The platform prototype for testing heterogeneous networks in IoT environment

Vladislav Shmatkov, Sergei Spynu, Vladimir Pimenov

ITMO University, 49 Kronverksky Pr., 197101 Saint Petersburg, Russia
shmatkovvlad@gmail.com, vadervega@gmail.com, tik119944@mail.ru,
http://en.ifmo.ru

Abstract. This article discusses the interaction of multimodal interfaces in a heterogeneous network environment of the Internet of Things. Methods are proposed for testing data exchange between devices using various data transmission protocols in various noisy environments of the studied network.

Keywords: Wireless sensor networks, Internet of Things (IoT), Wireless devices, Sensor Devices, Mobile devices, Actuator technology, Network traffic analytics.

1 Introduction

The Internet of Things is a concept of a network of physical objects interacting with each other or with the external environment [1]. The peculiarity of this concept is that it excludes human participation in various operations and actions of this system, but human interaction with the system remains through various interfaces: voice, sensory, graphic, visual, etc.

Heterogeneous networks have gained particular popularity and development in the field of IoT. IoT networks are not designed to stream data [2], but it is often necessary [3-4] for the correct interaction of some devices / interfaces. The interaction of several different system interfaces with the external environment (multimodal interfaces) allows the system to uniquely identify the command given or the event that occurred, but at the same time there are a number of problems with the interaction of devices due to the use of different data exchange protocols, data processing, different subsystems and systems general etc.

The use of various protocols and technologies in IoT networks leads to incompatibility problems of some technical solutions [5].

In this paper, the problem of the interaction of devices (interfaces) in a heterogeneous network in the concept of Machine-to-machine (M2M) [6] is considered, namely the data exchange using popular technologies for transferring streaming data between devices when reacting to an initiating event is considered.

The purpose of this work is to test the interaction of devices in the conditions of the tested data network of the Internet of things, to track information losses during streaming data and to consider the data integrity when transmitting in various noise conditions of a wireless communication channel. Conducting these tests will serve as a starting point for creating a system of user interaction through multimodal interfaces (visual, voice, and sensory).

2 Communication of the Internet of Things

In modern systems the Internet of Things for communication between the M2M devices use heterogeneous data: the audio/video data, and streaming simple data packages with wearable devices, including sensors/actuators.

The devices used in the IoT environment must provide sufficient speed of transmission and processing of heterogeneous data. In this paper we consider the most common current models of network modules and single-Board computers used in the field of the Internet of things: single-Board computers, arduino, STM32, sensors and actuator, and etc.

To test the streaming of audio / video data, it is necessary to pay attention not only to the technical characteristics of the test devices, but also to the most popular codecs that allow to transfer data most efficiently. Among them were chosen popular codecs used in computer vision. As a test, the transmission of video data in the resolution: 360p, 480p, 720p, 1080p formats will be used:

Table 1. Video codec characteristics

Codecs	360p	480p	720p	1080p
H.265, Mb/s	3(min)	6(min)	10(min)	12/30
MPEG-4 AVC, Mb/s	0,77(352×288)	4 (max)	14(max)	20(max)
VC-1, Mb/s	2(352×288)	10(max)	20(max)	20(max)
MPEG-2 , Mb/s	4(352×288)	15(DVD: 9.8)	60 (HDV : 25)	60 (HDV : 25)
VP9, Mb/s	3,6(640×384)	7,2(1080×512)	12(1280×768)	18(2048×1088)

To check the flow of audio data, the most popular codecs were selected, including those used in the operation of voice assistants devices.

Table 2. Audio codec characteristics

Codecs	Speex	MPEG-1	FLAC	Opus	PCM (16 bit)
Bitrate, Kbit/s	44	64/128	986	6-510	176.4

When working with video data, a channel bandwidth of at least 1 Mb/s is required, and when transmitting a high-quality video stream at least 12-20 Mb/s, depending on the selected codec. Audio data is less demanding on data transfer bandwidth. These characteristics are used to select network modules and build an IoT testing platform.

3 Communication of the Internet of Things

3.1 Overview of the studied wireless data networks: WiFi, Bluetooth Low Energy (BLE), 6LoWPAN

The development of data transmission technologies has improved the existing modules and optimized power consumption, which has a positive impact on the duration of various devices, including in the field of IoT.

