Development of Resource-Demand Networks for Smart Cities 5.0

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Abstract. In the paper, the new vision of "Smart City 5.0" is presented. It is based on a previously developed model of Smart City 4.0 and implementing the concept of the complex adaptive system for balancing conflict interests of different city actors. These actors can include business, transport, energy and water supply providers, entertainment and other services and can be unified based on resource and demand model.

The paper describes the general principals, functionality and the architecture of the digital multi-agent platform for creating eco-system of "Smart City 5.0". It is designed as holonic p2p network of smart services and technological components for supporting demand-resource relations.

It is shown that in proposed eco-system smart services can interact both vertically and horizontally supporting competition and cooperation behavior on the basis of specialized protocols of p2p network. In the future, each smart service is considered as an autonomous cyber-physical multi-agent system which can be decomposed on a lower level of smaller services recursively.

The first prototypes of smart services and their interaction are presented, the next steps for future research work are outlined.

Keywords: Smart City 5.0 · Holonic system · Digital eco-system · Smart services · Multi-agent technology · Artificial intelligence

1 Introduction

Smart Cities are constantly growing, both in the number of inhabitants and the number of smart services provided for citizens. One of the major problems of vast growing is a lack of interoperability [1]. The majority of smart services (SmtS) solve local tasks working on a certain small amount of data provided by the city government. It is difficult to find good examples of cooperative or better - co-evolution work of SmtS as one smart system.

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On the technological level, we can see the current trend for open standards and frameworks for SmartCity (SC) data use. For example, the EU Synchronicity program proposing to collect data from SC sources to be operated in one market place. The project targeting to create standard IOT protocols and organizational principals for semantic descriptions of data collected from various systems, making it more accessible for computer processing in different applications [2].

Another important trend in SC is digital ecosystems (Apple, Yandex) with integrated and unified information space of hardware, devices and software where users can easily switch from ordering food, to analyzing traffic jams, navigation, checking or planning sports activities and other cases.

On the methodology level, there is a trend for universal programs, frameworks and action plans to achieve a better quality of living, for example, the Green Cities Programme Methodology prepared by European Bank for Reconstruction and Development (www.ebrd.com).

Taking into account all current trends we make the first attempt to define Smart city as an open complex system, alive and constantly developing adaptive system that self-organizes and evolves in all its spheres with set of different Key Performance Indicators (KPI) like business, recreation, comfort, transport, environment, goods availability, medical care, education and prices for services, etc. It is obvious that such a system will have various actors and players sometimes with contradictory interests. The problem we want to solve is the overall integration at both the functional and technological level through creating an open platform architecture that allows adding different services and easily integrate them into a SC environment.

In the first and the second section of the paper, the problem is defined and the existing architecture solutions are evaluated. The third part describes the Smart cities 5.0 concept (compare with predefined SmartCity 4.0) based on the intelligent platform. It consists of two levels: the level of technologies and the level of services. In the fourth part of the paper, the Resource and Demand (RD) model as the core of every SmtS is presented. The concept of RD model is not new and has already been used in various MAT systems, but this article proposes to use it for the first time for interaction not only within one service but also between several services. In this new approach, a request created in one service can be satisfied by a comprehensive solution of multiple agents of different services. This RD model will help to build interaction between services both on the horizontal and on the vertical level of the platform. In the fifth section, we show several examples of SC services and models implementation based on RD model and examples of services co-evolution.

2 State of the Art

Smart city development is now considered a complex problem. But not so many researchers explore SC as a complex adaptive system, where "complex system" is used in prof. Prigogine meaning [3]. There are many efforts to create one universal architecture that can be applied to all modern cities. Usually, they meet difficulties because of too many actors, relations, diversities, etc. To overcome those difficulties, the novel approaches are trying to introduce distributed architectures and put knowledge about actors in the heart of SC development.

