MINISTRY OF SCIENCE AND EDUCATION OF THE REPUBLIC OF KAZAKHSTAN

Non-Profit Joint Stock Company
ALMATY UNIVERSITY OF POWER ENGINEERING AND TELECOMMUNICATIONS

Department ___Telecommunication systems and networks___

«Admitted»
Head of the Department _Baykenov A.S._
___d.t.s., professor___
(Surname and initials, degree, rank)
________ «____»________ **20__ y.**
(sign)

DIPLOMA PROJECT

Theme: The modelling of network M2M

Specialty: ___5B071900 – Radio engineering electronics and telecommunications___

Implemented by: Sissenova A.S. ICTe-14-9
(Student's surname and initials) group

Scientific Supervisor: Tumanbayeva K.Kh.
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________ «____»________ 20__y.
(sign)

Almaty 2018 y.

MINISTRY OF SCIENCE AND EDUCATION OF THE REPUBLIC OF KAZAKHSTAN

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ALMATY UNIVERSITY OF POWER ENGINEERING AND TELECOMMUNICATIONS

Institute of Space Engineering and Telecommunications (ISET)
Specialty: 5B071900 – Radio engineering electronics and telecommunications
Department: Telecommunication systems and networks

ASSIGNMENT

For diploma project implementation

Student: Sissenova Ainamkoz Seilkhankyzy
(name, patronymic and surname)
Theme: The modelling of network M2M

Approved by Rector order № 155 of « 23 » 10 2017 y.
Deadline of completed project: « 25 » 05 2018 y.

Initial data for project, required parameters of designing result, object initial data:
Coverage radius : $R_1 = 10$ km ; $R_2 = 30$ km
Average value of interval $T = 4,33$
Average service time of one package $T_{serv} = 1$
Hurst parameter:
$S_1 = 0,5027$
$S_2 = 0,6920$
$S_3 = 0,6039$

List of questions for development in diploma project or brief content:
1. Analysis of the current state of M2M networks
2. Analysis of existing narrowband networks for servicing M2M devices
3. Modelling of M2M traffic as RS of the type M/M/1/∞
4. Modelling of M2M service traffic as RS of the type Pa/M/1/∞
5. Comparative analysis of simulation results of two types of RSs
6. Life safety part
7. Economic part
8. Conclusion
9. Appendix A
10. Appendix B

List of illustrations (with exact specifying of mandatory drawing):

- Aim of the diploma work
- Tasks of the diploma work
- Concept of M2M and IoT
- Standard model of IoT
- Interaction of different M2M network domains
- Functional architecture of M2M
- Scenario of NB-IoT application
- Model of the NB-IoT system
- Probabilistic characteristics of message service in NB-IoT
- LoRaWan network architecture
- LTE Cat.0 technology
- Simulation model M/M/1 traffic services
- Fragment of the modelling report M/M/1
- Modelling of M2M service traffic as QS of the Pa/M/1/∞
- Life safety and economic parts. - Conclusion

Recommended main references:

1. Зарипова Э.Р., Андина П.А. Моделирование процедуры установления M2M-соединения по радиоканалу случайного доступа в сетях LTE. -Москва, Россия. -45-46с.
2. Jan Holler, Vlasios Tsiatsis, Catherine Mulligan, Stamatis Karnouskos, David Boyle. From Machine-to-Machine to the Internet of Things: Introduction to a New Age of Intelligence, -10, 61-129p.
3. Бешлиев В.О., Молчанов Д.А., Самуйлов А.К. Моделирование технологии узкополосного Интернета вещей (NB-IoT) для сотовых сетей связи. -25-26p.

Project adviser with corresponding sections specifying:

Section	Advisor	Dates	Sign
Main part	Tumanbayeva K.Kh.	01.06.18	
Life safety	Begimbetova A.S.	25.05.18	
Economic part	Tuzelbayev B.I.	31.05.18	
Application of comp.tech	Tumanbayeva K.Kh.	01.06.18	

S C H E D U L E
of diploma project implementation

№	Sections, list of developing questions	Dates of bringing to Scientific Supervisor	Notes
1.	Analysis of the current state of M2M networks.	15.01.18 – 23.01.18	Done
2.	The basic technologies of M2M and IoT	23.01.18 – 31.01.18	Done
3.	Analysis of existing narrowband networks for servicing M2M devices.	31.01.18 – 05.02.18	Done
4.	LoRa, LTE Cat.0 technologies	05.02.18 – 12.02.18	Done
5	Modelling of M2M traffic	12.02.18 – 19.02.18	Done
6.	Life safety part:	15.01.18 – 29.03.18	Done
	-parameters of microclimate;		
	- analysis of harmful factors;		
	- calculation of natural lighting;		
	-calculation of artificial lighting.		
7	Economic part;	19.01.18 – 29.03.18	Done
	-calculation of depreciation charges;		
	-calculation of programmer's salary		
	- calculation of payback period	19.04.18 - 05.05.18	Done
8.	Conclusion		

Assignment issue date «12» January 2018 y.

Head of Department: __________ Baykenov A.S
(sign) (Surname and initials)

Scientific Superviser: [signature] Tumanbayeva K.Kh.
(sign) (Surname and initials)

Assignment submitted for implementation:
[signature] Sissenova A.S.
(sign) (Surname and initials)

Аннотация

В данном дипломном проекте рассматривается вопрос моделирования сети M2M и анализ трех наиболее перспективных технологии для работы в сетях IoT и M2M. В работе исследовано текущее состояние и направление развития M2M сетей в Казахстане. Проведен анализ технологий NB-IoT. Приведен сравнительный анализ технологий LTE Cat.0 и LoRaWan. В ходе исследования построена имитационная модель сети M2M в программе GPSS WORLD. Осуществлена моделирования трафика M2M как СМО тип M/M/1/∞ и Pa/M/1/∞.

В данной работе также составлен бизнес-план проекта и предоставлено описание экономической эффективности проекта для расчета срока окупаемости. В разделе безопасности жизнедеятельности проведен анализ условий труда и микроклимата. Представлен расчет естественного и искусственного освещения рабочего помещения.

Аңдатпа

Бұл дипломдық жұмыста M2M желісін модельдеу және IoT және M2M желілер жұмысына арналған үш ең тиімді технологиялар талдауы қарастырылған. Жұмыста M2M желісінің Қазақстандағы даму бағыты мен ағымдағы күйі зерттелген. Қысқаша NB-IoT деп аталатын таржолақты IoT технологиясына талдау жасалынды. LTE Cat.0 және LoRaWan технологияларына салыстырмалы талдау жүргізілді.GPSS World бағдарламасында M/M/1/∞ және Pa/M/1/∞ түрлеріне M2M желісінің имитациялық үлгісі құрастырылды.

Бұл жұмыста жобаның бизнес-жоспары жасалынды және жобаның өтелу мерзімін есептеу үшін экономикалық тиімділігінің сипаттамасы көрсетілді. Өмір қауіпсіздігі бөлімінде еңбек шартының және микроклиматтың талдауы жүргізілді. Жұмыс ғимаратының табиғи және жасанды жарықтандыру есептеулері көрсетілді.

Abstract

In this diploma work, issue of modeling the M2M network and analysis of the three most promising technologies for working in IoT and M2M networks are considered. The current state of M2M networks in Kazakhstan was studied. The technology of narrowband IoT analyzed. Comparative analysis of LTE Cat.0 and LoRaWan technologies is given. Simulation model of the M2M network was built in the GPSS World program. M2M traffic simulations as M/M/1/∞ and Pa/M/1/∞ have been simulated.

In this work, the business plan of the project is also compiled and a description of the economic efficiency is provided to calculate the payback period. In the section of life safety, an analysis of working and microclimate conditions was carried out. The calculation of natural and artificial lighting is presented.

Content

Introduction

At the present stage of technological development in the digital age economy and the creation of a single digital market increase productivity is achieved through robotics production processes based on managed technical means and algorithms for optimal control. Technical means automation can be robots, machines and other types execution devices that require network connectivity automated management in order to effectively implement it and providing such management through various information channels connection. Thus, automated control networks built based on the convergence of information management networks and communication networks, providing access to terminal devices (actuators,sensors, etc.) to a set of elements combined into such networks, called networks M2M and infocommunication services of these networks are called M2M services.

Management services for M2M networks and Internet of things (IoT), which allow machines to share information with each other for implementation of procedures and algorithms for automated control production processes, or to transmit this information without participation or with limited human participation, or with limited human intervention as an end-user of M2M services can provided by operators of M2M / IoT networks and services.

The aim of the diploma work is modelling and analyzing the contemporary M2M networks.

For achieving this aim, it is necessary to solve the following tasks:

- study of the current state of M2M networks;
- resolve of existing narrowband networks for servicing M2M devices;
- make a network simulation model in GPSS World program;
- make calculations of economic and life safety parts.

1 Analysis of the current state of M2M networks

1.1 Concept of Internet of things and building local networks of IoT

According to the definition of the international telecommunication Union in ITU - T recommendation Y. 206, the Internet of things (IoT) is a global information society infrastructure that provides innovative services through the organization of communication between things (physical or virtual) based on existing and developing compatible information and communication technologies.

"Things" means a physical object (a physical thing) or an object of a virtual (information) world (a virtual thing, for example, multimedia content or an application program) that can be identified and combined using communication networks .

The international telecommunication Union also defines the term "device" (M2M device), which means an item of equipment or a thing that has the mandatory capabilities of communication and additional opportunities for measurement, actuation, as well as input, storage and processing of data. The devices collect various types of information and transmit it over information and communication networks for further processing. Some devices perform operations based on information received from information and communication networks.

On the Internet of things, the ability to identify, collect, process, and transmit data ensures the most efficient use of things and the provision of services based on these things and various applications.

Thus, IoT in the long term can be considered as a direction of technological and social development of human society. Consider the fundamental characteristics of the Internet of things [2,3].

Possibility of establishing a connection. Any thing can be attached to the global information and communication infrastructure.

Providing services related to things. The Internet of things allows for the provision of services related to things, given the inherent limitations of things, such as the protection of privacy and semantic coherence between physical things and their corresponding virtual things.

Heterogeneity. In IOT devices can be built on various hardware and software platforms, as well as on various communication protocols. In doing so, IOT devices should be able to communicate with other devices over different networks.

Dynamic change. On the Internet of things, the state of devices can change dynamically, for example, from sleep to active, connect/disconnect from the network, and the number of things, their location and speed.

A huge number of things. The number of devices that need to be managed and that communicate with each other will at least ten times exceed the number of devices currently connected to the Internet. There is a significant increase in the share of information exchange initiated by devices, compared with the share of information exchange initiated by people. The management and interpretation of the generated data for application purposes will become more important. This applies to the semantics of the data as well as to its efficient processing.

The IOT reference model includes four basic horizontal layers:
- the application tier;
-level of support for services and applications;
-the network layer;
-device level.

There are also management and security capabilities associated with these four horizontal tiers.

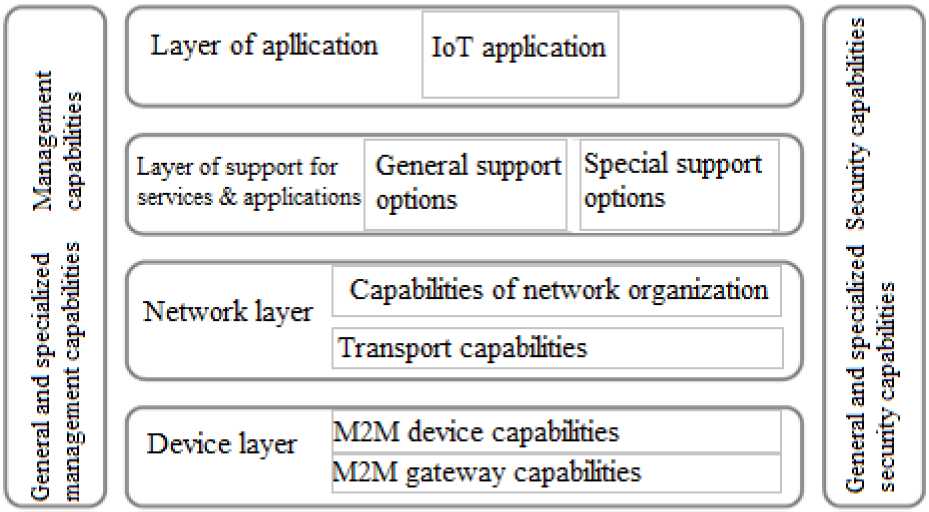

Figure 1.1 - Standard model of IoT

The application layer contains applications of the IoT. These applications use analytical methods to turn data into automated commands, improving the efficiency of physical and virtual things.

The layer of support for services and apllications includes general capabilities that can be used by various IoT applications, such as data processing or storage, and specialized capabilities that are designed to meet the requirements of specific applications.

The network layer combines network capabilities, such as access network and transport network resource management, mobility management, authentication, authorization, and accounting functions, and transport capabilities, such as network connectivity, to transfer information from various IoT services and applications.

The device layer includes the capabilities of M2M devices and M2M gateways. The functionality of the device is aimed at direct interaction with the communication network, indirect interaction with the communication network through the gateway and the organization of special networks. In addition, devices can support sleep and Wake-up mechanisms to conserve energy.

Gateway capabilities are to support wired and wireless interfaces with M2M devices (CAN, RS232, ZigBee, Bluetooth, Wi-Fi), as well as wired and wireless interfaces with an access network (Ethernet, DSL, GSM, UMTS, LTE). The gateway also supports Protocol conversion if the protocols of interfaces with devices and interfaces with the access network are different.

Management capabilities in the model of the Internet of things cover the management functionality of the network, Troubleshooting network, network configuration, UCT and billing, and managing quality and network security. The main control objects are devices, local networks and their topology, traffic and congestion in networks.

Network security capabilities are divided into general and specialized. General features security does not depend on the application and include:

- at the application level: authorization, authentication, privacy and integrity protection of application data, protection of privacy, security audit and anti-virus protection;
- at the network layer: authorization, authentication, data integrity protection of signalling;
- at the device level: authentication, authorization, device integrity check, access control, privacy and data integrity protection.

Specialized security features are closely related to the specific requirements of individual applications.

1.2 M2M network architecture

The main elements of the architecture of M2M networks are divided into three domains: the domain of M2M devices (the domain of the capillary network); the network domain (the core of the M2M core network) and the application domain. In addition to these domains, the M2M network will include the appropriate access network and transport network, which are built on 3GPP NGN networks. Interaction of different domains of the M2M network is shown in Figure 1.2.

M2M devices: allow you to quickly apply and use M2M services and domain network functions. The M2M device can be connected to the access network either directly or through the local M2M network.

Local networks M2M: provides a network providing a connection between M2M devices and M2M gateways. Examples: PAN-technologies, such as IEEE 802.15, SRD, UWB, Zigbee, Bluetooth or LAN, such as PLC, M-BUS, Wireless M-BUS.

M2M gateways: are equipment that provides M2M devices with guaranteed interworking and network connectivity and application domains. The M2M gateway can be used for various applications of M2M devices. Functionally, the M2M gateway can be combined in one module with a device or a M2M group.

Access networks: These are networks that allow the domain of M2M devices to connect to the core of the M2M network (the core network). The functionality of M2M access networks is based on the capabilities of existing access networks (xDSL, HFC, PLC, VSAT, GERAN, UTRAN, LTE, WLAN and WiMAX) and allow for the expansion of both the list of services and their capabilities.

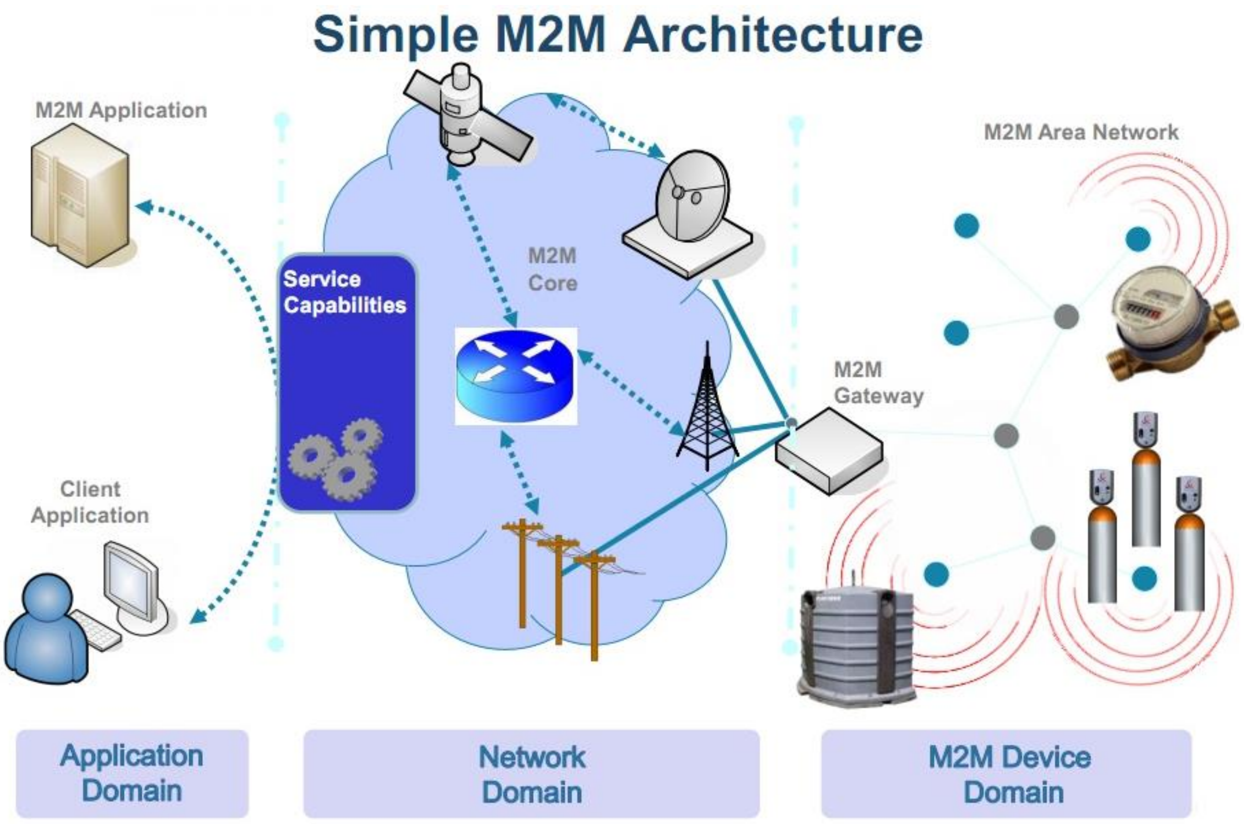

Figure 1.2 - Interaction of different M2M network domains

Transport network: is a network that allows transport of data between the network domain and the application domain. Functional capabilities of transport networks in M2M networks are based on the capabilities of existing transport networks and also as access networks allow to expand both the list of M2M services and their capabilities [10].

M2M core network (Core network): consists of a core network and its service functional characteristics.

M2M core network: provides the functionality of IP connection of M2M network elements, service and network management functions, interworking, roaming and security. The functionality of the M2M core network is based on the respective functionality of the existing 3GPP CN core networks (for example: GPRS, EPC), ETSI TISPAN CN.

Service functional modules M2M: implemented by the core network M2M and provide the ability to perform functions that can combine different applications. They interact on the basis of open interfaces of the M2M network. In addition to its own functionality, the M2M network allows the use of the functionality of the 3GPP and TISPAN core networks. Provide opportunities to simplify and optimize the used applications and services M2M. The basic functionality of the core M2M network (Service Capability), implemented by the corresponding functional modules of the M2M network includes:

- Application capability management - Application Enablement (xAE),

- Providing common relationships in the network - Generic Communication (xGC),

- Ensuring accessibility of devices / gateways, addressing and storage of data - Reachability, Addressing and Repository (xRAR),

- Selecting relationships - Communication Selection (xCS),

- Remote device management - Remote Enttity Management (xREM),

- Security Management - SECurity (xSEC),

- Saving history and data - History and Data Retention (xHDR),

- Query management - Transaction Management (xTM),

- Compensation management - Compensation Broker (xCB),

- Exposure of the core network to telecom operators - Telco Operator Exposure (xTOE),

- Interworking Proxy (xIP) interworking trust, where x is a variable indicating the point of application of these functions in the M2M network and assuming the values: N for networks containing the M2M core network infrastructure connected to gateways and M2M devices; G for gateways that directly control M2M devices in the local M2M network and are connected to the core network CN (M2M core network); D for M2M devices that can directly connect to the CN core network (M2M core network) or to the M2M gateway. The network functionalities of the M2M network can be either special, supporting M2M applications, or those that support common network capabilities: data collection and aggregation, multicast message delivery [11].

An example of a network architecture using the terminology defined above for functional modules is shown in Figure 1.3.

The main network interfaces of M2M networks are standardized and are given in TS. When developing them, three main aspects were taken into account, which were determined for the points of conjugation of elements of the M2M network in order to ensure the equivalence and completeness of the standardization of interfaces, namely:

−Terminological definition of the protocol / application interface (API);

−Identification of resources and sub-resources of the M2M network in the API used;

−Interaction with the protocols used, including the definition of key basic protocols. In accordance with the principles of constructing the functional architecture of M2M networks, the interfaces must meet the following requirements:

−Be applicable to a wide range of network technologies and not restrict their applicability when used on other networks (for example, using other protocols).

−Be invariant to all areas of application of M2M networks, be independent of M2M applications and access networks used.

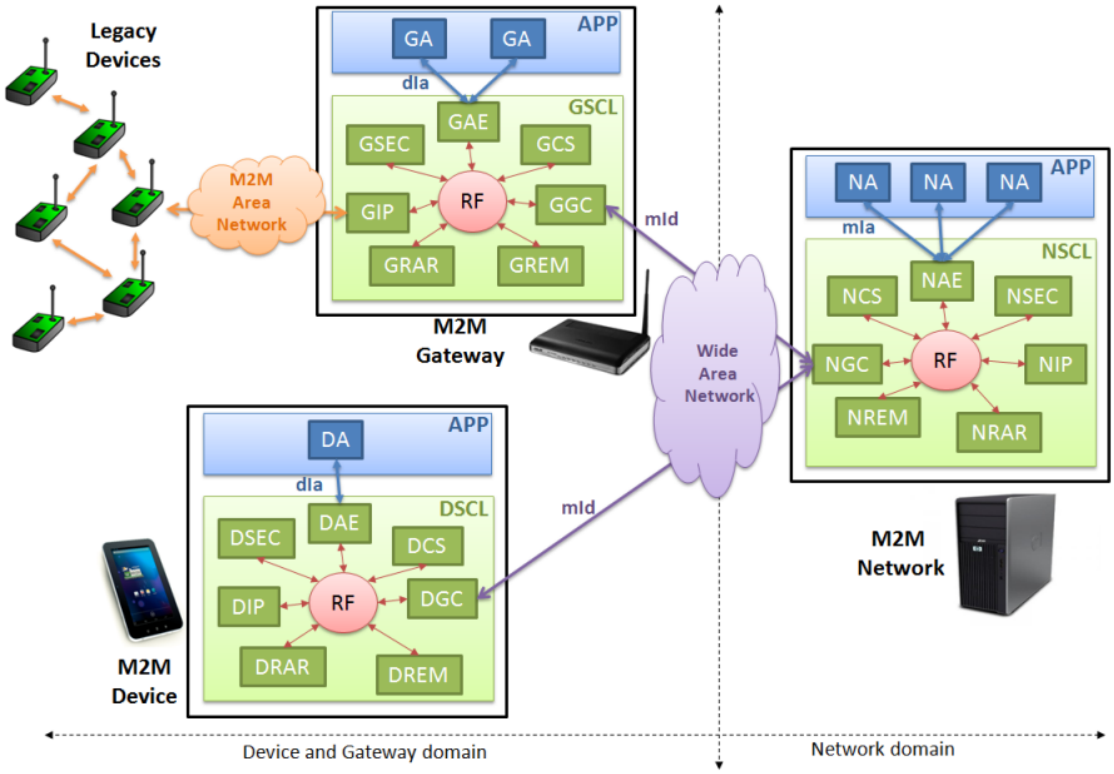

Figure 1.3 - Functional modules of the M2M network at the level of the core network (N), the gateway (G) and the M2M device (D)

M2M network interfaces mIa, dIa, mId: provide, based on the open interfaces principle, the interaction between the application domain and the M2M core network, between the application and functional level of the M2M device domain, between the M2M devices and the M2M gateway, respectively. Typical interfaces with binding to points of mating of elements of the M2M network are shown in Figure 1.4.

The m2a interface of the M2M network provides the interaction of the M2M application with the functional modules of the M2M core network or the application domain. The dIa interface of the M2M network allows the M2M application activated in the M2M device to communicate, have access to the function modules of this M2M device or M2M gateway, and also the interaction of the M2M application activated in the M2M gateway with the M2M device application, access the function modules of this M2M gateway.

The mID interface of the M2M network allows the M2M device or M2M gateway to communicate with the modules of the main M2M functions in the network and the application domain. The mID interface uses the functions of attaching the core network as its base layer.

