Telecommunication Infrastructures for Telemedicine in Smart Cities

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Abstract. Review of "Smart City" elements and their components are conducted in the article. Analysis and development of solutions for remote monitoring of the human health status due to the application of telemedicine devices are carried out. The tasks of hardware and software complex that implemented are displayed. The model of hardware-software complex based on MQTT protocol use with the combination of two architectures: client-server and publish-subscribe is offered. Data exchanged is carried out in protected-mode through SSL and HTTPS protocols. The reasonability of MQTT protocol use through its built-in QoS abilities to prioritize telemetric traffic is substantiated. The algorithms of hardware-software complex operation are developed. The procedure of human health monitoring with data transfer and analysis for telemedicine purpose is carried out. Simulation of the adopted solutions in the Cisco Packet Tracer 7 environment is performed. The practical value of created hardware software complex for similar tasks in other parts of human life is offered.

Keywords: Sensors, Telemedicine, Hardware and software complex, Internet of things, BigData, Smart city.

1 Introduction

The cities growth and increase of their role in human life, i.e., the process of urbanization take an important place in modern world processes and trends of the society development. In 1950, there were only 30% of the world's urban population. It is expected that by 2050 this indicator will increase to 68%. According to the UN in 2018, 55% of the world's population is concentrated in cities (North America (82%), Latin America and Caribbean (81%), Europe (74%) and Oceania (68%). The urbanization level of in

Asia is about 50%, and in Africa 43%. In 2018, the urban population in Ukraine is 69.4% [1].

The application of information technologies and IoT services makes it possible to solve a variety of problems in different areas of the city activitity. Internet of Things services are developing mainly in two directions: consumer (mass) and industrial (critical) [4].

The development of telemedicine systems including built-in means for registration of a number of physiological parameters and control of human physical activity is the essential application of IOT . At present, the average annual rate of telemedicine services growth is 19% [5]. Further development will result in the extension of devices for remote health monitoring with the mobile communication support.

According to [6,7], by 2020, around four million of patients in the world will carry out remote monitoring of their health. As the example, statistics data show that the frequency of the health-related webpages increased from 2010 to 2011 by 134% [5].

2 Analysis of literature sources

The authors of the article revised more than 150 scientific papers in domestic and foreign publications, as well as the Request for Comments (RFC) documents.

The main objective of the "Smart City" is to provide the residents with intelligent services that can save their time and make life easier. However, this objective can not be implemented without the introduction of modern information-communication technologies, which are the pledge of the city transformation into the smart one.

Choudhary M., in paper [22], distinguishes the following elements without which the "smarts" of the city can not be achieved:

1. Information and communication technologies Creation of the reliable two-way communication channel is important for ensuring the information acquision and exchange between the "smart city" members.
2. Internet of Things is the network concept consisting of interconnected physical devices that have built-in sensors, as well as software allowing to transmit and exchange data between the physical world and computer systems by means of standard communication protocols. Internet of Things provides the ideal communication pattern of physical devices providing smart solutions for daily city problems.
3. Sensors. These are hidden but general components of the urban infrastructure, which are essential components of any intelligent management system.
4. Geospatial technologies provide the necessary basis for the integration of all spatial data acquision and management tools for scientific, administrative and technical operations related to the production and management of spatial information. Such technologies make it easier to make software solutions for the intellectual city infrastructure.
5. Artificial intelligence. The "Smart City" generates BigData that are not useful until they are processed. Artificial intelligence carries out analysis of large data arrays and decision making, making possible such interactions as M2M, M2H.

6. Blockchain technology makes data transfer secure. Its integration into smart cities could connect all urban services better, increasing security and transparency. Blockchain technology uses smart-contracts for billing, transactions processing and control objects managing in the "smart city."

