Information-Communication Technologies of IoT in the "Smart Cities" Projects

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Abstract. In the computing environment of the "smart cities" projects actually a number of complex devices are operating. They are implemented in physical objects connected to the Internet. They, in turn, support a set of diverse communication means and protocols for data exchange. Such system integration ensures efficient supply of a wide range of services, forming due to the combination of both virtual and real physical devices, innovative services formed on the basis of modern information and communication technologies.

The authors analyzed existing in modern "smart cities" projects implementations and architectures developed on the basis of the IoT,, generalized them and defined the principles of their complex application with information technologies of other classes such as cloud computing, Big Data, analytical data processing technologies, as well as their integration with information models of heterogeneous processes and systems presented in the form of databases, stores and data spaces.

The authors designed and implemented the information-technological platform for telemetric accounting of water, heat, gas and electricity consumption focused on the implementation in the "smart cities" projects. Several generations of digital devices for telemetry data transmission with the ability of connection to the Internet network by means of network interfaces (LANs) and mobile network are used in the base version of the offered platform.

The data concerning the implementation in the leading Ukraine technical universities of the specialty "Information Systems and Technologies" majoring in "Internet of Things" with the curricula providing the study of "Internet of things for smart cities" subject are given.

Keywords: Internet of Things, Big Data, smart city.

1 Introduction

The concept of Internet of Things (IoT) was offered by Kevin Ashton in 1999, when the distribution of devices with intelligent sensors integrated with the appropriate communication tools started. Internet of Things are defined as self-organized systems having no conceptual limitations, being the part of the convergent systems and are designed to increase the efficiency of processes in these systems. In its turn the IoT-applications

[1] are defined as sets of connected or integrated objects or devices into the environment. These objects or devices use the standard communication protocols for information exchange. The results of the carried out investigations prove that at present the number of connected Internet of Things, exceed the number of the planet population and their variety and diversity include a lot of devices which can be used as unified block solutions while implementing the innovative projects of the future “smart cities”.

Two areas of the “smart city” concept were clearly defined by the researchers and experts working out the real innovative projects for implementation in modern cities. [2]. On the one hand, it is a methodological view on the technologically concentrated information and communication platform effectively providing the implementation of the key computing algorithms and IT service complexes and systematically integrates numerous diverse devices built into specific city objects and urban environment as a whole. On the other hand it is more socially concentrated concept focusing on the methods, means and ways of formation of the new knowledge-based urban society and innovative high-tech urban economy. A reliable bridge between them are the processes of selection and effective use of data concerning the urban activities, their complex analysis in order to generate powerful tuples of new information services designed to optimize the wide range of the processes of the modern city functioning related by specialist as hypercomplex system. Technology of Internet of Things (IoT) is regarded by many researches and experts as one of the key information technologies focused on effective implementation of such functions.

The term "Internet of Things (IoT)" in early professional publications was defined as Internet Everything, Internet of Everything, Internet of People, Internet of Signs, Internet of Services, Internet of Data, Internet of Processes [3].

In the paper [4], IoT is interpreted as a network of related physical objects. “IoT” integrates people, processes, data and things in order to make the network connections more relevant and valuable than ever before, transforming information into action and creating new areas of application, wider experience and unprecedented economic opportunities for enterprises, individuals and countries in general.

Internet of Things have sets of characteristics formed in accordance with the set tasks in a particular research area. Because of the incomplete formation of the terminology base, it is reasonable to provide the basic definitions and terms characteristic to modern innovation class of information and communication technologies. The basic concept of Internet of Things, technology is the implementation of the paradigm according to which "almost all Internet of Things are interconnected" transformed into the implementation of the following characteristics:

- Convergence provides the ability to process arbitrary types of data (text, photos, video and audio, etc.) by means of any technological device.
- Connectivity - allows you to connect anywhere and anytime.
- Connection - provides the means for communication with any network in any way.
- Content - available from anywhere at any time, without content restrictions.
- Calculations – are available to everyone who has knowledge concerning the principles of operation without limitation of duration and time of access
- Collections - are the set of services or any particular service available for solving an arbitrary list of tasks.