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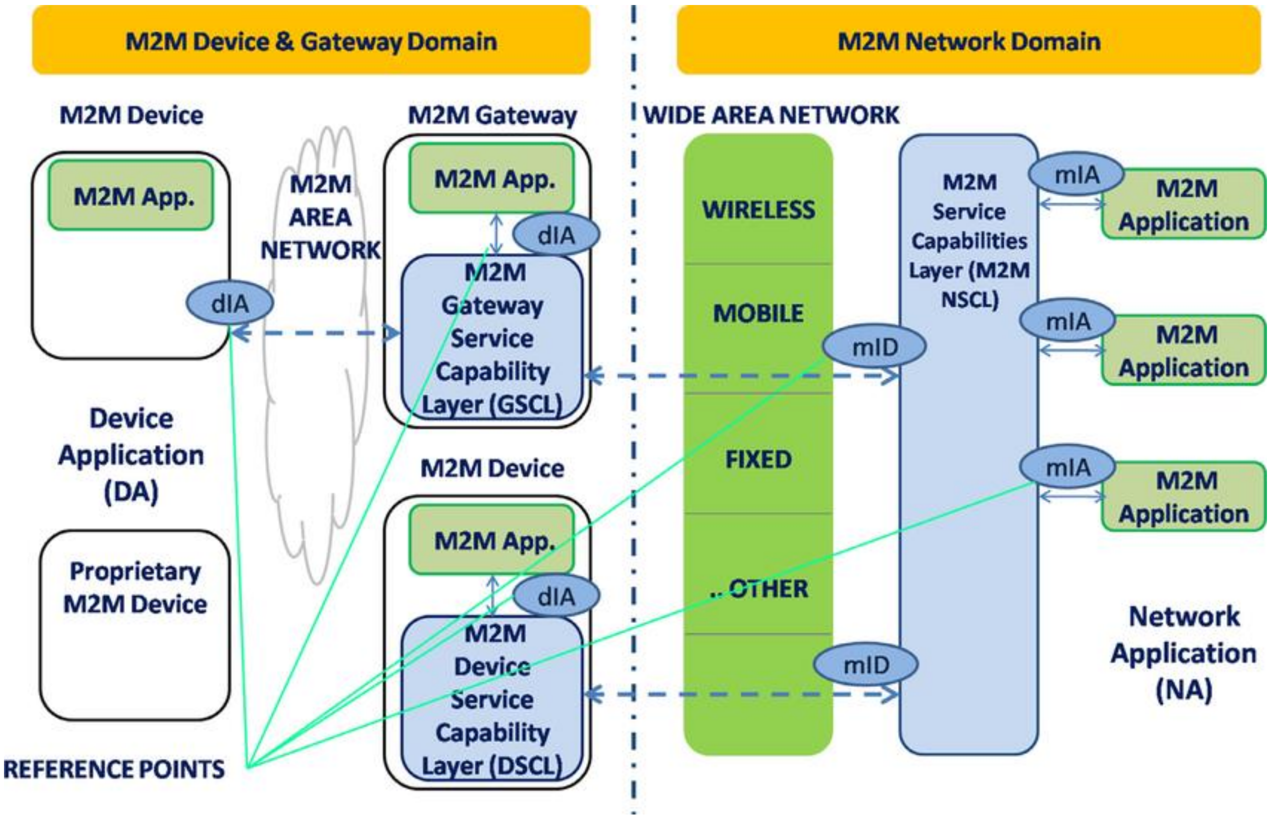

Figure 1.4 - M2M network interfaces and interface points

1.3 The basic technologies of M2M and IoT

Computing technology is developing not only in the direction of high-speed processing capabilities, but also allows you to run them on the smallest applications. There is a growing market for small-scale computing, such as 8, 16 and 32– bit microcontrollers with built-in RAM or flash memory, with I/o capabilities, network interfaces such as IEEE 802.15.4, which integrate tiny System-on-a-Chip (SoC) solutions. Such devices provide very limited space with a small area of several mm2, as well as a very low power consumption in the range from microvats to several milliwatts, but are capable of hosting the entire packet transmission control Protocol/Internet Protocol (TCP/IP), including a small web server [3].

There is a full range of M2M and IoT devices, and to avoid confusion, let's start by explaining what's called a device: a device is a hardware unit that can perceive aspects of its environment or power them, that is, perform tasks in its environment.

The device can be characterized as an object having several properties, such as:

- Microcontroller: 8 - bit , 16 - bit or 32-bit operating memory and storage.
- Power supply: fixed, battery, energy harvesting, or a hybrid.
- Sensors and actuators: on-Board sensors and actuators or schemes that allow them to be connected, sampled, conditioned and controlled.

Communication:

- Cellular, wireless or wired for LAN and WAN communications.

- Operating system (OS): Main-loop, event - based, real-time or fullfeatured Operating system.
- Applications: simple sampling of sensors or more advanced applications.
- User interface: display, buttons, or other features for user interaction.
- Device management (DM): provision, firmware, download and monitoring.
- Execution environment (EE): life cycle management of the application and the application programming interface (API).

For several reasons, one or more of these features are often hosted on the gateway instead. This can be used, for example, to save battery power by allowing the gateway to handle heavy features such as WAN connectivity or logical applications that require a powerful processor. This also results in lower costs because these are expensive components. Another reason is that it reduces complexity by allowing you to manage a Central host (gateway) with features such as device management and advanced applications, allowing devices to focus on discovery and provisioning.

Table 1.1 – Characteristics of the devices

	CPU	Memory	Supply	Communication	OS
Main	8– bit PIC , 8– bit 8051, 32– bit Cortex M	Kilobytes	Battery	802.15.4, 802.11, Z– wave	Main– Loop, Contiki, RTOS
Additional	32– bit ARM9, Intel Atom	Megabytes	Network	802.11, LTE, 3G, GPRS	Linux, Java, Python

Today, there are no clear criteria for categorizing devices, but instead there is a more sliding scale. In the work, we combine devices in two categories.

Basic devices: devices that provide basic services for sensor readings or actuation, and in some cases limited support for user interaction. LAN communication is supported by wired or wireless technology, so a gateway is required to provide a WAN connection.

Advanced devices: in this case, the devices also contain application logic and WAN connectivity. They can also contain device management and a runtime environment for hosting multiple applications. Gateway devices fall into this category.

Deployment may differ for basic and advanced deployment scenarios.

Sample deployment scenarios for core devices:

Home alarms: these devices usually include motion detectors, magnetic sensors and smoke detectors. The Central unit takes care of the logic of the application that triggers the security and beeps if the sensor is turned on when the alarm is turned on. The Central unit also processes the WAN connection with a Central alarm. These systems are currently based on proprietary radio programmes.

Smart meters: meters are installed in households and measure consumption, such as electricity and gas. The hub collects data from counters, performs aggregation, and periodically sends aggregated data to the application server over a cellular connection. Using the technology of capillary network (e.g., 802.15.4), it is possible to extend the range of a gateway hub, allowing instrumentation on the periphery to use other meters as a ple and interact with handheld devices on the side of the Home Area Network.

Building automation systems (BAS): such devices include thermostats, fans, motion detectors and boilers that are controlled by local facilities but can also be remotely controlled.

Autonomous intelligent thermostats: they use Wi-Fi to communicate with web services.

Meanwhile, for example, for advanced devices:

On-Board devices in vehicles that carry out remote monitoring and configuration via cellular communication.

Robots and Autonomous vehicles, such as unmanned aerial vehicles, which can operate both autonomously and remotely via cellular communication.

Video cameras for remote monitoring via 3G and LTE.

Monitoring of oil wells and collecting data from remote devices.

Connected printers that can be upgraded and maintained remotely [4].

Devices and gateways today often use legacy technologies like KNX, Z-Wave, and ZigBee, but the vision of the future is that every device can have an IP address and be directly connected to the Internet. Some of the examples above (for example, BAS) require some form of offline mode in which the system operates even without a WAN connection. In addition, in these cases, you can use IoT technologies to create an "Intranet of things".

These devices are often designed for the same purpose, such as measuring air pressure or closing the valve. In some cases, multiple functions, such as humidity, temperature, and light level control, are deployed on the same device. The hardware requirements are low, both in terms of processing power and memory. The focus is on keeping the material specification (BOM) as low as possible, using low-cost microcontrollers with built-in memory and memory, often on a SoC integrated circuit with all major components on a single chip. Another common goal is to turn on the battery as an energy source with a lifespan of a year or more using ultra – low-energy microcontrollers.

Table 1.2 - Characteristics of microcontrollers

Type	Number of pins	Flash/ RAM	Timers	Interfaces	LCD
F41x	64	32K/1K	BT,A3		96
FW42x	64	32K/1K	BT,A3,A5		96
F42x0	48	32K/512	BT,A3		56A
F42x	64	32K/1K	BT,A3	UART	128
FE42x	80	32K/1K	BT,A3	UART	128

F43x	64	32K/1K	BT,A3,B3	UART	128
F44x	100	60K/2K	BT,A3,B7	UART	160

The microcontroller typically has multiple ports that allow integration with sensors and actuators, such as the universal I/o (GPIO) and analog-to-digital Converter (ADC) to support analog input. For some drives, such as motors, pulse width modulation (PWM) can be used. Because low power operation is of paramount importance to battery powered devices, the microcontroller supports features that facilitate sleep, such as interrupts that can Wake the device on external and internal events, for example. when there is activity on the GPIO port or the radio as well as waking up by timer. Some devices even reach the collection of energy from the environment, for example. in the form of solar, thermal and physical energy. A serial interface such as SPI, I2C, or UART is typically used to communicate with peripherals such as storage or display.

These interfaces can also be used to communicate with another microcontroller on the device. This is common when there is a need to offload specific tasks, or when in some cases all application logic is placed on a separate host processor. For a microcontroller, there is nothing unusual to contain a security processor, for example. to speed up Advanced Encryption Standard (AES). This is necessary to provide encrypted communication over the radio channel without the use of a host processor. Because the underlying device doesn't have enough of the WAN interface, in accordance with our definition, the necessary gateway to any form. The gateway together with the connected devices forms a capillary network.

The microcontroller contains most of the radio functions necessary to communicate with the gateway and other devices in the same capillary network. However, an external antenna is required and preferably a filter that removes unwanted frequencies, such as a surface acoustic wave (SAW) filter. Due to the limited computational resources of these devices do not normally use a typical operating system. It can be something as simple as a single threaded main loop or low-end OS such as FreeRTOS, Atomthreads, AVIX-RT, ChibiOS/RT, ERIKA Enterprise, TinyOS or Thingsquare Mist/Contiki. These OSes offer basic functions, for example. memory and control of the concurrency model (drivers and radios), streaming, TCP/IP, and higher-level Protocol stacks. The actual application logic is located on top of the OS or in main loop. A typical task for application logic is to read the values from the sensors and provide them over the LAN interface in semantically correct with the correct units. For this class of devices, limited hardware and non-standard software limits third-party development and makes development very costly.

The gateway serves as a translator between different protocols, for example. between IEEE 802.15.4 or IEEE 802.11, to Ethernet or cellular. There are many different types of gateways that can operate at different levels in protocols. Most commonly, a gateway refers to a device that performs physical layer and link layer translation, but application layer gateways (ALGS) are also shared. The latter is preferably avoided because it adds complexity and is a common source of deployment errors. Some examples of ALG include ZigBee Gateway Device

(ZigBee Alliance 2011), which translates from ZigBee to SOAP and IP, or gateways that are translated from the limited application Protocol (CoAP) to HyperText Transfer Protocol/ State State Transfer (HTTP/REST). For some LAN technologies, such as 802.11 and Z-Wave, the gateway is used to enable and disable devices. Typically, this works by activating the gateway in turn-on or turn-off mode and pressing a button on the device that you want to add or remove from the network. We cover network technologies in more detail in the section : Local and broadband networks. For very simple gateways, hardware is usually focused on simplicity and low cost, but often the gateway is also used for many other tasks such as data management, device management , and on-premises applications. In these cases, more powerful hardware with GNU/ Linux is usually used. The following sections describe these additional tasks in more detail.

Typical functions for data management include the implementation of sensors and caching these data, as well as filtration, concentration, and integrating data before sending it to backend servers.

Examples of on-premises applications that can be hosted on a gateway include closed loops, home alarming logic, and ventilation management or data management functionality above and in section. The advantage of placing this logic on the gateway rather than on the network is to avoid downtime in the event of a WAN connection failure, minimize the use of expensive cellular data, and reduce latency. To facilitate efficient application management on the gateway, you must enable the runtime. The runtime is responsible for managing the application lifecycle, including installing, pausing, stopping, configuring, and uninstalling applications. A common example of a runtime environment for embedded environments is a Java-based OSGi: applications are built as one or more packages that are packaged in Java JAR files and installed using a so-called management agent. You can manage the management agent, for example, by using a terminal shell or by using a Protocol such as the network management Protocol (CPE WAN Management Protocol, CWMP). [5,6].

For example, packages can be obtained from the local file system or from HTTP. OSGi also provides security and versioning for the Bundles, which means that the relationship between the Bundles is controlled and there can be multiple versions. The advantage of version control and management functions lifecycle is that the OSGi framework should never be disabled during the upgrade, which allows you to avoid downtime in the system. In addition, Linux can be used as a runtime environment.

Device management (DM) is an essential part of IoT and provides an effective means to perform many management tasks for devices:

- Provision: Initialize (or activate) devices with respect to the configuration and features to be enabled;
- Device configuration: manage device settings and settings;
- Software update: installs firmware, system software, and applications on the device.
- Fault Management: enables error reporting and access to device status.

Examples of device management standards are TR-069 and OMA-DM. In the simplest deployment, devices communicate directly with the DM server. However, this is not always optimal or even possible due to network or Protocol limitations, for example. Due to firewall protocols or inconsistency. In these cases, the gateway acts as a proxy between the server and the devices and can work in three different ways:

- If the devices are visible on the DM server, the gateway can simply forward messages between the device and the server and is not a visible session participant.
- If the devices are not visible but understand the DM Protocol used, the gateway can act as a proxy server, essentially acting as a DM server to the device, and a DM client to the server.
- For deployments where devices use a different DM Protocol from the server, the gateway can represent devices and broadcast between different protocols (for example, TR-069, OMA - DM, or COP). Devices can be represented either as virtual devices or as part of a gateway (which is typically also a device managed by a DM server).

As mentioned earlier, the distinction between basic devices, gateways, and advanced devices is not stoned, but some of the features that can characterize an advanced device are as follows:

- A powerful processor or microcontroller with enough memory and storage to accommodate advanced applications such as a printer that offers features for copying, faxing, printing, and remote management;
- A more advanced user interface, such as display and advanced user input in the form of a keyboard or touch screen;
- Video or other high bandwidth features.

This is not unusual for an enhanced device to also function as a gateway to on-premises devices on the same local network. For these more intelligently capable devices, the OS can be, for example, GNU/Linux or commercial RTOS such as OSE from ENEA, VxWorks WindRiver or QNX from Blackberry. This class of devices comes with optimized and high-performance IP stacks, making networking hassle-free.

By offering a more General and open OS, along with standardized API standards, software libraries, programming languages, and development tools, the number of potential developers is increasing significantly.

This topic discusses the different device classes and the gateway role in an M2M or IoT deployment. There are other aspects to consider with regard to devices. The most important is security, both in terms of physical security and in terms of software and network security. Because this is a very broad topic, it is beyond the scope of this book. Another aspect that needs to be managed is the question of external factors that can affect the operation of devices such as rain, wind, chemicals and electromagnetic effects. These elements are slowly understood and studied in the context of cyberphysical systems as IoT applications move from the lab to real deployments. In fact, these external factors require adaptability and situational awareness as features of devices in this field, which are not usually taken into account in the software development phase. One of the main effects IoT will have on devices is breaking existing value chains, where one entity controls everything from device to service. This is due to the standardization and consolidation of technologies such as protocols, OS, software and programming languages (e.g. Java for embedded devices). New types of participants will be able to enter the market, for example. specialized device providers, cloud solution providers, and service providers. Standardization will improve communication between devices as well as between devices and services, leading to the commoditization of both. Another expected result of improved interoperability is the ability to reuse the same device for multiple services; for example, a motion detector can be used both for safety and to reduce energy consumption by detecting when no one is in the room.

The obstacle for new developers will be further reduced by consolidating software and interfaces, for example. you will be able to interact with the device using simple HTTP/REST, and easily install the Java application on the device, which will increase the number of developers.

Due to changes in hardware and networking technologies, completely new device classes and features such as:

- Battery powered devices with heavy-duty cellular connections.
- Devices that extract energy from the environment.
- Intelligent bandwidth management and Protocol switching, that is, the use of adaptive RF mechanisms to exchange between, for example, Bluetooth LE and IEEE 802.15.4.
- Multi-radio / multi-rate for switching between bands or transmission speeds (slower data rate implies better sensitivity in a wider range).
- Microcontrollers with multi-core processors.
- New software architectures for better concurrency handling.
- The ability to automate the design of integrated circuits based on business-level logic and use.

All these improvements, which IoT brings, will lead to the elimination of the final barriers that restrain the M2M market. In the next section, we'll look at the LAN and WAN technology blocks that allow devices to interact with information and communication technology (ICT) systems and the wider world.

A network is created when two or more computing devices exchange data or information. The ability to share information using telecommunication technologies has changed the world and will continue to do so in the foreseeable future, when applications will emerge in virtually all contexts of modern and future life. Typically, devices are called "nodes" of the network, and they exchange "links". In modern computing, nodes range from personal computers, servers, and specialized hardware packet switches to smartphones, game consoles, TVs , and, heterogeneous devices, which are typically characterized by limited resources and functionality. Restrictions typically include computation, energy, memory, communication (range, throughput, reliability) And the specificity of the application (e.g., specific sensors, broadband local and network drives, tasks). Such devices are typically designed to perform specific tasks, such as sensing, monitoring, and control. Network links are based on physical media, such as electrical wires, aerial and optical fibers, over which data can be sent from one network node to another. It is not uncommon for these media to be grouped as either wired or wireless. The selected physical environment determines a number of technical and economic considerations. Technically, the environment chosen or, more precisely, the technological solution developed and implemented for communication by this tool is the main factor of bandwidth without which some applications are not feasible. At the same time, various technological solutions require certain economic considerations, such as the cost of deploying and maintaining the network infrastructure. For example, consider the cost of wiring in a metropolis or in a larger geographical area (for example, electricity and legacy telephone networks). When direct communication between two nodes over physical media is not possible, network communication can allow these devices to communicate across multiple flights. To achieve this, hosts must be aware of all hosts with which they can communicate indirectly. It can be a direct connection on the same line (border, transition or link between two nodes by reference) or knowledge of the route to the desired (target) node by passing through interacting nodes on multiple edges. Look at the diagram. This is the simplest form of network that requires knowledge of the route for communication between nodes that do not have direct physical connections. Therefore, if node a wants to transmit data to node C, it must do so through node B. therefore, node b must be able to: communicate with both node a and node C and advertising with node a and node C, which it can act as an intermediary. Basic network requirements became apparent. You must uniquely identify each node in the network, and you must have interactive nodes that can associate nodes that do not have physical links between them. In modern computing, this is equivalent to IP addresses and routing tables. Thanks to IP standardization, in particular, physical media (links) should no longer be the same across the entire network, and nodes should not have the same capabilities or mission.

In addition to the basic ability to transmit data, the speed and accuracy of data transfer are crucial for the application. Regardless of whether you can bind devices without the required bandwidth, some applications become impossible. Consider the differences between streaming video from a surveillance camera, for example, and an intrusion detection system based on a passive sensor. Simplistically, streaming video requires high bandwidth, whereas the transmission of a small amount of intruder detection information requires tiny bandwidth, but a higher degree of reliability both on-line and on-line detection accuracy. Today we have complex, heterogeneous networks. The simple example above is useful for explaining the basics of networking for a child, but is also useful for abstracting the types of nodes that can be A, B, and C, the different physical links between them, and their methods of interaction.

Assume that host a is a device that can communicate only over a certain limited range wireless channel (for example, channel 11 in the ISM 2.4 GHz band, less than 200 meters). Node b can communicate with node a, but also with a serviceable application server (node C, with which it can connect using wired Ethernet, for example, a complex communication line using a standardized Protocol or a web service such as REST at the application layer) over the Internet. Now consider that node B can be connected to a subnet network (child nodes similar to node a) of up to a thousand devices with the same restriction (A1...an). These thousands of devices can be equipped with sensors specifically designed to monitor some physical phenomena. They can only interact with each other and node B and can interact with each other through one or more transitions (thus increasing the range of the sensing field, not all nodes requiring a direct link to B). This is typical of a traditional wireless sensor network (WSN).

Think of the WSN owner wants to get data from each of the (A1. .AN) of the devices in the WSN. However, the preferred way to read data is through a web browser or an app on a smartphone/tablet through site C. therefore, a network solution is required to transfer all WSN data from sites A1. In node C through node B. It is now a complex network infrastructure and is representative of many potential M2M and IoT technologies. This concept is directly mapped to the M2M functional architecture, where A1 nodes. M2M Area network, node B is M2M gateway, and node C is representative of M2M capabilities and applications. A local area network (LAN) has traditionally been different from a wide area network (WAN) based on geographical network coverage requirements, as well as for third-party communications infrastructure or leased infrastructure. In the case of LAN, a smaller geographical area, such as a commercial building, office block or house, is covered and does not require any leased communications infrastructure. WAN provide lines of communication that cover longer distances, for example, by metropolis, region or by definition of textbooks in global geographic areas. In practice, WAN is often used for linking local area networks and urban networks (MAN), where LAN technologies cannot provide communication ranges otherwise and usually link LAN and devices (including smartphones, Wi-Fi routers that support local area networks, tablets, and M2M devices) to the Internet. In quantitative terms, local networks tended to cover distances from tens to hundreds of meters, while the global network covered channels from tens to hundreds of kilometers. There are differences between the technologies that allow LAN and WAN. In the simplest case, for each of them, they can be grouped as wired or wireless. The most popular wired LAN technology is Ethernet. Wi-Fi is the most common technology for wireless local area network (WLAN). Wireless WAN (WWAN), as a descriptor, covers cellular mobile telecommunications networks, a significant departure from WLAN in terms of technology, coverage, network infrastructure and architecture. The current generation of WWAN technologies includes LTE (or 4G) and WiMAX. Acting as a link between on-premises networks and wireless personal networks (WPANS), M2M Gateway Devices typically include cellular transceivers and provide seamless IP connectivity on heterogeneous physical media.

A more intuitive example of such a device is a wireless access point, commonly found in homes and offices. At home, a "wireless router" usually behaves as a connection between Wi-Fi (WLAN and, respectively, connected laptops, tablets, smartphones commonly found at home) and digital subscriber line (DSL) broadband, traditionally arriving over telephone lines. "DSL" refers to Internet access via legacy (wired) telephone networks and covers numerous standards and options. "Broadband" refers to the ability to transfer multiple signals over multiple frequencies with a typical minimum bandwidth of 256 kbps.at the office, wireless Wi-Fi access points typically connect to a wired corporate (Ethernet) LAN, which is connected to a wider local area network (LAN) and the Internet backbone typically provided by an Internet service provider (ISP). Given the M2M and IoT applications, there is likely to be a combination of traditional networking approaches. There is a need to connect devices (usually integrated Microsystems) to Central data processing and decision support systems in addition to each other. The business logic and requirements for each implementation option will vary on a case-by-case basis. In practice, these devices do not guarantee individual connections to the leased network infrastructure (for example, placing a SIM card in each device and using a cellular network for fast IP-communication). It is believed that this approach is excessive due to cost, among other factors. A more likely scenario is that, like WLAN technologies, a geographic region can be covered by a network of devices that connect to the Internet through a gateway device that can use a leased network connection. The potential complexity of these networks is enormous. For example, the gateway device can access the underlying IP backbone over the WWAN link (for example, GPRS/UMTS/LTE / WiMAX) or over the WLAN line where the leased infrastructure [13].

will belong to the ISP providing the basic WLAN connection as mentioned above. It is worth extending the consideration of WAN and LAN to encompass the idea of WPAN, which is a description used for newer standards that manage low-power low-speed networks suitable for M2M and IoT applications. Indeed, the standard on which many popular latest networking technologies are built (including ZigBee, WirelessHART, Isa100.11a and other IETF initiatives such as 6LoWPAN, RPL, and COP are discussed later in this Chapter): "IEEE 802.15.4" wireless medium access (MAC) and physical layer (PHY) specifications for low-rate wireless personal networks (LR-WPAN)." This standard was first approved in 2003 and has undergone numerous changes over the past ten days. These amendments relate to the modification and extension of the PHY parameters to ensure a global utility with respect to the licensing and eligibility of the applications and modifications of the MAC layer. This is similar to the evolution of Wi - Fi WLAN technology (e.g. IEEE 802.11, a, b, g, n, etc.). The naming Convention is ultimately unintuitive because the communication ranges for IEEE 802.15.4 can range from tens of meters to kilometers. It is probably more appropriate to think of these technologies as "low-speed, low-power" networks.

It is reasonable to assume that the traditional boundaries between LAN and WAN technologies and their working definitions require updating to take into account modern amendments to standards and use cases to which they apply. From the point of view of ETSI M2M considers as part of its functional architecture, M2M Area Networks (the term "M2M Area Network", "Domain M2M Device" and "capillary network" are often used interchangeably to describe peripheral networks below Access and Core Networks). The device in M2M Area Network are connected to the IP backbone or a Network domain through a M2M Gateway device. As a rule, the gateway device is equipped with a cellular transceiver that is physically compatible with UMTS or LTE-Advanced, for example, WWAN. The same device will also be equipped with the necessary transceiver to communicate on the same physical media as the M2M Area Network (s) in the M2M device domain. This is described in more detail in section 6.M2M Area Networks can include a variety of wired or wireless technologies including: Bluetooth LE / Smart, IEEE 802.15.4 (LR-WPAN, e.g. ZigBee, IETF 6LoWPAN, RPL, COP, ISA100 .11a, WirelessHART), M-BUS, Wireless M-BUS, KNX and power line communication (PLC). "Internet of things", as a term, originated from a radio frequency identification (RFID) study in which the original concept of IoT was that any" thing "with an RFID tag could have a virtual presence on the"Internet." In fact, there is little conceptual difference between RFID and barcodes, or more recently, QR codes, they just use different technological tools to achieve the same result (i.e. "object" has an online presence). The original concept evolved from a reasonably simple idea with immediate utility in logistics (tracking and tracing, inventory management applications) to complex networks, functions and interactions without any satisfactory operational definitions. Because M2M applications become more synonymous with IoT, you need to understand the technologies, limitations, and consequences of the network infrastructure. In fact, the ability to remotely communicate with devices and, as a consequence, new opportunities, is what distinguishes modern thinking from the idea of the original concept. The following subsections describe the technologies that are commonly used to achieve WAN and LAN. We are also interested in abandoning traditional thinking about how to describe network and communication technologies based on simplified concepts around geographical coverage or leased infrastructure.