Scientists J. Lee, R. Phaal, S. Lee [23] divide the "smart city" technologies into five categories:

- Sensing is monitoring of any environment changes and transmitting of gathered data for processing and receiving of solutions in response to sensor signals.
- Processing is carrying out data analysis from the sensors to obtain the rational decision.
- Network is the connection of any device and the user to maintain effective communication.
- Interface is the convertion of information transmitted between devices or between users and devices into clearer form (graphical, textual).
- Security is control of unauthorized access to the information from users or objects throughout the intellectual environment and personal privacy protection.

Scientists E. Santana, A. Chaves, M. Gerosa, T. Hui, R. Sherratt, D. Diaz Sanchez [2] distinguish four main technologies used by the "smart city" software platforms. They include: cyber-physical systems, Internet of things, BigData and cloud computing.

Cyber-physical systems can be characterized as the use of computing and communication technologies in order to improve the physical systems characteristics. Existing ICT do not completely support the programs with dynamically changing physical contexts, and the application of cyber-physical systems can be the solution of problem.

Cyber-physical systems are related technologies with Internet of things. The first ones provide coordination, control and integration of individuals into information systems, and IoT connects devices to the Internet infrastructure.

BigData can be considered as the set of methods and tools for big data sets storage and manipulation, as their processing by traditional technologies is not efficient.

Consulting company Beecham Research Limited states that “smart city” full-fledged services supply is possible by combining such technologies such as cloud computing, distributed and boundary calculations, networks, smart end devices, data flow, analytics, and stored outdated data [24].

During the investigations carried out in 2007, the World Health Organization (WHO) identified over 104 definitions of telemedicine. WHO accepted the following common definition: "Providing health services under the conditions where distance is the critical factor, by health workers using information and communication technologies for exchange the necessary information in order to diagnose, treat and prevent diseases and injuries, carry out research and assessments, as well as continuous education of medical professionals in favor of improving the public health and local communities development "[8-10].

New achievements in informatics, radio electronics, communication, mathematics, biophysics, medical instrument-making and other knowledge-intensive industries are the means for various telemedicine systems architectures construction [11]. Three functional schemes of telemedicine systems: for biophysical experiments monitoring; for monitoring the patient functional state at home; of cancer diseases screening management in Kyiv are considered in paper [12].

The importance of telemedicine application in car crashes, emergency situations and remote monitoring is considered and the common architecture of the telemedicine system consisting of two major parts: telemedicine and doctor's department is offered in [13].

The comprehensive and up-to-date description of the communication networks use, as well as their advantages and restrictions of providing telemedicine services in the moving vehicle (ambulance) are given in [14].

The logical supplement to the above-mentioned papers is [15]. Body area wireless networks (WBANs) where the sensors are attached to the clothes or body, or implanted under the skin are analysed in this papper. Using WBAN, the patient experiences greater physical mobility and is no longer forced to stay in the hospital. The concept of wireless communication networks survey, as well as the example of intra-body and extra-body communications in WBAN and the wireless networks location in the wirelessnetworks field are offered.

In military medical institutions of Ukraine, measures regarding the telemedicine implementation are held. Particularly, equipment due to which everything happening in the operating room can be seen from any point in Ukraine or in the world is installed in the Main National Military Medical Clinical Center. This is important when urgent joint decisions are taken or recommendations of the well-known surgeons are needed during surgery [16].

The authors carried out the detailed analysis of the Law of Ukraine "On improving the availability and quality of medical care in rural areas" [18] and analysis of the existing telemedicine complexes used in Ukraine and other countries. The disadvantage of the investigated complexes is insufficient support of QoS-priority and little attention is paid to the application of modern mobile networks in telemedicine, and the use of wire and Wi-Fi networks results in geographically limited implementation of services

3 Complex architecture

In order to implement this complex, the concept of creating multi-level mobile personalized system with the combination of two architectures: client-server and publish-subscribe is offered. The structural organization of the publish-subscribe part for the problems of personalized medicine provides that user-identification procedures are performed at the customer level; data transmission from medical sensors, or key in the measurement data; local computing module and results display. The server generates the global database and performs comprehensive analysis (e.g. heart rate variability), which results are used to prevent the complication or possible disease progress.

