EVALUATING THE EFFICIENCY OF FOG COMPUTING ON THE INTERNET OF THINGS USING A NON-MARKOV MODEL

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As new technologies appear and submerge with each other, people get more and more dependent on them, and as more and more different devices connect with each other, the more important it gets to reach accurate decisions in the fastest possible way. With nowadays self-driving cars and other similar technologies it is most important to connect many different sensors and devices together and make them communicate and reach a decision as fast as possible. The article discusses a scenario in which several different sensors and devices on the Internet of things are connected together in a fog computing system for quick decision making. To estimate the efficiency of fog system, The non-Markov model of multichannel system of mass service with "heating" and "cooling" is proposed. It allows to take into account the peculiarities of the organization of fog calculations and calculates the waiting time before making a decision and after it. Another feature of the model is that it allows in many cases to improve the accuracy of the initial data set compared to the non-Markov model. A simulation is made and the model results are presented graphically and showed how Warm-up and cooling have great influence on the efficiency of fog computing and how the waiting time of each response is multiplied.

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Introduction

The Internet of Things (IoT) is a network of devices that connect to the Internet to communicate with other devices. Things exchange different information among themselves, enrich and give us a better understanding of objective reality, fully automating the management processes of groups of devices. IoT development is a global trend. The idea of the Internet of things plays a significant role in the development of the IT industry not only in Russia (the program «Digital Economy of the Russian Federation»), but also abroad. IoT is included in the list of breakthrough technologies in the USA, and in China - in the list of strategic industries. Development is well under way in Australia, Germany, India, Japan, South Korea, England and Singapore.

It is believed that the term «Internet of Things» was first proposed by Kevin Ashton in 1999 during a presentation at Procter&Gamble. The founder of the term was convinced that the concept of IoT was the ability to provide computers with additional information collected by sensors and RFID tags. After the emergence of the term, the development of this technology began to be relatively slow. Only in 2003 the first hardware platform of the Internet of things - Arduino - appeared. The Arduino platform is a single-board computer that allows you to connect sensors and actuators over the network, manage them and interact with the environment. In 2007, the online service Pachube was introduced, which serves to collect and visualize data. This solution allowed connecting data from multiple Arduino sensors around the world to a single service that could collect and process data from remote devices and provide new services such as weather services. The next landmark period was 2008-2009, when Cisco announced that the number of devices connected to the Internet exceeded the population of the Earth. In 2010 and 2011, methodologies for the development and further implementation of IoT technologies were introduced. The European Integration Project IoT-A (IoT – Architecture) offers a reference architectural model of the Internet of things with a description of all functional blocks. The iCore project proposed a number of concepts and algorithms for the development of a «smart» Internet of things with a number of self-tuning functions that could provide user queries [1]. This marked the beginning of a massive appearance and launch of successful IoT projects.

Related Work

In the recent years the topics of fog computing and IoT are among the most focused-on and desired between researchers, [2] for instance focused on the problem of formalizing the workload allocation problem in view of fog computing special aspects by using the device “offload” strategy. His approach is based on the optimization problem search space reduction through the candidate computing device set selecting. Likewise [3] dealed with the problem of workload distribution modeling in the system on the basis of fog-computing. Where he proposed a model of task distribution through the computing nodes, paying attention to the geographical distribution of nodes and to the transitory data transmission overheads.

In [4][5] the authors use queuing theory once to reach load balance in a cloud computing system and once to calculate the effect of monitoring on a cloud computing system, in both cases they calculated pre-processing and post-processing times of requests and showed there effect on the overall processing time. [6] Mentioned the security and privacy issues and recommended security measures which are faced while deploying internet of things. Where [7] proposed a middleware architecture to solve security issues, his security middleware acts as a smart gateway as it is meant to pre-process data at the edge of the network. Depending on the received information, data might either be processed and stored locally on fog or sent to the cloud for further processing.

The Internet of Things IoT

The Internet of Things is a system of interconnected objects connected to the Internet that can collect and transmit data without human intervention. Its basic architecture consists of four levels, which are represented in figure 1.