Wide area networks are usually needed to bring the M2M device domain to a network of transit networks, thus providing a proxy server that allows the transmission of information (data, commands) to heterogeneous networks. This is seen as a basic requirement for the provision of communications services between M2M service and physical deployment of devices in the field. Thus, WAN is capable of providing bidirectional communication lines between services and devices. This, however, must be achieved through a physical and logical proxy. The proxy server is reached using the M2M gateway device. Depending on the situation, there are, in General, a number of potential technologies to choose from. As before, the M2M gateway is usually an integrated micro-system with multiple communication interfaces and computing capabilities. It is a critical component in the functional architecture, as it should be able to handle all the necessary interfaces with M2M management capabilities and functions, which are mainly described in Chapter 6 and ETSI releases. As an example, consider a device that includes both IEEE 802.15.4-compliant transceiver (a popular legacy example of which is Texas

Instruments CC2420), capable of communicating with a capillary network of similarly equipped devices, and cellular transceiver (a popular example is Telit UC864-g), which connects to the Internet using the UMTS network. This assumes that the transfer of service to the backbone IP network is handled according to the 3GPP specifications. Transceivers (sometimes referred to as modems) are typically available as hardware modules with which the Central intelligence of the device (gateway or cell phone) interacts through standardized (sometimes specific) AT commands. This device can now act as a physical proxy between the LR-WPAN or M2M device Domain and the M2M network domain. The latest functional architecture of the ETSI M2M is shown in figure 1.6. Device types were discussed in more detail in the section . The access network and cores in the ETSI M2M functional architecture are intended to be operated by a mobile network operator (MNO) and can be regarded simply as a "global network" for connecting devices and data networks (Internet), thus M2M Applications , service capabilities, management functions and network management functions. WAN covers larger geographic regions using wireless (licensed and unlicensed spectra) as well as wired access. WAN technologies include cellular networks (using multiple generations of technology), DSL, WiMAX, wifi, Ethernet, Satellite [10,11].

WAN delivers a packet service using the default IP. However, you can also use schema-based services in certain situations. In the context of M2M important features of a WAN include:

The main function of WAN is to establish communication between capillary networks, host sensors and actuators, as well as support for M2M-service. The default connection mode is based on packets using a family of IP technologies [6].

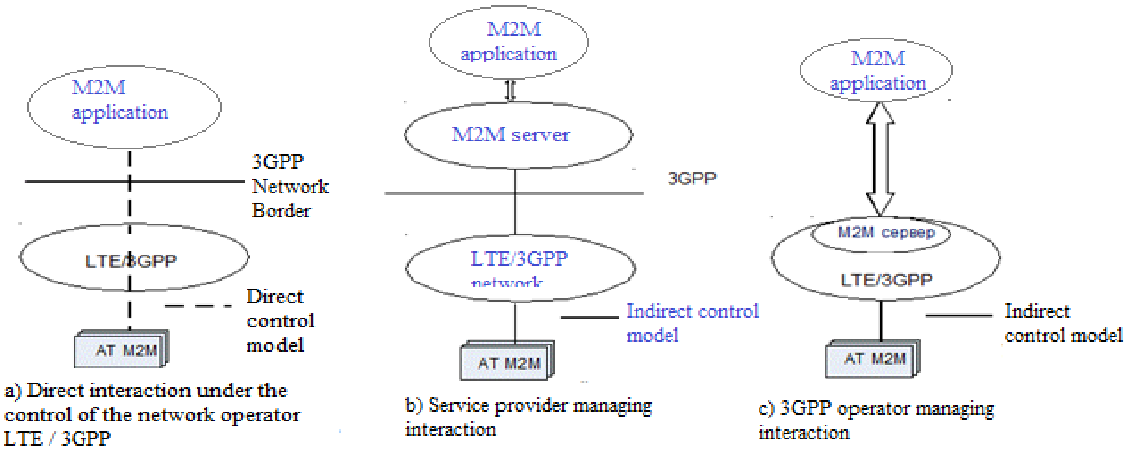

Figure 1.5 - Functional architecture

You can send and receive many different types of messages. These include messages that occur, for example, as a message sent from a sensor to the M2M Area Network and result in SMS message received from a gateway or M2M application (for example, by an appropriate stakeholder with SMS notifications configured for when the sensor readings violate certain sensitivity thresholds).

Using methods of identity management (primarily M2M devices) to cellular and extra-cellular domains to grant the right of use of the resource of the WAN. For this purpose, the following methods are used:

- MCIM (an identification module a Machine Communications Identity Module) for the remote provision of SIM cards for M2M devices.
- xSIM (x-Subscription Identity Module), such as SIM, USIM, ISIM.
- Interface identifiers, such as the MAC address of a device, typically stored at the hardware level.
- Authentication/registration type (focused on the device).
- Authentication, authorization, and accounting (AAA), such as RADIUS services.
- The dynamic host configuration Protocol (DHCP), for example. using deployment-specific configuration settings specified by device, user, or application settings in the directory.
- Subscription services (device-oriented).

Directory services, such as those containing user profiles and various device settings, settings, and combinations thereof. M2M-specific considerations include, inter alia:

- MCIM (see 3GPP SA3).
- Manage user data (such as subscription management).
- Network optimization (3GPP SA2).

2 Analysis of existing narrowband networks for servicing M2M devices

2.1 Narrowband - Internet of Things

With the development of the Internet of things (Internet of Things, IoT) the number of connections to mobile networks of operators will increase at times. According to Ericsson, by 2021 the total number of devices connected to the Internet in the world will be 28 billion. Of these, 1.5 billion will be consumer electronics and smart cars that interact with each other through mobile networks. In the coming years, the number of machine-to-machine connections (M2M) will grow by 25% per year, most of the M2M-devices delivered to the market will support the LTE standard. As the IoT market grows, it becomes apparent that for many uses of such solutions, existing mobile technologies are not sufficient due to insufficient coverage, the high cost of terminal terminals and the short life of their batteries.

The innovative technology of the Internet of things is the solution of narrowband IoT (Narrow-Band IoT or NB-IoT). This is a wireless narrowband version of low-power global networks (LPWA), which is primarily designed for inter-machine communication applications (M2M). The NB-IoT standard will open a wide range of new opportunities for companies specializing in the provision of telecommunications services. In particular, it will significantly increase the profitability of operators from one subscriber (Average revenue per user, ARPU). NB-IoT technology will take its low-speed niche in the class of solutions, where uninterrupted data transmission and low power consumption are of priority importance.

NB-IoT (NarrowBand IoT, NarrowBand Internet of Things) - the standard of cellular communication for telemetry devices with low volumes of data exchange. Developed by the consortium 3GPP in the framework of work on the standards of cellular networks of a new generation. The first working version of the specification is presented in June 2016.

The technology is intended for connection to digital communication networks of a wide range of stand-alone devices. For example, medical sensors, energy consumption meters, smart home devices, etc. In everyday life, such communication systems received a generalized name for the Internet of things. NB-IoT is one of three IoT standards developed by 3GPP for cellular networks: eMTC, NB-IoT and EC-GSM-IOT. eMTC has the highest bandwidth and is deployed on LTE equipment. The NB-IoT network can be deployed both on LTE cellular network equipment, and separately, including over GSM. EC-GSM-IoT provides the lowest bandwidth and deploys over GSM networks.

Among the advantages of NB-IoT:

- flexible management of power consumption of devices (up to 10 years in the network from a battery with a capacity of 5 W * h)
- huge network capacity (tens-hundreds of thousands of connected devices per base station)
- low cost of devices
- optimized to improve the sensitivity of signal modulation.

Table 2.1 - Comparison of the LTE Cat versions

	LTE Cat 1	LTE Cat 0	LTE Cat M1 (eMTC)	LTE Cat NB1 (NB-IoT)	EC-GSM-IoT
3GPP Release	Release 8	Release 12	Release 13	Release 13	
Downlink Peak Rate	10 Mbps	1 Mbps	1 Mbps	250 kbps	14 kbps
Uplink Peak Rate	5 Mbps	1 Mbps	1 Mbps	250 kbps (multi-tone) 20 kbps (single-tone)	
Latency	50-100ms	not deployed	Connected: up to 10 s Idle: up to 44 min	Connected: up to 10 s Idle: up to 3 hour	up to 52 min
Number of antennas	2	1	1	1	1
Duplex Mode	Full Duplex	Full or Half Duplex	Full or Half Duplex	Half Duplex	

Device Receive Bandwidth	1.08 -18 MHz	1.08 — 18 MHz	1.08 MHz	180 kHz	
Receiver chains	2 (MIMO)	1 (SISO)	1 (SISO)	1 (SISO)	
Device Transmit Power	23 dBm	23 dBm	20 / 23 dBm	20 / 23 dB	

A huge proliferation of Internet of Things devices with the possibility of mobile communication is expected. In this regard, cost and service costs become critically important. One of the ways to save - the refusal to install a physical SIM card. To this end, the GSMA consortium in 2016 adopted the Embedded SIM (eSIM) / Remote SIM Provisioning (RSP) specification. The eSIM standard allows you to integrate the functionality of the SIM card into the electronics of the modem, and RSP describes the infrastructure and algorithms for the interaction of trust centers for the emission of SIM parameters, the mobile operator and the consumer of communication services.

The first test networks are deployed in 2015 in Europe by Vodafone. Chips made Huawei, modems developed u-blox. Vodafone expects to begin commercial operation of the technology in 2017.

The NB-IoT standard was specified by the 3GPP consortium in 2016 in Release 13 (LTE Advanced Pro) and is currently being tested. Experts believe that the technology NB-IoT will become popular among operators, because its maintenance and operation will cost them cheaper than the advanced for today LTE and GSM networks. This is due to its characteristics. The NB-IoT standard is a two-way communication operating in a frequency channel of 200 kHz width. In order to start the network in operation, the operator only needs to install special software on the base station. This is true if you deploy the IoT network already at the existing frequencies.

3GPP considers the network operation model. The consortium offers three options for deploying the NB-IoT network. The first is the NB-IoT Guard Band, i.e. For Narrowband IoT, a separate frequency spectrum will be allocated. The second is In Band, i.e. technology will be placed in the protective frequency range of LTE networks. The third one is called Stand Alone. According to its concept, NB-IoT and LTE operate in the same frequency range. Thus, the NB-IoT network can be deployed in the frequency bands in which the GSM standard is currently operating, after their reframing in LTE, or in the "protective" intervals between the GSM and LTE networks. The data transfer rate in NB-IoT reaches 200 kbit / s, which is sufficient for devices periodically transmitting the same type of small data.

In a simplified form, the deployment options for the NB-IoT network can be represented as the following illustration:

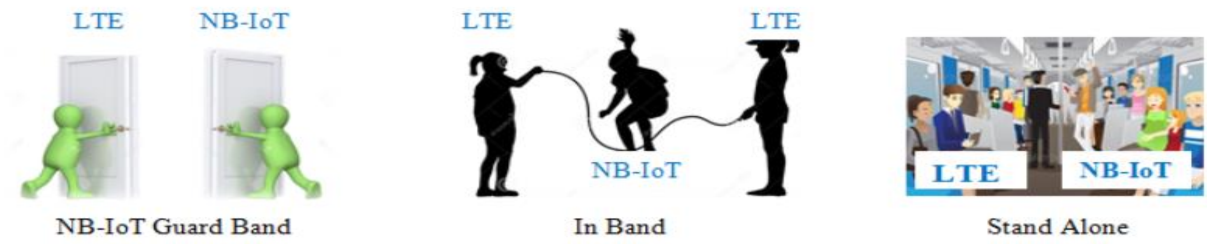

Figure 2.1 - Simplified version of the deployment of NB-IoT network

The next most important feature of NB-IoT technology is the ability to connect up to 100,000 NB-IoT devices to one cell of the base station, which exceeds the capabilities of existing mobile communication standards by tens of times. This allows you to obtain additional commercial benefits based on the application of IoT data analysis by the methods of large data (Big Data). In the framework of cooperation with related industries, operators, in addition to selling communication services, are able to sell analytical data to third parties.

Problems and development prospects NB-IoT

Many industries are interested in IoT products, which increase the efficiency of business processes. First of all, this is the housing and communal services, transport sphere, health care, automobile industry, etc.

The Internet of things provides more than fifty options for use, including intelligent sensors (for electricity, gas, water), facility management, security and fire alarm systems for home and commercial real estate, personal electronic health sensors, tracking systems for people, animals or objects, items infrastructure "smart" city (for example, street lamps or garbage containers, "smart" houses and connected industrial tools, etc.).

Analysts believe that it is the B2B segment that will become the driving force behind the development of the Internet of things and it will be he who will show the greatest interest in these products at the first stage of their commercialization. This is also due to the fact that a structured business procedure is easier to integrate into a smart device, than the needs of a private user. It is expected that the market volume Narrowband (Narrowband) IoT by 2022 will reach about 200 million dollars.

Experts call different numbers about the number of IoT devices connected in the next 4-6 years. The complexity of forecasting is explained by the fact that the Internet of things has a great potential in the industrial sphere, which is quite energy-intensive and requires a large number of connected devices.

It is expected that the first tests of the NB-IoT standard will begin on the border of 2016-2017. It is too early to talk about the commercial deployment of such networks. This is due not only to the lack of electronic components and allocation problems of allocated frequencies, but also to regulatory mechanisms.

Representatives of Huawei note that today Russia has no reason to remain behind the development of technology. Federal operators have firmly established LTE networks, which is very important for the progression of Narrowband IoT. Among the world developers of the standard NB-IoT, in addition to Huawei, we can name Qualcomm, Intel Corporation, Nokia Networks, Verizon, Samsung Group, AT&T and others [7.8].

Given that the NB-IoT standard has only been formed, their concept is still being refined. A number of developers plan to expand the functionality of the network in subsequent releases by voice service, because the speed of the network allows you to do this. Also, most likely, NB-IoT will become one of the components of the 5G network specification (Narrowband 5G).

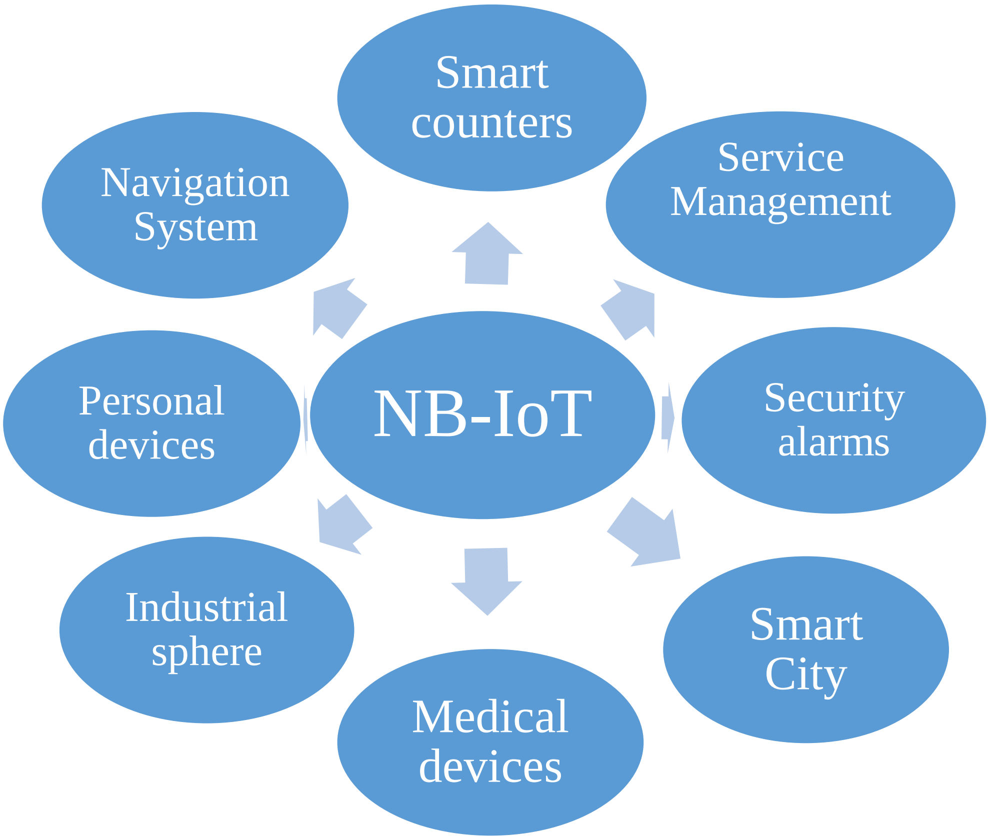

Figure 2.2 - Scenario of NB-IoT application

There are a number of characteristics that make NB-IoT technology optimal for LPWA deployment. For example, improved indoor coverage - 20 dB higher than GSM, low power consumption, the ability to connect a large number of devices. The ability to connect a large number of sensors allows you to ensure full connection of all devices in households. If you can connect about 50 thousand devices per cell and density of 1500 households per square kilometer in each, you can connect to 40 devices.

NB-IoT has a fairly extensive ecosystem - mainly thanks to the support of a number of leading operators.

3GPP offers three deployment scenarios: NB-IoT Guard Band, In Band and Stand Alone.

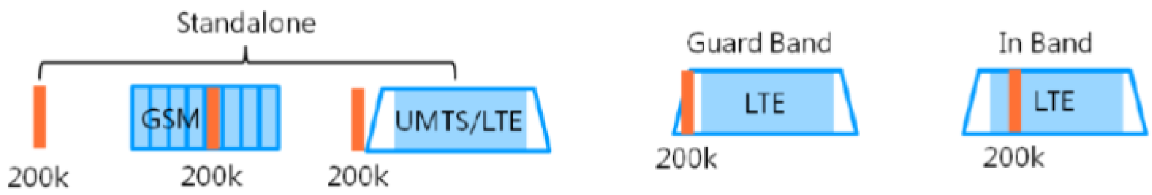

Figure 2.3 - Deployment Scenarios NB-IoT

The first scenario is when the resolved spectrum is out of the allowed frequency range of traditional 3GPP UMTS / LTE technologies. The second is when the guard interval for LTE technologies is used as the working band. And the third, the least optimal, is when the resources of the allowed spectrum of LTE frequencies are spent.

The deployment of NB-IoT in the 700, 800 and 900 MHz bands is optimal, as they already have a large installed base. For mobile operators working with GSM 900 MHz or LTE 800 MHz, relatively small investments are required to quickly deploy NB-IoT [15].

Speaking about the participation of mobile operators in IoT-projects, it should be noted that different business models are possible. The simplest is just the provision of a link: in this case, the operator assumes the minimum responsibility and receives the minimum ARPC (Average Revenue per Customer).

The next level in the value added chain is the status "NB IoT Operator", that is, the provision of the network as a service. In addition to providing communication, there are additional service opportunities, such as analytical processing of data obtained by Big Data methods and commercial implementation of this analytics.

And finally, the third level - when the operator acts as a service provider responsible for system integration, implementation, training and maintenance of the service. This is an option where ARPC increases dramatically, but the degree of responsibility of the provider increases.

On the basis of NB-IoT, solutions can be built for connecting both personal, home, public, and industrial IoT applications.

User case - use cases;

IoT Appliance - home IoT devices.

IoT Personal - IoT personal solutions;

IoT Public - public IoT solutions.

IoT Industry - industrial solutions IoT.

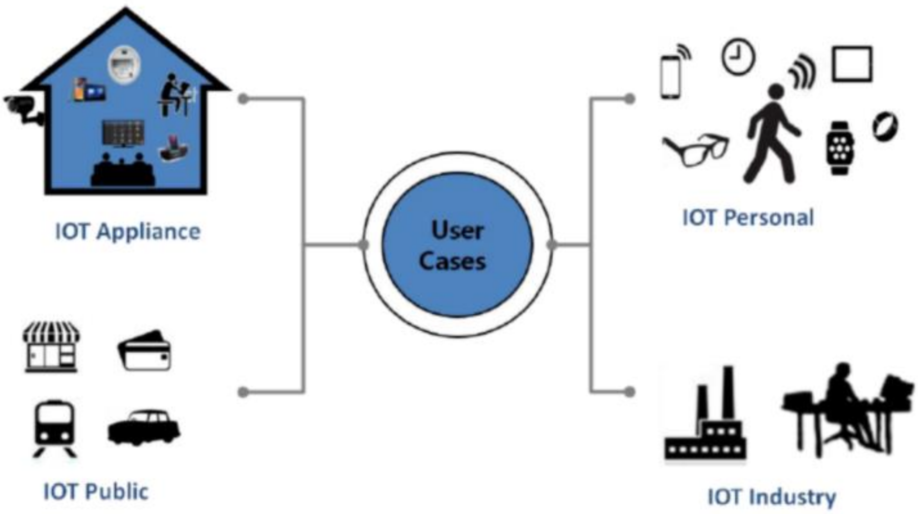

Figure 2.4 - Four scenarios for using NB-IoT

The most common public solution is to connect smart meters to the mobile network (Figure 2.5) - this saves time by using remote data collection of water, electricity and gas costs.

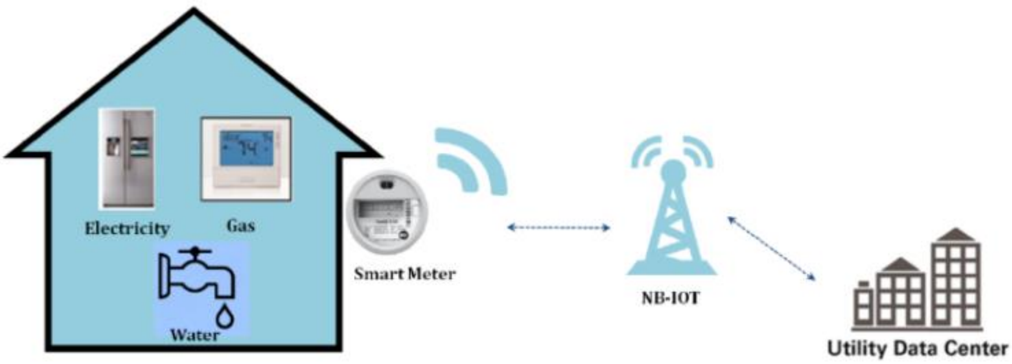

Figure 2.5 - Connecting to a mobile network of smart meters

To the same category include solutions for connecting warning and warning sensors. For example, notification of an intrusion into a dwelling, warning of smoke or elevated temperature, which may be due to a fire.

Among public decisions I would like to mention the so-called "smart" garbage containers. Such a container can tell how it is full, and thereby optimize the work of public utilities for garbage disposal. Based on the information from the container sensor, the optimal route of travel can be calculated and passed to the driver of the garbage truck.

Prospective is the "smart parking" solution (Figure 2.6), built on the basis of an inexpensive geomagnetic sensor.

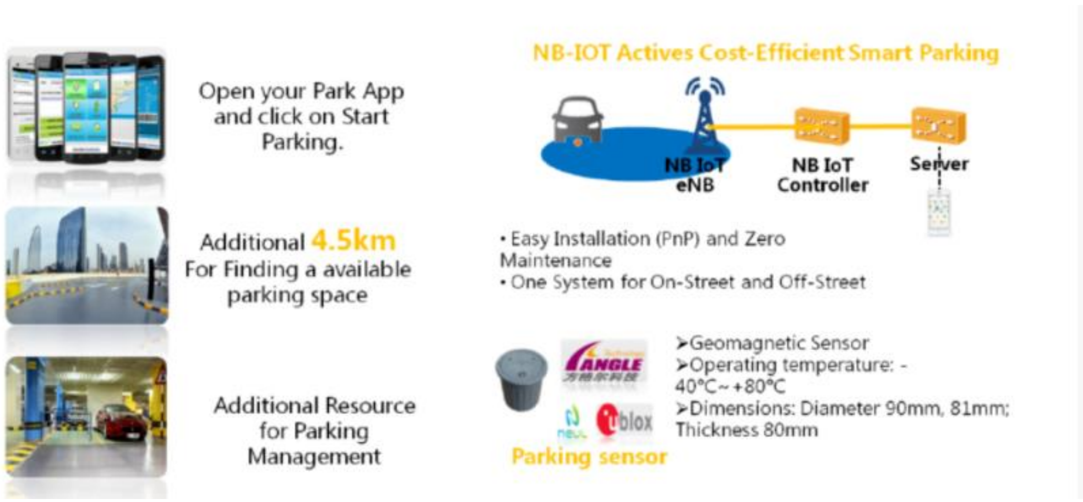

Figure 2.6 - Solution for the organization of smart parking

Industrial IoT applications mainly use low-power devices, for example in the case of logistics solutions and cargo tracking. The technology allows you to monitor the location of goods, and warnings and recommendations can be sent to technicians on their smartphones in real time.

You can track not only loads, but also industrial objects - by attaching a module that transmits information about its location. Broad opportunities for NB IoT are also being discovered in applications of "smart" agriculture. It also requires the use of sensors to automate irrigation, warning of abnormal situations (for example, in a greenhouse, high temperature or run out of water in tanks, etc.). Sensors can send information about the composition of animal feed, track the content of certain components in them, collect data for analysis.

Speaking about applications for smart home, it should be noted that they are usually deployed on the basis of short-range technologies, such as Z-Wave and ZigBee, and the connection to the Internet goes through the home gateway. However, the device with the built-in NB-IoT-chipset can become a more preferable solution.

Good prospects for NB IoT and for connecting personal devices. Recently wearable gadgets for fitness and health monitoring are gaining popularity, with which users can monitor the degree of their physical activity, count the calories spent, measure pressure, pulse and other parameters.

