of the global priority vector are calculated according to the formula 4 and are given in the last column of Table 8.

Table 8. **The results of calculating the values of the components of the global vector of priorities**

No.	Standard	Q_{i1}	Q_{i2}	Q_{i3}	Q_{i4}	C_i
1	LTE Cat 0	0,36	0,58	0,59	0,42	0,5395
2	eMTC	0,36	0,29	0,28	0,22	0,283
3	NB-IoT	0,09	0,04	0,06	0,22	0,0693
4	EC-GSM-IoT	0,18	0,07	0,05	0,12	0,0793
P_j		0,09	0,52	0,27	0,11	–

According to the maximum value of the vector components of the global priority C_i, considering the introduction of the quality index, the better information transmission standards selected should be LTE Cat 0.

Conclusion

The algorithm of the hierarchy analysis method related to expert methods is given. Four protocol standards for creating and modeling networks and in a smart home are described. An example of choosing the best IV protocol using MAI is given. According to the maximum value of the vector components of the global priority the better information transmission standards selected should be LTE Cat 0.

References

1. IoT Data Transfer Protocols. [Electronic resource]. URL: https://iot.ru/wiki/protokoly-peredachi-dannykh-iot.
2. Saati T. Decision-making. Method of hierarchy analysis. M., 2003.
3. Nikulshin B.V. [et al.]. System analysis and decision-making in project and management activities. Minsk, 2021.
4. Jamalipur A. Wireless mobile Internet: architecture, protocols and services. M., 2009.
6. Bezruk V.M., Chebotareva D.V. Multi-criteria analysis and choice of means of telecommunications. Kharkov, 2017. P. 268.