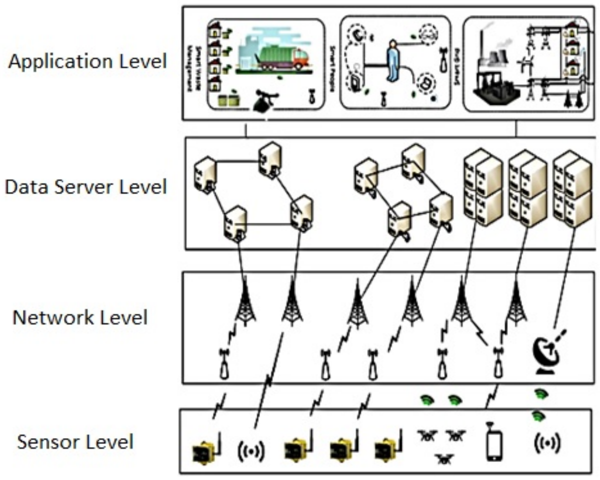

Fig. 1. Architecture of IoT

The sensor layer includes sensors and devices that collect data from the physical environment in real time, process it and then send it over the network.

The network layer consists of network gateways and data collection systems. At this level, analog data that have been collected from sensors are converted into digital data. The second layer also performs malware detection and data management.

The data processing level is the most important stage. Here the data is pre-processed and separated and then sent to the data center. This step includes IT analytics and data processing to make them more efficient and fully usable.

The application layer consists of clouds and datacenters, where data is carefully and accurately analyzed. They process and clean data to eliminate any errors and missed values. After this stage, the data is ready to be sent back and perform operations.

Advantages of IoT’s are: reduced costs through rapid problem detection (it not only saves time, but also minimizes major repair costs), efficiency and performance, mobility and flexibility (thanks to the use of IoT technology, operations can be performed remotely).

The disadvantages of IoT include possible security threats, possible compatibility problems of devices and lack of common international standards [8].

Fog Computing

The concept of Fog computing is defined either as an independent concept [9,10] or as an evolution of cloud computing [11], as cloud computing has proven to be reliable, supporting the operation of a number of software systems, High performance and sufficient scaling, but with the following disadvantages: The computational load on the Inland increases due to the need not only to process the received data, but also due to the calculations, The need to send large volumes of data increases the load on the sensors and communication infrastructure. In the context of our work, we will consider Fog computing as one of the directions of the further evolution of cloud computing. The layer of «fog» computing is located between the «edge» of the network, i.e. user devices, and the cloud, as shown in figure 2.

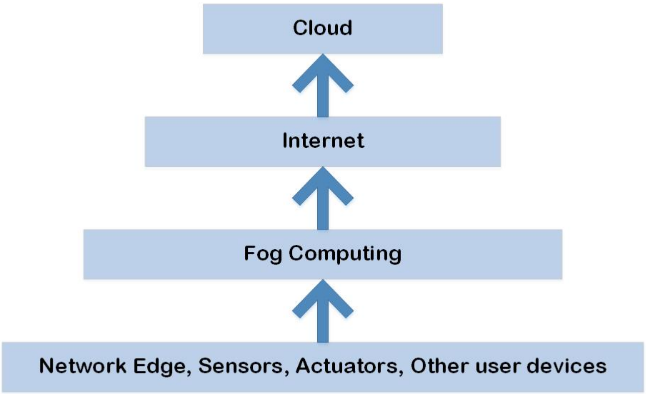

Fig. 2. Schematic representation of the concept of fog computing

Fog computing involves transferring computing and data storage from a traditional «cloud» to an intermediate layer of devices located closer to the edge of the network [12], which allows you to reduce the load on the communication medium and Inland devices.

Data communication

IoT communications are the communications infrastructure and services that help manage connecting different types of devices. For small environments, for example, low-power and short-range networks are suitable for homes or offices. Such networks are economical. Examples of such networks are summarized in table 1 [13].

The most popular networks are LPWAN networks, they are characterized by wide coverage area and low power consumption. The most common examples are presented in table 2 [14].

Networks are divided into licensed spectrum (communication operator required) and unlicensed spectrum (operator not required). The licensed spectrum includes: NB IoT, LTE-M, EC-GSM-IoT.

One of the specialized IP communication technologies is NB-IoT, which has three advantages:

- is useful when you need to transfer a small amount of traffic;
- the devices are located in an inaccessible place, for example, in the basement;
- Energy saving technologies.

