Smart City 5.0 as an Urban Ecosystem of Smart Services

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Abstract. In this paper, Smart City is described as a live and constantly developing complex adaptive system operating in an uncertain environment with many participants and actors involved. The vision of the "Smart City 5.0" concept as an ecosystem of smart services based on multi-agent technology is presented. It is characterized by the cooperation of Artificial Intelligence systems and humans, and can harmoniously balance all spheres of life and contradictory interests of different city actors. In this concept, each smart service is presented by an autonomous agent. They can compete or cooperate with each other through a service bus and interact both vertically and horizontally on the basis of specialized protocols. Top-level services can be constructed as autonomous multi-agent systems of a lower level, where an agent can recursively reveal a new service for itself. The paper describes the design principals and the general architecture of the digital platform including the basic agent of smart service, the architecture and basic principles of smart city ontologies and knowledge base. The paper shows how the platform can support the decision-making life cycle for managing any urban object and the adaptive behaviour of Smart City 5.0 is compared with the fixed scenarios Smart City 4.0.

Keywords: Smart City 5.0 · Ecosystem · Smart Services · Multi-agent Technology · Artificial Intelligence

1 Introduction. Problem Statement

Current Smart City (SC) concepts move towards closer integration of various control, information and communication technologies, including for example the Internet of Things (IoT) for managing urban resources.

However, the most promising future vision of Smart City concept comes from the fact that any city is a complex system of systems with many participants and actors, operating in an uncertain environment [1]. In that case it should be viewed as a constantly developing complex adaptive system [2] that self-organizes, evolves in all its spheres and constantly acquires new knowledge about citizens and services in order

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to make its inhabitants happy, to provide a comfortable and safe environment, efficient and reliable infrastructure of the city, reasonable prices for various services and other goals.

Today Smart City applications, in general, have nothing in common with Artificial Intelligence (AI) - systems associated with the digitization of knowledge and the automation of thinking processes, in particular, decision making [3]. Moreover, until now, the development of Smart City software solutions around the world is carried out without any possible end-to-end system integration and is designed for independent use. That creates the effect of local automation by a number of small services. This is also true for the data generated within the Smart City environment. It is fragmentary and heterogeneous, different in formats and sometimes contradictory.

The problem of combining different Smart City solutions and approaches in one semantic and functional space is becoming crucially important for many cities.

2 State of the Art

The problem of local automation and lack of bottom-up approaches has already been recognized by leading developers of Smart City solutions initiating a number of consolidation projects in Europe, Japan, China, United States and other countries [3].

Roscia et al. [4] present an approach of Smart City transformation based on a combination of interacting subsets. They describe the idea of dynamic infrastructure and creation of balanced solutions between different smart services. The general idea of the paper is that the future Smart City model should be intelligent, distributed, autonomous, based on smart agents and work as a collaborative network. The Intelligent Distributed Autonomous Smart City platform presented in [4] does not consider the semantic interoperability of Smart Services and provides more technical realization and a universal agent model. Also, it does not provide the answer to heterogeneous services collaboration.

Zygiaris presents in [5] the Smart City Reference Model. He opposes virtual gated communities and corporate enclaves at the heart of SC. He states that SC should be created as public-controlled integrated operating systems. Chamoso et al. [6] note the increasing demand for smart sensors to create SC based on the IoT. He analyses the functionality of different platforms (IBM Intelligent CitySDK, Sentilo, Open Cities, Operation Center, i-SCOPE, etc.) and shows the absence of a universal and open platform for encapsulating information and knowledge in SC. Krylovskiy et al. [7] describe the large-scale Smart City IoT platforms and their complexity, scalability and adaptability. The authors propose a micro service architecture to work on individual parts independently, maintaining its integrity and efficiency. But the current proposed architecture was considered by the authors as a compromise between simple design and implementation of personal services and complexity of distributed systems.

One of the most interesting unifying projects in EU is called “SynchroniCity” in which 8 European cities (Antwerp, Carouge, Eindhoven, Milan, Helsinki, Santander, Manchester, and Porto) participate [8]. The project, far advanced from the usual Smart City context, aims at developing a unique and unified “semantic” space which can be easily understood by an enormous growing number of City applications. The objective of the project is to create the software framework, IoT protocols and organizational principles for the semantic descriptions of data collected from various sources. This will help to make it more accessible for various applications and services.

