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SMART CITY SERVICES BASED ON SPATIAL-TEMPORAL LOGIC

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Abstract. The development and research of Smart City Service Systems is a very important area for the future of mankind. The urbanization process imposes new criteria for qualitative and quantitative assessment of population well-being, which will involve processing a very large volume of information, organizing the data exchange and processing. This paper proposes a Multi-Agent Smart City Services system based on Spatial-Temporal logic. In order to optimize the criteria for the qualitative and quantitative evaluation of services, the set of agents is divided into: the subset of agents that deliver services and the subset of service consumers agents. The system diagram, the synthesis of the agents, the operators of temporal and spatial logic was elaborated. The relationship between the subset of service delivery agents and the subset of agents of service consumers is determined by game theory models.

Keywords: *Spatial - Temporal Logics, Distributed Computing, Multi-Agent Systems, Swarm Intelligence, Collective Decision Making, Game Theory, Knowledge Bases.*

Rezumat. Dezvoltarea și cercetarea sistemelor Smart City Service prezintă un domeniu foarte important pentru viitorul omenirii. Procesul de urbanizare impune noi criterii de evaluare calitativă și cantitativă a bunăstării populației, care va implica procesarea unui volum foarte mare de informații, organizarea schimbului de date și procesarea acestora. În lucrarea de față se propune un sistem Multi-Agent Smart City Services bazat pe logica Spațial-Temporală. Pentru optimizarea criteriilor de evaluare calitativă și cantitativă a serviciilor, mulțimea de agenți este divizată în: sub-mulțimea de agenți care livrează servicii și sub-mulțimea de agenți consumatori de servicii. A fost elaborat diagrama sistemului, sinteza agenților, operatorii de logică temporală și spațială. Relațiile dintre sub-mulțimea de agenți care livrează servicii și sub-mulțimea de agenți consumatori de servicii este determinată de modele din teoria jocurilor.

Cuvinte chee: *Logica Spațial-Temporală, Calcul Distribuit, Sisteme Multi-Agent, Inteligența Roiului, Luarea Deciziilor Colective, Teoria Jocurilor, Baze de Cunoștințe.*

1. Introduction

The smart city can be defined as a set of services offered by a distributed computing system that explores large volumes of data and applies communication technologies in order to improve the quality of life of its citizens. The target objectives of the services offered by the smart city are oriented towards the application of knowledge bases and databases, at the same time being based on information provided by its citizens online. The paper [1] proposes a Smart City Service System that is implemented as an ontology-oriented system, which ensures decision-making based on reasoning and inference, and provides objective information characteristic of the situation in the city.

Designing a smart city is a long and complex process because it involves human, financial, technical and technological essential resources. In order to meet the requirements of the Smart City Service System, a holistic approach on the management process is necessary [2, 3], where service is the basic concept, or rather the element of interaction between the actors involved in the decision-making process (citizens, administration, enterprises, organizations, etc.).

The smart city system, in order to provide the most relevant information, requires the application of decision-making models' knowledge based or cognitive. A cognitive system has a complex structure that has the ability to self-develop by accumulating new information and knowledge in the process of evolution in space and time [4, 5].

Since the Smart City Service System has a spatially distributed structure, it is obvious that models based on architectures of distributed computing, parallel or cloud are applied for data processing [6-8]. At the same time, it can be mentioned that the same performance features are offered by Multi-Agent systems [9, 10] and collective / collaborative systems for decision-making [11], based on Artificial Intelligence methods and models [12, 13].

The smart city being a dynamic system that evolves in space and time requires a special approach to apply decisional models based on spatial-temporal logic in which geographical position and time to play a decisive role in decision making. In parallel with the definition of spatial-temporal logic, also appears the notion of event that takes place in space and time. Temporal logic also plays a very important role in agency theory, a field of science where the integration between philosophy, computer science and game theory takes place which provides paradigms for researching Multi-Agent systems that make decisions and gain new knowledge in real time [14]. The problem of combining and the relationship between spatial logic and temporal logic is analyzed in paper [15] which addresses how computational complexity and the expressive power of component logic are related to the complexity and expressiveness of spatial-temporal logic.

This paper proposes a method of applying spatial-temporal logic for the development of Smart City Service Systems. The system represents a distributed computing architecture consisting of a set of Agents working together aiming to solve a common problem. The set of agents is divided into two subsets: the first is the subset of Agents that deliver services, the second subset are the agents that request services. These two subsets are always in the process of concurrency the balance between which is regulated by the Nash Equilibrium [16].