Table 1

Short-range networks

Network	Description
Bluetooth	Provides high-speed data transmission and sends voice and data signals up to 10 meters.
NFC	Set of communication protocols for data exchange between two electronic devices up to 4 cm. NFC provides low-speed connectivity with easy configuration that can be used to support more powerful wireless connectivity.
Wi-Fi/802.11	Due to the low cost of operation Wi-Fi is the standard option for home and work. But this option is not suitable for all scenarios due to limited range of action and constant energy consumption.
Z-Wave	A multilink network that uses low-energy radio waves to communicate between devices.
Zigbee	Specification based on IEEE 802.15.4 for a set of high-level communication protocols used to create personal networks with small digital radios with low power consumption.

Table 2

Wide area networks

Network	Description
IoT 4G LTE	Such networks provide high power and low latency. This is a great option for Internet of Things scripts that require real-time information or updates.
IoT 5G	Internet of Things 5G is not yet implemented. It is planned that in the future they will support further innovation on the Internet of things, as well as provide a much faster download speed and connectivity to a much larger number of devices in a specific area.
Cat-0	These LTE based networks are the most economical. They provide the basis for Cat-M technology, which will replace 2G.
Cat-1	This standard for mobile IoT will eventually replace 3G. Cat-1 networks are easy to configure. This is a great option for applications that require a voice or browser interface.
LoRaWAN	Long-range wide area networks (LoRaWAN) provide communication between mobile battery-powered dual-directional devices.
LTE Cat-M1	These networks are fully compatible with LTE networks. They allow you to optimize the cost and power of the second generation of LTE chips designed specifically for Internet of Things applications.
NB-IoT (Narrowband Internet of Things)	NB-IoT/Cat-M2 uses direct sequence modulation (DSSS) to send data directly to the server. This eliminates the need for a lock. Setting up NB-IoT networks is more expensive, but with no gateway, their operation is less expensive.
Sigfox	This global IoT Network Service Provider offers wireless networks to connect low-power facilities that continuously generate data.

The non-licensed spectrum includes: LoRa, Sigfox, Stream, NB-FI and Open UNB. Unlicensed networks are used for local coverage in hard-to-reach locations (e.g., career or fields).

Narrowband networks (LoRa, NB-IoT, EC-GSM), which have reliability and high speed, are used for monitoring and control.

Ultra-narrowband networks (Sigfox, XNB, NB-FI, Open UNB) with energy efficiency, high penetration and range are mainly used for monitoring.

Among wired technologies, Power line communication (PLC) solutions play an important role. PLC is a communication technology that allows data to be sent and received via existing power cables. This enables the power and control of the IP device via the same cable [15].

General Feature of Fog Computation Model

In the world of IoT, it is very common to use and connect different types of devices with each other from different vendors, in this model different kinds of sensors from all types and shapes and sizes with different or similar functionality and in different locations are used, they all have limited transmission capabilities (mostly up to only 20-30 meters). That's why they are all connected to local area receivers and transmitters with much more higher transmission capabilities (Transmission distances measured in Km or miles). Through these long distance transmitters the sensors send packets of data to local area servers, this multi-transmission process takes the intensity □ with the processing time in each station μ_w.

The local servers gather the transmitted packets in queues and process them taking the intensity μ. Some processing might also need further or additional information or data needed to be collected or processed in major servers or from major Data bases, this process takes the intensity μ_c.

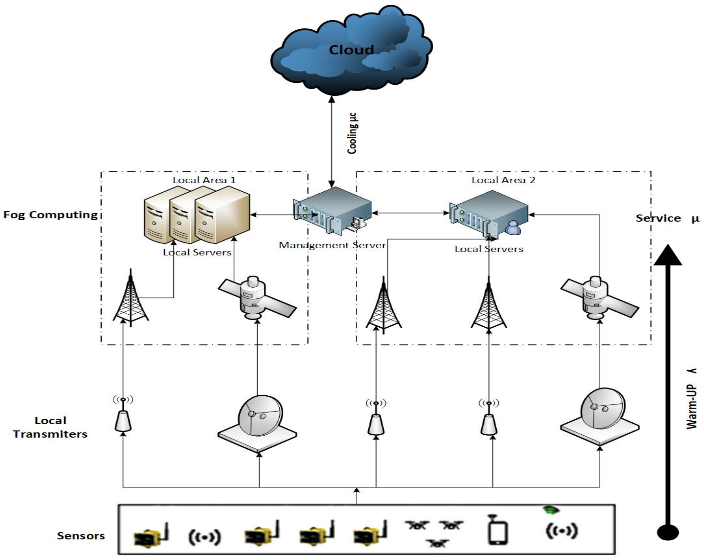

Fig. 3. A Fog computing model using different sensors from different locations

The model shows how it is full adaptive and can be used in real life with today's technology. It also shows how fog computing can play a big role in fast decision making for local area requests and by that deescalating the load on the far away data centers and mainframe computers.