Zygiaris in [4] describes his vision of the Smart City Reference Model. He opposes virtual gated communities and corporate enclaves at the heart of SC. In his opinion, Smart cities should be built and developed as public-controlled integrated urban operating systems. In addition, Zygiaris relies on the work of Belissent [5], emphasizing that the Smart city project should take into account the context of a particular city. As a result of his reasoning Zygiaris proposes a multi-level architecture of a SC, includes the following levels: The City Layer, The Green City Layer, The Interconnection Layer, The Instrumentation Layer, The Open Integration Layer, The Application Layer and The Innovation Layer. Significant development of the upper levels of the model is impossible without the development of the lower levels. Urban systems form the playing field on which an open integrated Smart City system can be built.

Hancke [6] defines a Smart city as an integrated model of all its infrastructure and citizen services and to the use of intelligent devices for monitoring and control. Based on this definition, in Chamoso et al. [7] note in their work that designing individual smart systems is not enough to build a SC. A Smart city should function as a single organic ensemble. This model inevitably contains a huge number of interrelated elements (M2M concept). To implement this concept, mechanisms are needed to support the volume of connections and the type of communication. Chamoso et al. refer to technologies ZigBee, Bluetooth, Wi-Fi, WiMax, PLC, GSM/GPRS, 6LoWPAN, EnOcean and Z-Wave to build M2M models.

Chamoso et al. [7] note in his review that more and more sensors are needed to build a SC based on the IoT. Therefore, they propose the model sensing as a service to Smart City design. Perera et al. [8] provide a comprehensive overview of sensing as a service model. They note the stability, scalability and power of the model. Chamoso et al. [7] analyze the functionality of the platforms Sentilo, IBM Intelligent Operation Center, CitySDK, Open Cities, i-SCOPE, People and IoTOpenplatforms. They come to the conclusion that at the moment there is no universal and open platform for encapsulating information and knowledge about the city.

Therefore, Chamoso et al. offer their own architecture consisting of a set of technological solutions for Autonomous information management and a distributed system providing analysis and services. The advantage of the architecture is a modular design that allows adapting the system to the needs of new cities.

Almeida et al. [9] consider the problem of the handle a large number of mobile sensors/devices, with high heterogeneity and unpredictable mobility. They propose the Multi-Technology Communication Platform for Urban Mobile Sensing. This architecture is based on the unified and extremely heterogeneous network uniting cars, aerial and aquatic drones, bicycles, and fixed sensors stations. The main elements of the system are monitoring sensors, mobile nodes, gateways, and a server. Experiments have shown that the described architecture has reduced the overhead of the network.

Krylovskiy et al. [10] note the complexity of the creation in practice large-scale Smart City IoT platforms that can scale and evolve over time adopting new technologies and requirements. They describe their early experience of applying the microservice architecture style to design a Smart City IoT platform. Krylovskiy et al. propose a microservice architecture which allows working on individual parts independently, maintaining its integrity and efficiency. In this case, different parts of the system can be implemented in different ways. In their architecture, there is no complex technology middleware. They use simple communication protocols and APIs. This has resulted in a significant reduction in coordination work. They come to the conclusion that at the current stage the proposed architecture is a compromise between simplifies the design and implementation of individual services and the complexity of distributed systems.

The most promising approach is presented by Roscia et al. [11]. Authors proved that the transformation of cities in smart systems should be based on different subsets that communicate and interact, in order to make the concrete realization of a smart city. They analyze and design the approach that simulates a dynamic infrastructure within the broader context of the envisioned Smart City. With full understanding that the final solution should be based on integration and finding the balance between SmtS the authors explore the idea of the Smart City Grid that should be intelligent, distributed and autonomous and based on smart agents that move the grid beyond central control to a collaborative network of almost biological complexity. They present IDASC model (Intelligent Distributed Autonomous Smart City) as a grid-wide computing network. This approach still does not consider of semantic interoperability of Smart Services, and provide more technical realization and universal agent model and also do not provide the answer of heterogeneous services collaboration.

Analysis of different existing Smart City services standards and frameworks shows the trend for open frameworks and flexible distributed structures, with step to the digitization of knowledge and the automation of decision making process.

3 Description of the New Smart City 5.0 Vision

In this paper, we present one of the possible future models of the Smart City - as a complex adaptive system is able to work under conditions of high uncertainty and dynamics of events.

