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A MULTI-AGENT SYSTEM ARCHITECTURE TO IMPROVE DISTRICT HEATING SYSTEMS

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Abstract. *Potentially energy-efficient and cost-effective district heating (DH) systems have been extensively used in Central and Eastern Europe to supply heat and hot water. In Western countries, the use of district heating system generating both heat and power is on the rise. Given that there has been a lamentable lack of maintenance and capital repairs in recent years, DH systems in Romania are plagued by inefficiency and excessive distribution losses. DH systems in Romania are a significant source of greenhouse gas emissions. Under the circumstances, the improvement of these systems has become a necessity. This paper describes a project aimed at technically improving the Suceava District Heating System using artificial intelligence techniques*
Keywords: *district heating, multi-agent system, artificial intelligence*

Introduction

Industries in Eastern Europe have gradually become more and more interested in how to work strategically and on a long-term basis with environmental issues, with focus on how to reduce the impact on the environment from their industrial activities. The demand for standardised environmental monitoring and management systems has increased. Together with other financiers, Suceava City Hall participates in a project aimed at assisting and promoting the industries' internal environmental work.

One major part of this project focuses on the Suceava district heating system. Suceava's heating infrastructure is in serious disrepair. In many parts of the city, the district heating system is simply being dismantled and replaced by electric heaters or building-level gas boilers. To alleviate this situation, City Hall has pursued the following objectives by implementing an ambitious project entitled "Suceava - utilitati si mediu la standarde europene":

1. Building local capacity to implement municipal energy efficiency projects and increasing actual investments in energy management;
2. Developing a local planning process designed to consider future energy needs;
3. Borrowing useful energy management experience from other countries in Europe;
4. Implementing pilot projects to demonstrate that small energy efficiency investments can reduce costs and improve comfort.

The Production and Transport of Heat

Many city households get their heat and hot water through a district heating system and not from individual oil or natural gas furnaces.

Most the heat in the district heating system is generated in large combined heat and power (CHP) plants. They take advantage of the surplus heat energy resulting from the electricity generating process. The hot steam driving the electric generator is used to heat the water which is then piped into the district heating system.

In addition to the CHP plants, dedicated district heating plants produce heat that is exclusively used to heat the water in the district heating system. This amount of heat, however, represents a small percentage of the total district heating output.

The water enters the district heating system at a temperature of 90 degree centigrade. It is piped to various distribution points around the city and then reaches consumers through a network of underground pipes. Inside the households, the water is piped through radiators and water heaters to heat rooms and tap water. The district heating system is a closed circuit. As the heat energy is released in the household, the cooled heating water returns to the power plant for reheating, and the cycle is repeated. Primarily, the power plants are coal-fired. Natural gas, oil, waste and biomass (e.g. straw and woodchips) are other fuels used in the generation of electricity and district heat.

The DH system has the following merits:

One large system is better than several small ones
One of the primary reasons for investing in district heating systems is to save energy. This is achieved in several ways.
First, a large central boiler plant is more efficient than small individual home-heating systems. Second, even greater energy savings are possible when cogeneration (combined heat and power generation) is used. In cogeneration, the heat from power generation wasted in conventional thermal power plants is used for district heating, increasing the overall efficiency of the combined process to almost 90%.
Also, the use of waste energy from industrial and other sources can save considerable amounts of fuel.
Flexibility in the choice of fuels is equally important. Compared with small boiler plants, large boilers or cogeneration plants serving entire district can use less expensive fuels such as solid waste, biomass or coal.

Environmental Preservation
As the various types of energy source (electrical, gas, oil, untapped energy) are effectively combined to run the heat source machinery, the energy consumption can be reduced. Moreover, the discharge of carbon dioxide (CO_2), which is the culprit for global warming, and of sulfur oxides (SOx), which are responsible for air pollution, can be controlled. Therefore, it contributes greatly to the global environmental preservation.

Efficient Energy Usage
Other than the electrical power and fossil fuel, the unconsumed city energy such as the heat discharge from buildings and incineration plants can be effectively recycled.

Enhancement of Space Utilization in Buildings
As it is not necessary to equip each building with heat source machinery, the space for the machinery installation is preserved. Thus, the utilization of space in buildings can be enhanced.

Fire Prevention
As the heat source machinery is concentrated in one or very few locations, the management of hazardous materials such as fuel is eased. Moreover, the power supply and water supply for daily living and fire fighting during fire breakout are also secured.

District heating requires careful engineering

To best utilize the full advantages of district heating, all parts of the system (from the heat generating plant down to the radiators in homes) have to be engineered carefully to function well together. Designing the optimal system requires extensive expertise and experience.