Mathematical Analysis

State of the system is defined by the two-dimensional vector (n, j), where n is the number of Processing servers and j is the number of Data packets sent from each sensor in the system, respectively. Based on the distribution function of the random variables involved in the formation of the model, we determine that the two-dimensional Markov chain describes the system in study.

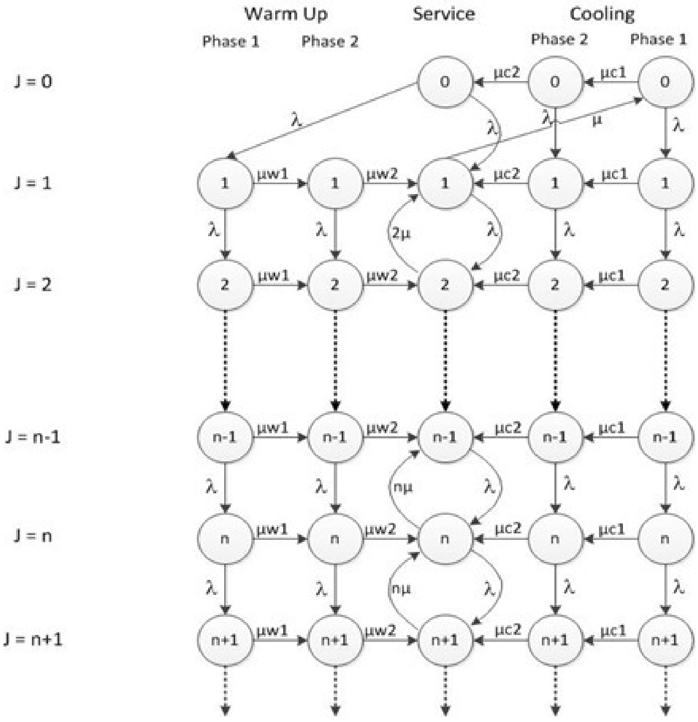

Fig. 4. Diagram showing transitions of $M/E_2/M/E_2/n$ type multi-channel queuing system

Here:

J=0—means that all channels are free, there are zero requests in the system.

J=1—there is one occupied channel, remaining channels are free, one request in the system.

J=2—there are two occupied channels, remaining channels are free, two requests in the system.

J=n—there are n occupied channels, zero free channels, n requests in the system, zero requests waiting in the queue.

J=n+1—there are n occupied channels, zero free channels, n+1 requests in the system, one request waiting in the queue.

J=n+m—there are n occupied channels, zero free channels, n+m requests in the system, m requests waiting in the queue.

Calculation of time response characteristics is based on the way described by (Khalil, Khomonenko) in articles [4, 5].

$$A_0=\begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ \lambda & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \lambda & 0 \\ 0 & 0 & 0 & 0 & \lambda \end{pmatrix},\ A_1=\begin{pmatrix} \lambda & 0 & 0 & 0 & 0 \\ 0 & \lambda & 0 & 0 & 0 \\ 0 & 0 & \lambda & 0 & 0 \\ 0 & 0 & 0 & \lambda & 0 \\ 0 & 0 & 0 & 0 & \lambda \end{pmatrix},\ A_n=A_1,\ n=2,3,\dots$$

$$B_0=0,\quad B_1=\begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \mu & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix},\ B_n=\begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & n\mu & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix}\quad n=2,3,\dots$$

$$C_0=\begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \mu c_2 & 0 & 0 \\ 0 & 0 & 0 & \mu c_1 & 0 \end{pmatrix},\ C_1=\begin{pmatrix} 0 & \mu w_1 & 0 & 0 & 0 \\ 0 & 0 & \mu w_2 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \mu c_2 & 0 & 0 \\ 0 & 0 & 0 & \mu c_1 & 0 \end{pmatrix},\ C_n=C_1,\ n=2,3,\dots$$

