UDC 004.9 **doi: 10.26906/SUNZ.2024.2.141**

I. Radchenko, O. Shekhovtsov, A. Kovalenko, O. Sytnyk

Kharkiv National University of Radio Electronics, Kharkiv, Ukraine

FORMATION OF CLUSTERS ON SINGLE-BOARD COMPUTERS IN IOT NETWORKS

Abstract. The article looks at the problem of using single -board computers for Internet technology . An analysis of current single-board computers in various countries was carried out. Single-board computers and clusters of single-board computers have found their place in the concept of edge computing, allowing optimization of hard computing by placing computing resources closer to the core. The idea of a "virtual cluster" lies in the unification and organization of disparate heterogeneous devices for the development of various complex computing tasks from the available resources of the existing infrastructure of edge computing, what is known in the area. First of all, we have secured the resources of single-board computers. Such a cluster will also allow the use of resources from the existing infrastructure in a more efficient way, for example, by activating additional services from processing and saving data.

Keywords: single-board computer, cluster, Internet of Things, edge computing.

Introduction

Currently, all over the world, Internet of Things technologies (IoT , Internet of Things) are increasingly becoming an integral part of our daily life, for example: smart home, smart city, agriculture, medicine, logistics, etc. The huge amount of data generated by Internet of Things devices requires further post-processing and analysis, including the use of machine learning. To process incoming information, "clouds" are used, where data center facilities directly analyze them and make decisions based on the results obtained. However, the number of devices connected to the Internet is constantly increasing, which leads to difficulties in processing data in the "clouds" due to an increase in incoming data, increased load on the network, increased delays in data transfer between nodes, etc.

One solution to this issue is the development of edge computing technologies, which allow us to take on part of the load and reduce the response time to an event. To organize edge computing, single-board computers are used, which have compact sizes and high energy efficiency, but low performance, which does not allow solving computationally complex problems using the resources of a single device. One solution to this problem is to create a local cluster consisting of computers with limited computing resources.

Analysis of current single board computers in various fields

Single board computer is a self-contained computer assembled on a single printed circuit board on which all the necessary components are installed to ensure its functioning: processor, RAM, input-output systems, etc.

The first truly single-board computer appeared back in 1976 and was called "MMD-1" (Mini-Micro Designer 1), but at the same time this format of computer execution became truly widespread and accessible only in 2012 with the advent of Raspberry Pi [1]. This computer is primarily aimed at the educational sphere and training in computer use, programming, etc. With a low price and sufficient performance to run a full-fledged Linux- based operating system, it has gained popularity among many enthusiasts and researchers from various fields. Thanks to the success of Raspberry Pi and other manufacturers began to offer their models of single-board computers and currently there are more than 200 models of single-board computers in the world. The most popular are various Raspberry models Pi 3 and 3b+ , RP Zero W and 2020 model Raspberry Pi 4, which has several variants with 2 GB, 4 GB and 8 GB of RAM. Among other manufacturers, it is worth noting Banana Pi M5, RockPro64, Odroid N2. Comparative characteristics of single-board computers are presented in Table 1.

Table 1 – **Comparison of characteristics of single-board computers**

	RAM (GB)	SoC	GPU	Ethernet	Storage
Raspberry Pi 3b+	1 LPDDR2	ARM Cortex A53	VideoCore IV	330 Mbit Ethernet, 2.4GHz and 5GHz IEEE 802.11.b/g/n/ac wireless LAN, Bluetooth 4.2, BLE	microSD cards
Raspberry Pi 4	2, 4, 8 LPDDR4	4 x Cortex-A72	VideoCore VI	1000 Mbit/s Ethernet 802.11b/g/b/ac WiFi 5 and Bluetooth 5.0	microSD cards
RP Zero W	0.5	1 x ARM1176JZFS	VideoCore IV	802.11 b/g/n wireless LAN, BLE 4.1	microSD cards
RockPro64	4 LPDDR 4	4 x ARM CortexA53 2x ARM Cortex A72	MaliT860-MP4	1000 Mbit/s Ethernet	slot for eMMC module
Banana Pi M5	4 GB LPDDR4	Quad-Core Cortex-A55	Mali-G31 GPU	1000 Mbit/s Ethernet	microSD – card + eMMC
Odroid N2	2, 4	Quad-core Cortex-A 73 Dual -core Cortex-A53	Mali-G52 GPU	1000 Mbit/s Ethernet Optional WiFi USB adapters	microSD – card +eMMC

Many manufacturers of single-board computers have taken the path of producing modular boards in the SO-DIMM connection format; an example is the Raspberry Pi3+ computing module, the distinctive feature of which is data storage in the form of an eMMc drive with 32GB of permanent memory, in contrast to the younger model with a micro -SD card . This solution is primarily designed for the industrial sector.