In paper [5], the “Smart cities” application architecture is presented in order to manage the data obtained with IoT devices, and in papers [6], [7] the connection scenarios of IoT devices using Service-Oriented Architecture (SOA) are concidered. Papers [8], [9], [10] provide the frameworks and control system for the analytical processing of BigData of the "Smart city", and paper [11] describes the platform for the provision of administrative services. Information on service-oriented cyber-physical systems for mobile applications of the "Smart city" is given in [12], and for production systems in paper [13]. The multi-level cloud architecture model is described in [14]. In a number of works, the service-oriented approach is actively used in the IoT architecture [15], the integration of IoT devices into traffic monitoring systems [16] and open data from IoT-devices [17], in the systems for monitoring environmental safety, health care and safety (EHS) industries [18], automobiles parking [19].

Creating applications on the IoT platform in the “smart cities” projects it is reasonable to formulate the comprehensive systemic view based on procedures of the unification of relative architecture, innovative information-technological principles and methods of Internet of Things interaction.

2 “Smart city” – Basic Concept

Information and communication technologies are focused on solving problems connected with the growing complexity of urban complexes, urban infrastructure networks, urban population, and stimulate the implementation of the innovative "smart cities" projects of the future. The concept of the "smart city" is intended to be implemented in the complex urban environment including a variety of complex infrastructure systems, the behavior of numerous urban communities, innovative advanced technologies, social and political structures, a diversified economy, etc. The "smart cities" projects provide for the implementation of sound management methods for urban components and subsystems, such as transport, health care, education, power engineering, the system of factors affecting protection and improvement of the environment quality, etc.

Over the past few years, the unprecedented increase in the amount of various types of information flows, which source are social networks [20] and the Internet, that in its turn caused the emergence of the new class of information technologies such as Internet of things technology (IoT) [21], [22]. Information flows from social and sensory networks can be integrated in order to search for hidden correlations and associations to extend the diversity of information and services provided in the "smart cities". Information-technology applications of such type are implemented in a number of innovative projects such as Wiki City [23], City Sense [24], Google Latitude [25]) and in the development of the diverse social and urban sensor networks [26], [27], [28]. The advantages of the integrated use of information resources of social networks and information flows generated by numerous Internet applications are clearly demonstrated in the "smart cities" projects , financially supported by the European Community [29], [30].

The rapid processing of Big Data of poorly structured data in the "smart cities" projects involves a wide range of activities concentrated on the selection, transmission, transformation, storage and analytical processing of information flows concerning the state and processes of environmental pollution, weather, accumulation and utilization of wastes, water supply and other natural resources, heat and energy sources, sensory of city events and incidents. At the same time, mining and transformation of data concerning urban life from social networks are carried out. The technologies of data transmission and selection formed by urban engineering components, are based particularly on the use of wireless sensors integrated into numerical industrial and service information-technological applications. The combination of data obtained from both physical sensors and social sources contributes to the formation of full picture of city-wide processes, complexes, subsystems and structures.

Information systems of the "smart cities" on the basis of modern information and communication technologies provide powerful, intellectual support both to the urban population in general and to municipal authorities, in particular. [31] Figure 1 represents the basic components of the modern innovative concept the "smart city".