To begin, consider the technical characteristics of the selected networks, taking into account the latest standards IEEE 802.11b/g/ac, IEEE 802.15.1, IEEE 802.15.4d.

Table 3. Network characteristics

Specifications	WiFi	BLE v.4.2	6LoWPAN
Standard	IEEE 802.11(b/g/ac)	IEEE 802.15.1	IEEE 802.15.4d
Frequency range, GHz	2.4 – 2.83/5.18 - 5.82	2.4 – 2.483	0.864 - 0.865
Bandwidth, Mbps	11 / 54 / 433	0.125 - 2	0.115 - 0.25
Communication range, m	140/140/30	60 - 100	before 4000
Maximum number of nodes in the network	30	7	65536

WiFi networks provide a high transfer rate and are the best option for working with video and audio data, but these WiFi modules have high power consumption and are most often used in stationary solutions with a constant power source.

The characteristics of BLE networks allow you to work with audio data and streaming data from devices. Low power consumption allows you to use these modules in wearable devices.

6LoWPAN networks are used to ensure maximum autonomy of remote sensors, the exchange of small amounts of data over long distances. This technology provides a high autonomy of the device when running on an AAA battery for up to 3 years, but it has a low data transfer rate and low reliability due to the lack of data validation. Widely used in IoT on various sensors, counters, widely used in solutions Smart Home [7-8] and Smart City [9-12].

3.2 Overview of data transfer devices, test methods

Transmission Device Modules. The most popular and stable modules for each considered network were reviewed and selected.
Devices using Wi-Fi and BLE protocols operate on the same frequency band, which can lead to poor communication quality and data transfer problems during simultaneous operation.

Table 4. Technical specifications of wireless modules

Device / parameter	ESP8285	nRF5284	MBee-868-30	AP6356S	cc2650	nRF52832	JDY -18
Standard	IEEE 802.11 b/g/n	IEEE 802.15.1	IEEE 802.15.4d	IEEE 802.11 ac	IEEE 802.15.4	IEEE 802.15.1	IEEE 802.15.1
Frequency range, GHz	2.4–2,483	2.4–2,483	0,864–0,865	5,18-5,82	2,4	2,4	2,4
Bandwidth Mbit/s	11/5	0,125-2	50-200	433	0,2	1-2	0,125
Output power, dBm	20/17/14	-20...+8	-32...+27	10-17	0...+5	-20...+4	0
Sensitivity, dBm	-91/-75/-72	-92.5/-89	-110	-32	-97	-96	-97
Number of channels	14	8	6	23	8	8	10
Average current consumption in transmission mode, mA	170/140/120	13,6	36	201	6,1-9,1	5,4	4

Local Area Network (LAN). Today, one of the most common and reliable data networks. In the field of the Internet of Things, it has received little development, since it does not provide sufficient mobility, but it allows maintaining high bandwidth and using Power over Ethernet (PoE) technology to provide power to devices remote from the transmission network.

Power-line communication (PLC). Power-line communication (PLC) is used to transmit data over a power line, allowing you to power and control devices on your home network. This technology implements the IEEE 1901.2 standard. It is mainly used for Smart Home solutions, which is well suited for Internet of Things.

Test methods for data transmission. In this paper, within the framework of the problem of data transmission in the Internet of Things environment, the following test options are considered [13]:

Connection Testing: wireless signal testing to monitor and optimize data exchange between devices.

Performance Testing: test the communication and computing capabilities of devices involved in testing.

Stress testing: to determine the number of simultaneous connections supported by the device.

Compatibility testing, verifies the correct operation of various protocols and configurations.

Evaluation of the efficiency of data transmission is organized using the tools of Wireshark, Tcpdump, OpenWSN [14-15]. The protocols used in the test (if the device supports): TCP, UDP, SCTP, MQTT, CoAP, AMQP.

It is worth noting that a large amount of traffic with different characteristics is generated in the IoT environment. Sensors and actuators, counters send a small packet of data at the time of activation, while streaming video requires a large amount of resources on the communication channel and its processing on the server.

Testing for "noise" is carried out by adding unrelated devices with a test bench operating at the same frequency to create natural interference.

4 The platform prototype for testing networks

The laboratory stand was assembled taking into account testing of heterogeneous networks and technologies used in the Internet of Thing environment.