In conclusion, it should be emphasized once again that NB-IoT opens a new field of activity for mobile operators, and they should invest in these solutions today to take a share in this promising market in time.

With the introduction of the NB-IoT standard, operators of traditional cellular communication will be able to connect to their networks hundreds of thousands of IoT-devices. It is assumed that networks

NB-IOT will find wide application in solutions for smart cities, smart garbage disposal and many other tasks. The paper proposes an analytical model for analyzing the main performance indicators of the LTE wireless network with NB-IoT support, namely, the probability of message loss in the system. For the model, the results of a numerical experiment for cells with a coverage radius of 10 and 30 kilometers are presented.

The proposed mathematical model can be used to analyze the characteristics of the Internet technology of things in telecommunication networks.

Low power consumption, affordable sensor price, high radio transmission distance, and support for a large number of connections are the basic requirements for an Internet-based wireless network. For such requirements, a new type of wireless networks LPWAN is developed - an energy efficient long-range network. The development of such technologies was initiated and supported by several leading bodies for the standardization of IEEE, ETSI and 3GPP. Currently, the NB-IoT standardization process is completed (in June 2016) and this technology is officially included in LTE Rel.13 [19].

The new technology can be relatively easily implemented in existing LTE cellular networks, adding several new categories of devices designed specifically to reduce the complexity of terminal devices. To achieve the required efficiency, the width of the wireless channel was reduced to 180 kHz, which allowed gaining the signal by 20 dB. These changes can significantly increase the effective range of small data transfers for low-power devices and increase their battery autonomy up to 10 years or more, depending on the scenario.

In this paper, the performance of NB-IoT technology is analyzed in terms of probabilistic service characteristics, such as the probability of message loss in the system. The presented model allows to define load ranges at which the specified parameters of service quality of devices are fulfilled. Numerical results are given for coverage radius of 10 and 30 kilometers.

System model

Suppose that the service area of the base station has the form of a circle with a radius R with uniformly distributed N devices in it. The density of sensors per 1 km2 is determined by the formula.

$$2\ \sigma = N\ \pi R \tag{2.1}$$

The intensity of receipt of an application from one device will be denoted by λt. Then λI = λtΔ is the message arrival rate during one slot, where Δ is the duration of one LTE frame. The sensors send a 100-bit message. Thus, for transmission of any message, one resource block NB-IoT [25,26] is required.

Consider the scenario shown in Figure 2.7. It is assumed that the sensor located in the service area, at a random time, generates data and, following a standard random access procedure, notifies the base station of the need for data transmission. The network planner receives the request and sends it to the waiting queue until the data channel is freed. At this time, before the direct data transfer, the device enters the standby mode. The entered queue provides the ability to control the maximum data transmission delays, because Sensors can be extremely sensitive to delays, especially when important information needs to be transmitted.

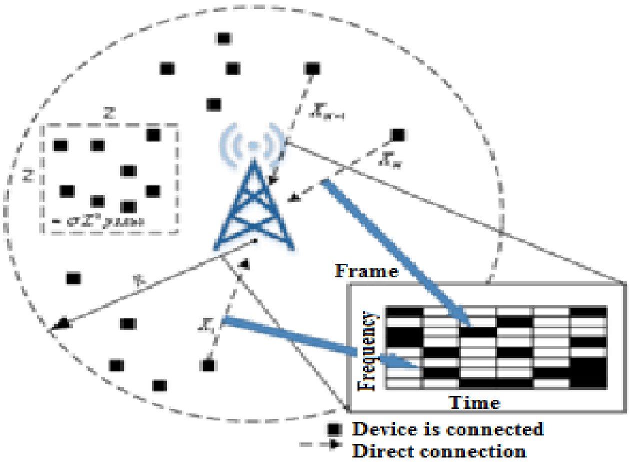

Figure 2.7 - Model of the NB-IoT system

It also allows you to monitor the energy consumption of the sensor, which is waiting all the time before the data transfer is in the listening mode of the channel.

If there are no locations in the buffer, the request to send the message is considered lost. As soon as there is an opportunity for data transmission, the base station allocates one NB-IoT channel to the sensor and it starts transmitting data at the installed transmit power. The required transmit power P (d) depends on the distance from the sensor to the base station and is determined by the formula γ P (d) = Ad, and where is a constant depending on frequency, and γ is the exponential decay.

Analytical model

The analysis of the system described in the previous section was carried out using a queuing system in discrete time. Taking into account that one sensor generates messages with intensity, λI and also the fact that the number of sensors in the service area is large enough, the total flow of messages from all sensors to the service area of the cell is Poisson with the intensity λ = Nλ I. Under NB-IoT, K = 6 × 12 = 72 virtual channels in one slot is allocated.

Thus, up to K messages are processed for each slot. As a result, a queuing system is simulated in discrete time with group incoming and outgoing messages. The service time of each application is constant [25].

Applications are submitted packs of no more than K pieces at the end of the slot. The state of the system is considered at the time immediately after the end of the service of the next pack. In this case, newly arrived applications can not instantly arrive at the service in the slot in which they came, but will be serviced only in the next, and if the system receives a bundle of i messages and there are already k messages in the system, that k + i> L, only Lk messages are received in the queue, and the remaining ones are lost.

Let A denote the number of messages received during a single slot. Then the probability that exactly k messages will arrive is determined by the formula [4, 5]:

$$A_k=\frac{(\lambda\Delta)^k}{k!}e^{-\lambda\Delta} \tag{2.2}$$

where k=0,1…

For the described system, the probability distribution of the loss i of messages is analyzed, the average value of the message delay time in the system. Consider the case of loss of exactly i, i = 1,2, ... messages in the n-th slot.

This happens when there are exactly k, k = 0,1, ..., L messages in the (n-1) th slot at the same time and the number of incoming messages to the n-th slot is L-k + i. Then the probability of loss of messages will be:

$$p_L=\frac{\sum_{k=0}^{B}\sum_{i=1}^{\infty}x_{D,k}A_{L-k+i}\frac{i}{L-k+i}}{1-e^{-\lambda\Delta}} \tag{2.3}$$

Numerical analysis

The probability of packet loss for cells with a radius of 10 and 30 kilometers is shown in Figure 2.8. Note that NB-IoT can provide reliable data transmission for 100 connected sensors per square kilometer, each of which generates approximately λI = 1 messages per minute. Both for the specified values and for a smaller number of connected IOT devices, reliable communication can be provided.

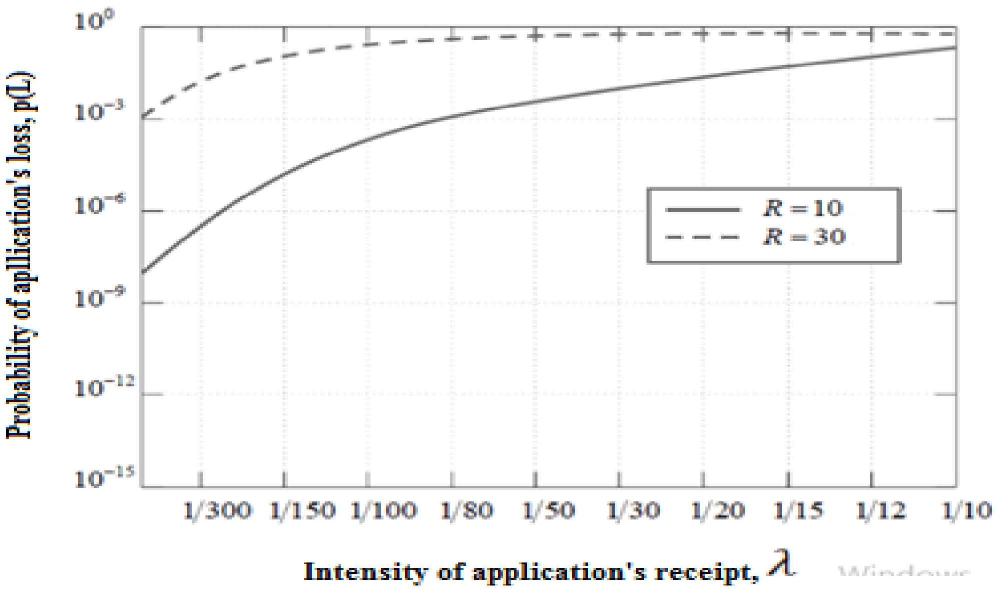

Figure 2.8 - Probabilistic characteristics of message service in NB-IoT

2.2 LoRa technology

In early 2015 Semtech Corporation and IBM Research Research Center presented a new open energy efficient network protocol LoRaWAN (Long Range

Wide Area Networks), providing significant advantages over Wi-Fi and cellular networks due to the possibility of deploying inter-machine (M2M) communications, diluting the lull in the wireless market technologies.

LoRa technology was born under the auspices of the non-profit organization LoRa Alliance, founded by companies such as IBM, Semtech, Cisco, etc., to adopt and promote the LoRaWAN protocol as a single standard for global networks with low power consumption (LPWAN) Power Wide Area Network).

Actually, the abbreviation LoRa combines the method LoRa modulation in wireless networks LPWAN, developed by Semtech, and the open protocol LoRaWAN.

LoRa Alliance developers position LoRa as a technology that has significant advantages over cellular networks and WiFi due to the possibility of deploying inter-machine (M2M) communications at distances of up to 20 km. and speeds of up to 50 Kbps, with minimal power consumption, which provides several years of battery life on a single AA battery.

The range of applications of this technology is huge: from home automation and Internet of things (Internet of Things, IoT) to industry and smart cities.

LoRaWAN architecture networks

Consider the architecture of LoRaWAN networks. A typical LoRaWAN network consists of the following elements: end nodes, gateways, a network server, and an application server.

The end node (End Node) is intended for performing control or measurement functions. It contains a set of necessary sensors and control elements.

Gateway LoRa (Gateway / Concentrator) - a device that receives data from end devices using a radio channel and transmits them to the transit network. Such a network can be Ethernet, WiFi, cellular networks and any other telecommunication channels. The gateway and end devices form a network topology of the star type. Typically, this device contains multi-channel transceivers for processing signals in several channels simultaneously or even several signals in one channel. Accordingly, several such devices provide a network coverage area and transparent bi-directional data transfer between the end nodes and the server.

A network server is intended for network management: scheduling, speed adaptation, storage and processing of received data.

Application Server (Application Server) can remotely monitor the operation of end nodes and collect the necessary data from them.

Ultimately, the LoRaWAN network has a star topology from the stars, has end nodes that communicate with the central server of the network through gateways that form transparent bridges. With this approach, it is usually assumed that the gateway and the central server are owned by the network operator, and the end nodes are the subscribers. Subscribers have the possibility of transparent bi-directional and secure data transmission to the end nodes [18].

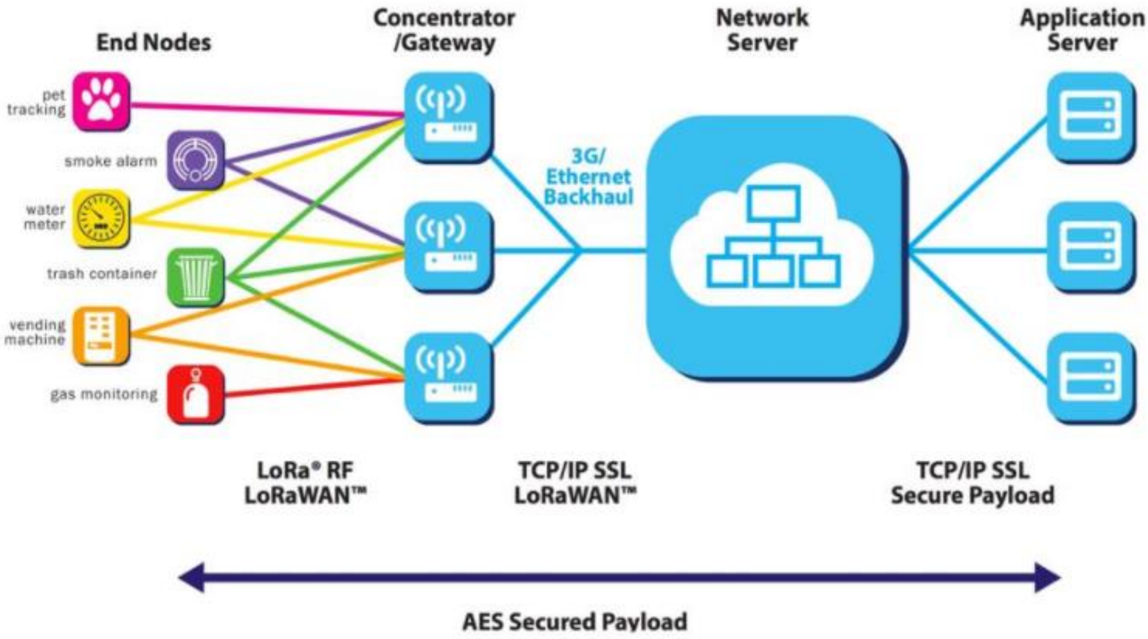

Figure 2.9 - LoRaWAN network architecture

Because LoRaWAN form a global network, the developers paid special attention to the security and confidentiality of the transmitted data, which are provided by AES encryption on several levels:

- At the network level using a unique network key (Unique Network key, EUI64).

- End-to-end security at the application level with a unique application key (Unique Application key, EUI64).

- And a special device key (Device specific key, EUI128).

To solve various tasks and applications in the network LoRaWAN provides three classes of devices:

1. Bidirectional end devices are "Class A" (Bi-directional end-devices, Class A). Devices of this class are used when the minimum power consumption is necessary with the prevalence of data transfer to the server. As the originator of the communication session, the end node acts by sending a packet with the necessary data, and then allocates two windows, during which it waits for data from the server. Thus, the transfer of data from the server is possible only after the end device communicates.

2. Bi-directional end-devices, Class B bidirectional devices. The main difference from the "Class A" devices is the allocation of an additional receiving window, which the device opens on a schedule. To create a schedule, the target device synchronizes with a special signal from the gateway. Due to this additional window, the server is able to start data transfer at a pre-determined time.

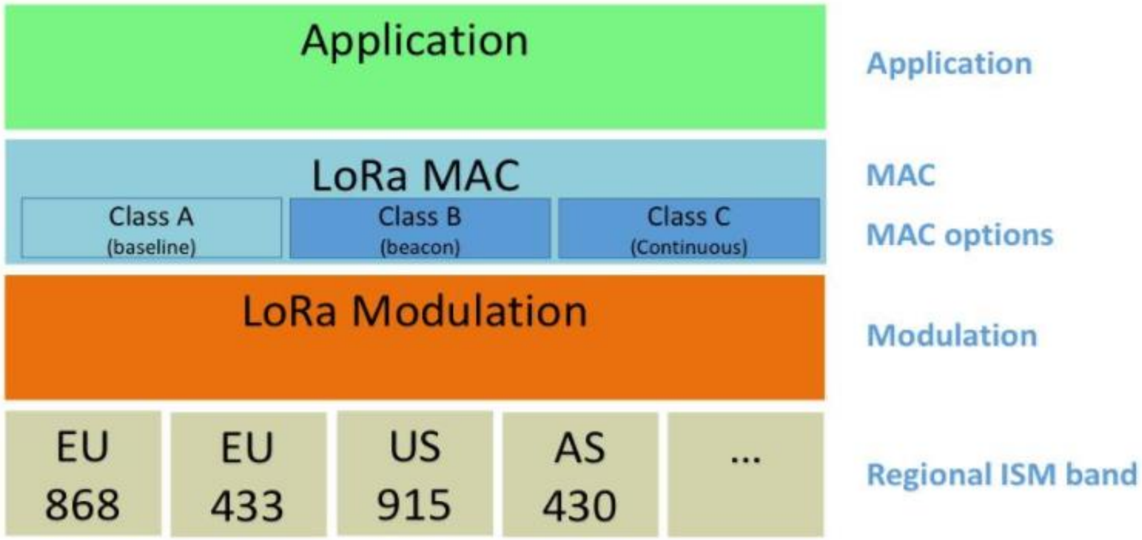

Figure 2.10 - Classes of devices in LoRaWAN networks

2. Bi-directional end-devices, Class B bidirectional devices. The main difference from the "Class A" devices is the allocation of an additional receiving window, which the device opens on a schedule. To create a schedule, the target device synchronizes with a special signal from the gateway. Due to this additional window, the server is able to start data transfer at a pre-determined time.

3. Bidirectional endpoints of "class C" with a maximum receiving window (Bi-directional end-devices, Class C). Devices of this class have an almost continuous window for receiving data and closes it only for the time of data transfer, which allows them to be used to solve problems requiring a large amount of data.

In total, LoRaWAN allows you to build global distributed wireless networks with a large number of end nodes. According to Semtech, one LoRa-gateway allows up to five thousand end devices to be serviced, which is achieved by:

- Network topologies;
- Adaptive data transfer rate and adaptive power output of devices specified by the network server;
- Temporal sharing of access to the environment;
- Frequency division of channels.

A feature of LoRa-modulation, allowing in one frequency channel to simultaneously demodulate signals transmitted at different speeds.

The central server of the LoRaWAN network, which addresses the nodes to the nodes (end-node) of the network, through gateways, resolves the problem of possible collisions while simultaneously transmitting data by several points, allocating time slots for transmission and reception individually for each end-node. Addressing occurs on 32-bit DevAddr, unique for each node (end-node) [20,21].

The central LoRaWAN server of the network decides on the need to change the data rate of the end-node data, the transmitter power, the transmission channel selection, its start and the time duration, controls the end-node battery charge, i.e. fully monitors the entire network and manages each subscriber unit separately.

Each LoRaWAN data packet sent by the end node (end-node) has a unique AppEUI application identifier belonging to the application on the server of the service provider for which it is intended and this ID is used by the central LoRaWAN server of the network for further routing of the packet and its processing application on the server (App Server) of the service provider.

In practice, as a rule, the services of the service provider are provided by the end-node manufacturer, which supports a data processing service where packets from the LoRaWAN network server are routed to work with these data to end users.

As a special case, the application server, the network server and the only network gateway (as a single-channel LoRa transceiver) can be combined to build a simplified network model in the laboratory. The kernel software of the network server is not freely distributed, but can be obtained after the conclusion of an agreement with the Lora Alliance, in the public domain there is a demonstration documentation.

Speed in LoRaWAN networks

LoRaWAN protocol regulates the speed of the radio traffic from 300 bps to 50 kilobits per second, the speed falls with the increase in the distance between the receiver and the transmitter. In fact, in existing devices, the speed can not exceed 11 kilobits per second, which is quite enough for the tasks solved by this technology.

For Europe (and Russia, including) one GFSK channel is available (from Gaussian Frequency-Shift Keying - modulation in the form of frequency manipulation, in which the Gaussian filter is used for smoothing) of information transmission with a data stream of up to 50 kbit / s. In North America, due to restrictions imposed by the FCC (Federal Communications Commission - US Federal Communications Commission), the minimum data rate is 0.9 kbit / s.

To extend the end-node battery life and optimize the overall network bandwidth, the LoRaWAN network server controls the data rate and RF output power of each end-node separately based on the distance from the gateway. Control is carried out using the adaptive data rate algorithm ADR (from the English Adaptive Data Rate). This is critical for high network performance and allows you to implement its necessary scalability [22].

The LoRaWAN protocol defines a specific set of data rates, but the terminal chip or the so-called physical layer (PHY, OSI media layer 1), that is, the integrated circuit itself, designed to perform the functions of the physical layer of the OSI network model, can give more options. For example, Semtech SX1272 supports data transfer rates from 0.3 to 37.5 kbit / s, and SX1276 from 0.018 to 37.5 kbps.

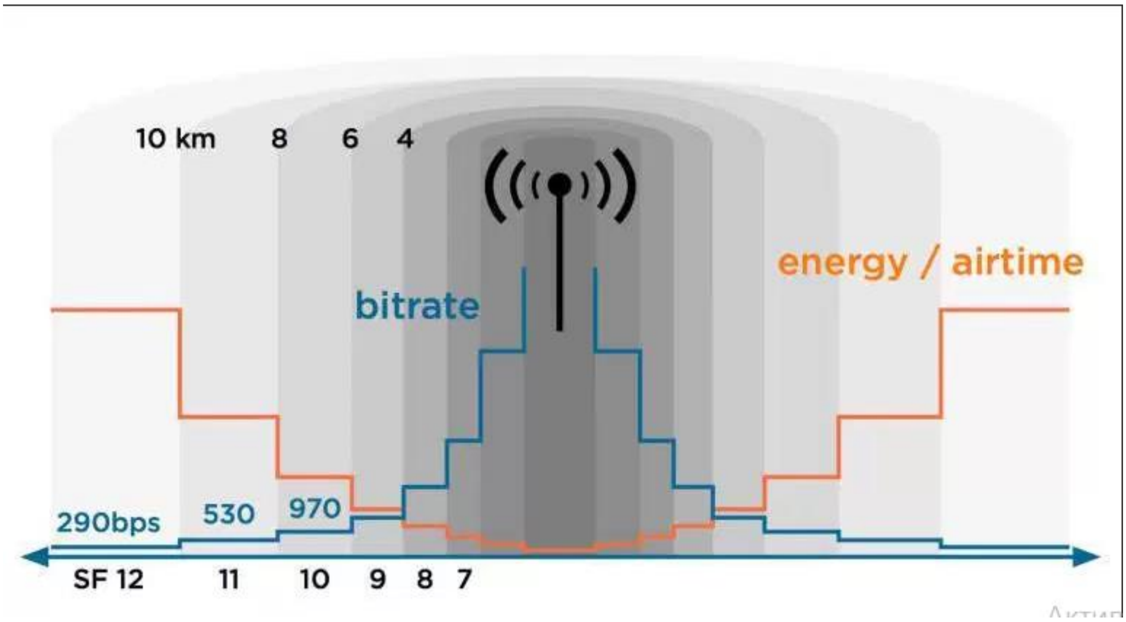

Figure 2.11 – Speed in LoRaWAN networks

Adaptive Data Rate ADR (Adaptive Data Rate) is a method in which the actual data rate is regulated in such a way as to ensure reliable delivery of packets, to ensure optimal network performance and the necessary scale for downloading it. So, for example, nodes (end-node) closer to the gateway will use a higher data rate (and, therefore, shorter time of active transmission over the radio channel) and lower output power. Only the most remote points (end-node) will use the low data rate and high transmitter output power. ADR's adaptive data rate technology can make the necessary changes to the network infrastructure and thus compensate for various losses on the signal transmission path.

LoRaWAN network can be deployed with minimal investment in infrastructure and with the capacity that is specifically needed for this application. If many gateways are deployed, then ADR technology will shift the data rate upwards, which will scale the network capacity in the range of 6 to 8 times.

Security in LoRaWAN networks

To protect against unauthorized access and distortion or interception of data transmitted by end-nodes, in LoRaWAN networks the standard provides for mandatory two-level data encryption with two different AES-128 keys according to RFC-4493 [21].

Complete data confidentiality is ensured when all the devices involved in the chain are passed, therefore the contents of the package are available only to the sender (end point) and the recipient for which it is intended, i.e. service provider application. The network server operates on the data in encrypted form, authenticates and checks the integrity of each packet, but does not have access to the payload (ie, payload). to the information from the sensors connected to the node [22].

Perspective areas of introducing Lora devices

- Power engineering. Building automated smart power grids to increase energy efficiency in buildings and manufacturing plants, as well as the stability of electricity supply. It is expected that wireless sensors and actuators will soon be integrated into all types of devices that consume energy (lamps, switches, televisions, etc.) and will be able to interact with energy suppliers to organize an optimal energy balance;
- Smart city. The once popular concept of "smart home" was replaced by the idea of "smart city", when all the devices of the city are interconnected. Wireless modules monitor mechanical, electrical and electronic systems used in modern buildings, as well as access control, while they absolutely do not depend on either the power supply system or communications. Monitoring systems for parking spaces, providing information to drivers about available seats;
- Health protection. Special stand-alone multifunction sensors can be used for remote health monitoring and warning systems for emergency changes in the state of the human body, as well as in fitness products measuring steps, weight, blood pressure, etc .;
- Transport. To carry out various functions of communication in transport systems, construction of traffic control systems, smart parking lots, logistics systems, as well as control of safety and assistance on the roads;
- Housing and communal services. The use of intelligent wireless meters helps to easily organize the automated accounting of energy (water, heat, gas, electricity) in apartments, cottages and office buildings, and also monitor the status of the equipment in real time and react to them promptly in case of emergencies.
- Agriculture. Animal lovers can study the migration of fauna, and pet owners - to track the location of their pets;
- Business. Vending machines can send an automatic signal to distributors when the goods are sold or the equipment needs repair;

2.3 LTE Cat.0

The LTE Cat.0 - Cat.1 and LTE Cat.M standards represent the evolution of LTE technology, adapted for IoT / M2M devices. These standards are implemented as wireless modules that support LTE networks [21].

The LTE.Cat.1 module, released by Gemalto, is fully standardized, is available for use, and is the first step in connecting IoT / M2M devices to an existing LTE network.

Currently among the above standards, the most interesting is the standard LTE Cat.0, or the so-called zero standard.

The LTE.Cat.0 standard, which meets the basic requirements for radio access systems, is characterized by low power consumption.

Characteristics of the standard LTE Cat.0:

- the throughput of the uplink and downlink is now reduced to 1 Mbit / s;

- the UE can now have 1 antenna instead of 2;
- the bandwidth of the UE is reduced to 1.4 MHz;
- the UE will continue to operate in all existing LTE bands up to 20 MHz.

More than 10 years battery lifetime with 2 AA batteries can be achieved for delay-tolerant traffic if the TAU cycle is 10 minutes.

Let’s compare the LTE Cat-1 and Cat-0 to find out what are the biggest changes.