At the end of 2022 and the beginning of 2023, boards in a new form factor of a modular solution began to appear; an example of such a board is the Raspberry single-board computer Pi Compute Module 4, like the previous model, this module has only a connection module to the main board, which was replaced from the SO-DIMM version in favor of 100-pin Hirose DF40C-100DS-0.4V mezzanine connectors, which made it possible to increase the data exchange speed between the boards and reduce the size the board itself.

Boards of this format are primarily intended for developers and the industrial sector; they have found their application in the field of the Internet of Things in the field of edge computing, and the board is also suitable for creating IoT projects of varying complexity.

Existing solutions for cluster formation

Single-board computers are classified as devices with limited computing resources, since their performance and physical resources of the device do not allow solving computationally complex problems and to solve this problem they are combined into clusters. Until recently, cluster computing was too expensive and complex for ordinary users, but the popularity of single-board computers has led to the emergence of low-cost clusters based on these devices.

Also, single-board computers and clusters of single-board computers have found their application in the concept of edge computing, allowing for the optimization of cloud computing by placing computing resources as close as possible to the source (network boundary), which also increases the efficiency of processing information from end devices [3]. The next step in the development of this concept is considered to be the implementation of " ultra-boundary computing" (Extreme edge), an example would be " smart" technology dust " ("smart dust") built on the use of wireless self-organizing devices for the purpose of processing and transmitting data in the system.

It is worth noting that since 2016, research has been underway to develop various methods and tools for organizing calculations and distributed data storage on single-board computers in edge computing, but at the moment there are no ready-made solutions in this area. But attempts to organize distributed computing on "available" computing systems have been made before.

Since 2012, single-board computers began to be widely used in research activities, as well as in developing their own projects and conducting experiments. As noted earlier, since 2016, special attention has been paid to research into the use of single-board computers in edge computing. Let's look at some cluster projects and their application in various fields.

Table 2 - **Overview of the application area of single board computers**

Application area	Devices used	Performed tasks
For educational purposes	Raspberry Pi	1) performing computational tasks; 2) testing system performance in various frameworks, including Hadoop
	Raspberry Pi B b .	Cluster Computing Training
	Raspberry Pi	testing system performance in various tasks
	Raspberry Pi	Evaluation of the use of single board computers for cyber operations
	Raspberry Pi 2	1) performing computational tasks. 2) about learning cluster computing
	Raspberry Pi(link is external) 2 Model B	Performing Computational Tasks Modeling and Forecasting
	Raspberry Pi 3 b+ (1060 devices)	performing computational tasks; demonstration of capabilities; about learning cluster computing
	Raspberry Pi 3 b+	Working with big data Performance Analysis of a Hadoop Distributed System
Edge computing computing)	Raspberry Pi	Cloud computing in the concept of edge computing
	Raspberry Pi	Using a cluster as a compute node for edge computing Benchmarking Container Services Performance
	Pi Stack	Managing remote Beowulf- based single board computers
	Raspberry Pi Odroid XU4 Lattepand 4G	Distributed Stream Data Processing End Device Management
	Raspberry Pi	Research on Cloud Computing on Single Board Computers Stream processing
	RockPro64	distributed deep neural network on a cluster of single-board computers
	Raspberry Pi	Architecture for clustered container applications edge computing

The works presented in Table 2 show only some of the developments being carried out in the direction of research and application of single-board computers; their importance in the future can hardly be overestimated.

Despite their modest performance, single-board computers have already found their way into many areas of industry, with particular response in the area of the Internet of Things and edge computing. However, all developments and attempts to implement high-performance computing on such a cluster are experimental in nature and there is no ready-made solution at the moment.

Application of clusters on single-board computers in Internet of Things networks

Clusters of single-board computers have proven their effectiveness not only in the field of education and training in working with cluster systems, but also their high efficiency of use in industry for controlling various systems, they have also found their application in robotics, in "smart systems", for example: parking lots, smart houses, street lighting. Cluster systems based on single-board computers are used to support web services and various servers, since such a system is able to effectively scale and connect additional nodes as the load on the system grows, thus ensuring energy efficiency of the complex as a whole. Moreover, if one of the nodes fails, the fault tolerance of the system is guaranteed, and the low cost of a single-board computer compared to a conventional system reduces maintenance costs. The number of single-board computers involved is constantly growing and in the future this growth will only increase, while the available resources of single-board computers or classic cluster systems are not always fully used or are completely idle.