The server used is a single-board computer Orange Pi RK3399 and Intel Nuc responsible for processing and analyzing traffic, including connecting external devices. Additional Orange Pi RK3399 is used to transfer streaming video and audio signal to the server using various codecs.

The sensor network is built using the Arduino Mega as a node (Node), external devices based on the Arduino Nano V3.0 are connected to it using WiFi, BLE, 6LowPAN modules. Each node (Node) collects and transmits information to the server.

The number of nodes in the network under the conditions of the testing task is limited to 5.

The listed devices are based on different architectures, such as ARM7, x86, Atmega328p.

5 The methodology

5.1 Test case 1

Testing the transmission of streaming video data to a receiver (server) device in various noise conditions of the channel used. The architecture of data transmission in a heterogeneous network is presented in Figure 1.

A device with a connected camera sends data to the server using various codecs and data transfer protocols over a WiFi network. The distance between the transmitter and receiver varies according to experiment [1,5,10,15,20,25 meters]. At each step, the characteristics of data reception and transmission are measured, including the addition of additional devices operating in the same room at the frequency of the tested communication channel.
The number of devices transmitting streaming data at the tested frequency varies from 0 to 25 in increments of 5 for each stage of testing. The test takes place in the same room.

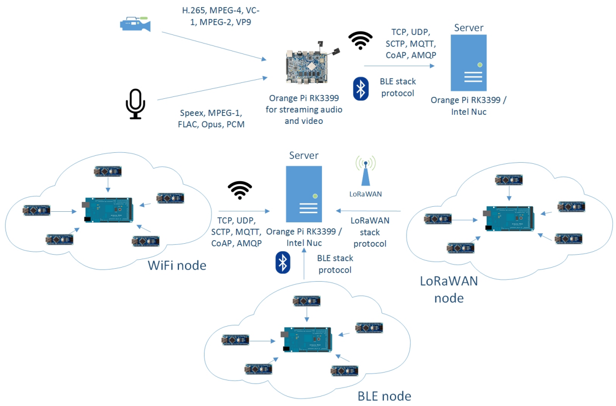

Fig. 1. Test case 1 architecture

5.2 Test case 2

The use of various technologies (standards) Wi-Fi, BLE, 6LoWPAN, as well as supported transport protocols in order to test the transfer of simple streaming data using various devices and protocols to a dedicated server in a heterogeneous network. The data transfer architecture is shown in Figure 2.

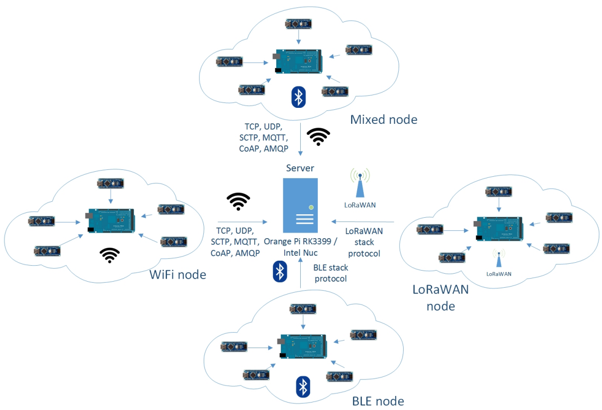

Fig. 2. Test case 2 architecture

We consider the loss, damage, delays in receiving data from devices on the network, depending on the number of requests sent per second and the number of devices and nodes in the network involved.

5.3 Test case 3

Testing the speed and synchronism of obtaining data from different sources in a heterogeneous network in response to a single triggering event. In this experiment are used: Node (node) - a device connecting nodes (protocol). One device (SD) —the device communicates with the server directly and transfers data. The server is a single-board computer with a Linux operating system that records the time and result of receiving data.

Each device sends a pre-created data packet indicating the number of the packet being sent, a fixed set of data and network parameters. This is the example of data package structure:

```
{
    Device: "Dev_#";
    Network: "Name_network Node_#";
    Network_node: "Number_#";
    Package_number: "Number_#";
    Data_set: "Test_data:";
}
```

The event is initiated artificially by giving a signal to all devices participating in the experiment. The test is carried out for all transport protocols supported by the device and the network. Each device in the network is responsible only for one data transfer protocol.

The test result allows you to determine the delay in receiving the packet, the time of desynchronization of the received data and their loss. This information will be used in the future to create multi-modal interfaces for user interaction with the system (Human-to-Device).

