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STUDY OF THE INTERNET OF THINGS NETWORK CONSTRUCTION TASKS

Abstract. The emergence and development of the Internet of Things stimulates the development of telecommunications and computing technologies. The current state of this process and its prospects allow the inclusion of a large number of devices connected to communication networks. This leads to the need to select an adequate model and methodological apparatus that allows working with such a quantity. The article discusses the concept of the IoT, which determines that any devices or things can now interact with each other at any time at any point in space.

Keywords: computer system, distributed system, fog computing, cloud computing, Internet of Things.

Introduction

Increasing the manufacturability of devices for receiving and transmitting information, reducing their cost and bringing together the capabilities provided by modern technologies and needs, due to the current state of social relations and human activity, served as an impetus for the development of the Internet of Things (IoT, Internet of Things). According to authoritative analysts, the total number of Internet of Things devices connected to communication networks is growing steadily. It has already exceeded the number of inhabitants on Earth.

In Fig. 1 shows statistical data for 2023 and a forecast for 2030 according to Statista [1, 2]. By 2030, the number of IoT devices is expected to be around 30 billion, approximately four times the human population. There are other forecasts.

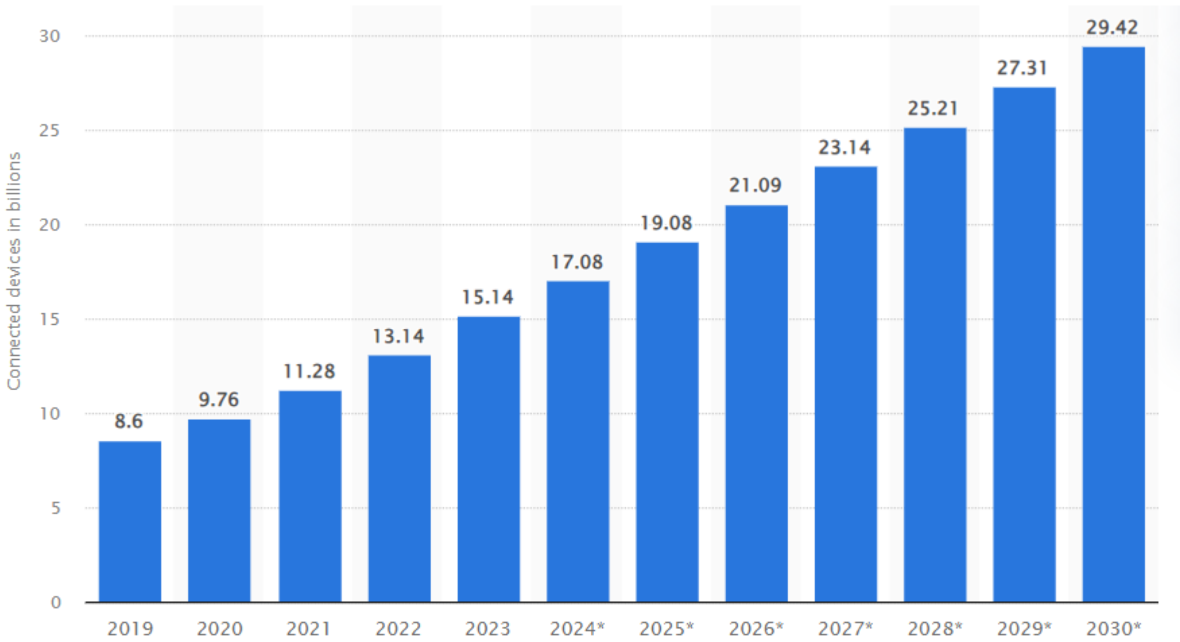

Fig. 1. Statistics and forecast of the growth in the number of connections to the number of IoT devices [1]

Main part

As defined by MCE-T in MCE-T-T Y.2060 [3, 4], the Internet of Things is “a global infrastructure for the information society that enables the provision of more complex services by combining (physical and virtual) things together based on existing and interoperable information and communication technologies (ICT).” The purpose of creating this infrastructure is to increase the availability of information in a global sense, which is illustrated in the Y.2060 recommendation [5, 6] as shown in Fig. 2.

The concept of this infrastructure assumes the presence of communication anywhere (on the street, at home, near a computer), at any time (day, night, moving) and any devices (between computers or devices between people) and devices directly between people without computers).

So, there is no doubt that IoT will develop in the long term. The main points of this process are [7, 8]:

• an increase in the number of devices connected to the interconnection in order to achieve a high-strength interconnection;

• the penetration of IoT technologies into various spheres of human activity, which entails the development of technical capabilities of these devices and advancements that are possible until the display of functional measures based on them;

• creation of both local specialized networks and penetration of this technology into global networks.

