End-to-end digital technologies in “smart cities” of Russia

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Abstract. The article is dedicated to the end-to-end digital technologies of Industrial Internet of Things, big data and artificial intelligence used in “Smart City” project. The focus is on TRL and CRL technologies technological and commercial readiness assessment systems. Information system for monitoring, remote control and support of engineering systems technical condition at Housing and Utility Infrastructure facilities is studied and its readiness for use in “Smart City” project is evaluated.

Key words: smart city, end-to-end digital technologies, technology readiness level, commercial readiness level

1. Introduction

Smart City is an integration of communication technologies and Internet of Things for municipal property and services control. World market of Smart City solutions has been showing high rates of growth in recent years; according to Grand View Research (2018) its volume can exceed $2.5T by 2025. The key segments of the world market include “smart” services and “smart” public administration. As estimated by Frost & Sullivan, the fastest growing market segments are “smart” energetics and “smart” transport. IT-solutions market volume for smart cities of Russia exceeded RUB 81B at the end of 2019 [1].

The first domestic standard called “Basic and Additional Requirements to Smart Cities (The Standard “Smart City”)” was approved in March, 2019 [2]. Currently there are another 8 national standards approved and three more are put out for public hearings. 19 cities from 11 regions of Russia are involved in the project; “Smart City” project is most actively implemented in Moscow.

Active promotion of “smart cities” concept is driven by such factors as a rapid growth of cities population, where up to 70 % of world economy is concentrated, high rates of Internet of Things world market development and implementation of new mobile communications standards, reduction of Smart City solutions implementation costs. State support of Smart City ecosystem development is a no small matter. The main barriers, restricting the full-scale development of smart cities, include the fact, that significant amount of Smart City solutions are still at approbation and introduction stage and are not ready
for scaling, while still being expensive [1]. Currently, in terms of opportunities to implement in Russian cities, the best Smart City solutions are the ones that are part of “smart” Housing and Utility Infrastructure, “smart” city transportation system, solutions in the area of intelligent technologies of data processing and control, “smart” health care.

The article is dedicated to the analysis of domestic digital technological solutions readiness to “Smart City” project implementation.

2. Main approaches to the problem

“Smart City” project should have large functionality of process solutions. They include “smart” Housing and Utility Infrastructure, ecological safety intelligent systems, “smart” city transport, “smart” municipal government, innovations for urban environment and communication networks infrastructure, public safety intelligent systems, tourism and service [3, 4].

Therefore, the basis of smart city implementation is a common usage of the end-to-end digital technologies, primarily of Industrial Internet of Things, big data and neurotechnologies and artificial intelligence.

*Industrial Internet of Things (IIoT)* is a concept of information and communication infrastructures building, implicating connection of any non-household appliances, equipment, gauges, sensors, etc. to Internet, as well as integration of these elements with one another, resulting in creation of new business models during both creation of products and services and their supply to consumers. The technological basis of Industrial Internet of Things consists of four levels: perception level, data transmission medium, IIoT platform and applications. Each of these levels includes a large amount of technologies and implementations [5].

IIoT platforms implementation uses distributed computing paradigm, including Cloud computing, Fog computing, edge computing, dew computing (DC) and their various combinations [5, 6]. Cloud computing is a distributed data processing technology, in which computer resources and powers are presented to a user as Internet services. Edge computing is a computational model, that allows to store and(or) process data at network edge and provide intelligent services near data source together with cloud computing. Fog computing assumes transfer of data computing and storing from traditional cloud to intermediate layer of devices located closer to network edge, allowing to reduce load on communication medium and devices. DC is based on microservices concept, its computing hierarchy is vertically distributed. DC approach simplifies usage of such resources as sensors, tablets and smartphones, that are easily connected [6].

There are several types of cloud computing architectures, implicating distributed logic of data processing, so called preprocessing. With increase of volume of transmitted data and IoT usage the number of problems appear. It includes the fact that computing capabilities with linear growth of centralized cloud computing cannot meet the demands of data processing from several data sources, network bandwidth and transmission rate became too low, number of mobile users connected as “thin client” is growing, and there is a necessity to provide data safety and maintain confidentiality [7, 8]. To solve such problems, when a system scale is too big (dozens of millions of devices) and network infrastructure covers thousands of square kilometers, it makes sense to use various combinations of abovementioned types of distributed computing [9-13].

*“Big data” end-to-end digital technology* is a new generation of technologies intended for cost-effective retrieval of useful information from extra large amounts of various data by means of high rate of data collection, processing and analysis. There are multiple evaluations of the limit, outside of which data are considered really big, from petabyte ($10^{15}$ bytes) to exabyte ($10^{18}$ bytes), however it is methodologically correctly to describe this scale using so called V-model. The most commonly named factors of this model are Variety, Velocity (processing rate) and Volume (storage amount). Some sources complement this model with such factors as Value, Validity, Veracity and many others [8, 14].
Data collected through IIoT for smart cities from smartphones, devices, video cameras, global positioning system, etc. are notable not only by large volumes, but also by vast variety. Therefore, intelligent analysis and efficient use of collected data become the task of importance.