The current solutions deploy innovative technologies in the public sector based on coherent and structured approaches for the digitalization and transformation. A good example is the Enterprise Architecture tool [1]. It can increase the organizational stability but this approach uses a multi-layered hierarchical architecture.

As we can see the current Smart City projects are mostly about the integration of various control sensors and ICT-based technologies for managing urban resources, but with the certain trend for open frameworks, flexible distributed structures, digitization of knowledge, and automation of decision-making process.

3 The Vision of Smart City 5.0

The main target of the paper is to offer a vision of "Smart City 5.0" which is characterized by cooperation between Artificial Intelligence (AI) systems and humans [9], and can harmoniously balance all spheres of life and contradictory interests of different city actors. This model offers the approach that can help to find a "consensus" between different services and, what is more important, with citizens. Reflecting real life, it should take into account not only past or current information but constantly real time changing interests, preferences and limitations of all the players who should be continuously recognized, analysed, transformed into plans, implemented and controlled.

In this concept, various actors of the Smart City can cooperate and compete with each other. Considering the Smart City, a complex adaptive system, we can see opposite Key Performance Indicators (KPI) in its development. The city, for example, must save and protect its history and architecture, and create opportunities for business and growth. It should be environmentally friendly and have green areas and a good transport infrastructure and parking lots, be comfortably lightened in the evenings and at the same time energy friendly, be an attractive centre of tourism, education, culture, entertainment and sports, comfortable, quiet and peaceful for its residents.

The future and truly intelligent and comfortable "Smart City - 5.0" should be designed on the following principles:

- **Common semantic space.** All elements of the Smart City should interact with each other in one formal "language" described in the "explanatory dictionary" of ontology - a formalized knowledge model of the domain represented as a semantic network of concepts and relationships currently implemented in the framework of the Semantic Web.
- **Digital eco-system of smart services.** The digital ecosystem should combine all smart services of a Smart City. The negotiation can be on a horizontal level when for example "The Smart apartment" services manage all the devices in a local place, but also on a vertical level, when "The Smart Apartment" can negotiate with "The Smart Building", and "The Smart Building" can be a part of the global "Smart District" system. The district will have to know the forecast of energy consumption in its homes, which can be effectively sold in a smart grid with discount.

- **Personal engagement.** Is represented by the involvement of every citizen through a personal account and virtual agent. Residents will become not only consumers of services but also they will form through negotiations better living environment for themselves. This bottom-up approach (without virtual agents) was successfully implemented in Amsterdam (TransformCity – a platform for urban planning and transformation).

To achieve the mentioned principles, the described Smart City 5.0 framework initially should be based on the unified semantic space and the methodology of complex adaptive systems, where each part can operate completely autonomously, but able to interact and negotiate, and through concessions make consistent decisions with other systems [10].

The SC 5.0 concept is based on the theory of complex adaptive systems, new models and methods of collective decision-making. Multi-agent technologies and knowledge bases are used as industrial solutions and applications for solving problems of adaptive resource management [11, 12]. The core "brain" part of Smart City 5.0 will be the virtual "round table" of agents of smart services, similar to the teams of inter-disciplinary experts solving complex problems. In the future, smart service frameworks will be designed as autonomous smart cyber-physical systems (ASCPS), functioning without human participation, able to analyse the situation, make decisions and plan their actions, as well as monitor the execution of plans and results, predict the development of the situation and communicate with all participants [13].

The most important advantage of the proposed intelligent ecosystems will be openness. It will allow new smart systems to enter or leave the digital ecosystem easily, and provide an opportunity for full authorized access to an unified semantic space [14].

4 Smart City 5.0 Platform Architecture and Functions

The Smart City 5.0 will allow to integrate the Smart -* capabilities to the traditional service-oriented systems and modify them in a step by step way to autonomous systems.

The main target of the Smart City 5.0 digital eco-system is to define KPI sets using the knowledge base of the problem domain and to achieve goals [15]. The proposed platform offers the development of a situational approach, which is based on the "model of a situation" ("scene"). The model of the situation in any urban subsystem is determined by:

- The set of goals to be achieved.
- The current state of objects and processes and the connections between them.
- The Log as the history of transitions from the initial to the current state (chain of events).
- The current action plan of participants on the time horizon.
- The values of KPIs, reflecting the gap between the desired (target) and current state.