Table 2.2 - Comparison of Lte Cat 0 and Cat 1

Feature	Cat 1	Cat 0 REL. 12
UE RF Bandwidth	20 MHz	20 MHz
DL Peak Rate	10 Mbps	1 Mbps
Max. no. of Downlink layers	1	1
UE Peak Rate	5 Mbps	1 Mbps
No. of RF Rx chains	2	1
Max. UE Tx power	23 dBm	23 dbM
Duplex Mode	Full	Half and full duplex

As we can see a 3GPP Release 12 UE now shows the DL and UL Category separately. Also from the same message you can see if UE is using Half Duplex or not.

The main companies working in cellular IoT are Ericsson, Nokia, Huawei, Sierra Wireless, Telit and U-Box. But along with these there are some new players like France Sequans and Israel Altair Semiconductor.

These companies think that the LTE M2M business is going to boom and also see the 450 MHz band-31 as the global LTE Cat-0 M2M band.

3 Modelling of M2M traffic

3.1 Features of modeling different types of M2M traffic

With further growth, the traffic of inter-machine interaction will have a big impact on the quality of service in wireless networks. An analysis of this issue is an urgent task posed by many researchers [1,2,3,4]. An effective method for investigating such problems is simulation modeling. In the simulation model, we need to simulate incoming M2M traffic, so consider the features of modeling different types of M2M traffic.

When modeling traffic, it is necessary to describe its characteristics, define parameters. The main parameters are:

a) the intervals between the arrival of packets to the service node;

b) the number of packets arriving per unit time;

c) the number of bytes arriving per node per unit of time.

In works [1,2,3] in M2M networks, three main types of traffic are conventionally distinguished: indirect, pseudo-deterministic and service.

The indirect traffic is generated by active control system devices. If the measured value hits a certain interval (for example, an emergency situation), the device is triggered. In this case, the properties of traffic depend on the properties of the controlled quantity. In this case, to ensure reliability, the technical condition of the devices is monitored and the transfer of service information, the volume of which may exceed the amount of useful information, is carried out.

Pseudo-deterministic traffic is generated by automatic systems with passive sensors. In this case, the host that collects data is the master or central node that requests data from passive sensors. In this case, the properties of the traffic depend on the interval between the transmission of data requests. Intervals can be deterministic or can be selected by a certain algorithm.

Service traffic is generated by active sensors when certain external influences occur, leading to the need to perform operations to preserve the operability of the technical system of the system.

The presented types of traffic can be modeled in the simulation environment of GPSS World (General Purpose System Simulator). This system is intended for writing simulation models of systems with discrete events. It is most convenient in GPSS World to develop models of queuing systems, which are characterized by relatively simple rules for the functioning of their constituent elements [17].

Let's consider features of modeling of the mediated traffic. So, the mediated traffic is generated in systems with active devices under the influence of the external environment. Such active devices include alarm systems (fire, housing and utilities and others), human environment threats (seismic, environmental, pollution), devices for monitoring dangerous human conditions (blood pressure control, glucose level and so on) . It should be borne in mind that here the traffic volume can dramatically increase with the onset of some events (for example, seismic, weather).

In the development of mediated traffic, the following conditions must be met [17].

Traffic generates n devices, each of which can be in a passive or active state. In the passive state, the device generates technological traffic with a specified deterministic period t.

When the device goes into an active state, it is in it for a while, producing a random amount of traffic. The traffic volume is also random, has a uniform distribution.

In the active state, the device goes over at some event (emergency), which occurs at random independent instants of time. In modeling, we can assume that the time intervals between events are distributed according to an exponential law.

In GPSS World, an event can be generated by the GENERATE block (Exponential (1,0, M)). Here M is the average value of the time interval.

When modeling pseudo-deterministic traffic, one should keep in mind the following. Traffic of this kind is generated in monitoring and dispatching systems.

Suppose the system has n servers, each of which collects data from k sensors installed on the monitored objects. Traffic between each server and a separate device is a deterministic server request data stream and sensor responses. In such systems, the sensors transmit data at the request of the main device (node). The traffic properties depend on the method of selecting the time interval between the polling times of these sensors. Moments of interviews are often not random, they either occur at regular intervals, or according to a certain schedule.

In the case of deterministic intervals between the receipt of responses from all sensors, the total traffic will also be deterministic. If the intervals between the receipt of responses are random, then the total traffic will also be random.

The third type of traffic, service, is created by active sensors that control the operation of the technical system. In the event of a hardware or software failure, the sensor sends the same amount of data packets. Moments of the onset of events are random.

3.2 Modelling of M2M traffic servicing as a QS of the type M/M/1/∞

We will analyze the process of servicing M2M traffic. Let's assume that messages are coming to the cell in the LTE network from all devices that are in the zone of one base station. Then the traffic comes from all three types on the cell, forming aggregated traffic.

In [18], devoted to the task of servicing M2M traffic in the networks of subsequent generations of 4G and 5G, in the construction of a model of a cell with traffic of inter-machine interaction, it is allowed that the traffic will be Poisson, that is, the intervals between packets will be distributed according to an exponential law.

Assume that the intervals between the incoming packets are distributed according to an exponential law, then the incoming packet stream is the simplest one and is described by the Poisson distribution [18].

The simplest is a stationary, ordinary flow without aftereffect.

The simplest flow is given by the family of probabilities $P_i(t)$ of arrival of i calls in the interval t.

The probability $P_i(t)$ is calculated by the formula:

$$P_i(t) = \frac{(\lambda t)^i}{i!} e^{-\lambda t} \tag{3.1}$$

where λ is the flux parameter, a constant value, since the flow is stationary;

λ = μ, since the flow is ordinary, μ is the intensity of the incoming flow, therefore λ is called the intensity of the simplest flow.

The formula (3.1) is called the Poisson formula or the Poisson distribution.

We will develop a model of a service node in the form of a queuing system M / M / 1 / ∞, in which the intervals between the arrival of packages and the service time are distributed according to an exponential law (see Figure 3.1).

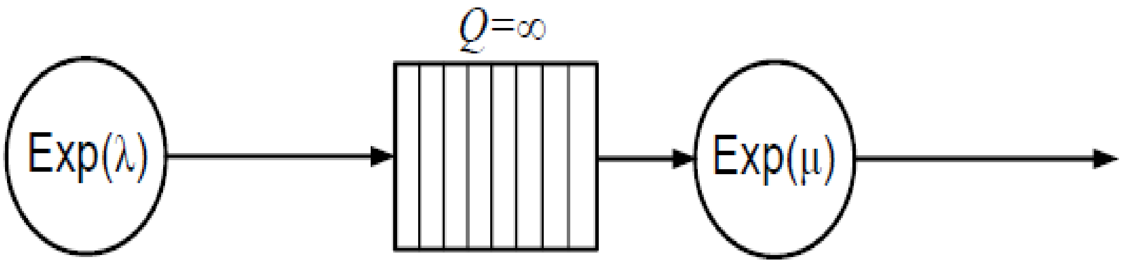

Figure 3.1 - Simulation model M / M / 1 traffic services with exponential distribution.

The following parameters are accepted for modeling:

- the intensity of the incoming stream $\lambda = 1 / T$, where T is the interval between packets receipts, the average value of the interval is T = 4.33;
- service flow intensity $\mu = 1 / T_{ser}$, where T_{ser} is the average service time of one packet, $T_{ser} = 1$;

The model is developed in the GPSS World simulation system, presented in Appendix A.

The results of the simulation are shown in Figure 3.2

GPSS World Simulation Report - 26.5.1
Wednesday, May 30, 2018 10:15:01

START TIME   END TIME   BLOCKS   FACILITIES
STORAGES
0.000   4324086.290   13   1   0

FACILITY   ENTRIES   UTIL.   AVE. TIME AVAIL. OWNER PEND
INTER RETRY DELAY
M2M   1000000   0.231   0.998   1   0   0   0   0   0

QUEUE   MAX CONT. ENTRY ENTRY(0) AVE.CONT.
AVE.TIME AVE.(-0) RETRY LINE   10   0 1000000 768801   0.069
0.300   **1.297**   0

SAVEVALUE   RETRY   VALUE
1   0   **1.393**
TIME   0   **4324084.897**
DELTA   0   **7.413**

Figure 3.2 - Fragment of the modeling report M/M/1

In the report presented in Figure 3.2 in cell 1 the service time of the packet was saved, in the cell TIME the absolute model time is stored, in the cell DELTA - the value of the function that computes the intervals between the receipts of the packets.

Also from this report, you can get metrics that reflect the quality of incoming traffic, such as the maximum queue length-10, the average wait time in the queue - 1, 297. For 1 million packets, the node stay time was 4324084.897.

As a result of the simulation, a histogram was obtained reflecting the distribution of the intervals between the packets receipts (see Figure 3.3).

As can be seen from figure 3.3, the mathematical expectation of the values of the intervals between packets arrivals is 4.324, and the standard deviation is 4.321.

In this case, the maximum number of packets arrives in the interval 1-2, and then the units of packets arrive.

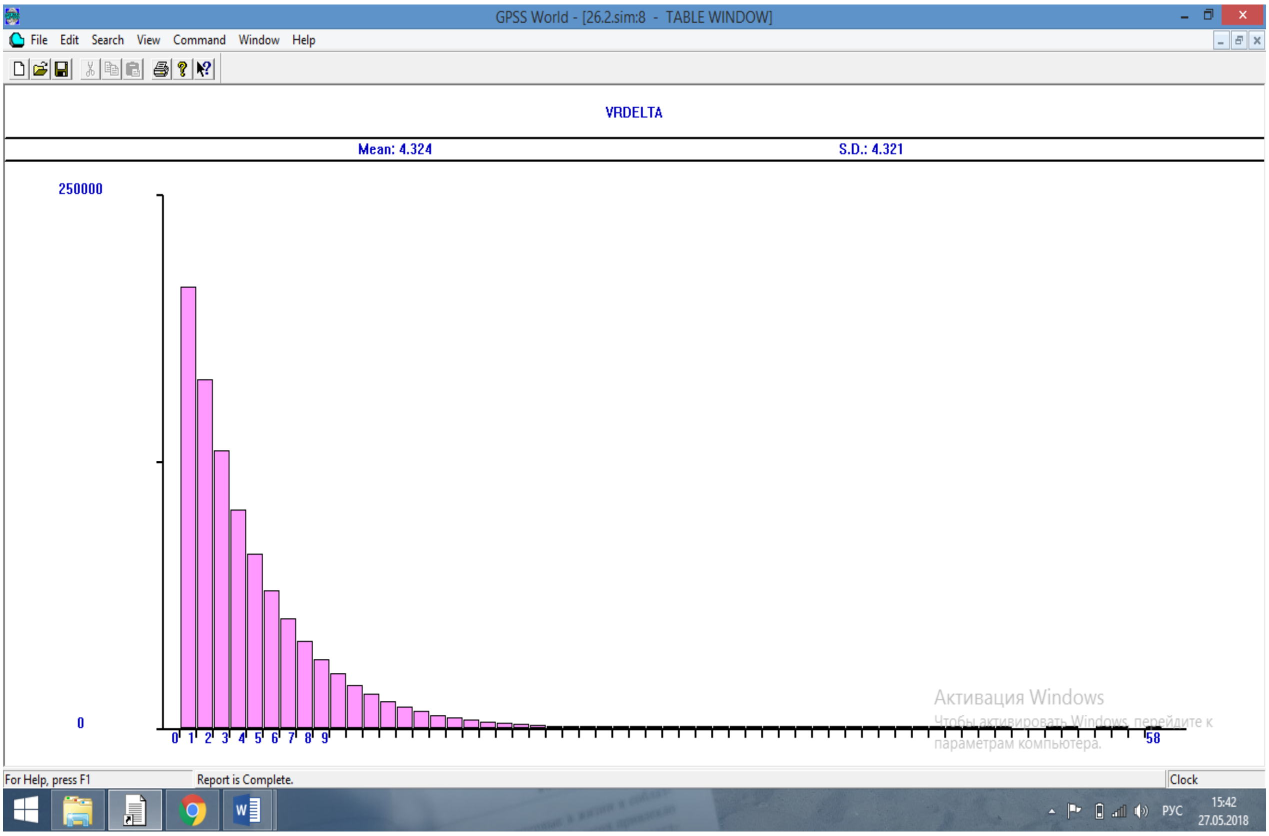

Figure 3.3 - Histogram of the distribution of the intervals between the receipts

Let's perform experiments on this model, changing such an input value as the average value of the interval between the arrival of packets in the service node. The results of the experiments are presented in the following tables and graphs.

Table 3.1 and Figure 3.4 show the dependence of the average waiting time of a packet in the queue on the intensity of packet arrival (the number of packets arriving per unit of time) λ. In the program, the value of the interval between the receipts of neighboring packets T, the packet arrival rate λ = 1 / T is set.

Table 3.1- Dependence of the average waiting time of the packet on the intensity of receipt

Intensity λ	0,12	0,13	0,15	0,18	0,23	0,3	0,43
Average waiting time of the packet in queue	0,137	0,159	0,180	0,232	0,300	0,435	0,77

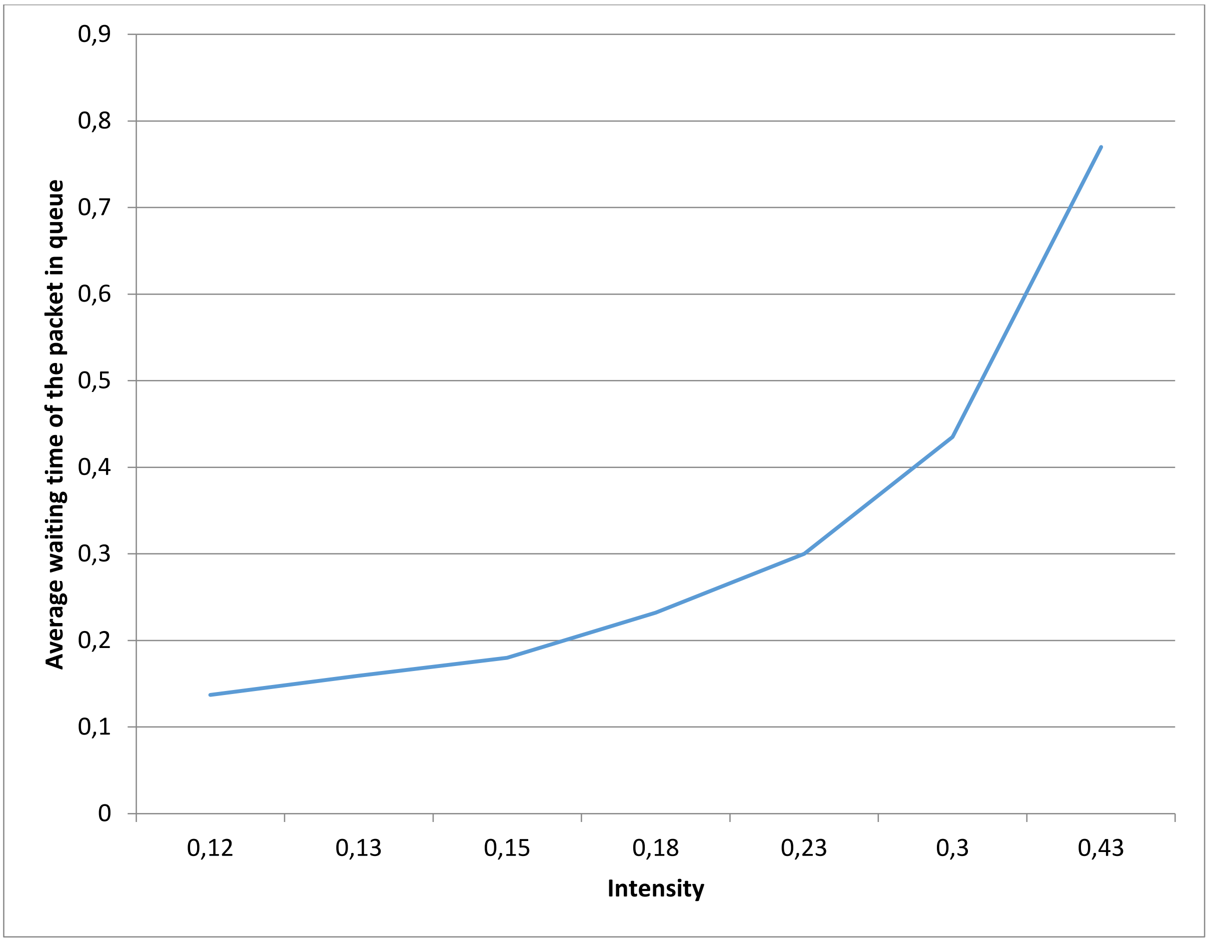

Figure 3.4 - Dependence of waiting time in the queue on the intensity of the flow λ

Table 3.2 and Figure 3.5 show the dependence of the queue length (the number of waiting packets) on the packet arrival rate (the number of packets arriving per unit of time) λ.

Table 3.2 - Dependence of the length of the queue on the intensity of the receipt of packets

Intensity λ	0,12	0,13	0,15	0,18	0,23	0,3	0,43
Average length of the queue	0,137	0,159	0,180	0,232	0,300	0,435	0,77

As can be seen from the graph in Figure 5, the queue length, as waiting time in the queue increases with increasing intensity of the incoming flow.

At λ> 0.3, the length of the queue begins to increase sharply.

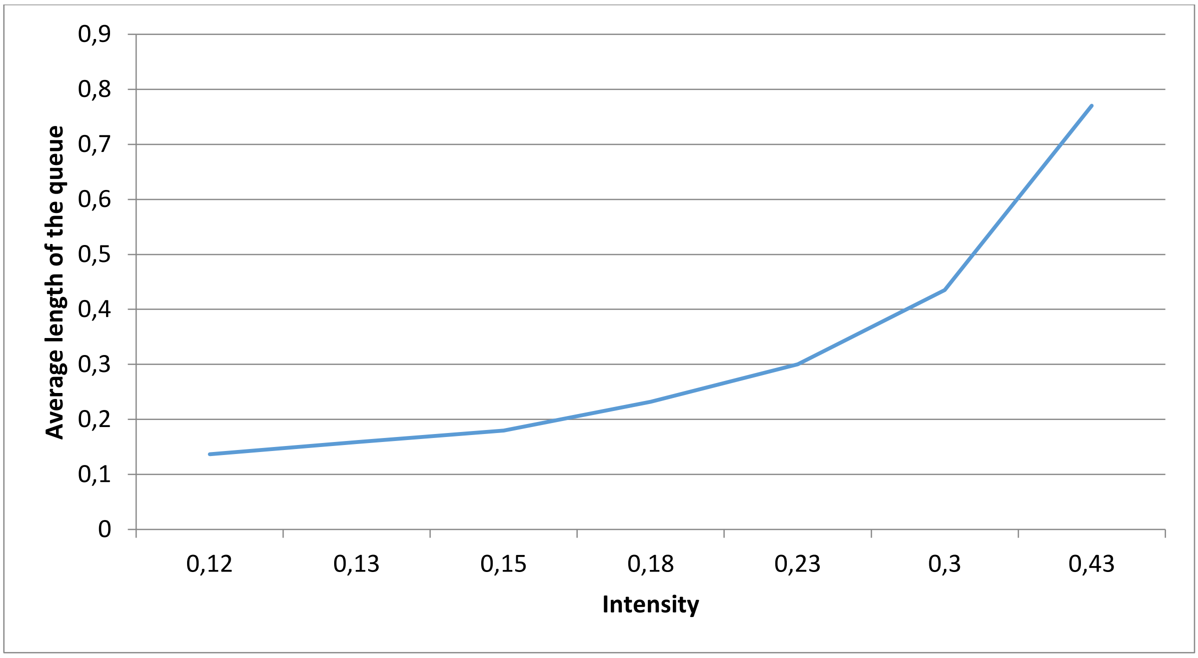

Figure 3.5 - Dependence of the average queue length on the intensity of the incoming flow λ

A histogram of the packet maintenance time was also obtained (see Figure 3.6).

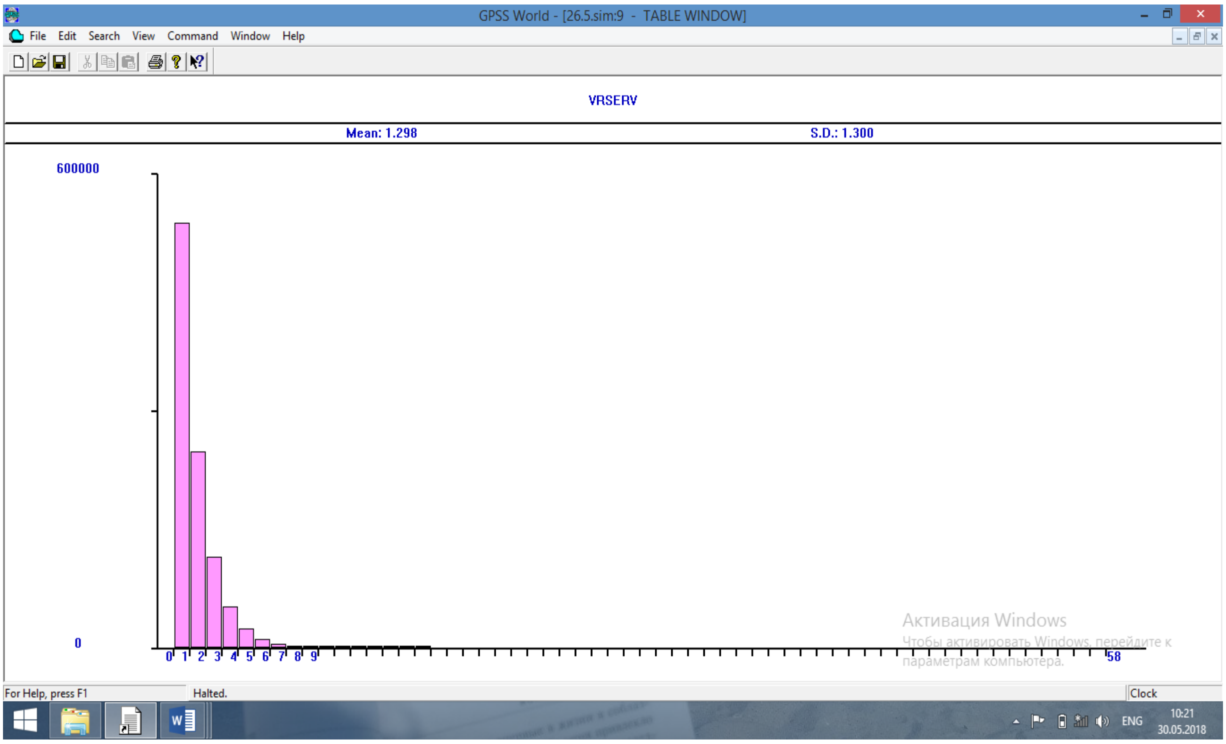

Figure 3.6 - Histogram of the time of packet maintenance

In the second experiment on this model, the input value changed as the average packet servicing time in the service node. The results of the experiments are presented in the following tables and graphs.

Table 3.3 and Figure 3.7 show the dependence of the average waiting time of a packet in the queue on the intensity of packet servicing (the number of packets serviced per unit of time) μ.

Table 3.3 - Dependence of the average waiting time of a packet in the queue on the intensity of service

Intensity μ	0,83	0,9	1	1,11	1,25	1,42	1,66
Average waiting time of a packet in the queue	0,460	0,324	0,300	0,382	0,507	0,693	1,033

In the program, the average time for servicing the package of packages T_{ser} is given, the packet maintenance rate is $\mu = 1 / T_{ser}$.

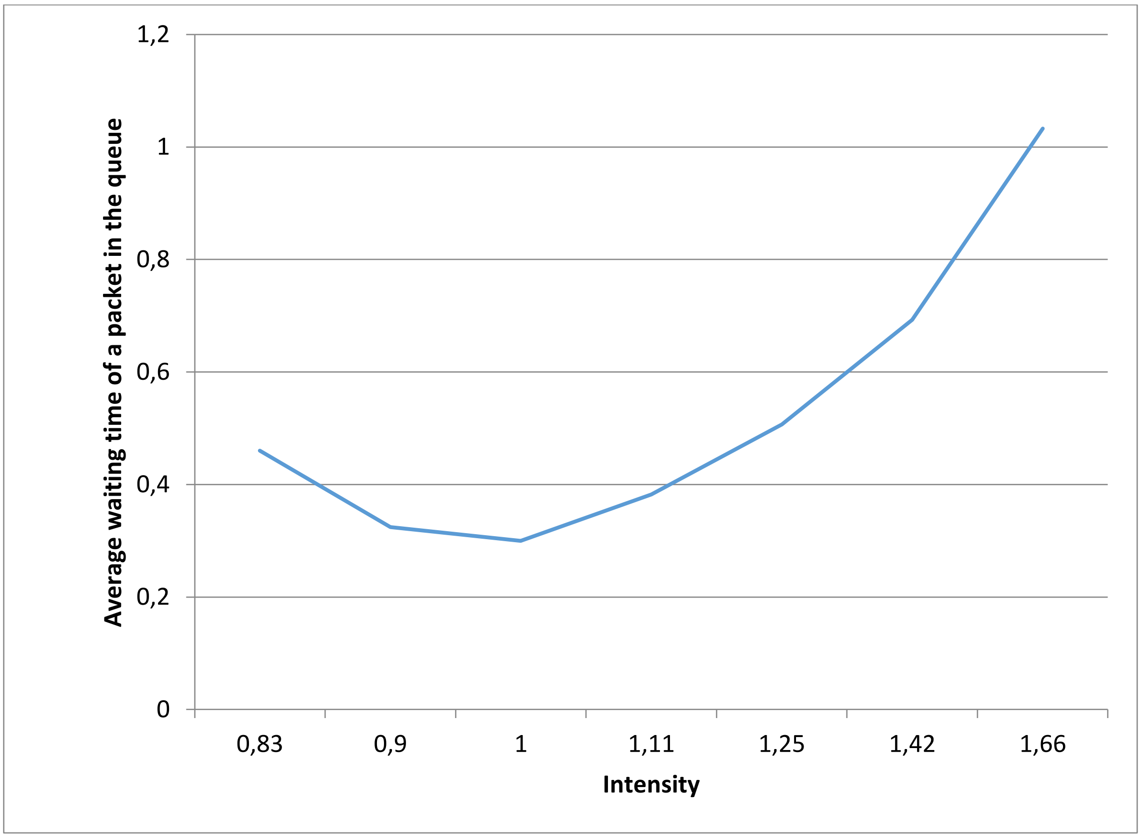

Figure 3.7 - Dependence of packet waiting time in the queue on the intensity of packet maintenance μ

Table 3.4 and Figure 3.8 show the dependence of the queue length (the number of packets waiting to wait) on the packet service intensity (the number of packets serviced per unit of time) μ.