Supervision and Control

Automation systems for district heating involve much more than controlling pumps and valves in the distribution network. Today's computerised supervision and control systems integrate heat generation and distribution to ensure the most economical energy supply at all times, whatever the demand and supply situation. Normally every substation must have its own local controller for heating and tap water. This control unit can also be connected in a network and supervised by a central station.

Improving the Efficiency of District Heating Systems

The technical and economic improvement of the DH system in Suceava requires major changes in almost all its key sections.
The efficiency of any DH system depends on the effective functioning of each of its components:

- production of heat by DH boilers;
- distribution through the network of pipes;
- consumption in DH-heated buildings.

One way to obtain a high efficiency consists in introducing technical improvements to increase heat production and distribution efficiency. These refer to:

- *the automation equipment*: the equipment provided for automation ensures the sequential start/stop of the boilers, the heat carrier temperature regulation in agreement with the exterior temperature, the maintenance of the pre-established pressure in the heating installation;
- *the metering system*: the heat meter provides information on the amount of heat required for the heating supplied by district heating stations to consumers. They are highly sensitive and reliable.

These improvements can be correlated with advanced process control and artificial intelligence elements, more specifically with the multi-agent paradigm.
The use of the agent/multi-agent system paradigm has increased sharply as an important field of research within the Artificial Intelligence area. This paradigm has been applied to different fields such as process control [3, 8], mobile robots [8], air traffic management [5] and intelligent information retrieval [4].
A lot of agent definitions can be found in the literature, yet there is no one to have been fully accepted by the scientific community. A definition that is seldom mentioned was proposed by Wooldridge and Jennings [9]. According to them, an agent is defined by its flexibility, which implies that an agent is:

- *reactive*: an agent must answer to its environment;
- *proactive*: an agent has to be able to try and fulfill his own plans or objectives;
- *social*: an agent has to be able to communicate with other agents by means of some kind of language.

The term “agent” selected as name for a tool implies that the latter should be able to satisfy the above mentioned requirements. Nowadays, a small percentage of the existing software follows this definition.
Parunak [7] argues that agents are appropriate for applications that are modular, decentralised, changeable, ill-structured, and complex. Wernstedt and Davidsson [1, 2] have focused on several major characteristics of district heating systems:

- *modular*: each entity of a district heating system, i.e., substations, heat production plants, pumps etc., can be described using a well-defined set of state variables that is distinct from those of its environment. Also, the interface to the environment can be clearly identified for each entity.
- *descentralised*: the entities of a district heating system can be decomposed into stand-alone geographically distributed autonomous nodes capable of performing useful tasks without any continuous direction from some other entity.
- *changeable*: the structure of a district heating system may change as new entities are added or old enitites are replaced. In addition, there are short-term changes in the system when individual substation or parts of the network are malfunctioning.
- *ill-structured*: all information about a district heating system is not available when the monitoring and control system is being designed.
- *complex*: district heating systems are considered to be very complex systems [3]. The entities of a district heating system exhibits a large number of different behaviours which may interact in sophisticated ways. In addition, the number

of entities in a district heating system can be very large, up to a couple of thousands.

There are also more general arguments for the selection of an agent-based approach [2]. From a methodological perspective, the concept of "agents" introduces a new level of abstraction that provides an easier and more natural conceptualisation of the problem domain. Other advantages are increased, e.g., *robustness*, the distribution of control to a number of agents often implies no single point of failure, *efficiency*, less complex computations and communication are necessary if control is distributed, *flexibility*, the use of agent communication languages that support complex interaction between entities provides a flexibility that is difficult to achieve using traditional communication protocols, *openness*, by having a common communication language, agents implemented by different developers are still able to interact with each other, *scalability*, it is easy to add new agents to a multi-agent system, and finally, *economy*, since agent technology provides a natural way to incorporate existing software.

The district heating system structure

A district heating system structure is presented in figure 1. It usually consists of a heat production plant and some substations. The substations can be connected in sub-networks like in figure.
Substations are customer-related. It is normally composed of two or three heat exchangers and a control unit, which receives hot water from the district heating network.
The substation heats both cold tap water and the water in the radiator circuit by exchanging the required heat indirectly from the primary flow of the distribution network. The hot network water is returned to the network at a somewhat lower temperature. Both the temperature of the returning water and the flow rate in the network are dependent on the consumption of substations. When the water, returned by substations, arrives at the heat production plant it is heated and again pumped into the distribution network. There are some measuring points along the pipe networks.