The situation will be recognized as a problem when a significant discrepancy between the given goals and the observed values of the KPIs are discovered. The emergence of a problem situation will initiate the virtual "round table" and negotiations between agents of the services involved. These services will coordinate through negotiation their decisions, adapt their plans of actions and implement these plans in reality.

The general architecture of the digital ecosystem supporting the decision-making life cycle for managing any urban object is presented in Fig. 1.

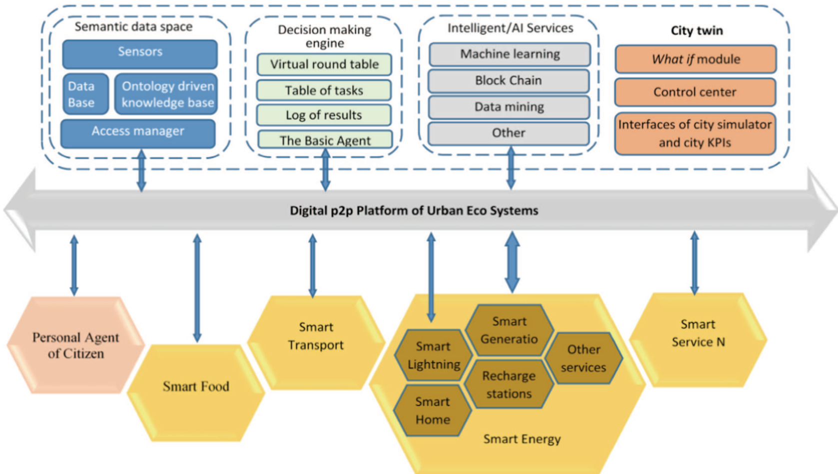

Fig. 1. Digital platform of urban ecosystems

The proposed solution requires Peer-to-Peer (p2p) network of planners on a platform layer, which unites heterogeneous systems and allows them to communicate with each other in order to achieve coordinated and optimal results. It will also allow negotiating personal schedules with each other.

The architecture of the new Smart city platform includes the following main components:

Semantic Data Space. For proper real time work, the Smart City 5.0 framework should use a unified semantic data space. It is a complex module that includes: sensors for real time data collection, a database for data storage, an ontology-driven knowledge base to collect and describe formal and informal logic of decision making and transfer data to knowledge. The last element of the semantic data space is an access manager that helps to organize the collection, storage and validation of data and to manage the access to data for Smart Services.

Decision Making Engine. The mathematical method and model for solving management issues between Smart Services or within one service will be based on multi-agent technology. It allows representing the process of managing urban infrastructure as a process of negotiation, evaluation and consensual decision making at a virtual round table (in this concept services act as an independent group of actors and interdisciplinary experts of a certain problem domain). Each smart service is presented by an autonomous agent that is trying to achieve the given objectives and maximize the satisfaction function with the use of virtual bonuses and penalties. Detected conflicts are solved between agents by negotiations in the interests of all parties and of the Smart City as a whole.

Intelligent/AI Services. Artificial Intelligence, blockchain, data mining and other services will constantly work providing better decision making on a technical layer of the framework (e.g. data mining tools can help collecting and formalizing knowledge in the ontology-driven knowledge base); they may also provide additional functionality for Smart Services (e.g. the new food service can use for better sales intelligent services).

City Twin. The City twin is a computational model of the city based on its ontological model and integrated data layers of the city's life. It can be used for ongoing simulation and forecasting. Results can be presented by the main control centre of the system. In this module the users can observe the virtual twin of the real city, use *what if* games with City twin, check and manage technical characteristics and also see the KPIs of the real and simulated Smart City in real time. The economic results of the city services are recalculated in real time based on events and data from sensors, and shown on different business radars. The discrepancy between the plan and the reality on the radar motivates the system to revise decisions.