Table 3.4 - Dependence of queue length on packet service intensity

Intensity μ	0,83	0,9	1	1,11	1,25	1,42	1,66
Average queue length	0,106	0,087	0,069	0,088	0,117	0,160	0,239

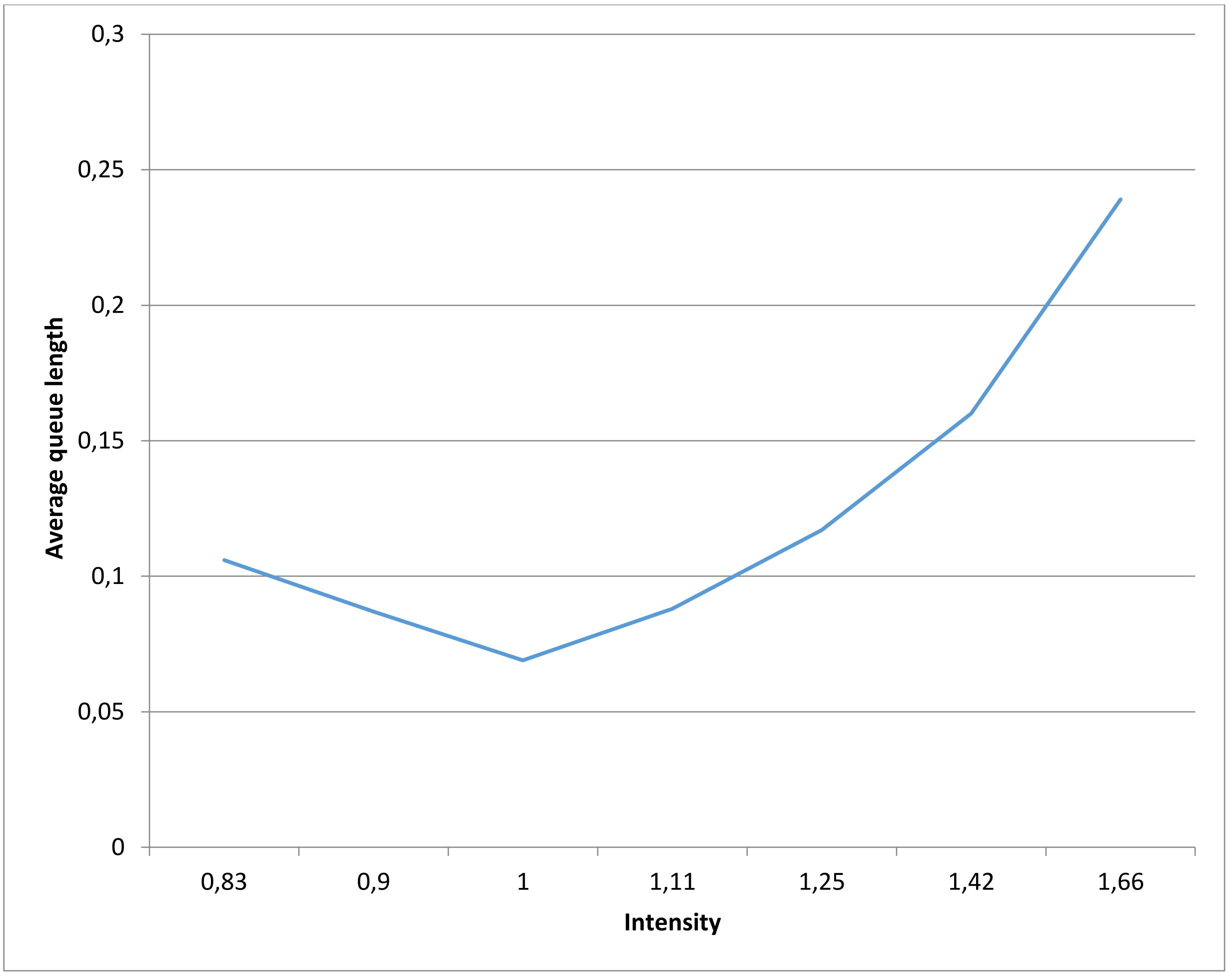

Figure 3.8 - Dependence of queue length on packet service intensity μ.

Table 3.5 and Figure 3.9 show the dependence of the delay time on the packet service intensity μ.

Table 3.5 - Dependence of the delay time on the packet service intensity μ.

Intensity μ	0,83	0,9	1	1,11	1,25	1,42	1,66
Delay time	1,671	1,532	1,393	1,546	1,741	1,970	2,312

Let $\rho = \lambda / \mu$, this quantity in the theory of queuing systems is called the system load. Let us construct the dependence of the quantity on the load ρ (see Figure 3.7).

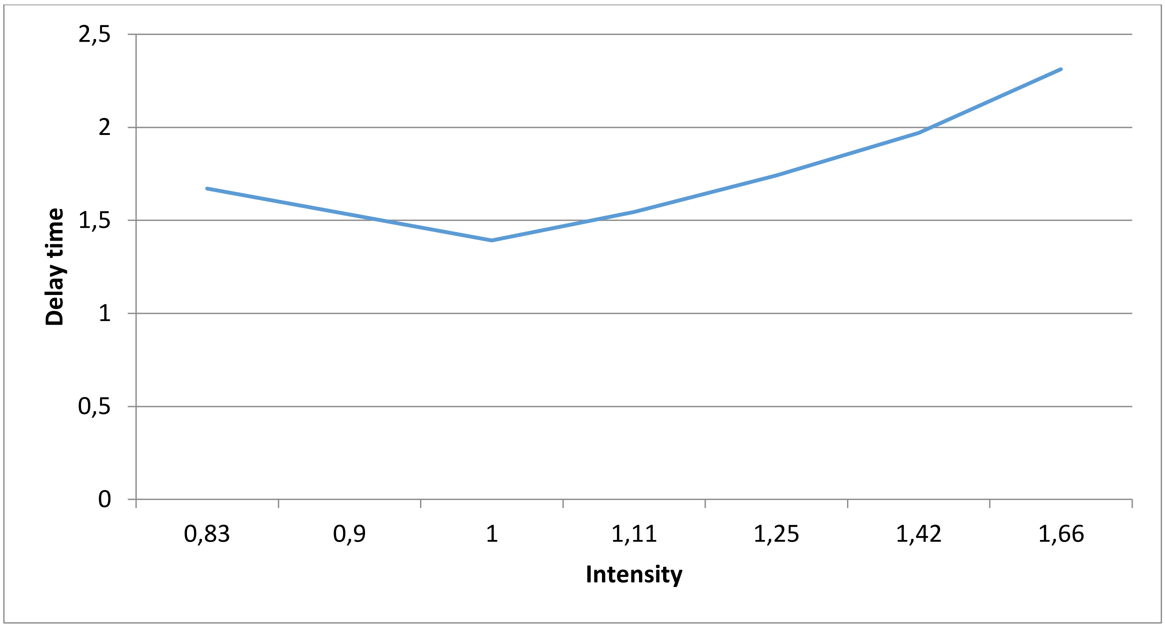

Figure 3.9 - Dependence of the delay time on the packet maintenance intensity μ

Table 3.6 - Dependence of the delay time on the load value ρ

Load ρ	0,1	0,2	0,3	0,4	0,5	0,6	0,7
Delay time	1,11	1,25	1,43	1,67	2	2,5	3,33

As can be seen from Figure 3.10, as the load increases, the delay time increases. As shown in Figure 3.4, as the intensity λ increases, the waiting time in the queue increases, which is the main part of the delay.

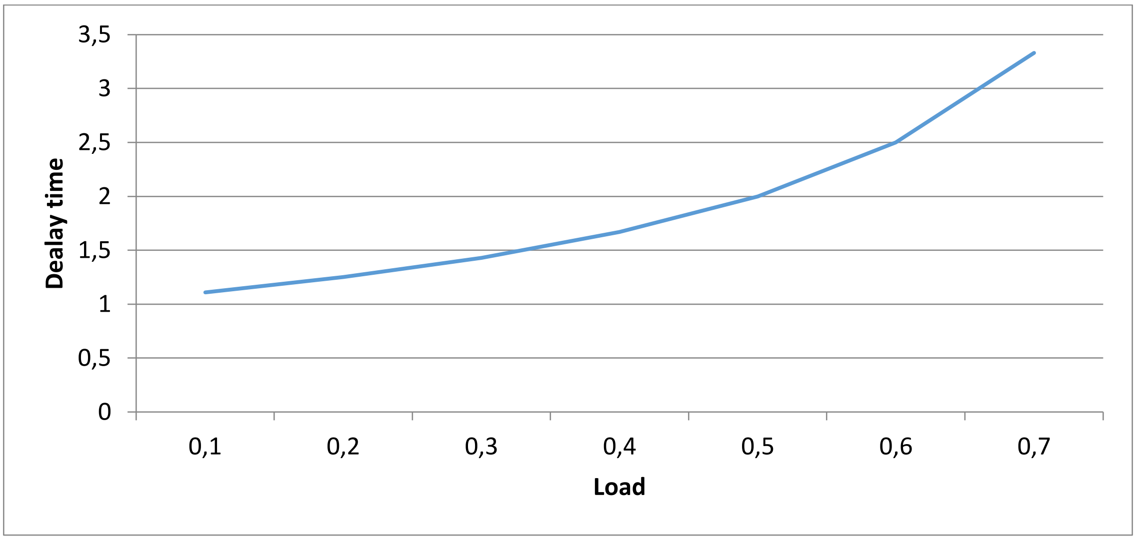

Figure 3.10 - Dependence of the delay time on the load value ρ of the QS

3.3 Modelling of M2M service traffic as QS of the type Pa/M/1/∞

In [19] three categories of M2M networks are considered: automatic meter reading (S1), vehicle fleet management system (S2) and a network of vending machines (S3). Each M2M subnet device S1 transmits packets periodically, it is characterized by low mobility, since in most cases such devices are stationary. In subnetwork S2, each device is monitored regularly, but overall the traffic is random, the mobility of devices is high. The S3 subnet devices are stationary and transmit packets periodically. In all cases, services have a small packet size.

The results of modeling the described network with three subnets S1, S2 and S3 in the OPNET environment are presented in [20]. In the simulation model, the law of distribution of time intervals between packets arrivals is arbitrary.

The simulation results show a self-similar structure of the aggregated traffic of each of the three subnets and the aggregated total traffic. The values of the Hurst parameter are given in Table 3.7.

Table 3.7 - Values of the Hurst parameter

Type of traffic	S1	S2	S3	Aggregated traffic
Hurst parameter	0,5027	0,6290	0,6039	0,7012

Consider a simplified model of M2M traffic in the GPSS World simulation system. Assume that the network device or server receives aggregated traffic from all M2M devices, the intervals between requests are random, distributed according to the Pareto law.

In [3,5,7] it was shown that self-similar traffic can be modeled by the Pareto distribution.

The function of the Pareto distribution law is:

$$F(t) = 1 - \left(\frac{k}{t}\right)^{\alpha}, \ k>0, t>0, \alpha>0, \tag{3.2}$$

where t is the time interval between the requests for the server;

k is the coefficient;

α is the Pareto distribution parameter.

It was also shown in [3,7] that when modeling a self-similar flow, one can take into account the value of the Hurst parameter. The relationship between the Hurst parameter H and the Pareto distribution parameter α has the form:

$$\alpha = 3 - 2H. \tag{3.3}$$

We will carry out experiments on the simulation model in the GPSS World environment. The time for servicing traffic will be subject to the exponential distribution law. Limitations on the length of the queue and the time spent in the queue will not be imposed. Then the model of the service node M2M traffic will be a queuing system of the form Ra / M / 1 / ∞ (see Figure 3.10). The input values are α, k and Tobs is the maintenance time [21,22].

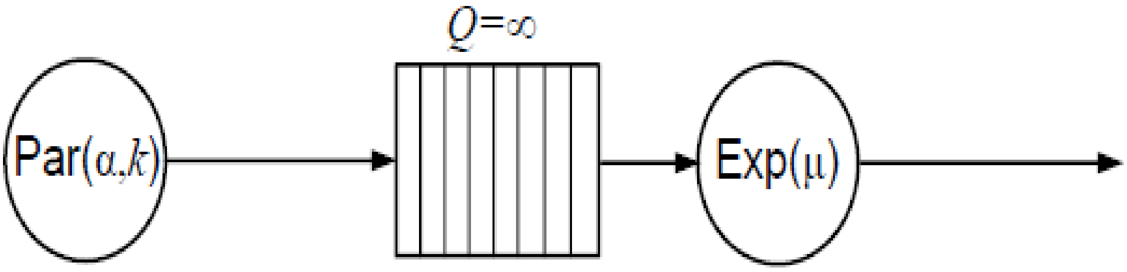

Figure 3.10 - Simulation model of Pa/M/1/∞

The model is listed in Appendix B. In the model, we take the Hurst parameter H = 0.7, then α = 1.6. Suppose that k = 1.

The results of the simulation are reflected in the report's fragment (see Figure 3.11). The average waiting time in the queue is 1.436, the average service time of one packet is 0.908, the maximum queue length is 11, the average latency at the node is 1.393.

GPSS World Simulation Report - Untitled Model 1.2.1
Monday, May 28, 2018 11:54:33

FACILITY ENTRIES UTIL. AVE. TIME AVAIL. OWNER PEND INTER RETRY DELAY
M2M 1000000 0.375 0.998 1 0 0 0 0 0
QUEUE MAX CONT. ENTRY ENTRY(0) AVE.CONT. AVE.TIME AVE.(-0) RETRY
LINE 11 0 1000000 697897 0.163 0.434 1.436 0
SAVEVALUE RETRY VALUE
1 0 1.393
TIME 0 2659588.416
DELTA 0 1.009

Figure 3.11 - Fragment of the simulation results report

As a result of the simulation, a histogram of the distribution of the intervals between the packet receipts, the packet service time histogram, and the waiting time of the packet in the queue are also obtained.

Figure 3.12 shows the histogram of the mathematical expectation of the intervals between receipts of neighboring packets to the service node.

As can be seen from figure 3.12, the mathematical expectation of the interval between the arrival of packets in a stream distributed according to the Pareto law T = 2.680, the standard deviation is 11.299.

In this case, the Pareto parameter α = 1.6. As noted above, the Pareto distribution for the intervals between the incoming packets is chosen for the reason that it well approximates the intervals between the arrival of the packets in a self-similar process.

In the GPSS World simulation system, traffic is generated using the GENERATE block and the library of standard functions [23,24].

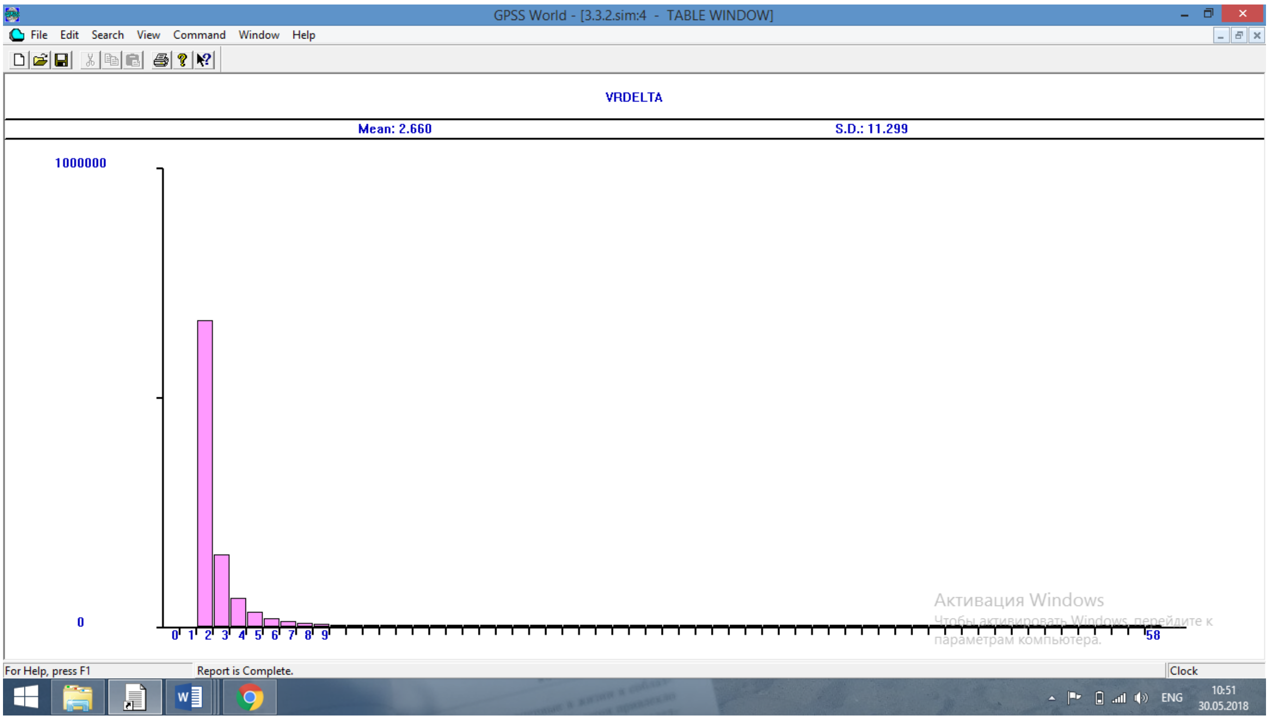

Figure 3.12 - Histogram of the distribution of intervals between packets received in the Pareto distribution

To determine the influence of the value of the Pareto distribution parameter α on waiting time in the queue, experiments were performed on the simulation model. The results of the simulation are presented in Table 3.8 and in Figure 3.13.

Table 3.8 - Simulation results

Parameter α	1,3	1,4	1,5	1,6	1,7	1,8	1,9
Waiting time in the queue	0,339	0,320	0,402	0,434	0,467	0,500	0,534

The graph in Figure 3.13 shows the increase in waiting time in the queue with the growth of the Pareto distribution parameter α.

As noted earlier, the Pareto parameter is interrelated with the Hurst parameter;

$$\alpha = 3 - 2H \tag{3.4}$$

Consequently,

$$H = \frac{3-\alpha}{2} \quad (3.5)$$

The Hurst parameter reflects the self-similarity properties of the process [25]. For H> 0.5, we can assume that the process has this property.

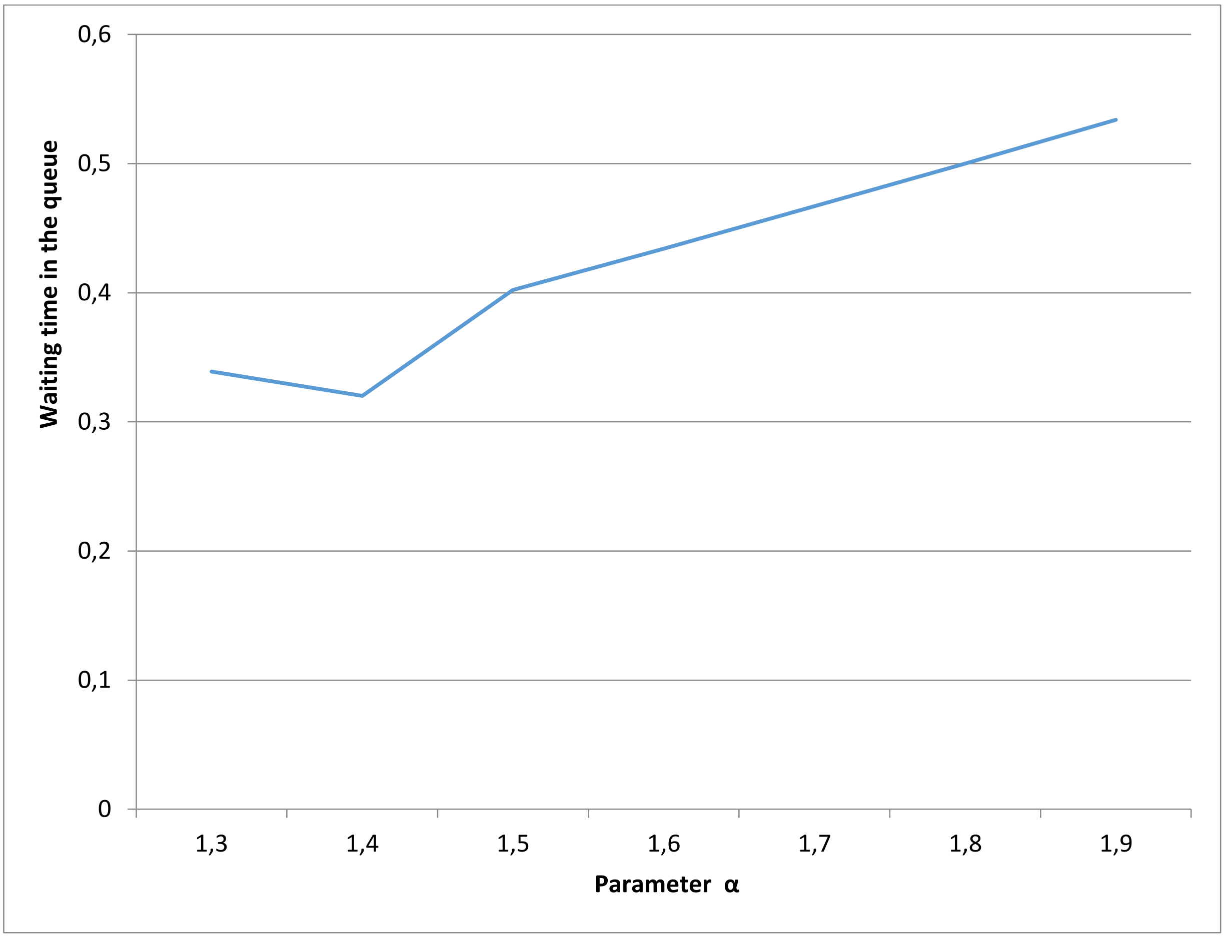

Figure 3.13 - Dependence of waiting time in the queue on the parameter α

Table 3.9 and Figure 3.14 show the dependence of the average queue length on the Pareto distribution parameter α. The dependence shown in Figure 3.14 is close to linear.