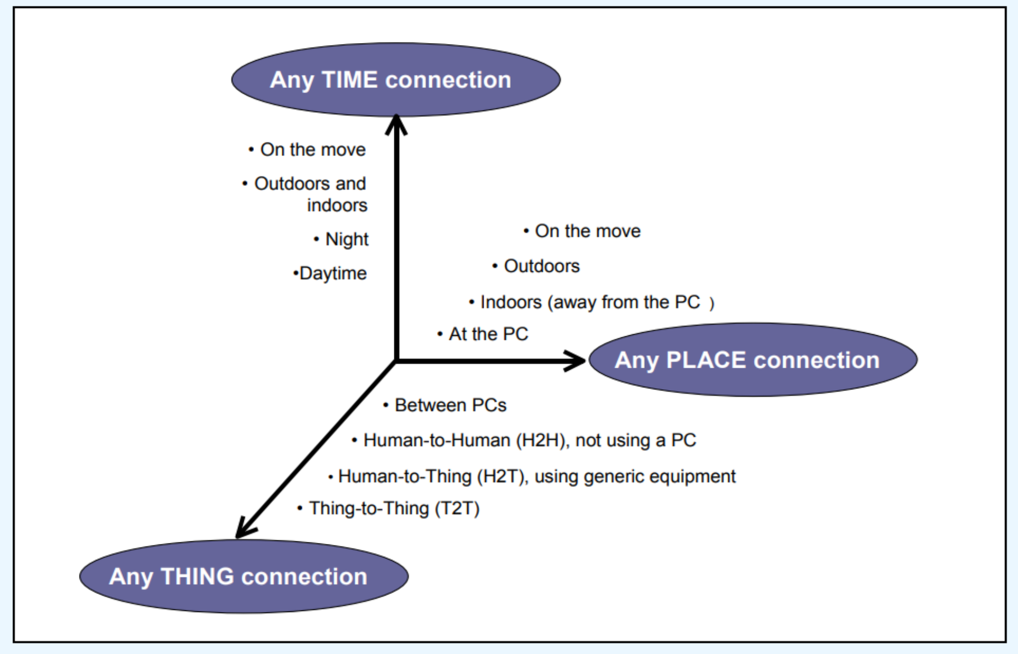

Fig. 2. Concept of the Internet of Things [2]

As a matter of greatest importance, it is important to consider the number of connections of devices, which outweighs the number of connections that were previously necessary in the boundaries, where the number of connections was assigned to Only a number of subscribers (customers).

The concept of the Internet of Speeches is in line with the recommendations of MCE-T and has low over-performing characteristics.

The growth of IoT leads to an increase in the number of devices connected to the limit. They are important for those that these devices are often localized in a whole area of space, so they should be brought to such a high concentration, so that the number of expansion per space increases. In this case, there may be a lack of flat (two-dimensional) model, the fragments of the device can be placed and interact in tridimensional space, and the third dimension (height) may be even more noticeable from the point of view organizing interaction between nodes. For example, a heterogeneous IoT network can include elements located on earthly platforms, including high-altitude and space platforms. Such gaps also occur in various areas: many surface water bodies and water bodies, at industrial sites and, possibly, in other situations. The main sign of this is that it is necessary to see how trivial the division of its nodes is in space. Since the service area is such that its "height" can be equalized with the other two dimensions, then such a measure can be considered as trivial, for example, in the area of altitude oblivion indicated in Fig. 3 [9, 10].

The most characteristic feature of a high-strength mesh is that in the area of connection of a sufficiently taken mesh node, it may appear that there are a lot of mesh nodes that actively flow into its work. This influx manifests itself in a reduced throughput capacity of the barrier. In fact, this imposes interconnection and can negatively affect the intensity of the IoT traffic generated by the nodes.