In comparison with predefined approach of Smart City 4.0 [12] - model based on adoption and of Industry 4.0 concept principles, characteristics and integration of computing technologies, we offer a model that can be characterized as a fully distributed autonomous cyber-physical system for resource management. It will allow to support of different KPIs of many actors, continuous growing and evolution of the system as a whole when some autonomous parts can be replaced “on-the-fly”. The platform will provide open access for all participants in real time. This advantage will help to create SC when it is difficult to characterize from the very beginning all parties who will be involved [13].

The developed vision of SmartCity 5.0 is based on the concept of a digital platform for creating eco-system of smart services. The architecture of the new SC platform includes the following main layers: technology level and service level (see Fig. 1). The technology level can have several instruments: data management instruments, decision making engine, intelligent/AI technologies, big data, simulation tools, etc. The service level consists of different Smart Services of various kind of managing resources.

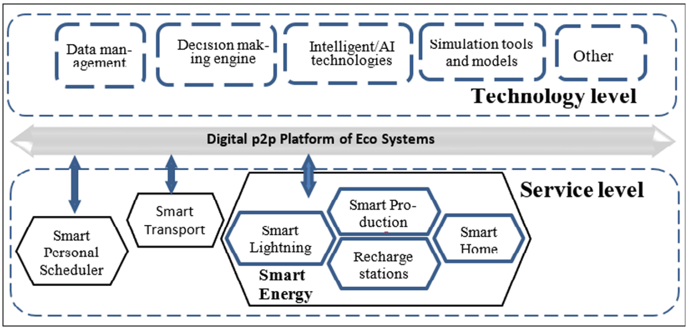

Fig. 1. Smart City 5.0 system architecture.

Every service in this platform can be functionally unique but common in the core architecture and created on the same basic principles. The core of every service is a Resource and Demand model and open access to collective data space. This allows services to solve their internal task, but also be part of bigger services (holons) [14].

In this concept each smart service is presented by an autonomous agent. They can compete or cooperate with each other through a service bus, interacting both vertically and horizontally on the basis of specialized protocols. Top-level services are constructed as autonomous multi-agent systems of a lower level, where any agent of such a system can recursively reveal a new service for itself.

The proposed solution also requires Peer-to-Peer Network (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 close to optimal results.

4 Development of Resource Demand Model for Smart Services Interactions

The basic approach for supporting the interaction of SmtS is a resource and demand (RD) model which advanced by new types of agents, satisfaction functions and bonus-penalties and compensations [15]. This means that every problem solved by the SmtS can be described as a combination of resource and demand interactions [16].

Let us define the basic ontology model tailored-made for a smart city. Practically, we can simulate different city sectors as it is shown in Fig. 2 using different simulation software for transport, energy, land use, environment, or other segments.

Energy demands are connected with nodes of energy consumption, production or storage. Transport demands are represented by a set of the origin-destination (O-D) lines to which are assigned typically two parameters: the number of vehicles in both directions in given time and the quality of transportation such as travel-time (the number of parameters can be extended based on applications). Land use is defined as the domain (geometrical shape) with a lot of attributes like square meters, reason of use (parking slots, green areas), etc. The assigned demand agents could be extended in a similar way to other sectors like waste management, water supply, safety and security.

In multiagent systems we can organize negotiations among demand agents through different simulation tools [17]. Our approach to a smart city is like puzzles of different pieces (urban areas) which could be assembled into higher urban units like districts or whole cities.

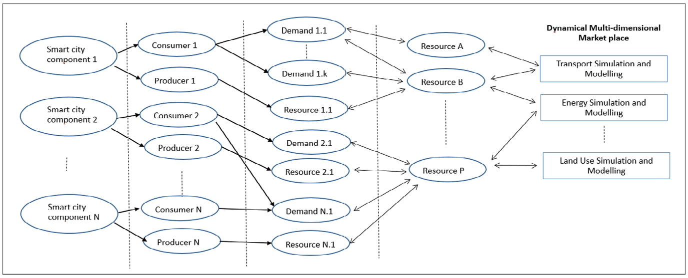

Fig. 2. System architecture of resource-demand model for smart cities

Each technical component (building, street light, charging station, etc.) or different users (citizen, municipality, group of people) requires limited resources (energy, transport, parking slot, land, etc.) in given time interval t (dynamical demand requirements). These requirements are represented by Demands Agents which are able to negotiate among themselves [17].