Table 3.9 - Dependence of the average queue length on the Pareto distribution parameter α

Parameter α	1,3	1,4	1,5	1,6	1,7	1,8	1,9
Average queue length	0,081	0,107	0,135	0,163	0,192	0,222	0,253

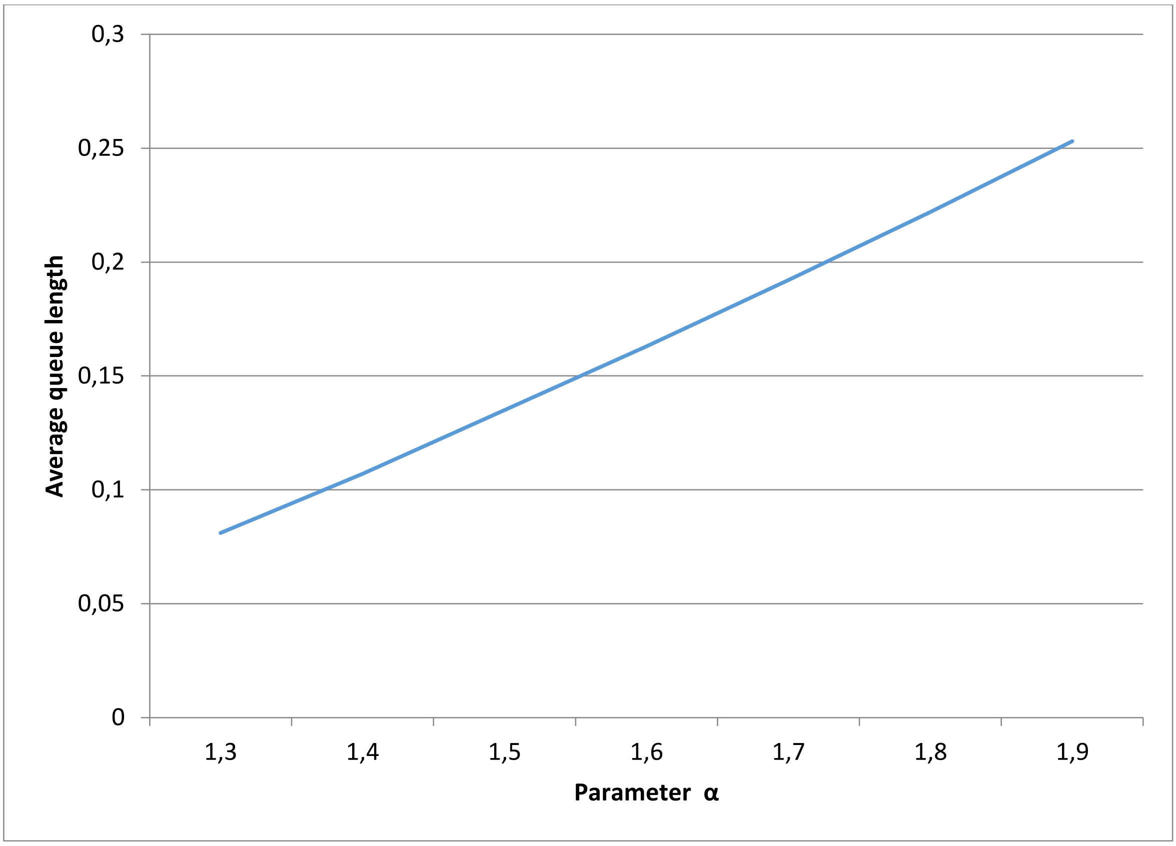

Figure 3.14 - Dependence of the average queue length on the parameter α

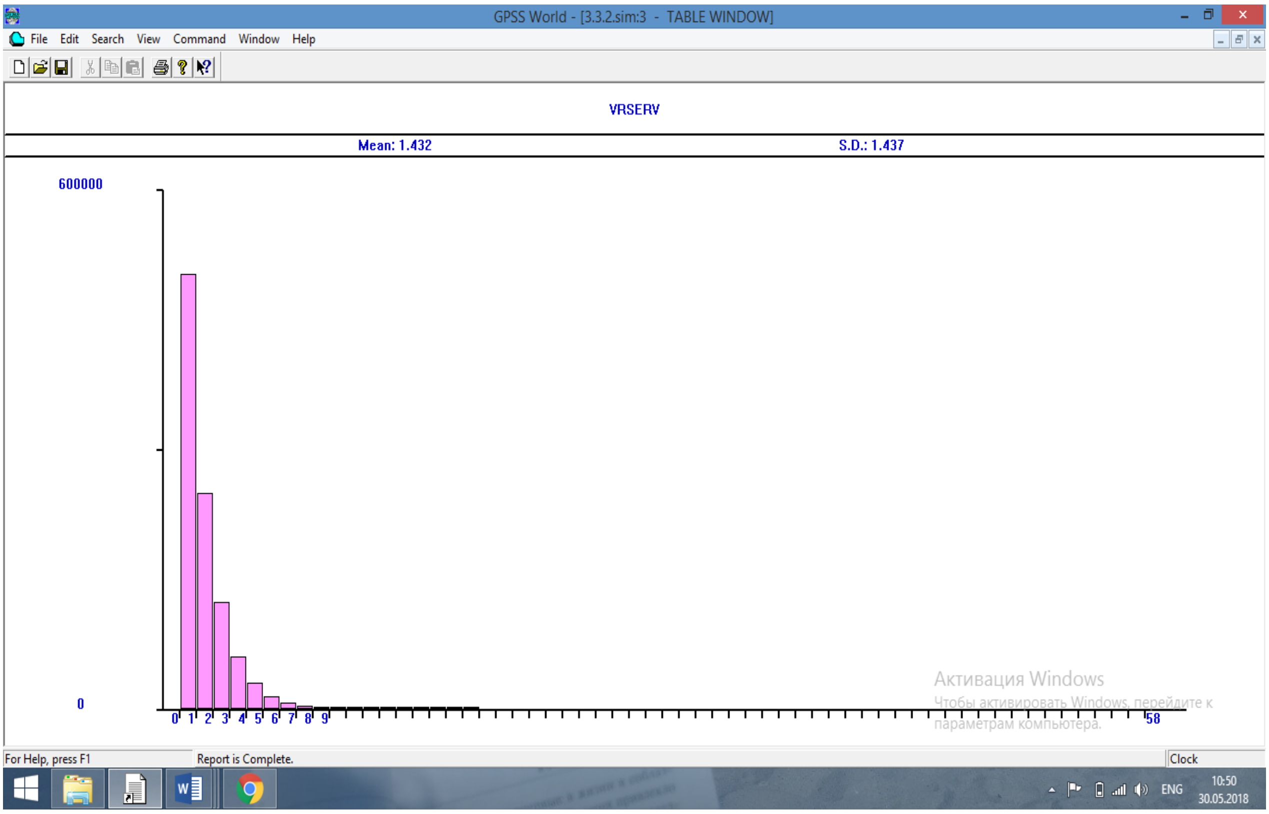

Figure 3.15 - Histogram of the packet service time

As can be seen from Figure 3.15, the mathematical expectation of the packet servicing time, when the stream is distributed according to the Pareto law T_{ser} = 1.432, the root-mean-square deviation is-1.437.

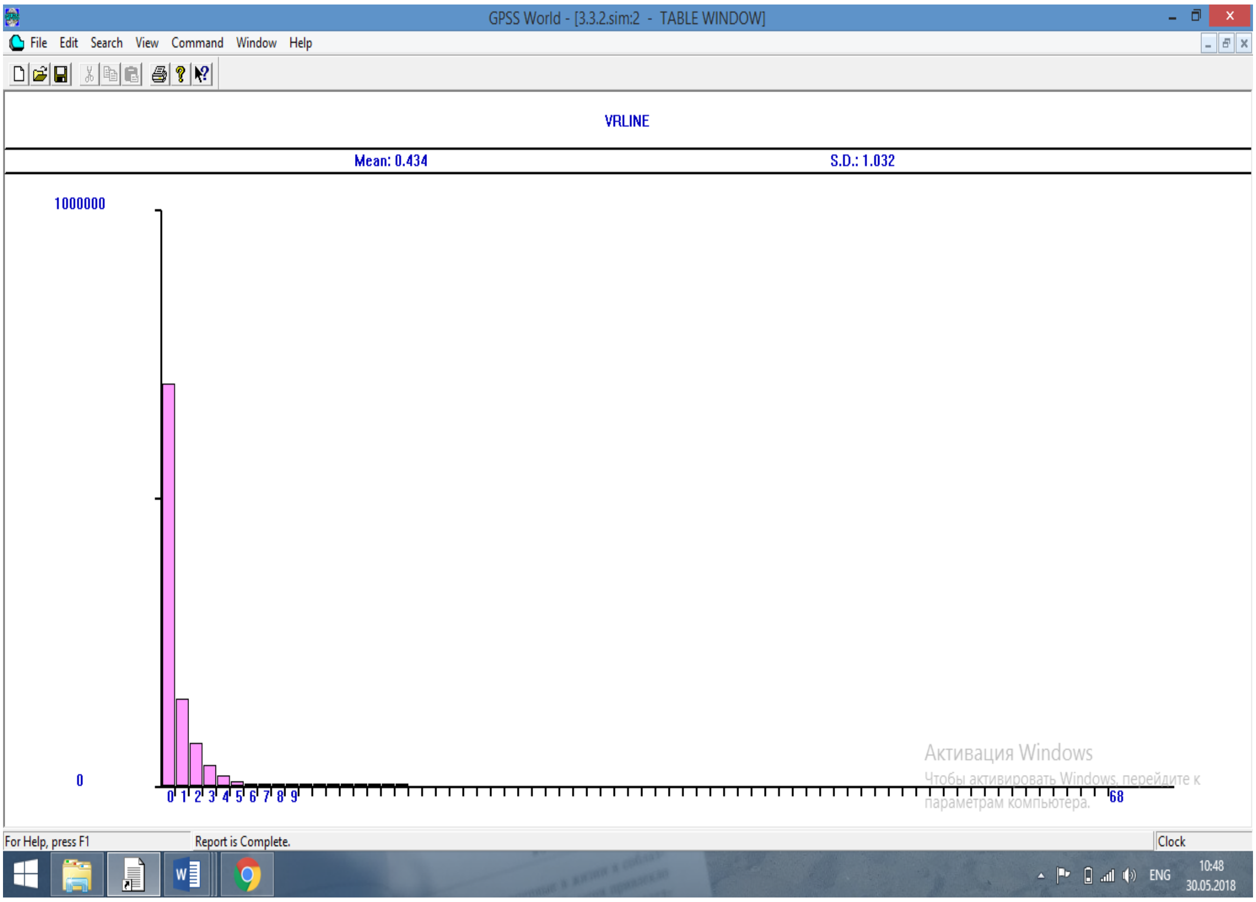

Figure 3.16 - Histogram of the waiting time of the packet in the queue

To determine the effect of packet servicing time on waiting time in the queue, experiments were performed on the simulation model. The simulation results are presented in Table 3.10 and in Figure 3.16.

Table 3.10 - Modeling results

Intensity μ	0,83	0,9	1	1,11	1,25	1,42	1,66
Average waiting time in the queue	0,855	0,616	0,434	0,296	0,193	0,118	0,066

With increasing service intensity, the average waiting time of the packet in the queue decreases. Here it is necessary to remember that the intensity of the service $\mu = 1/T_{ser}$, that is, it is the inverse of the service time, which means that this dependency shows that as the service time increases, the waiting time in the queue increases.

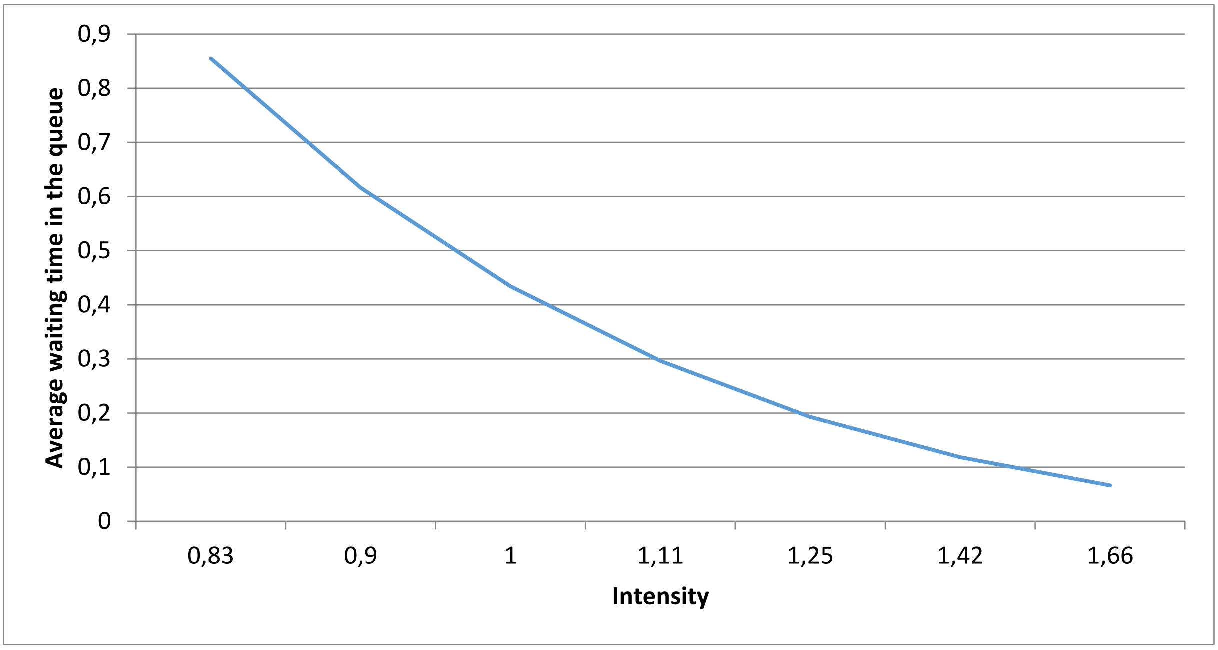

Figure 3.17 - Dependence of the average waiting time on the intensity μ

Table 3.11 - Dependence of the queue length on intensity

Intensity μ	0,83	0,9	1	1,11	1,25	1,42	1,66
Average queue length	0,322	0,232	0,163	0,111	0,073	0,045	0,025

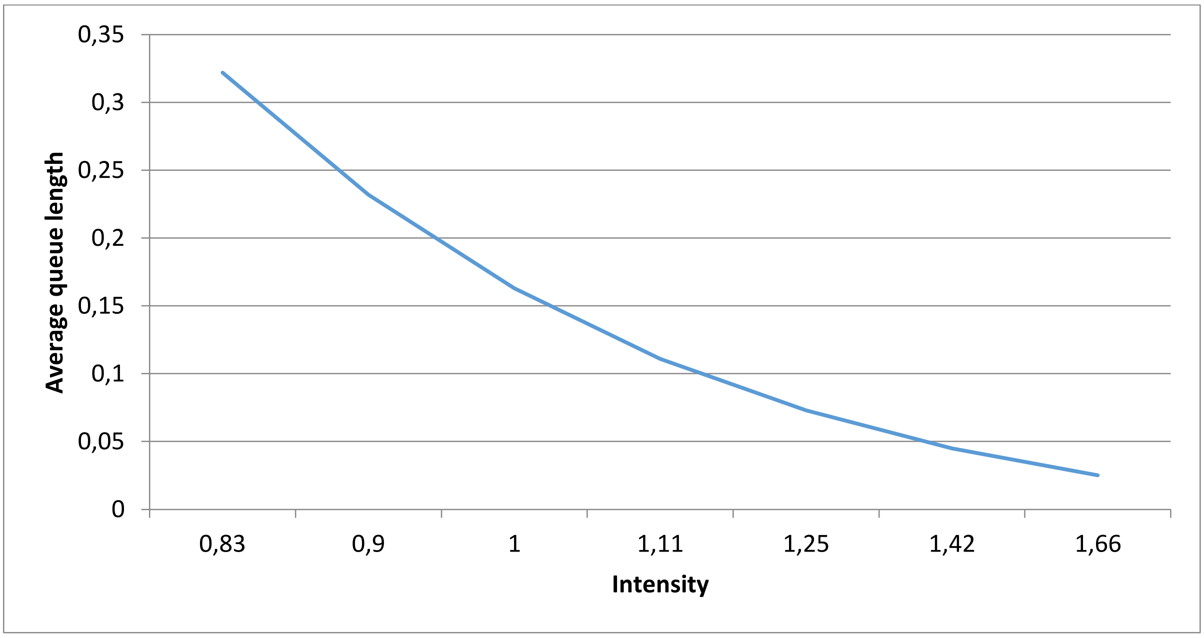

Figure 3.18 - Dependence of the length of the queue on the intensity μ

In the figures 3.17 and 3.18, we can see dependence of the average waiting time and dependence of the queue length on the intensity μ.

3.4 Comparative analysis of simulation results of two types of QSs

The main indicator of quality of service in wireless networks is the delay. Let's construct the dependencies of the delay time in the service node in the wireless network for two types of QSs. In the first case, QS of the form M/M/1/∞ was considered, in the second case, QS of the form Pa/M/1/ ∞.

In the part 3.2, the delay time was shown as a function of the loading of the system ρ under the exponential law of the distribution of intervals between the receipts of packets. As can be seen from Figure 3.10, the delay time increases with increasing load.

Now let's consider how the change in the load ρ affects the delay time of the packet in the system, when we assume that the intervals between packets are distributed according to the Pareto law.

Table 3.12 and Figure 3.18 show the dependence of the delay time on the loading ρ for the distribution of intervals according to the Pareto law. As can be seen from Figure 3.18, as the load increases, the delay increases

Table 3.12 - Dependence of the delay time on the loading ρ for the distribution of intervals according to the Pareto law.

Load ρ	0,1	0,2	0,3	0,4	0,5	0,6	0,7
Delay time	1,0	1,09	1,24	1,51	1,97	2,7	4,36

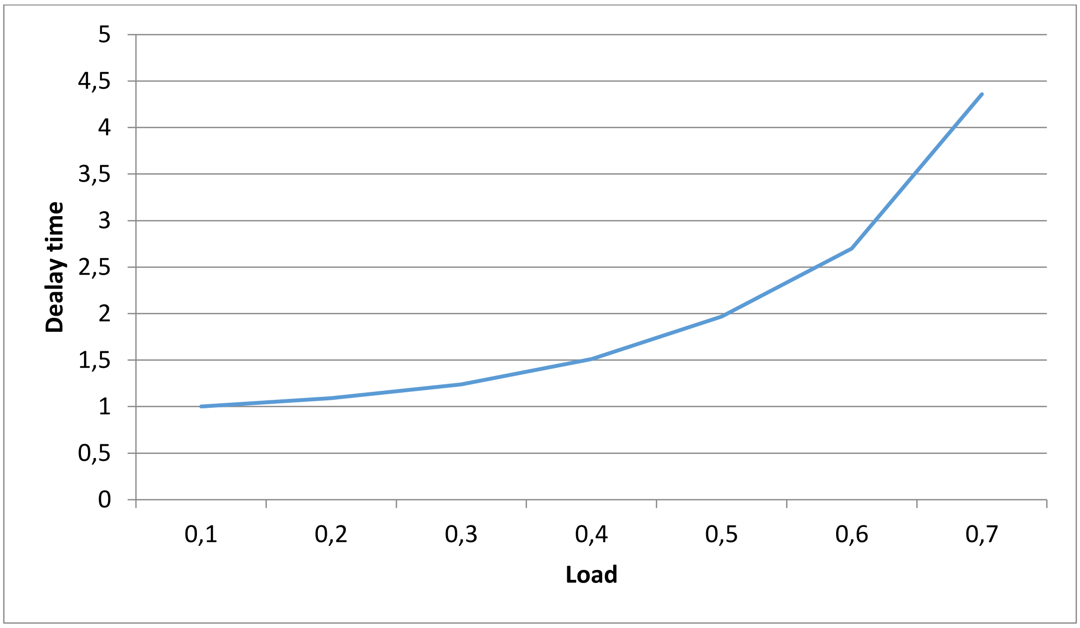

Figure 3.19 – Dependence of the delay time on load

For a comparative analysis of these dependencies, one depiction of the delay time on loading in the distribution of the incoming flow according to exponential law (1) and Pareto law (2) is shown in one figure 3.20. The figure shows that the value for the Pareto distribution is higher than for the exponential distribution, and increases more for large values of the load.

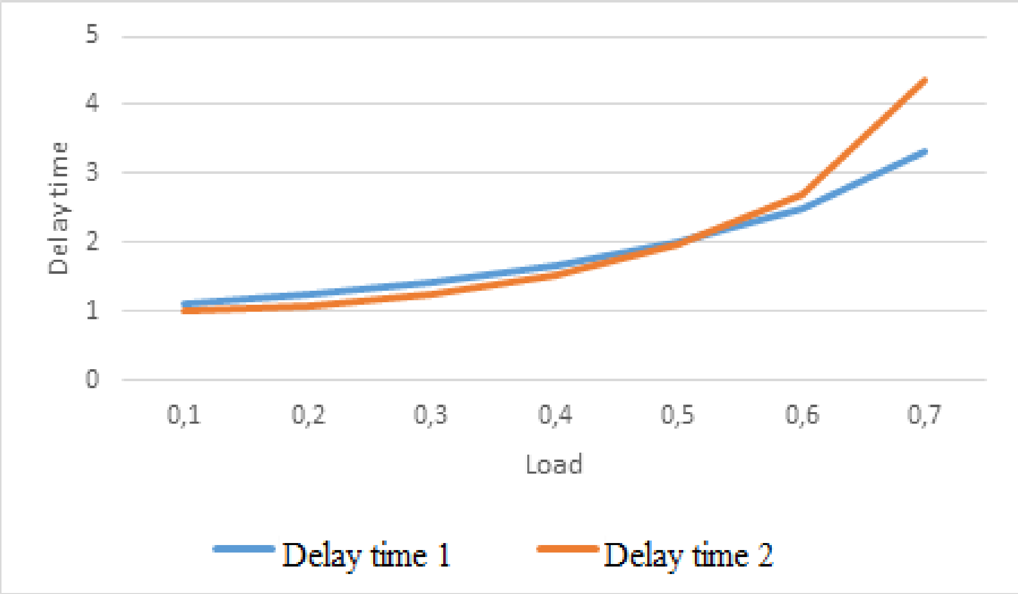

Figure 3.20 - Dependence of the delay time on loading with the distribution of the incoming flow according to the exponential law and the Pareto law

So, we can make the following conclusions. Serving incoming packet flow from automatic devices to the LTE cell site can be simulated using queuing systems. Two types of QS are considered: M/M/1/∞ and Pa/M/1/∞, in the first system the intervals between packets are distributed according to the exponential law, in the second Pareto law. In the first case, such traffic is called the simplest, in the second - self-similar.

Results of simulation modeling in the GPSS World system showed that with exponential distribution, such important indicators as delay, average waiting time in queue, average queue length, total delay in the service node receive an underestimation. Therefore, when simulating M2M traffic, one can not neglect such a property as self-similarity.

4 Life safety part

Present bachelor work is a research and does not involve any physical works. Consequently, the workplace of a software engineer can be described in the life safety section. In this case recommendations on the organization of the mode of work for a computer (PC) shall be specified, measures for ensuring ergonomics and safety of a workplace of the engineer are considered. Also in this section the calculation of illumination of a production room will be made, and data on utilization of production materials and outdated office equipment are given.

In the work the office of the engineer-programmer is considered; Room dimensions: 6x6x3 m; There are two window apertures measuring 1.6x2.2 m; the total area of the window openings is 7.04 m2. The placement of equipment and documentation in the office as well as the calculation of these parameters are given below.

4.1 Operating mode of the computer engineer-programmer

Characteristics of the working conditions of the engineer-programmer.

It is known that at work with the computer the person is exposed to a number of dangerous and harmful production factors: high-frequency electromagnetic fields, infrared and ionizing radiation, noise and vibration, static electricity. In addition to all of the above, work with the computer is characterized by significant mental stress and nervously emotional stress operators, high visual stress and a sufficiently large load on the muscles of the hands when working with the keyboard PC. The rational design and arrangement of workplace elements is of great importance, which is important for maintaining the optimal working posture of a human PC operator.

4.2 Organization of an effective mode of operation

To reduce the harmful effects of computers to negligibly small requires compliance with the correct mode of work and rest. Otherwise, the staff has a significant strain of the visual apparatus with the appearance of complaints of dissatisfaction with work, headaches, irritability, sleep disorders, fatigue and pain in the eyes, lower back, neck and arms. All this leads to a decrease in efficiency and is a symptom of harm to human health.

To prevent the harmful effects of work on the PC, the Ministry of health of the Republic of Kazakhstan has developed appropriate standards of work.

Table 4.1 provides information on the regulated interruptions that must be made when working on a computer, depending on the length of the working shift, types and categories of work with VDT (video display terminal) and PC:

Table 4.1 - Time of regulated interruptions at work on the computer

Job category with a VDT or PC	The load level for a shift in the types of work with VDT			Total regulated time	
	Group A, number of digits	Group B, number of digits	Group B, hours	8-hour shift	12-hour shift
I	up to 20 000	up to 15 000	up to 2,0	30	70
II	up to 40 000	up to 30 000	up to 4,0	50	90
III	up to 60 000	up to 40 000	up to 6,0	70	120

Note: break times are given subject to the said sanitary rules and regulations. If the actual working conditions do not meet the requirements of sanitary rules and regulations, the time of regulated breaks should be increased by 30%.

All work activities related to the use of the computer are divided into three groups:

A: work on reading information from the VDT screen or PC with a preliminary request.

B: Work to input information.

In: Creative work in a dialogue mode with a computer.

The work of the software engineer according to the above classification corresponds to group B in the type of work and category of work II or III, depending on the task. The working regime must be strictly observed; the efficiency of breaks is increased in combination with industrial gymnastics or the organization of a special room for staff rest with comfortable upholstered furniture, an aquarium, etc.

4.3 The parameters of the microclimate

Microclimate parameters can vary widely, while the necessary condition for human life is to maintain the constancy of body temperature due to thermoregulation, i.e. the ability of the body to regulate the return of heat to the environment. The principle of normalizing the microclimate-creating optimal conditions for heat exchange of the human body with the environment.

Computer technology is a source of significant heat, which can lead to an increase in temperature and a decrease in relative humidity in the room. In rooms where computers are installed, certain microclimate parameters must be observed. The sanitary norms SN-245-71 set the values of microclimate parameters, creating a comfortable environment. These standards are established depending on the time of year, the nature of the labor process and the nature of the industrial premises.

The volume of rooms in which employees of computing centers are placed shall not be less than 19,5 m3/person taking into account the maximum number of simultaneously working in change. The microclimate norms of fresh air supply to the premises where computers are located are given in tables 2 and 3:

Table 4.2 - Microclimate Parameters for premises where computers are installed

Period of year	The parameters of the microclimate	Value
Cold	The temperature of the air in the room Relative humidity The velocity of air	22…24 °C 40…60 % up to 0,1 м/с
Warm	The temperature of the air in the room Relative humidity The velocity of air	23…25 °C 40…60 % 0,1…0,2 m/s

Table 4.3 - Feed rate of fresh air into the room with the PC

Characteristics of the room (the volume of the room in m3 per person)	Volume flow rate of fresh air supplied to the room, m3 per person/hour

Up to 20 20…40	Not less than 30 Not less than 20

To ensure comfortable conditions can be used as organizational methods (rational organization of work depending on the time of year and day, alternation of work and rest) and technical means (ventilation, air conditioning, modern heating system).

4.4 Analysis of harmful factors

When working with a personal computer, a number of harmful factors and hazards may occur, including:

1. increased or reduced air humidity;
2. increased or reduced mobility of the air;
3. insufficient illumination of the working area;
4. straight and diffused brilliance;
5. increased noise levels in the workplace;
6. an increased level of static electricity;
7. increased level of electromagnetic radiation;
8. increased value of the voltage in the electrical circuit, the closure of which can pass through the human body;

4.5 Lighting

Let's focus more on the lack of light in the working area where the PC is installed. Properly designed and performed industrial lighting improves visual working conditions, reduces fatigue, contributes to the increase of labor productivity, has a beneficial effect on the production environment, having a positive psychological impact on the worker, increases labor safety and reduces injuries [27].

Insufficient lighting leads to eye strain, weakens the mind, leads to premature onset of fatigue. Excessively bright lighting causes glare, annoyance, and pain in the eyes. The wrong direction of light in the workplace can create sharp shadows, glare, disorientate workers. All these reasons can lead to an accident or occupational diseases, so the correct calculation of illumination is so important.