The general scheme of the remote monitoring system of health status using IoT services and 4G / 5G data transmission technology is shown in Fig. 1.

Terminal devices using IP-protocol provide data acquisition and transmission. After authorization, the customer or his/her authorized persons gain access to the data gathered by means of interaction with the web-server according to client-server principle.

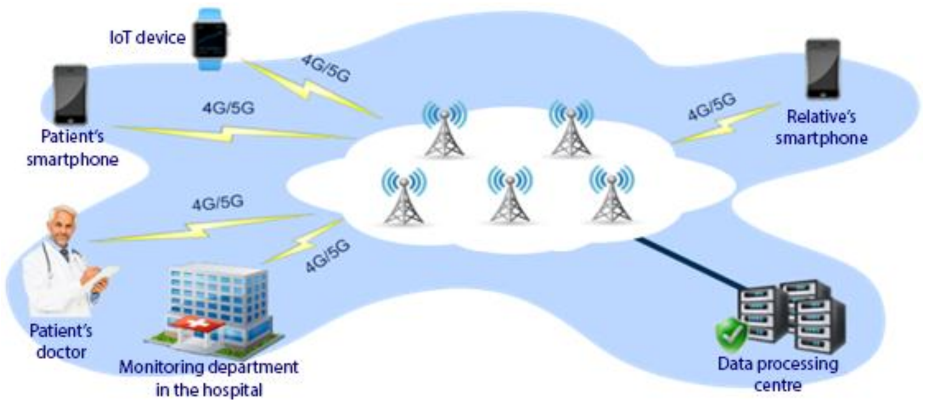

Fig. 1. Scheme of the developed system of remote monitoring of health status indicators

The hardware and software complex implements the following tasks:

- automation of telemetry data acqusitionusing IoT technologies based on 4G/5G telecommunication networks providing QoS-priorities;
- analysis of gathered data in order to prevent nosogeny of possible diseases and their complications;
- immediate response to critical changes of health status indicators;
- improvement of the quality and level of medical services supply to various groups of population by means of the latest mobile technologies;
- providing the on-line diagnostics with the individual approach to the patient;
- extension of the variety of telecommunication technologies application by due to telemedicine implementation on the basis of mobile operator networks.

The developed complex is scaled solution in the field of telemedicine. It can be deployed for single hospital, for the whole district or within the country. While implementating the project, it is offered to locate monitoring stations in the hospital carrying out continuous monitoring of the patient's health status, and in the case of critical situation to inform the personal physician.

When implementing the project which includes the city or region services, we offer to locate the monitoring station in the separate institution. This minimizes the cost of complex maintenance by eliminating the monitoring stations duplication in each hospital. The algorithm of the remote health care system operation (Fig. 2).

The hardware-software complex provides two-level structure of the health status diagnosis. At the first level the users have the opportunity to monitor their performance and physical activity levels independently.

At the second level the comprehensive analysis of the obtained data, access to professional software of specialized physicians, more detailed examination of measurement results, express data analysis and formulation of appropriate recommendations are provided.