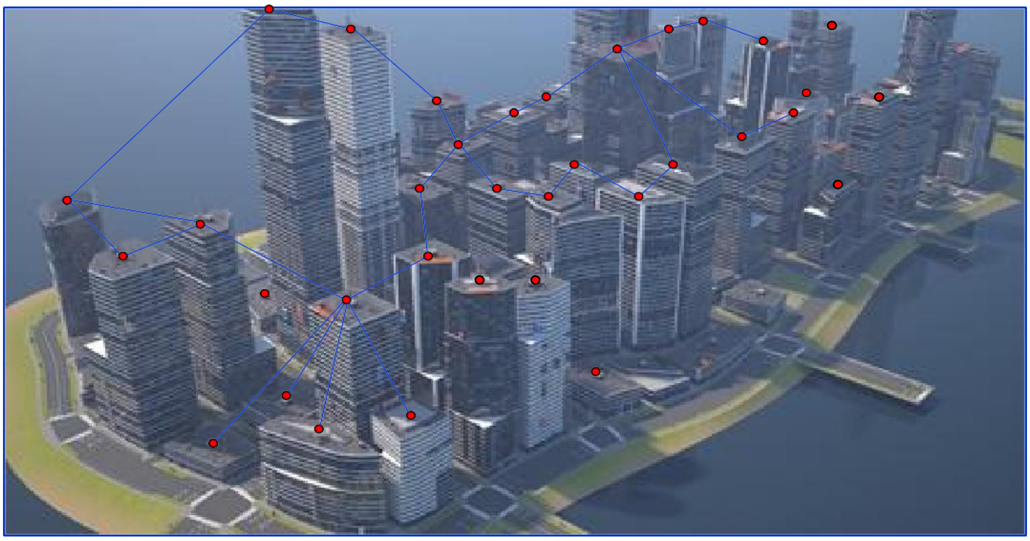

Fig. 3. Model of a potential site for hosting 3D networks of the Internet of Things [4]

Along with the negative properties, there are also positive qualities if the Internet of Things networks have a high density. Due to the high density of nodes, there is a high probability of finding a node near an arbitrarily chosen point in space [11]. This quality allows you to build a network of the structure that is necessary for some reasons, for example, it is one of the structures shown in Fig. 4.

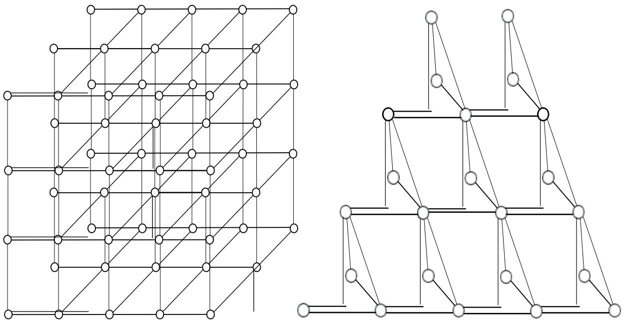

Fig. 4. Examples of high-density network structure modeling

This property also allows you to simplify some procedures. For example, in some cases it may be easier to find the shortest route in such a network, because the shortest distance is determined by a straight line, so the nodes included in this route are also most likely to be located near this straight line. Of course, such simplifications are not always possible. It is not always possible to obtain data about the coordinates of network nodes, so it is necessary to have methods that allow you to choose the network structure and manage it in conditions of a large number of nodes [12–14].

A three-dimensional network can have a different structure, in particular, it can be a regular structure in the form of a different kind of lattice or an arbitrary structure. However, in most cases, the structure of such a network is related to the structure of the environment in which it is created [15–17].

Selection of cluster master nodes in high-density Internet of Things networks. Let us assume that the Internet of Things network consists of n nodes:

$$V = \{v_1, \ldots, v_n\}, \quad (1)$$

distributed in three-dimensional space, an example is shown in Fig. 5.

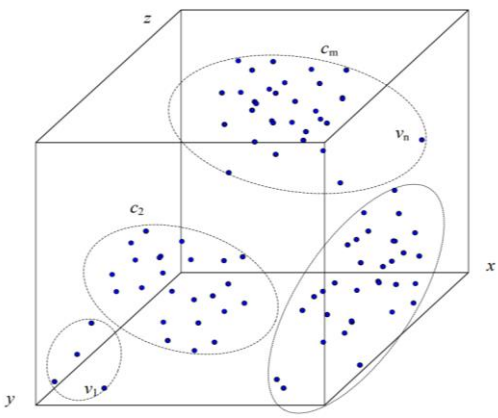

Fig. 5. Model of the Internet of Things network in three-dimensional space

We will also assume that clusters of nodes can be allocated in the network using the clustering method.

The task of building a network is to choose the positions of the main nodes in the Internet of Things network. In the general case, there may be several clusters in the network, making up a set of clusters

$$C = \{c_1, \ldots, c_K\} \quad (2)$$

from K extraordinary clusters, which can have an arbitrary shape and number of elements.

If nodes within a cluster form a connected ad-hoc network, then one or more master nodes can be used to service them, Fig. 6.