5.4 Test case 4

Collect statistics of power consumption of devices at all stages of the experiment. The data obtained are necessary for analysis and application in further work.

5.5 Test case 5

Testing the influence exerted on network parameters of a heterogeneous network connected to nodes. The testing model is based on the methodology for determining the connectivity of nodes in a heterogeneous network [15]. The model under test also uses the model of an energy-efficient network based on the connectivity of devices [16]. The model was built using 25 data transfer devices, 5 arduino mega, which perform the functions of central nodes, implement primary data processing and send data to the server, using a single-board computer Orange Pi RK3399 and Intel Nuc as the server, including connection of external devices.The number of concentrating nodes (central nodes) varies from 0 to 5. After each step, the network characteristics are measured and the quality of the transmitted data is determined. After that the number of nodes in the circuit is increased by one.Thus, this model makes it possible to assess the impact of the number of nodes on the quality of the transmitted data and the parameters of the network itself.

6 Methodology for analyzing the results

During throughput testing, the number of bytes transferred per second is recorded. Calculated throughput, as the ratio of the number of bits of information successfully transmitted during the test to the time of testing [13].

$$T = \frac{N_{bits}}{t} \tag{1}$$

where T is the throughput; N_{bits} is the number of bits successfully transmitted during t; t is the test time.

The delay is calculated as follows:

$$D = \frac{\sum_{i=1}^{n} \left(t^i_{recieved} - t^i_{sent}\right)}{n} \tag{2}$$

where n is the number of transmitted packets; $t^i_{recieved}$ - the time of receipt of the i-th packet; t^i_{sent} is the departure time of the i-th packet.

Packet loss we can find using formula:

$$L = \frac{n_{dropped}}{n_{sent}} \tag{3}$$

where $n_{dropped}$ is the number of lost packets; n_{sent} is the number of packets sent.

The IEEE 802.11a and IEEE 802.11g standards specify the bitrate when two devices interact, depending on the distance between them using two one-dimensional data arrays with one-to-one correspondence: each distance value has its own bitrate value.

Using the method of least squares, we can obtain the coefficients a and b of the linear function y = ax + b, which will describe the dependence of the bitrate on the distance with sufficient accuracy.

To determine a similar dependency for Bluetooth, you need to use additional calculations and transformations to obtain a similar functional dependency based on data from the Bluetooth standard IEEE 802.15.1. To obtain the bitrate values, the Shannon-Hartley theorem is used:

$$C = B \log_2 \left(1 + \frac{RSSI}{N}\right) \tag{4}$$

where B is the throughput, N is the average power of noise and interference in the passband.

To calculate the bitrate, it is necessary to calculate the values of the RSSI value - the power of the received radio signal, measured in dBm. This value is found using a formula based on the Friis transmission equation [17-18]. This formula implies that the transfer is carried out in ideal conditions.

$$RSSI = P_0 - 10n \lg \left(\frac{d}{d_0} \right) \tag{5}$$

where d, m is the distance between the device and the transmitter; d_0, m - the distance between the device and the point where the signal power P_0 was measured; n is the signal energy loss coefficient (for air, $n = 2$).

Next, you need to convert power values from dBm to W. This is done using the following formula:

$$P_W = 10^{((P_{dBm} - 30)/10)}, \tag{6}$$

These mathematical models for WiFi and Bluetooth are used in the interaction of two devices.

Since the study conducted experiments with several transmitting devices, as well as the communication channel is noisy, the above mathematical model for WiFi and Bluetooth changes for more than two interacting devices. Based on the data obtained during the experiments, a new mathematical model is compiled, taking into account the number of devices, the noise of the communication channel and the distance from the data transmission nodes to the receiving server. The function of two variables is considered: $b(d, n)$, where b is the bitrate, d is the distance, n is the number of devices. The function itself is obtained by approximation of experimental data.

7 Future directions and conclusion

In the course of the work, test cases were compiled and a test model of the Internet of Things data transmission was chosen. The results of this test will serve as a starting point for designing Multimodal User Interfaces based on voice recognition, image and gesture control using wearable things.

Also in the future it is planned to consider models of interoperability of devices based on semantic technologies.