The SC simulation model can be understood as the virtual market place for MAS that represents available infrastructure together with their parameters (limited energy resources in the given node, maximal traffic flow in selected roads, maximal environmental parameters in the district, etc.).

Negotiation among Demand agents with city simulation model will yield into dynamical resources assignments represented by Resources agents that offer the best possible service to each consumer. In case one consumer does not accept the assigned resources it must change their demands. The negotiation can be repeated once again under new conditions.

The negotiation process among agents should result in the time schedule of customers' assigned resources (energy, transportation, parking slots, etc.). In future, we can enlarge our approach to take into account also the energy, traffic and parking control strategies.

The resulting approach as a user interface between aggregated demand agents assigned into different smart city components and aggregated urban sustainability parameters (economic, environmental and social) is depicted in Fig. 3. The decision-makers, typically municipality, should specify the sustainability parameters (KPIs) for the whole urban area. The demand and resource agents mutually negotiate with a city simulation model to propose to each smart city component the reduced comfort to fulfill the requested KPI.

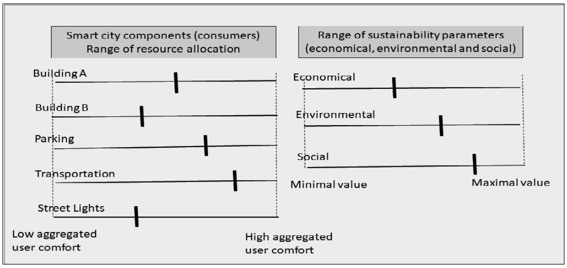

Fig. 3. Smart city "equalizer"

With respect to the presented system architecture we can define the following illustrative services for different users:

- strategical planning of green areas (modeling of the urban ecosystem together with its optimized future evolution);
- strategical planning of resource consumptions in different areas;
- recommendation of apartments'/residents' number in an urban area with respect to transportation, energy, etc.;
- recommendation for advanced building operation (category, consumption, transport);
- change of time schedule of public transport (time tables, transport services);
- change from the fuel to electric buses in public transport (environmental and economic impact);
- change of traffic control strategy (green lines, environmental impact);
- recommendation of active intervention during rush hours;
- recommendation of better reaction to unexpected events (accidents, disasters, blackout, crises management, etc.).

5 Smart City Services Implementation Based on Resource and Demand Model

Below we present several Smart Services and models as part of the Smart City 5.0 concept.

5.1 Transportation Service

Transportation system (TS) is the core element of every city. Within the overall system, we can perceive it as a subsystem with certain input values and output KPIs [18].

Inputs cover:

- (IP) RG: Road geometry (incl. nodes, sections, parking, etc.);
- (P) TD: Travel demand (incl. origin-destination (OD) matrices for particular vehicle classes);
- (IP/P) TC: Traffic control (signal plans, traffic signs, etc.);

- (P) PT: Public transport (lines, bus stops, time schedules);
- (P) TD_VRU: Travel demand for pedestrians and cyclists;
- (P) SP: Simulation and model parameters (acceleration, gap acceptance, etc.); and
- (-) CD: Data for calibration (travel times, queue length, etc.).

The simulation process has several stages. During the first stage, a basic model is created. This is a model of the existing situation. In order to ensure that the model corresponds to reality, a calibration process must take place. Here, the parameters of the model are modified until the behavior in the model corresponds to the real work situation. Typically, travel times or for example queue length is used for this comparison. After we have a calibrated model, different alternative scenarios can be evaluated.