Smart Services. Every service in the platform is initially built as a "smart service". This means it can work autonomously and separately and as part of a bigger service. Like the system as a whole every service works in a cycle of autonomous operating, reacts to events, makes decisions and coordinates these decisions with other services. Every service based on the unified construction pattern has its own basic program agent. The service agent has access via a digital platform to the technical level of the Smart City 5.0 framework (including data from sensors or AI) and to other service agents.

Personal Agents of Citizens. To achieve full personal engagement of all city residents every citizen will have an opportunity to install its own program agent. The agent is adjusted for every user and helps to find better services, provides full access to city news including city wiki, questionnaires and petitions. The personal agent can be installed as an application on the mobile device in an advanced mode that provides personal real time planning. Connecting in one space both schedulers of services and people will lead to the advanced intellectualization of future smart services because of bringing new reach operational context of mobile users into consideration.

City components could be organized into higher urban building blocks: Street, Square, Park, District, Campus, Shopping area, Sports area, Factory area, etc. Integration into higher urban building blocks can be solved through negotiations among the agents [16] in virtual space.

The Virtual World of Smart City or the City Twin is a cyber-physical model of a real city, and can be used in different operation modes:

- **Normal mode** – real time resource allocation, planning, optimization, monitoring and control under given global and local criteria and simultaneously looking for the best service quality to maximally satisfy all users of Smart City;
- **Critical mode** – reacting at global disruptive events or critical priorities to guarantee the city resiliency, anti-fragility or graceful degradation together with the best and fast return to normal operation mode;
- **Forecasting, simulations and development mode** – forward-thinking simulations, forecasting.

All these modes can run in parallel with the use of advanced planning and simulation tools [17].

4.1 The Basic Smart City Agent

The digital ecosystem has a number of smart services that can be represented by agents. To unify all agents we introduce the concept of Basic Smart City Agent (BSCA). The BSCA includes four parts as shown in Fig. 2. The energy case is considered - every node of the smart grid (numbered 1, 2, .., N) can be at the same time a producer of energy (solar panels on roof), a consumer of energy (appliances), a storage of energy (battery) or a purchaser of energy (buy energy from external suppliers).

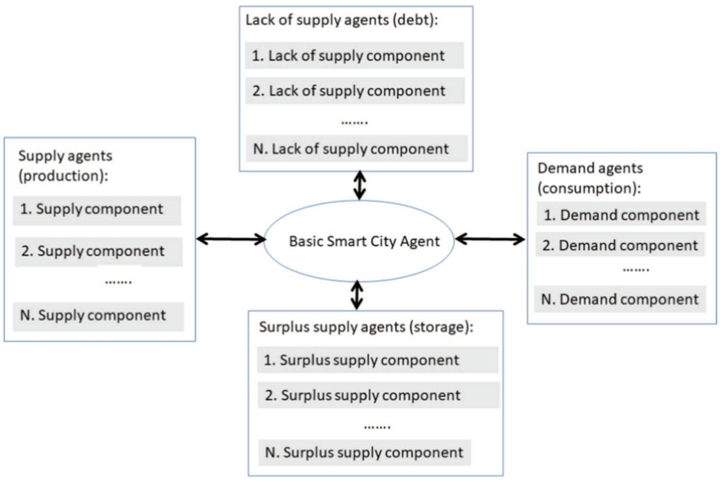

Fig. 2. Basic Smart City Agent

This solution enables optimizing different nodes of complex smart grid networks (buildings, street lights, transportation, etc.) both on the demand side (optimization of energy consumptions) and on the supply side (tailored-made energy production/sharing of energy storage). Some nodes could be only simple consumers buying energy from the external energy supplier, others could still produce their own energy, and the more advanced nodes can effectively work with stored/shared/debt energy.

Other city networks (transportation, health, safety and security, etc.) can be organized in the same way. Negotiation among all network agents yields into cross-disciplinary optimization of the whole city area – if there is not enough energy for electric vehicles in the morning the new virtual round table will be required to find appropriate decisions to solve the problem, for example, by changing the working hours in offices, schools, etc.

4.2 Smart City Ontologies and Knowledge Base

The different city models could be represented by ontologies that guarantee a common language for communication among agents. With respect to different Smart City components, this ontology can be generalized for all service in Smart City (Fig. 3).