“Neurotechnologies and artificial intelligence” end-to-end digital technology is based on intelligent data analysis methods and machine learning. Data Mining includes methods of identification of hidden patterns or relations between variables in large sets of unprocessed data. It is divided into tasks of clustering, classification, recognition, modeling, forecasting and others [15, 16]. In terms of smart city systems, the most interesting is a creation of devices, that use methods and tools of applied artificial intelligence for objects parameters analysis and arrangement of bidirectional communication of a device and monitoring and control system.

Under Smart City concept these three end-to-end digital technologies are used for completing the tasks of efficient use of city physical infrastructure to support economical, social, cultural development, interaction with residents on community affairs and for making decisions by means of electronic interaction, implementation of electronic control elements with participation of citizens and collaborative design of urban environment, achieving high level of adaptation to new technological solutions implementation[17].

3. Proposed approach
Let’s make a comparative analysis of domestic developments readiness in these areas. For assessment we use international systems Technology Readiness Level (TRL) and Commercialization Readiness Indicators (CRI). Assessment of Technology Readiness (TRL) is a system of 9 indicators, defining technology readiness levels at various stages of their development: main principles of new technologies are established; concept is formed; analytical and experimental validations of the concept are received; prototype is laboratory tested; prototype is tested in conditions similar to actual; technology demonstration using the prototype; technology demonstration under service conditions; the technology passed the tests and approved; operational use of the technology[18]. Assessment of commercial readiness (CRI) supposes usage of 6 levels: early venture stage – potential opportunity of commercial application; sales – the first commercial applications; growth – scaling of commercial product; commercial application area extension; business – active extension, operation on competitive market; stable business, access to bank assets [19].

The corresponding sub-technologies were identified in road maps of end-to-end digital technologies (2019) [20]. Their readiness assessment is presented in Fig. 1.
Therefore, the majority of domestic developments are at 5-7 level of technology readiness, i.e. either the technology was tested using prototype under conditions close to actual or the technology was demonstrated using the prototype or under service conditions. They all show significant potential opportunity of commercial application. State support, presented in Road Maps for NTI, is required for the further development of technologies.

Let’s examine the information system (IS) for monitoring, remote control and support of engineering systems technical condition at Housing and Utility Infrastructure facilities in smart cities, developed earlier by the article authors (IS class – “Smart Housing and Utility Infrastructure”) [5, 7, 8].

IS developed is fully based on digital technologies examined above; its main functions include:

- equipment status monitoring and fault detection,
- determination of fault cause (fault classification),
- equipment status monitoring and determination of fault cause (fault detection and classification),
- fault prediction,
- determination of anomalies and deviations from normal operation of equipment (equipment health monitoring),
- prediction of the best time for maintenance based on operation data (predictive maintenance) [8].

The system architecture assumes distributed logic of operation and implements preprocessing based on edge and cloud computing concepts, that provide the following functions: characteristics reading from sensors, local real-time analysis, filtering (“poor” artificial intelligence). Preprocessing is performed based
on developed association rules [21] and implemented as a developed control and monitoring controller with obtained patent [22]. Predictive analytics, implemented based on cloud computing, include data storing, knowledge extraction based on intelligent data analysis, reporting, predictive analytics, decision making. Predictive analysis in the monitoring system is performed using Markov chains and cluster analysis [23].

4. Results
The considered development is at the interface of such sub-technologies as “Industrial Internet of Things platform,” “Big data collection,” “Big data processing and control” and “Recommendation systems and intelligent decision-support systems” and is typical for the Russian Federation. Let’s evaluate its readiness level for usage in smart city.

This development has passed demonstration using the prototype, and, based on techno-economical feasibility, showed a significant potential opportunity of commercial application. Results of Markov chains usage for solving the problems, arising during Housing and Utility Infrastructure devices status prediction, were acceptable. The examined devices include heating boilers, vent systems, conditioning systems, etc. The observed results were used in implementation of fault prediction function for predictive maintenance of actual equipment.

Therefore, the examined development belongs to level 7 of TRL and level 1 of CRI. Innovations transfer is required for its further commercial application, since the system’s intellectual rights are acquired, and organization, by means of self-investment or selling the technology rights, can transfer to innovative product production, and later to production extension.

5. Summary
In this article we presented the assessment of readiness of domestic developments in the area of “Smart Cities” using the example of a typical development, particularly – information system intended for Housing and Utility Infrastructure facilities monitoring. The observed results show potential of these solutions commercial application.

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