There are three types of lighting - natural, artificial and combined. Let's take a closer look at this classification.

1) Natural light lighting of premises by daylight penetrating through light apertures in external protecting designs of rooms. Natural light is characterized by the fact that it varies widely depending on the time of day, time of year, the nature of the area and a number of other factors.

2) Artificial lighting is used when working in the dark and during the day, when it is not possible to provide the normalized values of the coefficient of natural light (cloudy weather, short daylight).

3) Combined is called illumination, which is insufficient according to the norms of natural light supplemented with artificial.

Artificial lighting is divided into working, emergency, evacuation, security. Working lighting, in turn, can be General or combined. General-lighting in which the lamps are placed in the upper area of the room evenly or in relation to the location of the equipment. Combined-lighting in which local lighting is added to the General lighting.

When performing works of high visual accuracy (the smallest size of the object of distinction 0.3...0.5 mm), the value of the coefficient of natural light (DF) should not be less than 1.5%, and in visual work of medium accuracy (the smallest size of the object of distinction 0.5...1.0 mm), the DF should not be less than 1.0%. As sources of artificial lighting commonly used fluorescent lamps type LB or DRL, which are combined in pairs in fixtures that must be placed above the work surfaces evenly.

Requirements for lighting in rooms where computers are the following: when performing visual tasks of high accuracy General illumination shall be 300 lx, and combined – 750 lx; similar requirements when performing work of average precision - 200 and 300 lx respectively.

In addition, the entire field of view should be lit fairly evenly – this is the basic hygienic requirement. In other words, the degree of illumination of the room and the brightness of the computer screen should be about the same, because bright light in the peripheral vision area significantly increases eye tension and, as a consequence, leads to their fatigue. Next, we will calculate natural and artificial lighting for a standard production room (cabinet of a software engineer).

4.6 Calculation of natural lighting

Room type: Office of the engineer-programmer
Room parameters (L x B x H), m: 6 x 6 x 3
The height of the window, m: 1.5
The category of visual work: IV, b
Reflection coefficients: $\rho_{ceiling}$ =70%, ρ_{wall} =50%, ρ_{floor} =30%
Light belt: Almaty
The distance to a nearby building, P, m: 18
The height of the building, H_b, m: 30
The calculation is made by the formulas:

a) at side illumination of premises [27,28]:

$$S_0=\frac{S_n \cdot e_N \cdot K_3 \cdot \eta_0}{100 \cdot \tau_0 \cdot r_1} \qquad (4.1)$$

where S_o is the area of the light apertures in side lighting;

S_n - floor area of the room;

e_N is the normalized value of DF for buildings located in different areas;

K_s is the safety factor;

K_b - coefficient, taking into account the shading of windows opposing buildings;

η_0- light characteristic of the window;

r_1- coefficient, taking into account the increase in DF at the side light, reflected from surfaces room and underlayer.

τ_t - the overall coefficient of light transmission ,

τ_1- light transmission coefficient of the material for double-glazed windows

τ_2 - the coefficient considering losses of light in covers of the light aperture

τ_3 -the coefficient taking into account the loss of light in the load-bearing structures in side lighting is 0.9.

τ_4 - coefficient taking into account losses of light in the sun devices.

$$S=l*b \tag{4.2}$$

$$S= 6*6=36\ m^2$$

$$e_n=e*m*c \tag{4.3}$$

where e=1.2 (IV category)

m=0.9;

c=0.8

$$e_n=1.2*0.9*0.8=0.864$$

$$h_1=h_w+h_n-h_{r.p} \tag{4.4}$$

where $h_{r.p}$ = 0.7-0.75 m;

h_n=0.8 m;

h_w=1.5 m

$$h_1= 1.5+0.8-0.75=1.55\ m$$

Ratio of the distance between the calculated point and the outer wall to depth of the room:

$$l/b=1 \tag{4.5}$$

Ratio of the depth of the room to the height of the level of the conditional working surface to the top of the window:

$$b/h_1=6/1.55=3.87$$

η_0=10.5

We find the coefficient K_b, which takes into account the shading of the opposing building with respect to:

$$\frac{P}{H_b}=\frac{18}{30}=0.6$$

It means that K_b=1.7

Determine the total light transmission coefficient:

$$\tau_0= \tau_1*\tau_2*\tau_3*\tau_4 \qquad (4.6)$$

$$\tau_0=0.8*0.8*0.9*1=0.576$$

Determine r_1- coefficient, taking into account the increase in DF at the side light, reflected from surfaces room and underlayer (it is tabulated value) [29].

r_1=4.3

$$S_0=\frac{36*0.864*10.5*1.7*1.2}{100*0.576*4.3}=2.69m^2$$

4.7 Calculation of artificial lighting

Discharge of visual work I(a), therefore the normalized illumination is 200 lux.

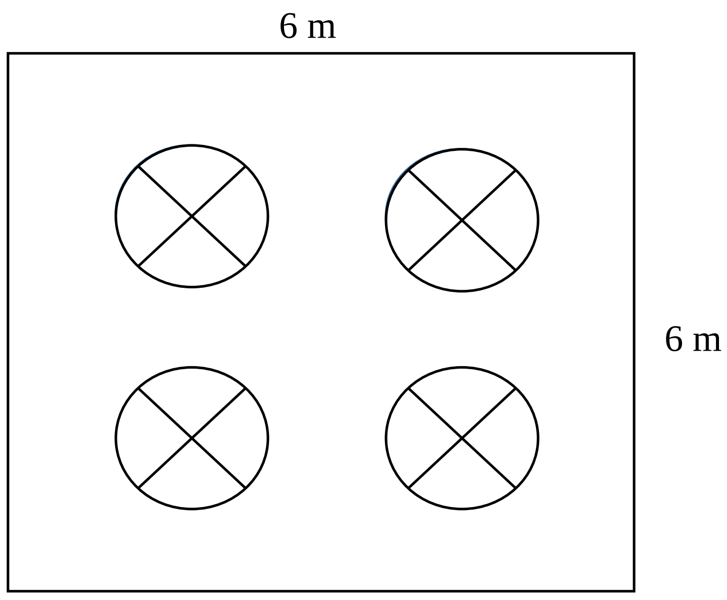

Figure 4.1- Location of the lights

We shall verify the correspondence of a given quantity and type of luminaires to a standardized value using a point method.

Determination of the calculated suspension height:

$$h_{calc}=H - (h_{worksp} + h_{overhang}) \quad (4.7)$$

$$h_{calc} = 3 - (0,7 + 0,2) = 2.1 \text{ m}$$

Distance between luminaires (Z):

$$l_A=4/4=1 \text{ m}$$

We designate a control point A. For it, we determine the total conditional illumination of all fixtures as follows:

We find the projection of the distance to the ceiling from point A to the luminaire - **d_i**.

Next, determine the angle between the ceiling and the line di. On this angle we find conditional illumination. We verify that condition:

$$E_Г \geq E_{norm} \quad (4.8)$$

$$E_Г = F \cdot \mu \cdot \frac{\sum_{i=1}^{m} e_{Гi}}{1000 \cdot K_з} \quad (4.9)$$

Coefficient of stock $K_з = 1.5$

Coefficient considering the action of equidistant fixtures μ=1.15.

Light flow F=3740 lm

Luminaire type: PVLM 1*40.

$$e_{Гi}=\frac{I_{\alpha_i} cos^3(\alpha_i)}{h^2_{calc}} \quad (4.10)$$

where

$$\alpha_i=\text{arctg}(\frac{d_i}{h}) \quad (4.11)$$

The distance from the central point to the luminaire d_1 is found as:

$$d_1=d_2=d_3=d_4=2.36 \text{ m},$$

then

$$\alpha=\text{arctg}(\frac{2.36}{3})=66^0, \text{ on this value } I_\alpha \approx 45 \text{ cd}$$

$$e_1=\frac{45*0.067}{3*1.5}=0.67 \text{ lx}$$

Calculate $E_{Г2}$:

$$d_2=2.36 \text{ m}$$

$$\alpha=\text{arctg}(\frac{2.36}{3})=66^0, \quad I_{\alpha2} = 45 \text{ cd}$$

$$e_2=\frac{45*0.067}{3*1.5}=0.67\ lx$$

Calculate $E_{Г3}$:

$$d_3=2.36\ m$$

$$\alpha=arctg(\frac{2.36}{3})=66^0,\quad I_{\alpha 2}=45\ cd$$

$$e_3=\frac{45*0.067}{3*1.5}=0.67\ lx$$

Calculate $E_{Г4}$:

$$d_4=2.36\ m$$

$$\alpha=arctg(\frac{2.36}{3})=66^0,\quad I_{\alpha 2}=45\ cd$$

$$e_4=\frac{45*0.067}{3*1.5}=0.67\ lx$$

The total conditional illumination is:

$$\sum e_Г=4*0.67=2.68\ lx$$

The total illumination is:

$$E_{TI}=\frac{\mu*F*2}{1000*K_S}*\sum e_Г=\frac{3740*1.15*2.68}{1000*1.5}=7.68\ lx$$

Illuminance in the ination.

We will perform the reconstruction using the coefficient of utilization method.

Define the index of the room (i):

$$i=\frac{A\cdot B}{h_{calc}\cdot(A+B)}=\frac{14\cdot 8}{3.1\cdot 22}=1.64$$

Let us determine the coefficient of use of the light flux (η):

Number of lamps with the necessary illumination E=200 lx:

$$N=\frac{E_n\cdot S\vdots Z\cdot K_3}{F\cdot\eta} \tag{4.12}$$

where Z – coefficient of uneven lighting, equal to 1,1÷1,2;

К₃ – coefficient of uneven lighting, equal to

$$\Phi=\frac{E_{min}*K*S*K_3}{N*\eta}=\frac{400*1.5*6*6*1.15}{4*0.6}=10350\ mF$$

To provide the necessary illumination of the classroom with the parameters 6x6x3 we select a DLL lamp with a power of 250 W and a light flux of 11500 mF. The number of lamps remains the same 4 pieces.

Conclusion

In the first part of the work the calculation of natural light was given. When designing the natural lighting of rooms it is necessary to determine the area of the light apertures that provide the normalized value of the DF. In the assembly room with the parameters 6 × 6 × 3 to provide a normalized value of the DF, $e_N = 0.864$ the I characterization of the visual work requires an area of light apertures in the total amount of 2.69 m^2.

In the second part of this work, the calculation of artificial lighting was carried out. Calculation of illumination by a point method showed that a given number of luminaires was not enough to provide sufficient illumination of the room. To ensure the necessary illumination of the laboratory it was suggested to increase the number of lamps to 4 pieces and change their type.

Calculation by the point method allows to do the calculation analysis at the level of nominal illumination, and the main drawback of this method is that it is impossible to say how effectively the lamps are used. Calculation of the coefficient of utilization method makes it possible to determine how efficiently and economically it is possible to use these or other fixtures. The coefficient of use method is the most accurate in calculating production lighting.

5 Economic part

In this graduation project, an information system was developed for "M2M network". The result of this task will be the software of modern computers, which should provide a sufficiently high speed of information processing [5]. The purpose of this section is to calculate the costs. As a result of calculation, the cost of the application program is found.

Find the cost price it is necessary to take into account:

a) depreciation charges for the full restoration of hardware and software;
b) the complexity of developing a software product;
c) payment for the programmer;
d) surcharges and surcharges to wages;
e) expenditure of electricity consumed by technical means;
f) overhead costs;
g) unified social tax.

5.1 Calculation of depreciation charges

In this research work the following technical means are used:

1) IBM compatible computer;
2) LCD monitor Acer 19 ".

The purchase price of the computer is 120,000 tenge, the monitor – 40,000 tenge, the printer – 20,000 tenge. Let's take the rate of depreciation for technical means 20%.

Total cost of technical equipment, tenge:

$$C_{te}=C_c+C_m+C_p \quad (5.1)$$

where C_c - the cost of the computer;

C_m - the cost of the monitor;

C_p - the cost of the printer.

From here:

$$C_{te}= 120000+40000+20000=180000 \text{ tenge}$$

To create the software package, which is the final result of the research, the following software was used [31]:

- Windows 8 platform - 15000 tenge;
- GPSS WORLD - 10000 tenge.

The total cost of the software is 25000 tenge.

The total cost of hardware and software, tenge:

$$C_{tot}= C_{te} + C_{soft} \quad (5.\ 2)$$

$$C_{tot}=180000+25000=20500$$

Annual depreciation for the full restoration of hardware and software is calculated by the formula, tenge [30]:

$$A_{tot} = C_{tot}\cdot N_a \quad (5.3)$$

$$A_{tot} = 205000\cdot 0.2=41000$$

Depreciation charges for the period of creating a software product, tenge:

$$A_p=\frac{A_{tot} \times K_d}{K_{wd}} \quad (5.4)$$

where K_d = 55 days - number of days worked;

K_{wd}= 280 days - number of working days per year.

$$A_p=\frac{41000\times 55}{280}= 8054$$

5.2 Calculation of energy consumption costs

The PC on which the program was developed is a consumer of AC electric power with a voltage of 220 V. According to the technical documentation, the total power consumed by the computer and the monitor is:

$$P_{tot}=250\ Wt\cdot hour$$

The expenditure of money resources connected with the energy consumption of technical means can be found by the formula, tenge:

$$C_e=K_d\cdot B_w\cdot P_e\cdot C_{en} \tag{5.5}$$

where K_d - the period of writing the program, days, K_d = 55 days;
B_w - duration of the working shift, hours, B_w = 6 hours;
P_e - power consumed by technical equipments, kWt·hour;
C_{en} - the cost of electricity at current tariffs, tenge / kWt·hour;
The price is 22 tenge per kWt·hour.
From here:

$$C_e= 55\cdot 6\cdot 0{,}25\cdot 22=181$$

5.3 Calculation of the programmer's salary

Based on the actually worked time of the programmer, which was 55 workers six-hour days, we will find the amount of actually worked time,h [32].

$$T_a= K_d\cdot B_w \tag{5.6}$$

where T_a - actually worked time, h .;
K_d - number of days worked, days;
B_w - the duration of the working day, h.

$$T_a=55\cdot 6=330$$

Taking the hourly salary of the programmer in the calculation of 400 tenge, we get the basic salary, tenge:

$$S_{bas}=T_a\cdot T_{hour} \tag{5.7}$$

where T_{hour} is the hourly rate of the programmer.

$$S_{bas}=330\cdot 400=132000$$

To determine the total amount of labor costs, it is necessary to take into account surcharges and allowances. We accept the specific type of surcharges and allowances in the amount of 15% of the basic salary, rubles:

$$S_{sur}=S_{bas}\cdot 15\% \tag{5.8}$$

$$S_{sur}=132000\cdot 0.15=19800$$

Hence we find the total cost of labor, tenge:

$$C_{total}=S_{bas}+ S_{sur} \tag{5.9}$$

$$C_{total}= 132000+19800=151800$$

It is necessary to take into account the overheads shown in Table 5.1.

Table 5.1 - Cost of materials:

	Unit of measurement	Amount	Price per unit	Sum, tenge
Office paper	bundle	1	1000	1000
CD-RW	pc.	2	150	300
Pen	pc.	1	80	80
Folder	pc.	1	300	300
Total:				1680

5.4 Calculation of the total cost of creating a software package

Total, the cost of creating a package of programs are, tenge:

$$T=A_p+ C_e + C_{total} + C_{mat} \tag{5.10}$$

$$T= 8054+1815+151800+1680=1633494.6$$

Find the selling price, it is necessary to take into account:
- profit from sales of 15%;
- value added tax 18%.

$$C_{tax}= T + P_t \tag{5.11}$$

where P_t - profit from the sale of the product, tenge.

$$P_t=T\cdot 0.15 \tag{5.12}$$

$$C_{tax}= 163349+1633497*0.15=187851$$

Cost of software package including VAT, tenge:

$$C_p= C_{tax} + VAT \tag{5.13}$$

where VAT = $C_{tax} \cdot 0.12$ - value added tax.

$$C_p= 187851 + 187851\cdot 0.12=210393$$

So, the selling price of the program is 210393 tenge.

5.5 Calculation of the annual costs of operating the program

Calculation of annual costs is necessary for the subsequent analysis of the effectiveness of this software product.

The annual operating costs of the program are:

$$C_{an}=n\cdot C_d+E_n\cdot C \tag{5.14}$$

where C_{an} - the cost of one direct decision on a computer, tenge;
E_n - normative coefficient of complexity (0.2-0.5);
C - the cost price of the developed program;
n - density of the flow of applications = 10 s / year.

The cost of one direct solution is determined, tenge:

$$C_d = C_{hour} \cdot T_d+30\cdot Q_p\cdot K_p \cdot C_{in} \tag{5.15}$$

where C_{hour} - the cost of one hour of work on a computer;
T_d - time for solving the problem on the computer;
Q_p - the complexity of the programmer spent on solving the problem on computer (50 hours);
K_p - the district coefficient (1.3);
C_{in} - costs are indirect.

$$C_d = 8\cdot 50+400\cdot 50\cdot 1.3\cdot 1.1=29000$$

$$C_{an}=10\cdot 2545+0.3\cdot 150000=70450 \text{ tenge.}$$

5.6 Calculation of annual costs for performing work previously used

A comparative variant is one in which the calculations are carried out, as a rule, manually. To determine the costs for manual processing of data, it is necessary to have data on the qualification of a specialist and the time required for numerical processing. In the absence of data, the costs of manual processing are calculated by timing the work of the graduate student when performing calculations on this method. In order to find the annual costs for performing calculations by the previously used method, it is necessary to know the cost of all works for the performance of one calculation. It will be, tenge [28]:

$$C_{pre}=S \cdot T \cdot K_d \cdot O \tag{5.16}$$

where C_{pre} - cost of performed calculations previously used;
S - the salary of a specialist who carried out calculations earlier used way;
T - time spent by a specialist on one calculation (150 hours);
K_d- the district coefficient (1.3);
O – overheads.

$$C_{pre}=400 \cdot 150 \cdot 1.3 \cdot 1.1=85800$$

Knowing the density of the flow of applications for this calculation, we determine the annual costs, tenge:

$$C_{pre.year}=n \cdot C_{pre} \tag{5.17}$$

$$C_{pre.year}=10 \cdot 85800=858000$$

5.7 Determination the economic effect of the program

When calculating the economic effect, a negative result can be obtained.
This suggests that the chosen method from the point of view of economic analysis is less effective.
The annual savings are determined by the formula, tenge:

$$E_{year}= C_{pre.year} - C_{an} \tag{5.18}$$

where $C_{pre.year}$ - annual costs for the solution previously used;
C_{an} - annual costs of the machine solution of the problem.

$$E_{year}= 858000-70450=787450$$

Determining the estimated cost-effectiveness of the program. The calculation of economic efficiency is carried out to determine the most cost-effective option for processing information. Economic efficiency characterizes the ratio of the total magnitude of the effect to the costs that caused it, tenge.

$$E_c= E_{year}/(C+C_{an}) \tag{5.19}$$

where C - cost of the program.

$$E_c = 787450/(150000+70450)=3.57$$

5.8 Payback period of the developed program

The payback period characterizes the period of time during which the total costs of compiling the program are compensated for by saving current expenses. The payback period is the ratio of the costs of compiling the program to the economic effect of its implementation, year:

$$T_p = (C+C_{an})/E_{year}=1/E_c \tag{5.20}$$

where T_p is the payback period.

$$T_p = 1/3.57=0.28$$

It follows from the calculations that the program will pay off in 4 months.

The chosen method of solution is considered to be cost-effective.

Table 5.2 – Final table of effectiveness of the project

Indicator	Sum, tenge
Depreciation charges	8054
Energy consumption	1815
Cost of labor	151800
Cost of materials	1680
Selling price of the program	210393
Payback period	4 months

Conclusion for economic part

In order to increase labor productivity by reducing the labor intensity of the product and reducing the number of workers at the enterprise, a number of organizational and technical measures are carried out: the use of new technologies, a precise cut, the replacement of morally and physically obsolete equipment with more technological and high-performance equipment. The proposed measures make it possible to increase the competitiveness of this type of product by reducing the prime cost and the selling price of the product.

As a result of the calculations carried out in the economic part of the diploma work, a production program was determined in natural and value terms.

To determine the production program in value terms, calculation of the costing of the product, of wage funds by categories of employees and the total planned wage fund of industrial personnel was made, which amounted to 151800 tenge. The cost of creating a package of programs are 163349 tenge. The economic effect of the program is equal to 787450 tenge. The payback period characterizes the period of time during which the total costs of compiling the program are compensated for by saving current expenses and in my case equals to 4 months.

The results of the calculations show that the projected shop for the manufacture of women's night shirts is cost-effective and economically justified, and the selling price of the manufactured product, being acceptable to the consumer, will ensure the competitiveness of products on the domestic market of goods and services.

Conclusion

In this diploma work, M2M traffic was analyzed in wireless networks.

The first part analyzed the current state of the IoT / M2M service market, the prospects for its development in Kazakhstan and the world, M2M network architecture and basic technologies.

In the second part of the diploma work, we analyzed existing narrowband networks for servicing M2M devices such as NB-IoT, LoRa technology and LTE Cat.0 technology. According to our theoretical information we made comparison table where clearly shown the characteristics of each technology. For NB-IoT we made analytical and numerical models and construct graph of probabilistic characteristics of message service in NB-IoT

In the third part, experiments were conducted on an imitation model in the GPSS World environment. Results of simulation modeling in the GPSS World system showed that with exponential distribution, such important indicators as delay, average waiting time in queue, average queue length, total delay in the service node receive an underestimation. Therefore, when simulating M2M traffic, one can not neglect such a property as self-similarity.

In the section of life safety, an analysis of working and microclimate conditions was carried out. The calculation of natural and artificial lighting of the working room is presented.

In the economic part, the business plan of the project is also compiled and a description of the economic efficiency of the project is provided to calculate the payback period and it is equal to 4 months.

Abbreviated terms

1. M2M – Machine-to-Machine
2. IoT – Internet of Things
3. NB-IoT – Narrow Band Internet of Things
4. LTE Cat.0 - Long-Term Evolution Category 0
5. GPSS World - General Purpose Simulation System World
6. LoRaWan - Long Range Wide Area Networks
7. QS – Queuing System
8. CAN - Controller Area Network
9. RS232 - Recommended Serial 232
10. Wi-Fi - Wireless Fidelity
11. DSL - Digital Subscriber Line
12. GSM - Groupe Special Mobile
13. UMTS - Universal Mobile Telecommunications System
14. 3GPP - 3rd Generation Partnership Project
15. NGN – New Generation Network
16. PAN - Personal Area Networking
17. IEEE 802.15 - Institute of Electrical and Electronics Engineers 802.15
18. SRD - Short Range Device
19. UWB - Ultra-wideband
20. LAN – Long Area Network
21. PLC - Programmable Logic Controller
22. M-BUS - Meter-Bus
23. VSAT - Very Small Aperture Terminal
24. WLAN - Wireless Local Area Network
25. WiMAX - Worldwide Interoperability for Microwave Access)
26. CN - Core Network
27. GPRS - General Packet Radio Service
28. EPC - Electronic Power Control
29. ETSI - European Telecommunications Standards Institute
30. TISPAN - Telecommunications and Internet converged Services and Protocols for Advanced Networking
31. API - Application Programming Interface
32. SoC- System on a Chip
33. TCP - Transmission Control Protocol
34. KNX - Konnex Networks
35. RAM - Random Access Memory
36. GPIO - General - Purpose Input/Output
37. PWM -Pulse Width Modulation
38. UART - Universal Asynchronous Receiver/Transmitter
39. SPI - Stateful Packet Inspection
40. SAW- Surface Acoustic Wave
41. CPE - Customer Premises Equipment

42.HTTP - HyperText Transfer Protocol
43.WSN -Wireless Sensor Network
44.ISP – Internet Service Provider
45.MAC - Media Access Control
46.RFID - Radio Frequency Identification
47.PLC – Power Line Communication
48.MNO – Mobile Network Operator
49.ARPU – Average Revenue Per User
50.MIMO - Multiple Input Multiple Output
51.SISO - Single Input, Single Output
52.EU – European Union
53.US United States
54.GFSK - Gaussian Frequency Shift Keying

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Appendix A

Listing of the M/M/1 simulation model in the GPSS World

```
VrDelta TABLE X$Delta,0,1,60
         INITIAL X$Time,0
VrServ   TABLE MP2,0,1,60
Avit      EQU 4.33
Tserv    EQU 1
Fun      VARIABLE (AC1-X$Time)
         GENERATE (Exponential(17,0,Avit))
         SAVEVALUE Delta,V$Fun
         SAVEVALUE Time,AC1
         TABULATE VrDelta
         MARK 2
         QUEUE Line
         SEIZE M2M
         DEPART Line
         ADVANCE (Exponential(45,0,Tserv))
         RELEASE M2M
         SAVEVALUE 1,MP2
         TABULATE VrServ
         TERMINATE 1
         START 1000000
```

Appendix B

Listing of the Pa/M/1 simulation model in the GPSS World

File Edit Search View Command Window Help

3.3.gps

```
VrDelta TABLE X$Delta,0,1,60
        INITIAL X$Time,0
VrServ  TABLE MP2,0,1,60
VrLine  QTABLE Line,0,1,70
Alpha   EQU 1.6
k       EQU 1
T_serv  EQU 1
Fun     VARIABLE (AC1-X$Time)
        GENERATE (k#(Uniform(1,0,1)+1E-6#Uniform(1,0,1))^(-1/Alpha))
        SAVEVALUE Delta,V$Fun
        SAVEVALUE Time,AC1
        TABULATE VrDelta
        MARK 2
        QUEUE Line
        SEIZE M2M
        DEPART Line
        ADVANCE (Exponential(45,0,T_serv))
        RELEASE M2M
        SAVEVALUE 1,MP2
        TABULATE VrServ
        TERMINATE 1
        START 1000000
```