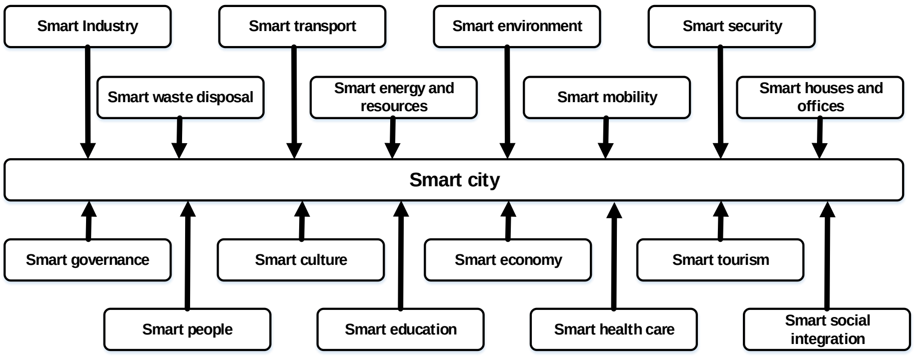

Fig. 1. Components of the "smart city" concept

Analyzing the methodological principles of the development of the integrated information system of the "smart city" of the future the high level of such systems complexity should be taken into account. In general, the modern system of informational-technological support of the main business processes, maintenance of urban engineering infrastructure networks, formation and maintenance of procedures for making optimal decisions at the level of municipal management, efficient formation and functioning of the city socio-communicative environment can be referred to the category of hyper-complex systems. One of the most effective tools for such systems analysis is the structural functional-decomposition approach, the main subject of which is to analyze the basic functions of the separate components of the hyper-complex system, the means and methods providing the performance of these functions and implementing the hyper-complex inter-component interaction of elements of a functionally separated part (subsystem) of the general hyper-complex system. In this case the selection of such functional complexes as the "sensory" subsystem of the "smart city", the network infrastructure of the IoT technologies cluster in the "smart cities", integration of IT technologies with Big Data and Cloud computing technologies, data stores and spaces, as well as Data mining and OLAP are concerned. Only such generalized system approach to the construction of the comprehensive "smart city" information system of the future can generate significant innovative energy effects from its implementation and large-scale implementation with new qualities for its inhabitants living conditions.

3 Sensory Structure of the "Smart City".

At present the primary sensor complexes implemented in specific physical objects or numerous smartphones of the city inhabitants and guests playing the role of socio-communicative mobile sensors, are the informational-technological foundations of IOT technologies cluster in the "smart cities".

Sensors implemented in systems and domain elements of the "smart city" concept are the main sources of generating heterogeneous information sets. Information from sensors is collected due to IoT devices connected to the communication networks. Smartphones connected to mobile networks GSM / 3G / 4G are used for selection and transmission of socially oriented urban data. The data collected in such a way are processed and analyzed in the "smart city" analytical data processing center which virtual prototype is reasonably to deploy on the cloud platform using cloud data stores [32]. The combination and consolidation of data obtained from the sensors in complexes of the domains of different types make it possible to improve significantly the parameters of services and information-technology services provided by the "smart" urban program-algorithmic applications (Fig. 2).

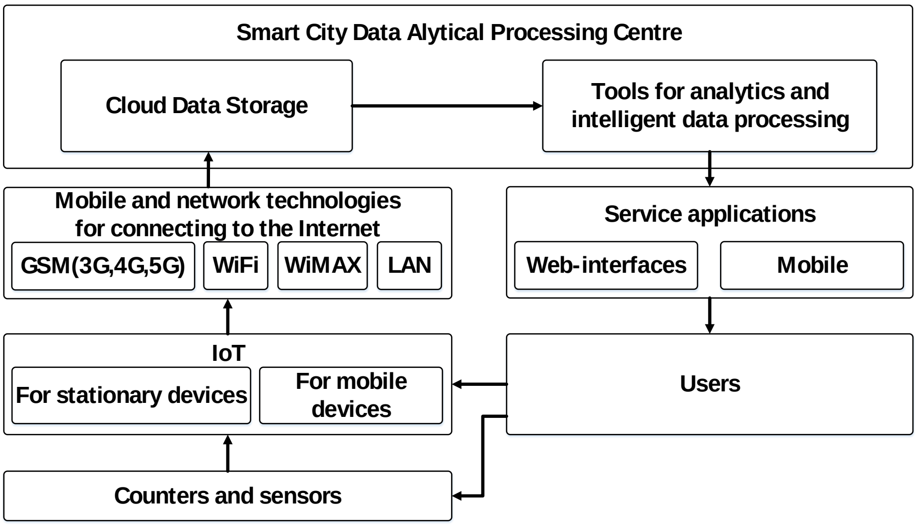

Fig. 2. Virtual "cloud prototype" of the "smart city" analytical data processing centre

The examples of such information-technological applications formed on the basis of functional sensors physically implemented in real objects, as well as socio-oriented sensors such as smartphones, tablets, etc. are:

- "smart illumination" - designed to reduce energy consumption [33] accomplished due to IoT light sensors use [34] along with the comprehensive system for street illuminating adaptation [35].
- "smart noise control" - designed to detect noise sources and identify the points of excessive noise pollution of the urban environment in real time mode [33].

- "smart surveillance cameras" - designed to monitor the security situation in order to track suspicious actions that may endanger the city residents or municipal property [36].
- Modern sensors in the "smart cities" projects are able to generate Big Data. Contextual analysis of data obtained from sensors for identifying hidden correlations plays a key role in the development of "smart" urban information-technological applications [37].