The list of inputs above also consists of specification whether the given group of parameters is implicit (denoted - IP), or whether they can be used as parameters (denoted - P). Some scenarios require implicit changes in the model (typically changes in road geometry such as different number of traffic lanes, changes from signal control to roundabout, etc.), some just changes in input parameters (for example changes in travel demand as a result of certain policies, changes in public transport, changes in the number of pedestrians, time shift of the demand and others). Using different policies (for example support of car sharing etc.) has a direct influence on the OD matrices. This is a way how different subsystems can influence each other.

With all of this said, the transportation model is addressed by the remaining agents (sub-systems) in the following way:

$$O_i^S = TM(t,\ p, ip) \tag{1}$$

The output of a certain scenario, *S*, depends on the inputs, *p*, and input parameters, *ip*, at a given time *t*.

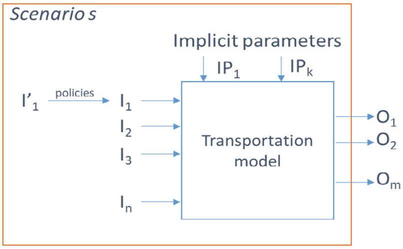

Fig. 4. Scenario oriented transportation model

Typically, the performance of the system (i.e. output or KPIs) cover the cost of a given situation (scenario) and its influence on the environment (emissions, fuel consumed, and others), but also for example characteristics such as travel time or the delay of the vehicles in the network (Fig. 4).

With respect to the energy, the model can be perceived as a black box with input and output variables. The other subsystems must not know about its internal behavior. There are however some issues that cannot be dealt with on an aggregated level. The two most important are discussed below:

Dynamic behavior – transportation is rather a complex system with many dependencies. For example, simple variables such as travel time (TT) are not constant. This is a dynamic parameter and its value depends on several parameters, but mainly the actual travel demand, D.

$$TT(t) = f(t,\ D) \tag{2}$$

Interactions among different elements – several approaches (such as highway capacity manual) allow the analytical description of the behavior on a single network element, for example, road segment or an intersection. They, however, do not offer to model of interactions among such elements. For example, unsuitable control algorithm or too high travel demand can lead to a situation that a queue caused by the first intersection influences not only speed on the given road section, but can cause the fact that vehicles cannot clear the adjacent intersection.

In order to provide a sufficient level of details and realistic behavior, a microscopic simulation model is the preferred solution for MAS. It is able to deal with the first two challenges described above, but they do not allow the modeling of human decisions. Changes in the destinations are not part of the model and must be dealt with prior to the simulation. It does not react to changes in the attractiveness of certain parts of the network etc.

5.2 Smart Energy Service as Part of Smart City Concept

In many cities lack of energy and other resources are becoming stop factor for future growth and intensive development of the economy and social infrastructure. Almost all Smart cities are characterized with a constantly growing need for energy resources that identify the number of existing constraints (infrastructure, network, the difficulty to predict consumption, etc.). Every city is characterized by unique energy, gas, heat and water supply network model. The task of the Smart energy service is to find the optimal balance between reasonable consuming and smart sufficient production.

To solve this problem, the Smart Energy Service prototype based on the principles of Smart grid [19] was developed (see Fig. 5). It allows automating the process of adaptive dynamic distribution of requests for resources, taking into account various criteria. The system can also simulate devices and sensors for collecting information from the bottom level, the state of networks, the capacity of suppliers.

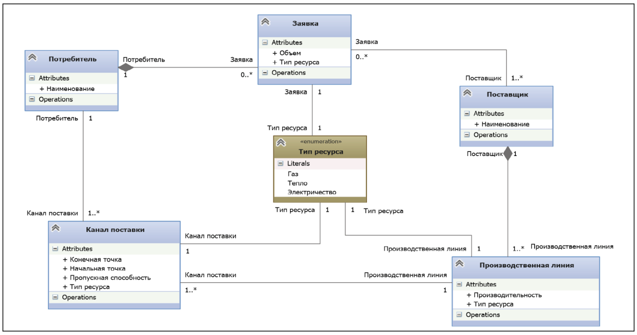

Fig. 5. E-R diagram of the entities of the Smart Energy service

The developed model will allow performing the following functions:

1. Set the initial configuration of the network, including consumers and suppliers of resources and communication lines with their parameters.
2. Set the required performance indicators of the network (cost, equal load, etc.).
3. Set the list of events with time, coming to the network as input.
4. Simulate the process of (re)distribution of requests for resources in the network.
5. Create unexpected events: for example, the unexpected rise of consumption, the breakdown of any resource or implementing of a new resource to the system, changing the parameters of the resource, etc.