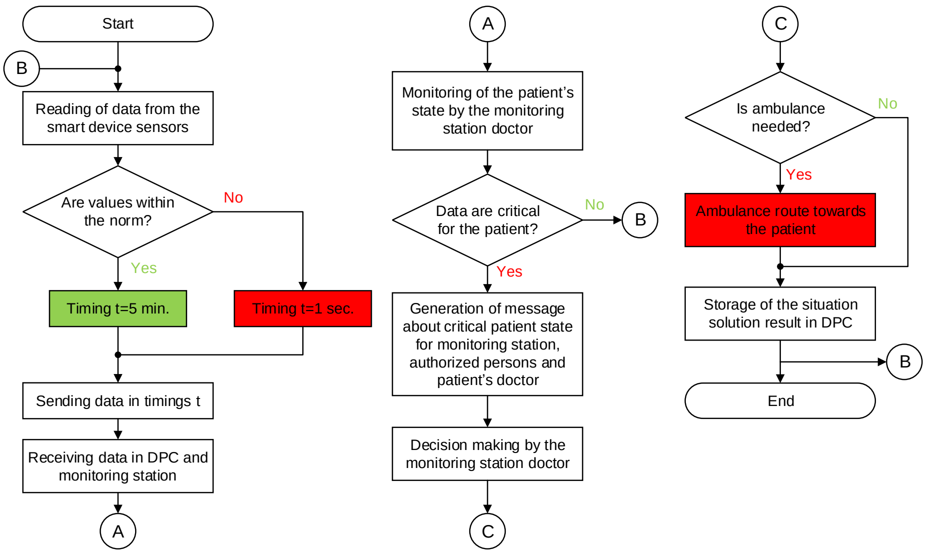

Fig. 2. Block diagram of the remote health care system operation algorithm

4 Requirements to IOT device for the developed HSC

The device for monitoring health status should be equipped with 4G / 5G module, GPS-tracker, built-in battery and wireless charging capability. The battery charge should be enough for at least 72 hours of the off-line operation. To continue the work you can equip the device with the mechanism of recharging during active movements, and for complete battery charge you can use the induction charging technology. So, placing the charger near the bed, you can charge the device while sleeping without removing it from your hand.

Smart devices for monitoring health indicators monitoring can be made in the form of the bracelet, plasters, belts, sensors, which are fixed to the clothes or directly to the body, or implanted under the skin. Typically, the method of the device manufacturing depends on the factors it should measure (temperature, blood pressure, heart rate, ECG, SpO2 level, insulin levels, etc.).

Let us note that the above mentioned devices can also measure external environment factors (for example, the level of toxins in the air) and inform the patient [15]. Sensors select information in real time mode and process it.

5 Technical implementation of the complex

The hardware and software complex for monitoring of human life and activities ensure the interaction of such end devices: patient's IoT device, authorized persons' terminals, doctor's terminal and monitoring station. Let us concider the purpose of each of the end device:

- patient's IoT device includes sensors measuring the human life and activity factors and transmits data through 4G/5G network;
- terminals of the patient's authorized persons include include smartphones, tablets, computers, or other devices that have access to the network. The authorized persons have the opportunity to receive information about the patient's health status from the analytics server;
- the doctor's terminal has access to the information about the current patient's health status, as well as to the statistics contained on the analytics server;
- the monitoring station performs round-the-clock observation of the patient's health status. In case of health deterioration, it informs the doctor who makes the expert decision.

For each of the above listed devices a number of requirements depending on the functions and services they are provided with can be put forward. For example, the main purpose of the patient's IoT device is the round-the-clock measurement of health indicators and their transfer to the server. Since this device can be associated with critical IoT services, it should provide high reliability and availability. In addition, the highest possible user mobility is an important requirement. It should be achieved not only by extension of the mobile coverage, but also by reducing the battery charge consumption. Considering the above mentined requirements, we regart that it is reasonable to use the MQTT protocol to ensure optimal devices interaction.

MQTT (Message Queue Telemetry Transport) is simplified messaging protocol providing network customers with the simple method of telemetry information distribution [18]. The protocol principle design minimizes the requirements to both the network bandwidth capacity and device resources. This makes it suitable for use in E2E-communications, IoT or for mobile applications where the problems of battery capacity and battery power are important [14].

The MQTT protocol operates on the publish / subscriber principle (Pub / Sub). Pub/Sub separates the client who sends the message (publisher) from the customer who receives it (subscriber). This protocol architecture provides three types of demarcation: spatial – tit is not necessary for sender and receiver to know each other (for example, the IP address or port), time - the sender and the receiver may not work at the same time, synchronization - operations on both customers do not stop while publishing or receiving the message. Separation is implemented by means of MQTT broker [10].