Nowadays the implementation of a large number of projects concerning the development of multi-type monitoring systems particularly for tracking the location of bicycles, cars, and free space in public parking, etc. using sensor complexes and IoT infrastructure is carried out (Fig. 3).

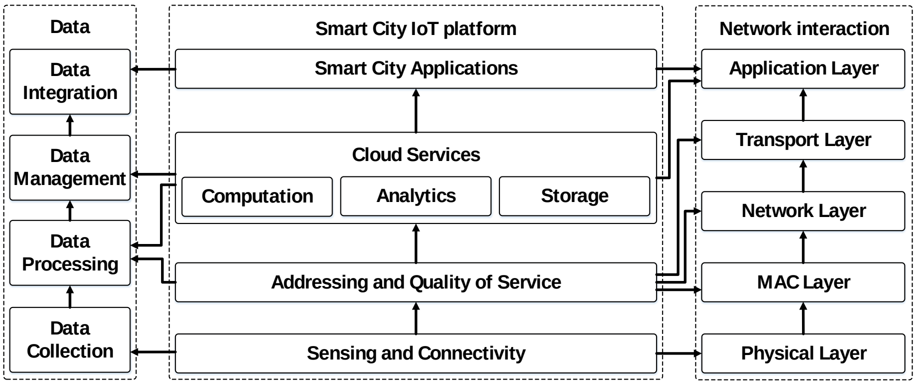

Fig. 3. IoT infrastructure along with the data and communication stacks

Sensor devices and sensors, of RFID and WSN technologies are the main ones in the given architecture at the "sensory and connection" level. RFID technology provides automatic identification of network objects. Wireless Sensor Networks (WSN) are able to collect, process, analyze and distribute data generated in different environments [38]. Due to the availability of compact, cheap, intelligent and widely used sensors (such as built-in video cameras), WSN plays an important role in implementing IoT-based urban applications.

The development of social networks and the widespread use of the smartphones defined the new sensory paradigm. According to it the active participation of citizens in the processes of primary data files formation and their use for management and interaction with the municipal authorities is rapidly growing.

The addressing system provides a unique identification of objects allowing to recognize hundreds of thousands of devices and providing the ability to control them remotely. All devices connected to the network are uniquely identified by their location and have functional able to provide scaled addressing space. It is effective to use IPv6 protocol having the extended addressing space and providing new IoT-devices with unique addresses. The protocol is compatible with state-of-the-art devices and communication technologies, provides versatility, stability, scalability, manageability and ease of use when applied in the devices with limited resources [39].

For the implementation of the "smart city" comprehensive information system of the future wide networks of stationary and mobile sensors, video cameras, street emergency stop buttons and a number of other devices are expanded on the basis of the IoT. The types of sensors used in the “smart city” information systems [40] and by the municipality, the city residents and guests to make optimal decisions based on intelligent analysis of poorly-structured Big Data in real-time mode are shown in Fig.4.