As a method of solving optimization task, we used resource and demand model based on multi-agent technology and the market approach of optimization.

In the simulation model of the system, we have many resources producing water, heat and electricity designed to meet different needs, with different performance and cost parameters. They all are connected by a network with different capacity parameters. At random time, the system receives events, for example, new orders (demand) in a certain place of the network. New demands can be consolidated into larger orders for a certain time horizon. Time and amount characteristics of orders may be unknown until the arrival. Every provider of water, electricity and gas has its own tariff price, as well as each communication line has its own capacity and cost.

Every order (demand) and opportunity (resource) in the network will receive its agent. Resource agent primarily evaluates the possibility to execute the order. If it is impossible, the resource agent requests neighboring resources for assistance. As a result, the agents of resources and demands negotiate with each other, knowing their requirements and deadlines. In this case, a flexible resource allocation plan is built adaptively, determining who will execute which order. Agents not only form but also control the execution plan and the maximum possible load. The plan can be adjusted as new orders arrive or new resources are connected or disconnected.

Network agents evaluate and try to find the most appropriate route. It is assumed that the agent of any node has all the necessary information about the neighboring nodes (with possible interference and delays), and any node is reachable during the sequence of negotiations. Negotiations are made with the aim of redistribution of load in the network. The most open capacity “attract” the load from other capacities and, as a result, the load is distributed evenly over the network or moves where it is cheaper. If resource breaks orders reallocate to other resources.

Every agent of the consumer (demand) object has the ability to plan its work on the time horizon, building a schedule of consumption and respectively resource agents can plan production. The system can work both on a microservice level collecting the orders from a smart apartment or smart house, or on the macro level to analyze the vast growing demand (for example, a new house or a new industrial factory is planned to be connected to the network).

Characteristics of resource demand model:

- the expression of all optimization parameters: time, volume, characteristics of the network bandwidth, is considered through the universal cost characteristics represented in internal currency;
- setting the rules of agent’s negotiations aimed to increase the local profit of every agent by reducing costs in the internal currency, that leads to a dynamic improvement of the network parameters;
- the automatic finding of the optimal dynamic balance of a multi-agent system by exchanging virtual money;
- use of the component-by-component change of parameters of optimization of the modeling system for the purpose of alignment of indicators.

It is obvious that the complexity of such a model will not allow creating one centralized system for the whole city, suitable for all levels: from a separate apartment – to the whole city. In this regard, this project proposes to create such a system as a holonic and network-centric, built as an adaptive p2p network of individual planners capable to coordinate their decisions both vertically (top – down and bottom – up) and horizontally among themselves [20].

Holonic, in this case, means that the system can act autonomously at the level of a smart apartment for example, but act together as a bigger more generic system at the level of a smart house or district. It provides higher openness, flexibility, performance, scalability, reliability and survivability of the system.

5.3 Smart Personal Scheduler as a Part of Smart City Concept

Smart Service for personal tasks scheduling is focused on providing a flexible dynamic real time planning with a capability to automatically improve the plan according to changing environment and events. All existing software applications used for this purposes show major limitations in real time (re)scheduling, semantic descriptions of events and p2p dependencies between users [21]. As a result, scheduling now is very time-consuming and becomes a challenge - users spend more time for planning and tracking daily tasks.

For solving this problem, Smart Personal Scheduler based on RD model and extended market-based reasoning mechanisms is proposed. In a virtual market agents of orders and resources recognize conflicts and try to re-allocate orders between resources using negotiations and taking in account not only their current states, given goals and preferences but also special kind of virtual money, which they get proportionally as the profit and which works as the energy for creating and revising developed links between agents. In this case, there are no needs to stop or restart scheduling manually it works continuously in real time.