References

1. Statistical information on the number of IoT devices, Retrieved January 29, 2014, from `https://newsroom.cisco.com/press-release-content?type=webcontent&articleId=1334100`
2. Borthakur D., Dubey H., Constant N., Mahler L., Mankodiya K.. Smart fog: fog computing framework for unsupervised clustering analytics in wearable internet of things. 2017 IEEE Global Conference on Signal and Information Processing (GlobalSIP), 08 March 2018, 472-476.
3. Yannuzzi M., Milito R., Serral-Gracià R., Montero D., Nemirovsky M. Key ingredients in an IoT recipe: Fog Computing, Cloud computing, and more Fog Computing. 2014 IEEE 19th International Workshop on Computer Aided Modeling and Design of Communication Links and Networks (CAMAD), 325-329.

4. Dupont C., Giaffreda R., Capra L.. Edge computing in IoT context: horizontal and vertical Linux container migration. FBK Create-Net, via alla Cascata 56/D, 38123 Trento, Italy. 2017
5. R. Chander V. , Saswati Mukherjee S., Elias S. An applications interoperability model for heterogeneous internet of things environments. Computers & Electrical Engineering Volume 64, November 2017, Pages 163-172.
6. Belloa O., Zeadally S., Badrac M., 2016. Network layer inter-operation of Device-to-Device communication technologies in Internet of Things (IoT), Elsevier, 15 March 2017, Pages 52-62
7. Biljana L., Risteska S., Trivodaliev K., 2016. A review of Internet of Things for smart home: Challenges and solutions: Journal of Cleaner Production (2016), 1 - 22.
8. Soliman M., Abiodun T., Hamouda T., Zhou J., Chung-Horng Lung., 2013. Smart Home: Integrating Internet of Things with Web Services and Cloud Computing. 2013 IEEE International Conference on Cloud Computing Technology and Science, (2013), 317 - 320.
9. Beccali M., Bonomolo M., Ciulla G., Galatioto A., Brano V., 2015. Improvement of energy efficiency and quality of street lighting in South Italy as an action of Sustainable Energy Action Plans. The case study of Comiso (RG), Elsevier (2015), 1-15.
10. Zanella A., Member S., Bui N., Castellani A., Vangelista L., Member M., Zorzi M., 2014. Internet of Things for Smart Cities, IEEE internet of things journal, vol. 1, no. 1, February 2014, 22-32.
11. Hammi B., Khatoun R., Zeadally S., Fayad A., Khoukhi L., 2017. IoT technologies for smart cities, The Institution of Engineering and Technology, September 2017, vol. 7 Iss. 1, pp. 1-13.
12. Centenaro M., Vangelista L., Zanella A., Zorzi M. Long-Range Communications in Unlicensed Bands: The Rising Stars in the IoT and Smart City Scenarios. IEEE Wireless Communications, Vol. 23 , Issue: 5 , October 2016, 60-67.
13. Esquiagola J., Costa L., Calcina P., Fedrecheski G., Zuffo M., 2017. Performance Testing of an Internet of Things Platform, In Proceedings of the 2nd International Conference on Internet of Things, Big Data and Security (IoTBDS 2017), pages 309-314.
14. Cognizant (2016). The internet of things: Qa unleashed, from `https://www.cognizant.com/InsightsWhitepapers/theinternet-of-things-qa-unleashed-codex1233.pdf` Last accessed: December 2018
15. Koucheryavy A., Nurilloev I., Paramonov A., Prokopiev A. Provision of connectivity of wireless sensor nodes in heterogeneous network. TELECOM IT electronic scientific journal. The Bonch-Bruevich Saint-Petersburg State University of Telecommunications.
16. Magno M., Aoudia F., Gautier M., Berder O., Benini L. 2017, WULoRa: An Energy Efficient IoT End-Node for Energy Harvesting and Heterogeneous Communication, 2017 Design, Automation and Test in Europe (DATE), 1528 -1533.
17. Saveliev A., Malov D., Tamashakin M., Budkov V.. Service and multimedia data transmission in IoT networks using hybrid communication devices, 12th International Scientific-Technical Conference on Electromechanics and Robotics “Zavalishin’s Readings” - 2017.
18. Rutledge D., “Encyclopedia of practical electronic” (2002)
19. James P., Yang T., Lee C., eds., Future InformationTechnology: 6th International Conference on Future Information Technology, 184 (2011)