The idea of a "virtual cluster" is to combine and organize disparate heterogeneous devices to solve various complex computing problems using free (available) resources of the existing infrastructure located in the field of edge computing. First of all, designed to use the resources of single-board computers. Such a cluster will also make it possible to use the resources of the existing infrastructure more efficiently, for example, by deploying additional services for data processing and storage.

Conclusions

1. The article discussed single-board computers and their application in the field of the Internet of Things. A review of current single-board computers and their use in the development of clusters involved in the educational sector, as well as in edge computing, was carried out, including a possible approach to creating compact cluster modular systems on a single backplane.

2. In this work, single-board computers refer to computers with limited computing resources due to hardware limitations imposed on them by the manufacturer, the lack of ability to expand quality characteristics (RAM, central processor, etc.), including the overall computing performance is not allowing you to solve computationally complex problems on par with standard computers. However, when several devices are combined into a cluster, it becomes possible to use their resources to solve distributed tasks.

REFERENCES

1. Zuev, A., Karaman, D., Olshevskiy, A. (2023). Wireless sensor synchronization method for monitoring short-term events. *Advanced Information Systems*, 7(4), 33–40. doi: https://doi.org/10.20998/2522-9052.2023.4.04
2. Fatlawi, A., Al Dujaili, M.J. (2023), Integrating the Internet of Things (IoT) and Cloud Computing Challenges and Solutions: A Review. *AIP Conference Proceedings*, 2977(1), 020067. doi: http://dx.doi.org/10.1063/5.0181842
3. Qayyum, T., Trabelsi, Z., Waqar Malik, A., Hayawi, K. (2022). Mobility-aware hierarchical fog computing framework for Industrial Internet of Things. *Journal of Cloud Computing*, 11(1), 72. doi: https://doi.org/10.1186/s13677-022-00345-y
4. Petrovska, I., Kuchuk, H. (2023). Adaptive resource allocation method for data processing and security in cloud environment. *Advanced Information Systems*, 7(3), 67–73. doi: https://doi.org/10.20998/2522-9052.2023.3.10
5. Li, G., Liu, Y., Wu, J., Lin, D., Zhao, Sh. (2019). Methods of Resource Scheduling Based on Optimized Fuzzy Clustering in Fog Computing. *Sensors*, MDPI, 19(9). doi: https://doi.org/10.3390/s19092122
6. Kuchuk, N., Mozhaiev, O., Semenov, S., Haichenko, A., Kuchuk, H., Tiulieniev, S., Mozhaiev, M., Davydov, V., Brusakova, O., Gnusov, Y. (2023). Devising a method for balancing the load on a territorially distributed foggy environment. *Eastern-European Journal of Enterprise Technologies*, 1(4 (121), 48–55. doi: https://doi.org/10.15587/1729-4061.2023.274177
7. Kuchuk, N., Kovalenko, A., Ruban, I., Shyshatskyi, A., Zakovorotnyi, O., Sheviakov, I. (2023). Traffic Modeling for the Industrial Internet of NanoThings. *2023 IEEE 4th KhPI Week on Advanced Technology*, KhPI Week 2023 - Conference Proceedings, 2023, doi: 194480. http://dx.doi.org/10.1109/KhPIWeek61412.2023.10312856
8. Sharma, Sh. Saini H. (2019). A novel four-tier architecture for delay aware scheduling and load balancing in fog environment. *Sustainable Computing: Informatics and Systems*, 24. doi: https://doi.org/10.1016/j.suscom.2019.100355

Received (Надійшла) 27.02.2024
Accepted for publication (Прийнята до друку) 10.04.2024

Формування кластерів на одноплатних комп'ютерах у мережах IoT

І. В. Радченко, О. В. Шеховцов, А. А. Коваленко, О. В. Ситник

Анотація. У статті розглянуто проблему використання одноплатних комп'ютерів для технології Інтернету речей. Проведено аналіз сучасних одноплатних комп'ютерів у різних галузях. Одноплатні комп'ютери та кластери з одноплатних комп'ютерів знайшли своє застосування в концепції граничних обчислень, дозволяючи реалізувати оптимізацію хмарних обчислень шляхом розміщення обчислювальних ресурсів якомога ближче до джерела. Ідея «віртуального кластера» полягає в об'єднанні та організації розрізнених гетерогенних пристроїв для вирішення різних складних обчислювальних завдань з використанням вільних (доступних) ресурсів вже існуючої інфраструктури граничних обчислень, що знаходяться в межах досяжності насамперед розрахованої області знаходження датчиків IoT. Такий кластер також дозволить використовувати ресурси існуючої інфраструктури раціональніше, наприклад, розгорнувши додаткові сервіси з обробки та зберігання даних у шарі граничних вузлів.

Ключові слова: одноплатний комп'ютер, кластер, Інтернет речей, граничні обчислення.