2. Synthesis of the Diagram for Smart City Service System

Nature-based computing provides a designer with the most efficient methods and models for developing complex systems, especially Smart City Service systems, which can be considered as multi-dimensional and dynamic systems in space and time. Therefore, solving the problem of finding the optimal solution in the definition space requires the involvement of essential resources for processing a very large volume of data coming from a lot of heterogeneous sensors or stored on distributed systems. Reducing the complexity of these systems can be achieved by applying computational models based on intelligence agents and evolutionary algorithms [17-19] with distributed or concurrent data processing.

The Spatial-Temporal Diagram of the Smart City Service System is shown in Figure 1, where: SDA - Service Delivery Agent; SCA - Service Consumer Agent; GPS - Global Positioning System; $G5$- Fifth-Generation Technology Standard for Mobile Communications.

Let be in the activity space $S \subset (R^K \cup X \cup Y \cup Z \cup T)$ the Multi-Agent decisional distributed system is defined:

$$A^S = \{SDA,\ SCA,\ GPS,\ G5\}, \tag{1}$$

where: K are the total set of services and parameters defined for the Smart City activity; X, Y, Z are the spatial coordinates of the agent; T is the time coordinate; $SDA = \{SDA_n, n = \overline{1, N}\}$ is the set of Agents that deliver services; $SCA = \{SCA_m, m = \overline{1, M}\}$ is the set of mobile or stationary agents of services consumers; GPS is global positioning system that provides information for the spatial positioning of agents; $G5$ is the communication system that ensures the transfer of data between the set of agents and the temporal synchronization.

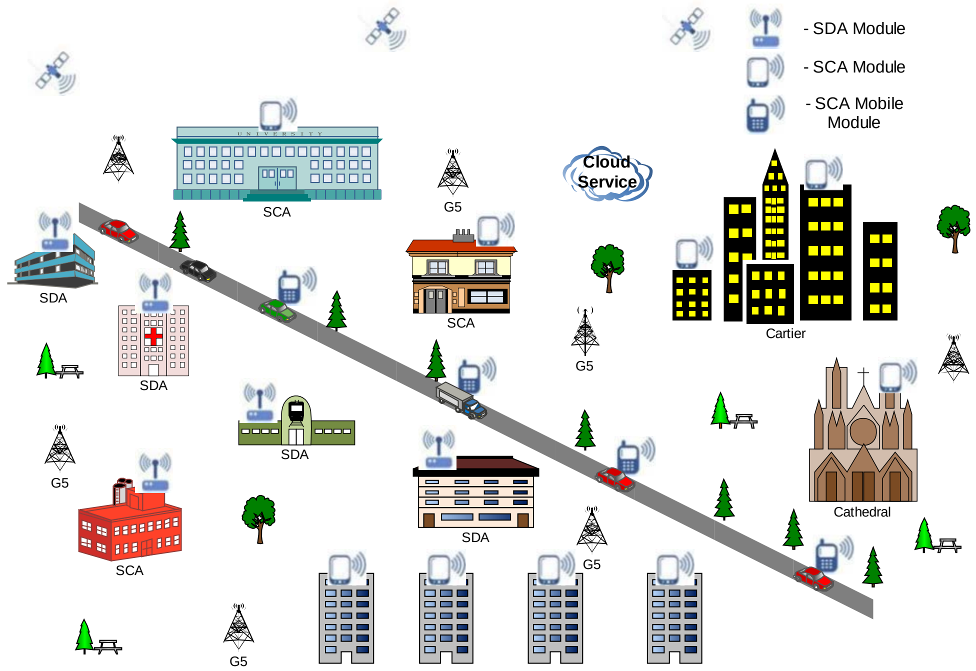

Figure 1. Spatial-Temporal Diagram of the Smart City Service System.

3. Agent Synthesis

The Smart City Service System includes two types of Agents: SDA - Service Delivery Agents and - Service Consumer Agents.