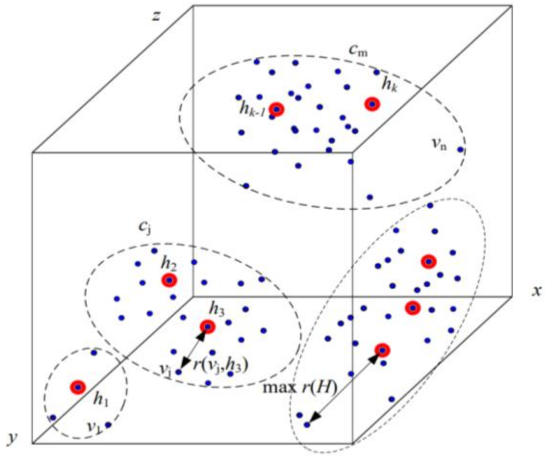

Fig. 6. Examples of a three-dimensional cluster

Let $r(v_j,h)$ be the distance between the *j-th* cluster node and the nearest master node. The position of the head node h should be chosen so as to minimize the distance to the most distant network node, i.e. ensure acceptable communication quality in the worst case.

This problem can be considered as an optimization problem in which the objective function

$$r(h) = \min\left(\max_{v \in V}\left(d(v,h)\right)\right), \quad h \in V. \quad (3)$$

It should be noted that selecting one node is often not enough; in this case, we are talking about selecting many main nodes.

$$H = \{h_1, \ldots h_k\}, \quad H \subset V. \quad (4)$$

Problem (4) is the task of finding the center of a graph formed by cluster nodes.

The center of the graph is the vertex from which the maximum distance (length of the shortest path) to the other vertices is minimal.

The problem of finding the center of a graph is solved by searching for all shortest paths in the graph, for example, using the Floyd-Warshall algorithm and finding the center of the graph from this data. Using this approach is quite acceptable if the number of cluster nodes (vertices in the graph) is not too large, both in terms of computational complexity and in terms of the ability to service the traffic they produce.

The computational complexity is that searching for all shortest paths requires time determined by the cube of the number of nodes (vertices) $O(n^3)$. This is a solvable problem, but with a large number of nodes, the time it takes to solve it can be unacceptably long.

In the case of a high-density Internet of Things network, one can resort to simplifying the problem due to the fact that the length of the shortest path in such a network is close to the distance between vertices. This logically follows from the fact that the shortest distance between two points is determined by a straight line passing through them, and in the case of a high-density Internet of Things network, there is a high probability that the transit nodes of the path will be very close to this straight line. In this case, it is enough to know the distance between the nodes or their coordinates.

Serviceability is determined by the performance of the head node and the capacity of the routes. More often than not, one head node is not enough to serve all network nodes. Then the problem can be considered as a search for several nodes. This problem is known as the k-fold graph center problem.

Conclusions

So, to build high-density Internet of Things networks, it is necessary to develop a method that allows solving problems of modeling and managing a network with a large number of devices, that is, it takes into account the specific features of a given network.