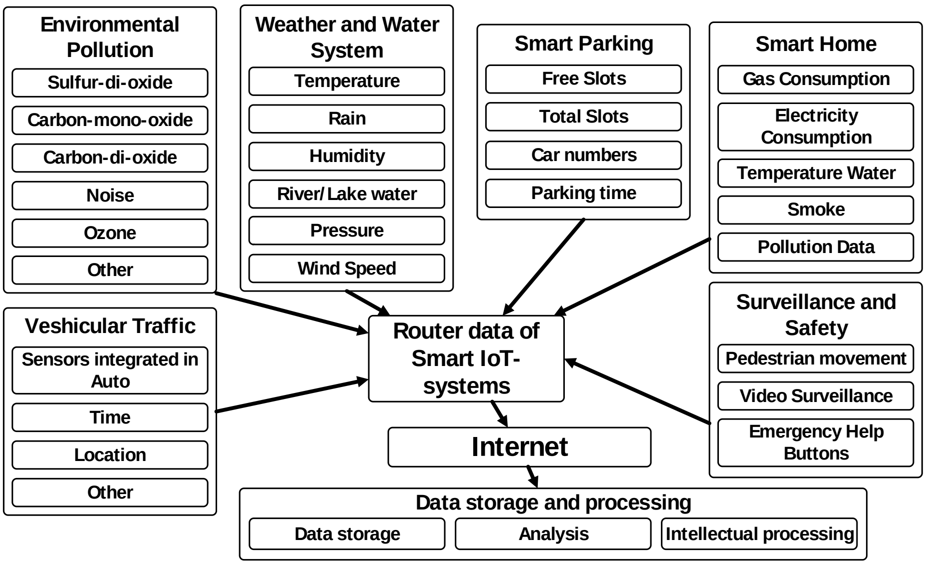

Fig. 4. Sensory structure of the "smart city" using IoT

In "smart houses" as the structural components of the "smart cities", telemetric data from sensors in real-time mode are constantly controlled. Smoke and temperature sensors are used to detect fires, and flowmeters of different types provide monitor processes for electricity, water, gas and heat consumption. "Smart" cars parking places implement the function of intelligent vehicle driving. Meteorological monitoring systems provide data concerning the state of weather, external temperature, precipitation, humidity, atmospheric pressure, wind speed and water level in rivers, lakes and other urban ponds. Usually, rains and melting snow cause floods, so meteorological sensors are used to predict the level of water in reservoirs.

The subsystem of data collection dealing with the state of the environment can generate from the messages about gas pollution, the level of ozone and noise in the city.

4 Generalized Architecture of the "Smart City" Information-Technological Platform

The investigations carried out by the authors made it possible to formulate and specify the basic requirements for the generalized architecture of the "smart city" information-technological platform. The reference architecture model developed according to the indicated requirements provides effective implementation of a wide range of information-technological innovations, such as cloud computing, IoT, BigData, Data Mining, information models of processes and systems in the form of databases, data stores and data spaces in certain realizations. Figure 5 represents the generalized architecture of the “smart city” information-technological platform using the IoT technology cluster roughly decomposed into 6 levels: sensory level, network level, receiving level, storage, processing and visualization level. The sensory level in its turn is relatively divided into three components. The sensors sublevel contains water, gas, electricity and heat consumption meters. It is supposed that both mechanical and smart meters of consumed resources and services can be used in the system. It is predicted that the indicators of mechanical flow meters are recorded by means of impulse converters. The counters are systematic-connected to IoT devices on the basis of the industrial M-BUS protocol, RS485 and RS232 interfaces, analogue and pulse inputs represented in the appropriate sub-level (Interfaces for connecting sensors).

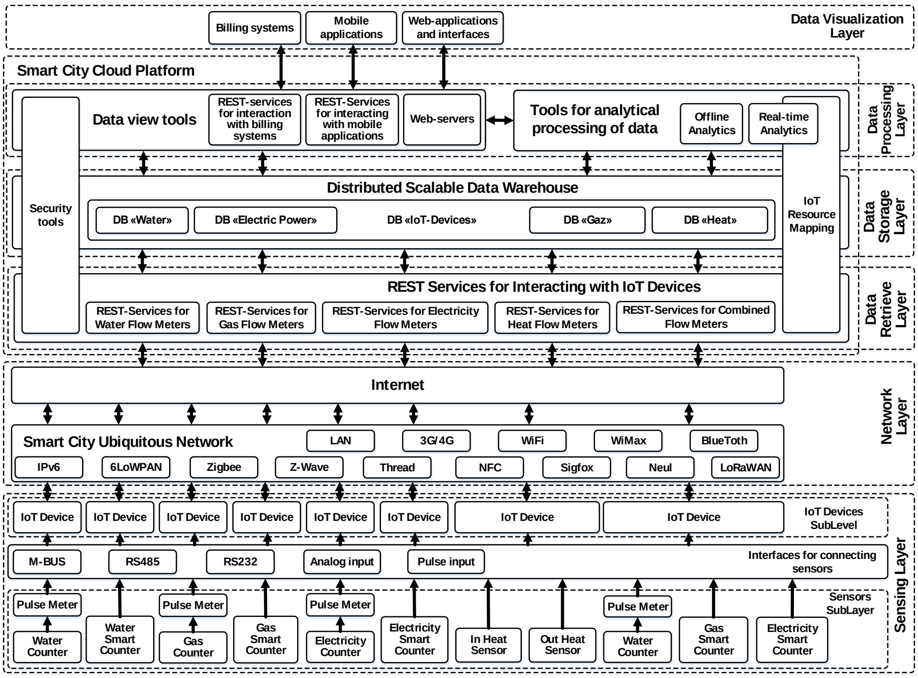

Fig. 5. Generalized architecture of the the "smart city" information-technological platform

At the next sublevel the IoT-devices are provided assuming that different types of IoT-devices with connected meters can be implemented. In order to take into account heat consumption indicators, the use of input and output heat sensors is predicted. In this case, the amount of the consumed heat is calculated as the difference between their indicators.