3.1. Service Delivery Agent Synthesis

The functional model [22,24] of the Service Delivery Agent is defined by the expression (2):

$$A_{SDA} = \{k_{Sv[T]},\ KB[T],\ SD: (Ev[T], TLP[T], SLP[T], Sv[T])\}, \tag{2}$$

where: $k_{Sv[T]}$ - the request coefficient for the services offered by SDA for SCA; $KB[T]$ - the knowledge [20,23] base available to the SDA agent at the time T; SD - data processing logic applied by the SDA agent; $Ev[T]$ - the set of events used by the SDA agent for data processing for the purpose of delivering quality services to SCA agents; $TLP[T]$ - temporal logic operators used for data processing; $SLP[T]$ - spatial logic operators used for data processing; $Sv[T]$ - the multitude of services offered by the SDA agent at the time T.

3.2. Service Consumer Agent Synthesis

The functional model of the Service Consumer Agent is defined by the expression (3):

$$A_{SCA} = \{k_{SQ[T]}, KB[T], SC: (Sv[T], TLP[T], SLP[T], SQ[T])\}, \tag{3}$$

where: $k_{SQ[T]}$ - the quality coefficient of the services used by SCA provided by SDA; $KB[T]$ - the knowledge [20,23] base available to the SCA agent at the time T; SC - data processing logic applied by the SCA agent; $Sv[T]$ - the set of services provided by SDA agents used by the SCA agent for data processing; $TLP[T]$ - temporal logic operators used by the SCA agent for data processing; $SLP[T]$ - spatial logic operators used by the SCA agent for data processing; $SQ[T]$ - the result of the evaluation of the quality of the services used by the SCA agent.

4. Temporal Logics Operators

Temporal logic operators [21] present mathematical models for events processing $Ev[T]$. The model and basic components of an operator are specified in the expression (4):

$$O(\tau): \{Op_1(\tau), Op_2(\tau), \ldots, Op_I(\tau)\}, \tag{4}$$

where: $Op_i(\tau)$, $i = \overline{1, I}$ is the set of operands involved in the operator $O(\tau)$.

The operand model is defined by the expression (5):

$$Op_i(\tau) = \{Ev_i[T], p_i(t)\}, i = \overline{1, I}, \tag{5}$$

where: $p_i(t)$ is the coefficient of decisional influence of the event $Ev_i[T]$ within the operand $Op_i(\tau)$.

For the evaluation of the coefficients $p_i(t)$ three models of temporal evolution are defined: events in the past, events in the present and events in the future.

The mathematical model for calculating the coefficients of decisional influence for past events $p_i^t(t)$ is performed based on the formula (6):

$$p_i^t(t) = Ev_i[T]/(k + t^2/\beta), t = \overline{T, +\infty}. \tag{6}$$

The mathematical model for calculating the coefficients of decisional influence for present events $p_i^p(t)$ is performed based on the formula (7):

$$p_i^p(t) = Ev_i[T]/(k + t^2/\beta), t = \overline{-\infty, +\infty}. \tag{7}$$

The mathematical model for calculating the coefficients of decisional influence for future events $p_i^v(t)$ is performed based on the formula (8):

$$p_i^v(t) = Ev_i[T]/(k + t^2/\beta), t = \overline{-\infty, T}. \tag{8}$$

In formulas (6), (7) and (8) are mentioned: $Ev_i[T]$ the event underlying that operand; k is the coefficient of credibility; t is the time interval in which the coefficient of decisional influence is evaluated; β is the coefficient of decision stability.

The list of temporal logical operators is defined according to the functionality of the Smart City System. The following are some examples of temporal logic operators present in the most Smart City Systems:

1) $O(\vee^{\tau}) = \max\{Op_1(\tau), Op_2(\tau), \ldots, Op_I(\tau)\}$;
2) $O(\wedge^{\tau}) = \min\{Op_1(\tau), Op_2(\tau), \ldots, Op_I(\tau)\}$;
3) $O(\cup^{\tau}) = \cup\{Op_1(\tau), Op_2(\tau), \ldots, Op_I(\tau)\}$;
4) $O(\cap^{\tau}) = \cap\{Op_1(\tau), Op_2(\tau), \ldots, Op_I(\tau)\}$;

5. Spatial Logics Operators

Spatial logic operators present mathematical models for event processing $Ev[s]$, where $s \subset (X \cup Y \cup Z)$. The model and basic components of an operator are specified in the expression (9):

$$O(s): \{Op_1(s), Op_2(s), \ldots, Op_J(s)\}, \tag{9}$$

where: $Op_j(s)$, $j = \overline{1,J}$ is the set of operands involved in the operator $O(s)$ and $s = \sqrt{(\Delta x)^2 + (\Delta y)^2 + (\Delta z)^2}$.