This approach will provide the capability to develop a model for managing virtual market by the amount of accumulated money, level of satisfaction of agents, factors based on a number of communications between different agents in different parts of schedule and strength of agent links which will show the stability of scheduling.

Self-organization in our approach means the ability of scheduling system to revise and change links between agents of demands and resources, tasks and operations, which are triggered by different events or started proactively [22].

The key elements of the model:

- the advanced virtual market mechanism based on resource demand model;
- self-regulation and self-adaptation for managing quality and efficiency of scheduling;
- level of satisfaction and virtual money for agents;
- trade-offs for balancing decisions between different criteria;
- support p2p interactions of intelligent schedulers in adaptive networks;
- pro-active interaction with users.

The personal scheduler can work not only reactively and pro-actively but also can be triggered by entering external events from other planners. The development of multi-swarm schedulers will not only provide a number of new benefits including open architecture, high scalability and performance (every swarm runs on its hardware), reliability but also will help to test the designed approach applicable for “Smart City 5.0”.

5.4 Examples of Coevolution of Services

Examples of coevolution of services are demonstrated in two cases. The first case presents the negotiation between Smart Energy Service and Smart Transport Service. The optimized consumption plan of energy resources in the real world is easily ruined by the transport system. Delay in trams schedule can ruin the energy plan and can cause a tremendous rise in consumption. As a solution we offer change of time schedule of public transport (time tables, transport services), change the type of transport - bus instead of the tram (cab be negotiated with Smart Environment Service), change of traffic control strategy (green lights).

The second, more complicated case is based on Smart Personal Scheduler. Smart City 5.0 model, can evolve as a user-centric concept we intelligent personal schedules as the main access instrument to Smart services.

Personal plan can be renegotiated several times through the connection to different Smart Services. As an example - a lingered meeting can be the reason for the whole day or week rescheduling as the result of automatic conflict-driven reasoning in the intelligent scheduler. This event will trigger for example the cancellation of lunch with a friend or its reallocation to another day, the shift of the other meetings. But with respect to the late trip to the airport intelligent personal scheduler can check current traffic situation and traffic model and recommend to use the train instead of personal electro car. In that case, the next recharge of the car is rescheduled. This example shows different Smart services cooperation: Smart Personal Schedulers, Smart Food Service, Smart Transport Model, Smart Energy Service.

In this view, the advanced intellectualization of future smart services becomes possible because of bringing new reach operational context of users into consideration. This approach gives new opportunity for SME to build shared networks of clients aggregating services [23]. The personal scheduler unites separate people into one dynamic collaborative group that quickly reacts to upcoming events, performs adaptive scheduling in real time and efficiently carries out coordinated plans. But, the most advanced innovation will take place when intelligent schedulers described above will start working together demonstrating co-evolution of self-organized systems.

6 Conclusion

The Smart City 4.0 model [12] based on Industry 4.0 principals shows integrating ICT and computing technologies throughout whole production enterprise enable to share data, information, and instructions between all agents during all phases of the production value chain. The presented concept of Smart City 5.0 provides a new vision of a city as a digital platform and eco-system of smart services where agents of people, things, documents, robots and other entities can directly negotiate with each other providing the best possible solution for formed demand.

The proposed concept of digital eco-systems will allow these services to interact and coordinate decisions and achieve consensus (balance of interests), instead of a simple transfer of data from one service to another. In this concept agents of services will compete or cooperate with each other, interacting on the basis of specialized protocols - both vertically and horizontally. Top-level services will be constructed as autonomous multi-agent systems of a lower level, where any agent of such a system can recursively reveal a new system for itself.

All smart services in this concept are created based on resource demand model. This approach is not fundamentally new, but in this article we propose to use it for the first time for a Smart city. The second contributed result is the use of RD model for interaction not only within one service but also within several services and models to increase flexibility, efficiency, scalability and high performance and reliability of the solution.

The proposed concept of RD model allows creating a new generation of Smart City applications that can show co-evolution of self-organization of systems.

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