$$D_0=\begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ \lambda & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \lambda+\mu c_2 & 0 \\ 0 & 0 & 0 & 0 & \lambda+\mu c_1 \end{pmatrix},\ D_1=\begin{pmatrix} \lambda+\mu w_1 & 0 & 0 & 0 & 0 \\ 0 & \lambda+\mu w_2 & 0 & 0 & 0 \\ 0 & 0 & \lambda+\mu & 0 & 0 \\ 0 & 0 & 0 & \lambda+\mu c_2 & 0 \\ 0 & 0 & 0 & 0 & \lambda+\mu c_1 \end{pmatrix},\ D_n=\begin{pmatrix} \lambda+\mu w_1 & 0 & 0 & 0 & 0 \\ 0 & \lambda+\mu w_2 & 0 & 0 & 0 \\ 0 & 0 & \lambda+n\mu & 0 & 0 \\ 0 & 0 & 0 & \lambda+\mu c_2 & 0 \\ 0 & 0 & 0 & 0 & \lambda+\mu c_1 \end{pmatrix}\ n=2,3,\dots$$

Fig. 5. Diagram showing M/E2/M/E2/N multi-channel system transitions matrices

Waiting time of again arrived request is defined by a system microstates right after its arrival. We will enter for each tier of the chart a row vector $\pi_j=[\pi_{j,1}, \pi_{j,2}, \ldots, \pi_{j,h}]$, $j=\overline{1,R}$, final distribution of probabilities of microstates of system right after arrival of the next request.

Vector components j represent the relative numbers of arrivals of requests with which arrival the system passed into the appropriate microstates as in equation (1):

$$\pi_j=\gamma_{j-1}A_{j-1}/\sum_{i=0}^{R}\gamma_i A_i l_{i+1} \tag{1}$$

Where l_i – the single column vector of $h_i \times 1$ size.

We will also define $B_{n+1}(S)$ as a matrix of the conditional LSC of exponential distributions of lengths of intervals before transition of QS from the microstates $(J+n, i)$, $i=1, h_{n+1}$ on completion of service increased by system transition probability in one of $(J+n-1, l)$, $l=1, h_{n+1}$ microstates. The matrix has the dimension $h_{n+1} \times h_{n+1}$, its elements are calculated according to equation (2):

$$b_{n+1,i,l}(S)=\frac{b_{n+1,i,l}}{\sum_{r=1}^{h_{n+1}} b_{n+1,i,l}+s},\ i,l=\overline{1,h_{n+1}} \tag{2}$$

We will similarly define a matrix of $C_{n+1}(s)$ LSC of distributions of duration of transitions between QS microstates on one tier (in case of the fixed number of requests in system), caused by the phases “cooling” (“warming-up”). The matrix of $C(s)$ has dimension $h_{n+1} \times h_{n+1}$, its elements are calculated according to equation (3):

$$C_{n+1,i,l}(S)=\frac{c_{n+1,i,l}}{\sum_{r=1}^{h_{n+1}} c_{n+1,i,r}+s},\ i,l=\overline{1,h_{n+1}} \tag{3}$$

Waiting time in queue of the k-request represents the amount of durations of k of advances of queue on completion of service plus “cooling” time if the system is in the appropriate mode as shown in equation (4).

$$W_k(S)=\pi_{k+n}B_n^k(S)\sum_{i=0}^{r}C_{n+1}^{i}(S) \tag{4}$$

Where r – number of sequential phases of “warming-up” & “cooling”.

Simulation and Results

To improve the accuracy of probabilistic analysis, modeling requires the application of realistic and hence more general assumptions about the types of distributions of component processes. The advantage of this approach is that it provides a visual representation of an approximating random process in the form of a combination of Markov phases, applicability to any probabilistic process, ease of recording the system of equations, describing the behavior of the respective model. Phase division in this case is no more than a mathematical technique useful in the study of non-exponential distributions, it has no physical meaning as to the nature of the random process in question.

Since in practical use the moments of the original non-Markovian distribution are usually unknown, there is difficulty in determining the source data for an approximation. Generally, the approximation uses two-stage distributions (otherwise it is necessary to calculate the older starting points). Numerical experiments show that this is enough for engineering calculations. Examples of practical use of phase-type distributions for probabilistic modeling of applications are given in [18.19].