In a generalized architecture, the network layer contains a widespread urban network of the “Smart city” which by means of LAN, 3G / 4G, WiFi, WiMax or BlueTooth and

IPv6, 6LowPAN, ZigBee, Z-Wave, Thread, NFC, Sigfox, Neul, or LoRaWAN communications technologies provides access of IoT devices to the Internet network.

The next three levels are implemented on the basis of on the "smart city" cloud platform. At the data acquisition level the REST-services for interacting with IoT-devices can be implemented either as specialized (for a certain service, such as water, gas, heat or electricity supply), or combined flow meters. The data sets collected at this level enter the next level and are stored in the distributed scalable data store where the corresponding set of information entities is generated for each IoT-device. Information entities can be grouped into thematic databases. Offline and real-time analytical processing tools and data entries such as REST-services for interaction with billing systems, REST-services for interacting with mobile applications and web servers are grouped on the Data Processing Layer. These tools are used to interact with billing systems, mobile applications, web applications, and interfaces located at the visualization level. Represented in the generalized architecture of the “smart city” information-technology platform Security tools and the IoT Resource Mapping technologies cluster provide security procedures, access rights differentiation and IoT-devices identification.

On the basis of the offered generalized architecture the authors have designed and implemented the information-technological system of telemetric recording of water, heat, gas and electricity consumption focused on the implementation in the "smart cities" projects. Several generations of digital devices for telemetry data transmition with the abilities to be connected to the Internet by means of network interfaces (LAN) and mobile networks were used in the basic version of the offered system. Sensors can be connected to the digital devices using interfaces for connecting sensors.

Newer generations of digital devices can communicate with the REST-service on the remote web server in a dialogue mode. The received data sets concerning consumed services are stored in the distributed scalable database. The next versions of the system predict significant expansion of its functional possibilities using the architecture and data exchange methods typical of IoT-technologies.

5 Educational Course "Internet of Things for Smart Cities"

The citywide information system of integrated monitoring and analysis of payments for consumed resources along with the maintenance of production-business functions can serve as an effective educational-methodological tool in educational processes increasing the urban community "knowledge potential" dealing with the problems of economical consumption and the efficient use of the wide range of resources and services . The processing and analysis of Big Data from sensors, meters and flow meters allows us to develop recommendations for consumers regarding optimal time profiles, operating modes of household equipment and predicted volumes of necessary resources.

At the same time, this system can be used as the training-laboratory stand model for conducting classes with students of a number of specialties, implementation of real course projects and simulation of many processes requiring the study and analysis in the "smart cities" integrated information systems based on information-technological IoT platform.

According to firm CISCO [41] report the IoT market by 2022 will be $ 14.4 billion and will make it possible to:

- improve the customer experience;
- reduce the time needed from the idea of new product creation till its market appearance (time-to-market);
- improve the ways of delivery and logistics;
- increase the employees productivity;
- use the assets effectively while reducing overhead costs.

Training new generation of specialists who are aware in the IoT field is becoming more and more important.

New educational and professional curricula for training specialists in the field of “Information Technologies” are developed in the Universities of Ukraine in cooperation with IT-firms. New methods and approaches to the training of respective Bachelors and Masters at the Universities are changed.

The National University “Lviv Polytechnics” implemented the joint project of the University and the Lviv IT-cluster concerning creation of educational and professional curricula on specializations "Internet of Things", "Artificial Intelligence Systems", "Data Science".

In the Ukrainian Catholic University implemented the innovative Bachelor's curriculum in computer sciences developed in cooperation with the IT-industry representatives.

The specialists training in the educational-professional curriculum on specialty "Information Systems and Technologies" was initiated by a number of leading Ukrainian universities. One of the Master's educational program specialization for specialists training is particularly the ‘Internet of Things”. Within the framework of the above mentioned program, the course "Internet of Things for smart cities" was introduced to the Master's level curriculum. It is based on the knowledge gained in such disciplines as algorithms and data structures; object-oriented programming; database and knowledge; distributed and parallel computing systems; data store; intelligent data analysis for business analytics; web technologies and web design; architecture of computers and networks; information technology for monitoring and data analysis; information systems design.