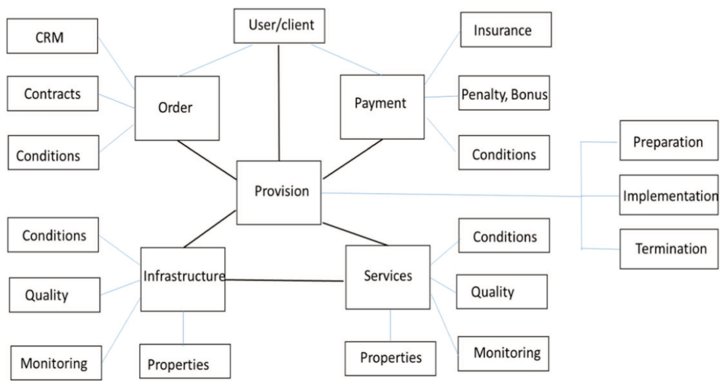

Fig. 3. Generic ontology for Smart City services

The relationships among the above mentioned instances are shown in Table 1.

Table 1. The relationship among instances in the ontology model

Instance 1	Relationship	Instance 2
User/client	provides	Order, Payment
User/client	expects	Provision
Provision	depends on	Order, Payment
Provision	uses	Infrastructure, Services
Service	links to	Infrastructure
Provision	consists of	Preparation, Implementation, Termination
Order	consists of	CRM, Contracts, Conditions
Payment	consists of	Conditions, Insurance, Penalty, Bonus
Infrastructure	consists of	Conditions, Quality, Monitoring, Properties
Service	consists of	Conditions, Quality, Monitoring, Properties

The User starts by filling in an Order that is tailored to his requirements. The Order consists of Customer Relationship Management (CRM) - agreed Conditions and is finalised with an accepted Contract. In accordance with the Contract conditions, the Payment is requested from the User, and involves Insurance, Conditions, Penalty or Bonus.

A user expects Provision in line with agreed Order and realized Payment. The Provision uses both Infrastructure and Services and consists of three phases: Preparation, Implementation and Termination. Both Infrastructure and Services consist of Conditions, Monitoring, Quality and Properties. Services are linked to Infrastructure.

This model is applicable to all different areas and enables the sharing of information among specialization. The different parts of the model can be described as:

User:

- Information about clients (their categorization, identification, etc.)

Order:

- CRM – customer relation management, communication with clients, marketing of services
- Conditions – services parameters/details/classes, priorities, parameters
- Contract – accepted price, the conclusion of contracts, complaints procedures

Payment:

- Insurance – unexpected events, damage, injury
- Conditions – payments mean, virtual currency, pre- or post-payments
- Penalty, bonus - loyalty programs, compensation of bad service quality

Provision (of services):

- Preparation – reservation, time scheduling, preparation of infrastructure
- Implementation – service deployment to customers with respect to contracts
- Termination – clearance, handover for further use

Services:

- Conditions – service time schedule, service access conditions
- Quality – assessment of service parameters, complaints, user service evaluation
- Properties – real-time changes of service both by a user or by a service provider
- Monitoring – diagnostics of service parameters, critical situations (blackout, etc.)

Infrastructure:

- Conditions – GIS localization, infrastructure ID
- Quality – assessment of infrastructure, usability, attractiveness
- Properties – components of infrastructure
- Monitoring – remote diagnostics, predictive infrastructure maintenance

4.3 Adaptive Behavior of Smart City 5.0 vs. Fixed Scenarios Smart City 4.0

Let us suppose the smart city on which we can observe parallel M information variables $O_1, O_2, \ldots O_M$. From the system point of view, it is reasonable to distinguish among j-th smart service specializations (transport, energy, environment, business).

The experts typically have available the set of L predefined fixed scenarios $\left(S_{j,1}, S_{j,2}, \ldots, S_{j,L}\right)$ within each j-th specialization.

The intention of Smart City 5.0 is to replace step by step the fixed scenarios by adaptive ones created by multi-agent systems. Consequently, such an approach can better react to extraordinary situations (accidents, disaster, etc.) and better represent the knowledge of real city processes.