The MQTT broker acts as an agent between the message publisher and its receiver. First of all, the broker is responsible for receiving messages, their filtering and sending them to all signed customers. Message filtering can be carried out in three ways. The first way is filtering by topic. The broker has a certain number of topics in which some customers publish the message, while others subscribe to a specific topic and receive all the messages that come to it. It should be noted that the topic is part of the MQTT message format. Another way is filtering based on content. The broker uses the specific content filtering language, so the customers can receive messages according to the specified filters. The third method of filtering is common while using the object-oriented approach, when each message belongs to a particular class. Thus, the customer can be signed to receive all messages belonging to the type of Exception or its other subtype [10].

The broker also provides authorization and authentication for the customers. Encryption for data transmission through the network can be performed by means of SSL protocol, apart from MQTT protocol itself. It should be noted that the broker provides an opportunity to integrate their own security policies.

The important feature of MQTT protocol for telemetry implementation is its ability to provide QoS levels. There are three QoS levels in MQTT:

1. At most once (0) is message transmission from the sender to the broker once without waiting for confirmation from the broker.
2. At least once (1) is guaranteed delivery of messages to subscribers with the probability of sent messages duplication.
3. Exactly once (2) is guaranteed delivery of messages to subscribers without sent messages duplication [18, 20, 21].

Methods of the developed system implementation using MQTT protocol are shown in Fig. 3.

The MQTT-broker provides the real-time monitoring service to the patient, that is, ensures communication between IoT device, hospital monitoring department and doctor's terminal. IoT devices act as Publisher-a. Monitoring stations and doctor's terminal act as Subscriber-a. The MQTT broker can be located in the data processing center. Each IoT device publishes its data to the relevant Topic, and the monitoring stations are subscribed to the Topic of the relevant device. All data sent by IoT devices are stored in database. To provide communication of database with the MQTT-broker, let us introduce the intermediate link which is signed on Topic-e and performs the function of converting the data received from the Topic-a into the relative database tables.

The full-fledged system operation is provided by the analytics server, which is also located in the data processing center (DPC). The analytics server processes the data of IoT devices from database, i.e, forms statistics, forecasts possible diseases, etc. It stores the information obtained during analysis in database. Moreover, the analytics server acts as a web-server providing terminal devices access to database data through HTTPS protocol.

Monitoring stations have installed software used by MQTT protocol to track the current patient health status. The possibility of communication with the analytics server through HTTPS protocol is also implemented.

Indicators entering the patient's device can be divided into two categories: normal and critical. Threshold values are set on the basis of the complex in-patient examination results. Thus, the normal patient's health outcomes (so-called baseline) and the percentage of deviation from these outcomes are determined.