Introduction of the "Internet of Things (IOT) for the “Smart cities" course into the curriculum makes it possible to use the offered engineering-technical solutions in the process of Masters training in the educational professional program of "Information Systems and Technologies" specialty.

The "Internet of Things for smart cities" course study involves carrying out the cycle of laboratory works, the course project, as well as the development of series of analytical papers.

The topic of the laboratory work is connected with information- technological support of infrastructure engineering networks and life support systems of the city. These are particularly the information systems for recording of gas, water, heat, electricity consumption and other expenses.

The specified laboratory works of the cycle involves the execution of a number of tasks, such as the construction of structural schemes of the relative subsystems, consisting of four levels (measuring level, messages transmission level, data storage level and data presentation level).

At the measuring level the selection and interpretation of the primary measuring converters used to select data concerning the consumption of the relevant resources is predicted. It motivates the student to give arguments about the design decisions he or she made.

At the data transmission level the student analyses the available decisions, selects and explains the choice of the controller, carries out the comparative analysis of cellular network parameters.

At the data storage level the student analyzes the work of data acquisition modules, data loads, selects certain FTP-server, Web server and DBMS.

At the presentation level the student offers solutions concerning the peculiarities of the system web interface.

It should be noted that the topics of these laboratory works can be related to the most diverse aspects of the city functioning.

The students are offered to develop one of the information systems as topics for course project in "Internet of Things (IoT) for smart cities" course:

- monitoring the availability of the city car parking places;
- monitoring the measurements of vibration parameters of city buildings, bridges and historical monuments;
- the city smart illumination;
- analysis of waste pollution levels and optimization of routes for garbage disposal vehicles;
- control of the enterprises and automobile engines CO_2 release;
- monitoring the running water quality;
- monitoring and management of the city energy consumption;
- processes of the water supply network functioning, etc.

The course projects are developed in teams of 3-5 students, and the result of their implementation are mobile information and technological applications.

During semester the students are encouraged to make a report based on the scientific publications in professional journals and collections of scientific papers, scientific-technical reports and reports delivered at scientific and practical conferences. This includes particularly the development of analytical reviews concerning the state and results of scientific research and practical developments on important and perspective research topics. As an example, we give the suggested list of analytical reports:

1. Monitoring systems of leakage and waste release into seas, river basins and ponds in real time mode
2. Systems for monitoring changes in water levels in rivers and ponds on the example of Lviv, Transcarpatia, Ivano-Frankivsk, Odesa, Mykolaiv, Kherson regions
3. Monitoring systems for radiation level measuring in the cities located in the areas of the nuclear power plants influence
4. Monitoring systems for the detection of gas leakage in industrial environments
5. Systems for monitoring the products storage conditions

6. Monitoring systems for toxic levels of gas and oxygen at chemical plants.
7. Detection and monitoring of penetrations into the "Smart House" system
8. Systems for monitoring climatic conditions in museums, libraries, archives.

6 Conclusions

The materials given in this paper were developed by the authors according to the results of investigations carried out during two years in the virtual scientific-research laboratory "The smart city of Ternopil" at Ternopil Ivan Puluj National Technical University.

According to the results of the investigation we can confirm that:

- first, the use of information and communication technologies relating to the innovation technological Internet of things cluster in projects of the "smart cities" of the future is an important scientific task;
- second, the implementation of the "smart cities" information-technological projects should take place in the context of the most comprehensive use of the methodology of the system approach to hyper-complex systems, one of which is the system complex of the modern city;
- third, the information-technological platform for implementing the “smart cities” projects of the future should provide the integrated use of a number of modern technologies such as Cloud computing, Big Data, IoT, Data mining GIS, OLAP, Data Base, Data Weryhaus, Data Space, etc.;
- fourth, certain and almost the most important component of the “smart city” complex information system should be the IoT technologies serving as a methodological basis for the creation of sensory component of the innovation information-technological complex;
- fifth, the "smart cities" information-technological projects should be implemented on the basis of reference architecture model with the previous development of the models and prototypes complex on which industrial technology solutions are worked out;
- sixth, the large-scale design and deployment of the "smart cities" information-technological projects requires creative specialists training in relevant IT specialties and specializations.

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