References

1. She R., Sun M. Security Energy Efficiency Analysis of CR-NOMA Enabled IoT Systems for Edge-cloud Environment. Int. Journal of Computational Intelligence Systems. 2023. Vol. 16(1), 118. DOI: http://dx.doi.org/10.1007/s44196-023-00273-y.
2. Kuchuk G., Nechausov S., Kharchenko, V. Two-stage optimization of resource allocation for hybrid cloud data store. *Int. Conf. on Information and Digital Technologies*. Zilina, 2015. P. 266-271. DOI: http://dx.doi.org/10.1109/DT.2015.7222982.
3. Кучук Г.А., Коваленко А. А., Лукова-Чуйко Н. В. Метод мінімізації середньої затримки пакетів у віртуальних з'єднаннях мережі підтримки хмарного сервісу. *Системи управління, навігації та зв'язку*. Полтава . ПНТУ, 2017. Вип. 2(42). С. 117-120.
4. Sharma, M., Kaur, P. Reliable federated learning in a cloud-fog-IoT environment. *Journal of Supercomputing*. 2023. Vol. 79(14). P. 15435–15458. DOI: http://dx.doi.org/10.1007/s11227-023-05252-w.
5. Baucas, M.J., Spachos, P. Improving Remote Patient Monitoring Systems Using a Fog-Based IoT Platform with Speech Recognition. 2023. *IEEE Sensors Journal*. Vol. 23(15). P. 17611–17618. DOI: http://dx.doi.org/10.1109/JSEN.2023.3287916.
6. Number of Internet of Things (IoT) connected devices worldwide from 2019 to 2023, with forecasts from 2022 to 2030. Statista. Telecommunications. URL: https://www.statista.com/statistics/1183457/iot-connected-devices-worldwide.
7. Kowalczyk A. European IoT Spending to Reach Nearly $227 Billion in 2023, Despite Ongoing Market Uncertainty, 2023. URL: https://www.idc.com/getdoc.jsp?containerId=prEUR250941023&utm_medium=embedd&utm_campaign=idc_embedd&utm_source=referral
8. Rehan M.M., Rehmani M.H. Blockchain-enabled Fog and Edge Computing: Concepts, Architectures and Applications: Concepts, Architectures and Applications. Taylor and Fransis, 2020. 302 p.
9. Jonathan Bar-Magen Numhauser. Fog Computing- Introduction to a new Cloud evolution. Proceedings from the CIES III Congress, January 2012 (англ.) // Escrituras silenciadas: paisaje como historiografía / José Francisco Forniés Casals (ed. lit.), Paulina Numhauser (ed. lit.), Proceedings from the CIES III Congress, January 2012.
10. Hamid Reza Arkian, Abolfazl Diyanat, Atefe Pourkhalili. MIST: Fog-based data analytics scheme with cost-efficient resource provisioning for IoT crowdsensing applications // Journal of Network and Computer Applications. – 2017-03-15. – Vol. 82. – P. 152–165. – ISSN 1084-8045. doi: http://doi.org/10.1016/j.jnca.2017.01.012
11. Kuchuk G., Kovalenko A., Komari I.E., Svyrydov A., Kharchenko V. Improving big data centers energy efficiency: Traffic based model and method. Studies in Systems, Decision and Control, vol 171. Kharchenko, V., Kondratenko, Y., Kacprzyk, J. (Eds.). Springer Nature Switzerland AG, 2019. Pp. 161-183. DOI: http://doi.org/10.1007/978-3-030-00253-4_8
12. Коваленко А. А., Кучук Г. А. Методи синтезу інформаційної та технічної структур системи управління об'єктом критичного застосування. *Сучасні інформаційні системи*. 2018. Т. 2, № 1. С. 22–27. DOI: https://doi.org/10.20998/2522-9052.2018.1.04
13. Кучук Н. Г., Мерлак В. Ю., Скородєлов В. В. Метод зменшення часу доступу до слабкоструктурованих даних. *Сучасні інформаційні системи*. 2020. Т. 4, № 1. С. 97-102. doi: https://doi.org/10.20998/2522-9052.2020.1.14
14. She R., Sun M. Security Energy Efficiency Analysis of CR-NOMA Enabled IoT Systems for Edge-cloud Environment. *Int. Journal of Computational Intelligence Systems*. 2023. Vol. 16(1), 118. DOI: http://dx.doi.org/10.1007/s44196-023-00273-y.
15. Петровська І. Ю., Кучук Г. А. Розподіл обчислювальних ресурсів у хмарних системах. *Системи управління, навігації та зв'язку*. 2022. Вип. 2 (68). С. 75–78. DOI: http://dx.doi.org/10.26906/SUNZ.2022.2.075.
16. Kuchuk G., Nechausov S., Kharchenko, V. Two-stage optimization of resource allocation for hybrid cloud data store. *Int. Conf. on Information and Digital Technologies*. Zilina, 2015. P. 266-271. DOI: http://dx.doi.org/10.1109/DT.2015.7222982.
17. Essalhi, S.E., Raiss El Fenni, M., Chafnaji, H. A new clustering-based optimised energy approach for fog-enabled IoT networks. *IET Networks*. Vol. 12(4). P.155–166. DOI: http://dx.doi.org/10.1049/ntw2.12082.

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Вивчення задач побудови мережі Інтернету речей

О. О. Можаєв, Н. Г. Кучук, Д. С. Штепа, Б. В. Соробей

Анотація. Поява та розвиток Інтернету речей стимулює розвиток телекомунікаційних та обчислювальних технологій. Сучасний стан цього процесу та його перспективи дозволяють охопити велику кількість пристроїв, підключених до мереж зв'язку. Це призводить до необхідності вибору адекватної моделі та методичного апарату, що дозволяє працювати з такою величиною. У статті розглядається концепція IoT, яка визначає, що будь-які пристрої або речі тепер можуть взаємодіяти один з одним у будь-який час у будь-якій точці простору. для побудови мереж Інтернету речей високої щільності необхідно розробити метод, який дозволяє вирішувати задачі моделювання та управління мережею з великою кількістю пристроїв, тобто враховує особливості даної мережі.

Ключові слова: комп'ютерна система, розподілена система, туманні обчислення, хмарні обчислення, Інтернет речей.