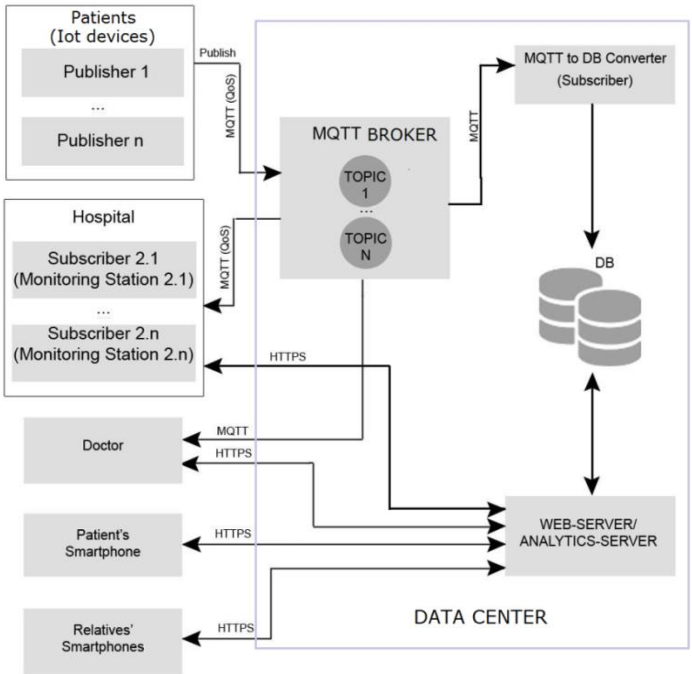

Fig. 3. Interaction of the project architecture structural units

There are two data transfer intervals: t1 - for normal outcomes; t2 - for critical ones. MQTT QoS 1 level is used for normal outcomes transmission, and MQTT QoS 2 - for the critical ones. Since MQTT QoS operate on 5-7 levels of the OSI model, then the well-known QoS mechanisms are used to provide quality services at lower levels (between second and third).

In the developed project the patient's IoT device sends statistics every 5 minutes. It should be noted that the interval between statistical data sending must be chosen in such a way as to provide the server with the optimal amount of data for conducting qualitative analysis (in this paper the value of "5 min" is selected only for illustration of the system operation). In this case, if the patient's health status deteriorates sharply, the device survey is performed every second. Thus, the timing parameters of sensor signaling can be carried out according to the following scheme: normal outcomes (sending data every 5 minutes); outcomes deviating from the norm (sending data every second).

The patient, doctor and authorized persons can view the patient’s information received from the analytics server due to the web-viewers on the terminal devices. This interaction takes place through HTTPS protocol. Communication of IoT device with data processing center and monitoring stations is via the mobile operator's network.

HSC emulation is performed in Cisco Packet Tracer environment (Fig. 4).
The complex architecture is created In Cisco Packet Tracer 7, and PT Script module and Script Engine are developed to provide interaction between the structural units.

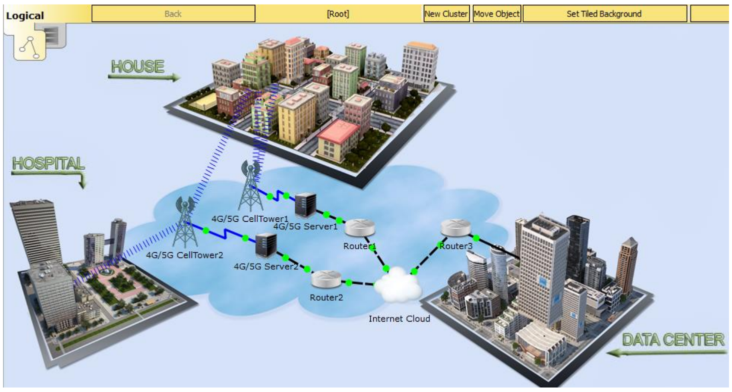

Fig.4. Project in Cisco Packet Tracer 7 environment

6 Conclusion

Analysis of the requirements to the human health status monitoring devices is carried out and algorithms of the remote human health status monitoring system operation are developed in this paper. MQTT protocol application for data exchange between information sensors and collection server and processing in data processing center is substantiated. Data exchange security is proved by SSL and HTTPS protocols application.

The use of MQTTs QoS tools increases reliability of traffic prioritization in the networks as it is built-in function of this protocol and is not linked to TCP protocol fields. It should be noted that telemetry data parameters can be prioritized depending on the importance of the set up tasks. Unlike the data flow-based prioretization, MQTT protocol allows us to determine priorities within the flow itself.

The HSC model for human life activities monitoring is created providing QoS priorities of telemetry data in the network. It is offered to create the complex on the basis of multi-level scalable mobile personalized system with the combination of two architectures: client-server and publish-subscribe.

The practical value of the developed HSC model is that the offered solutions can be applied for other similar tasks. For example, in the building state monitoring system. Sensors replacement makes it possible to use the solutions for building protection from invasion, fire safety monitoring and many other tasks.

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