Applying the Cox distribution and the second-order hyperexponential approximation distribution requires aligning the three initial moments of the maintenance time. The generalized Erlang distribution allows for precise alignment of the first and second points, which simplifies calculations. In addition, the coefficient of variation of the original distribution is strictly less than one for the real parameters (which is more common in the analysis of statistics in distributed data processing) and may exceed one when using complex-connected parameters. The above leads to the conclusion that the E_2 allocation is appropriate.

Two initial points are sufficient to determine the parameters of a two-stage generalized Erlang distribution.

A simulation was carried out for a system with a constant input flow for checking the change in the behavior of waiting time in the queue – *Wq* and the average time of the delivered packets in the system (including the service time) – W, when the warming-up & cooling intensities were changed which leaded to the results shown in figure 6.

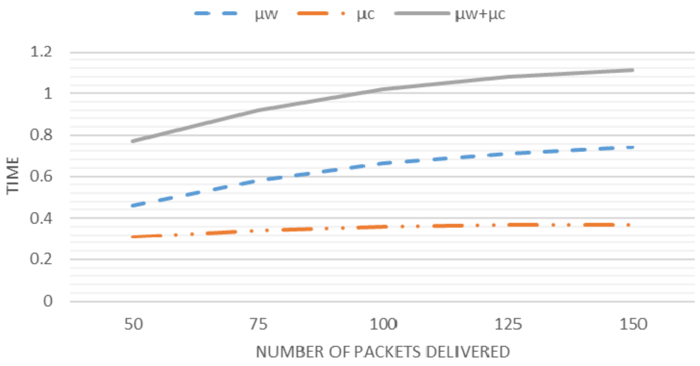

Fig. 6. Time for pre-servicing and post-servicing delivered packets

The results show that the time taken for data packets to leave the sensors and wait in the service queues is quite long. Add the time required for additional computing and data resources to make the final decision. As shown in Fig. (5) The total time required for decision-making is extremely long and should be taken into account in the development of real-time systems, where additional time lost may be life-threatening.

This information can be used by engineers to control forecasting calculations, to improve the accuracy of estimation of required computing resources.

Conclusion

The complex of models of multichannel non-Markian systems of mass service on the basis of phase type distributions is developed, Providing the ability to take into account additional time costs when evaluating the operability of nodes in distributed data processing information systems.

The results show a significant amount of time spent on each packet sent from the resource before the decision, the most time spent found in transactions between sensors and fog servers, which is understandable due to the low speed of communication technology compared to high-speed communication technologies used between Fog and Internet servers or central cloud servers. Research has also shown that time tends to become more stable for more packages. This means that the entire system is in stable condition, and the reason is that more servers or virtual machines are used to service the growing number of packages, hence the smaller packet queues that must be maintained.

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НЕ МАРКОВСКАЯ МОДЕЛЬ ОЦЕНИВАНИЯ ОПЕРАТИВНОСТИ ТУМАННЫХ ВЫЧИСЛЕНИЙ В ИНТЕРНЕТЕ ВЕЩЕЙ

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Аннотация

По мере появления новых технологий и объединения друг с другом люди становятся все более и более зависимыми от них, Чем больше различных устройств соединяются друг с другом, тем важнее становится принимать решения как можно быстрее. В современных беспилотных автомобилях и других подобных технологиях Интернета очень важно соединить вместе множество различных датчиков и устройств, заставить их общаться и принимать решение как можно быстрее. Рассматривается сценарий, при котором несколько различных датчиков и устройств в Интернете вещей соединены вместе в системе туманных вычислений для быстрого принятия решений. Для оценивания оперативности принятий решений на основе туманных вычислений предложена не Марковская модель многоканальной системы массового обслуживания с "разогревом" и "охлаждением", позволяющая учесть особенности организации туманных вычислений и рассчитано время ожидания до принятия решения. Еще одной особенностью модели является использование, что позволяет во многих случаях повысить точность задания исходных данных по сравнению с Марковской моделью. Результаты моделирования приводятся в графическом виде и обсуждаются.

Ключевые слова: *оперативность туманных вычислений, Интернет вещей, не Марковская многоканальная система массового обслуживания с "разогревом" и "охлаждением", аппроксимирующее распределение Эрланга 2-го порядка.*

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