The operand model is defined by the expression (10):

$$Op_j(s) = \{Ev_j[s], p_j(s)\}, j = \overline{1,J}, \tag{10}$$

where: $p_j(s)$ is the coefficient of decisional influence of the event $Ev_j[s]$ within the operand $Op_j(s)$.

For the evaluation of the coefficients $p_j(s)$ the formula is applied (11):

$$p_j(s) = 1/(k + s^2), s \in S, \tag{11}$$

where: k is the credibility coefficient of the event $Ev_j[s]$.

The following is a list of the most common space logic operators in the Smart City System:

1) $O(\vee^{s}) = \max\{Op_1(s), Op_2(s), \ldots, Op_J(s)\}$;
2) $O(\wedge^{s}) = \min\{Op_1(s), Op_2(s), \ldots, Op_J(s)\}$;
3) $O(\cup^{s}) = \cup\{Op_1(s), Op_2(s), \ldots, Op_J(s)\}$;
4) $O(\cap^{s}) = \cap\{Op_1(s), Op_2(s), \ldots, Op_J(s)\}$;

For the functional extension of the list of operators is possible a combination of temporal logic operands and spatial logic operands. The list of spatial-temporal logical operators is presented below:

1) $O(\vee^{st}) = \max\{Op_1(s), Op_2(s), \ldots, Op_J(s), Op_1(t), Op_2(t), \ldots, Op_I(t)\}$;
2) $O(\wedge^{st}) = \min\{Op_1(s), Op_2(s), \ldots, Op_J(s), Op_1(t), Op_2(t), \ldots, Op_I(t)\}$;
2) $O(\cup^{st}) = \cup\{Op_1(s), Op_2(s), \ldots, Op_J(s), Op_1(t), Op_2(t), \ldots, Op_I(t)\}$;
2) $O(\cap^{st}) = \cap\{Op_1(s), Op_2(s), \ldots, Op_J(s), Op_1(t), Op_2(t), \ldots, Op_I(t)\}$;

The list of operators for data processing based on spatial-temporal logic can be extended in relation to the complexity of the developed Smart City System.

6. Economic Model of the Smart City Service System

The economic model of the Smart City Service System can be interpreted as a model of economic relations defined by game theory (Nash equilibrium) [16, 24, 25], in which two sets of agents are involved: *SDA* and *SCA*.

The profit P obtained by the set of *SDA* agents as a result of providing services for the set of *SCA* agents is calculated in relation to $k_{Sv[T]}$ and $k_{SQ[T]}$ from the expression (12):

$$P = \rho\left(k_{Sv[T]}, k_{SQ[T]}\right), \tag{12}$$

where ρ is the calculation function.

The target objectives of the set of *SDA* agents are defined by the expression (13):

$$k_{Sv[T]} = \max_{s \in S}\Big(\nu\big(k_{SQ[T]}, Sv[T], s, t\big)\Big), \tag{13}$$

where ν is the calculation function.

Whereas the target objectives of the set of *SCA* agents are defined by the expression (14):

$$k_{SQ[T]} = \max_{s \in S}\Big(\upsilon\big(k_{Sv[T]}, SQ[T], s, t\big)\Big), \tag{14}$$

where υ is the calculation function.

Expressions (13) and (14) determine that the set of *SDA* agents will strive to provide with as many services as possible for the set of *SCA* agents, but the set of *SCA* agents will look for the solution to use the highest quality services offered by the set of *SDA* agents.

7. Conclusions

The research led in this paper is part of the development of distributed computing systems for Smart City Services. The functional logic of the system is based on spatial-temporal logic models in which the decision-making capacity of an event depends on its spatial position and its evolution over time.

The synthesis of the diagram for the Smart City Service System was performed. The decision-making functionality of the system is based on the presence of two subset of agents: Service Delivery Agents and Service Consumer Agents. Mathematical models of agents have been developed that include qualitative and quantitative parameters of decisional influence.

The functional logic of the Smart City Service system is based on the application of a set of temporal, spatial or spatial-temporal logic operators. An operator includes a lot of operands for which mathematical models of spatial-temporal evolution have been developed. An operand characterizes an event.

The economic model of the system is presented as a relationship between the subset of agents that provide as many services as possible and the subset of agents that consume high quality services.

There are planned researches in the development of the system at the level of hardware and software architecture for the future.

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Conflicts of Interest. The authors declare no conflict of interest.

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