Intuitively we suppose there is an unknown knowledge vector $(K_1, K_2, \ldots K_N)$ common for all specializations that characterize features of the real city. Sometimes this vector is mentioned as a city genetic code. All scenarios $S_{i,j}(K_1, K_2, \ldots K_N)$ together with their quality assessment functions $Q_{i,j}\left\{S_{i,j}(K_1, K_2, \ldots K_N)\right\}$ are supposed to be dependent on this vector. The cross-disciplinary algorithm should select the i_j-th scenario for each j-th specialization to minimize the weighted sum of quality assessment functions:

$$\min_{i_j} \sum_j Q_{i_j,j,}\left\{S_{i_j,j}(K_1, K_2, \ldots K_N)\right\} \tag{1}$$

The optimization of (1) should prevent the selection of contradictory scenarios used in different city specializations. Good solutions for traffic, for example, can be very bad for the environment. The best solution to safety and security can have a catastrophic impact on traffic, etc. The cross-disciplinary quality assessment must be common for all specializations and should include at least the cost, the energy consumption and the environmental impacts. Other criteria can be added based on additional city requirements.

4.4 Virtual World of Smart City 5.0

The Smart City digital ecosystem will be composed of different smart services represented by agents. On the top of the digital ecosystem, there is a Virtual World of City which is playing the role of twin - model of the real city and where all agents of all services can meet and initiate new virtual "round table" negotiations to solve a problem when required.

As an example, we present the fragment of Virtual World of Smart City for autonomous car transport shown in Fig. 4. In the virtual space the continuous negotiations among business (contract), infrastructure (resources) and operation (demands) agents is realized to achieve the appropriate solution for clients, car owners and service providers.

Similarly, a Virtual World as a MAS solution can be used for other smart city services, e.g. smart buildings, smart street lightings, etc. Clustering of specialized MAS into groups can create higher subsystems that can better negotiate among themselves.

In some cases, the cooperation in other competitions seems to provide better solution. As a result, Smart City will start to demonstrate Emergent Intelligence with spontaneous auto-catalytic reactions – as it must happen in complex adaptive systems.

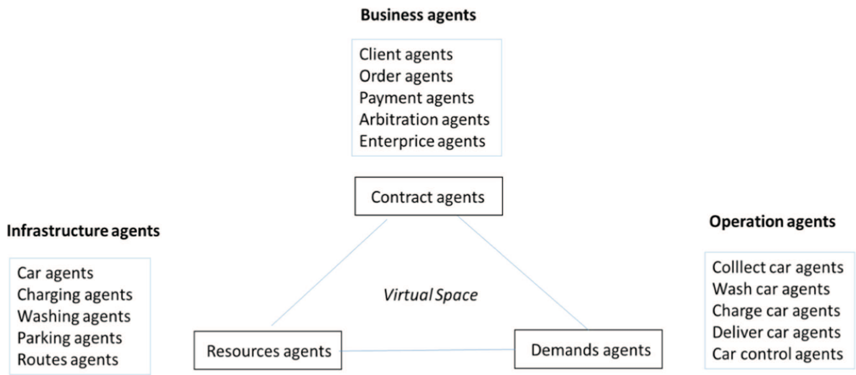

Fig. 4. The fragment of Virtual World for autonomous transportation in Smart City

The beauty of self-organization is that the real situation forces the adaptive reaction which can be extremely smart and generate the unexpected good solution. On the other hand, the system should monitor and avoid the bad results providing guided self-organization to avoid chaos.

5 Conclusion

The presented concept of Smart City 5.0 offers a vision of city organization as a digital ecosystem of smart services. It is in full match with the Industry 5.0 concept and the principles of the Internet of "everything" where agents of people, things, services, documents and robots can directly negotiate with each other providing the best possible solution for the current situation.

This approach provides fundamentally new opportunities for open, flexible, efficient, scalable, high performance and reliable solutions. The proposed platform and tools for collective decision-making will be applicable to solve a wide range of complex applied problems for urban services.

The next step of this research will be the development of Smart City 5.0 design and the development of a class of intelligent smart services as part of the digital ecosystem concept. Several Smart services will show interaction and coordination of decisions and achieving consensus (balance of interests).

Real time interaction of city residents, city authorities, investors, consumers and service providers in one ecosystem will make the link between "demand and resource" and open opportunities to organize new businesses. The proposed concept will allow creating a fundamentally new generation of Smart City applications, solving existing problems and having potential applications worldwide.

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