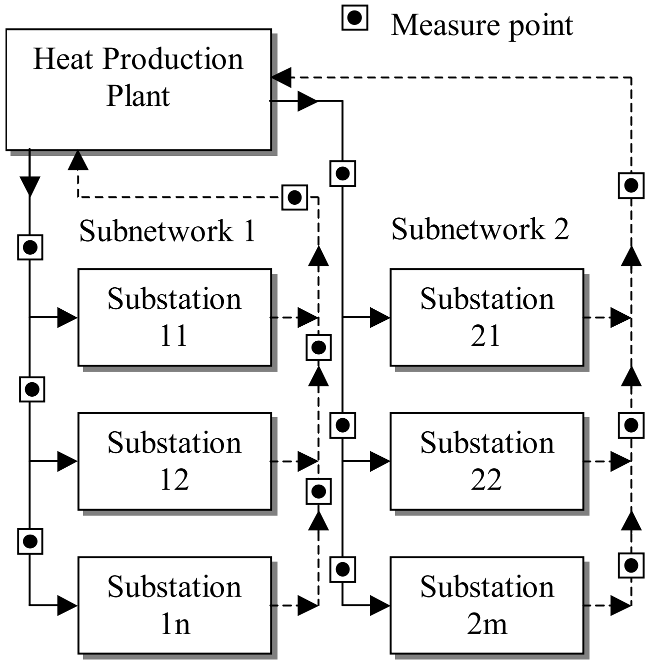

Figure 1. The district heating system structure

The proposed agents

One of the most important operations in developing a MAS is represented by the agents and services identification. Wernstedt and Davidsson [2] proposed a MAS architecture composed of one type of agents associated with the producers, responsible for the interaction between the heat production plant and the other agents of the MAS, and another type of agents associated with the consumers, responsible for the interaction between the substation and the other agents of the MAS (figure 2).
The goal of the *consumer agent* is to interact with the substation. It collects data from sensors and calculates predictions using historical data. It also creates new predictions for future consumptions. These predictions are based on actual and historical heat consumption, indoor and outdoors temperatures etc. The data collected by this agent is transmitted to the redistribution agent. Given that the process is inertial this agent can send the whole information in one or two minutes (the predictions can be sent at a larger interval).

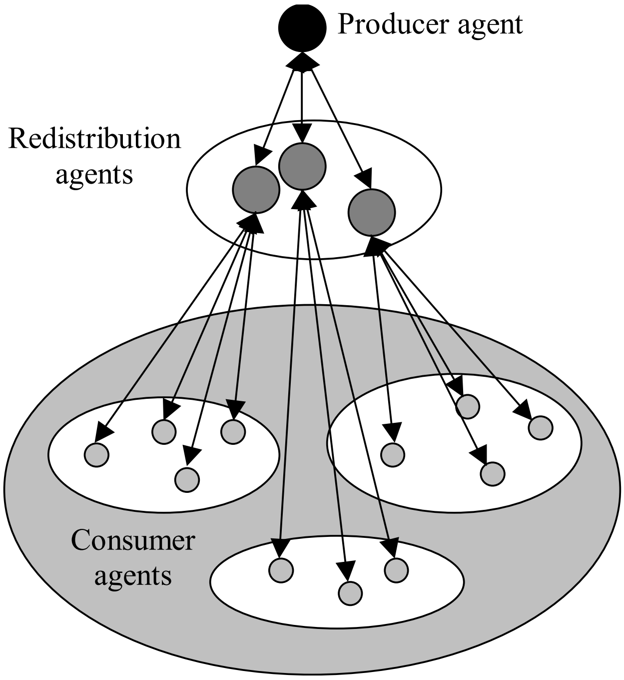

Figure 2. MAS structure

The *redistribution agents* monitorize the total consumption. Because the Suceava DH system consists of two sub-networks these agent's actions are very important. If one of the sub-network is trying to consume more heat than predicted, the redistribution agents invoke restrictions of consumption for sub-networks.

The *producer agent* receives predictions of consumption from the redistribution agents and it is responsible for the interaction with the control system of the heat production plant (possibly including human operators). The producer agent is also responsible for monitoring the actual consumption of consumer agents.

In order to assure a proper functioning of the district heating system, a diagnostic system is proposed. Modern industrial applications are composed of a variety of different technical units; they have different physical characteristics and demand the use of a variety of diagnostic methods. The fault detection and isolation community provides diverse diagnosis algorithms like statistical methods, knowledge-based techniques as well as model based approaches suitable to identify abnormal states of the equipment and of the process.

This system can be extended with a set of new cooperating agents:

- *data acquisition agents*: all data that is required by the diagnostic system is accessed and preprocessed by *data acquisition agents*. These agents are connected with the process control system and local controllers (substation) that inform about the current state of the application and the processes; also these agents transmit information to the *alarm agent*;
- *data manager agent*: this agent is handling historical and real-time data;
- *diagnostic agents*: these agents are in charge with different diagnostic techniques;
- *alarm agents*: these agents receive information from the *data acquisition agents* and perform some actions depending on the state of the entire process (figure 3): sending SMS, updating the Web page or sending notification e-mails;

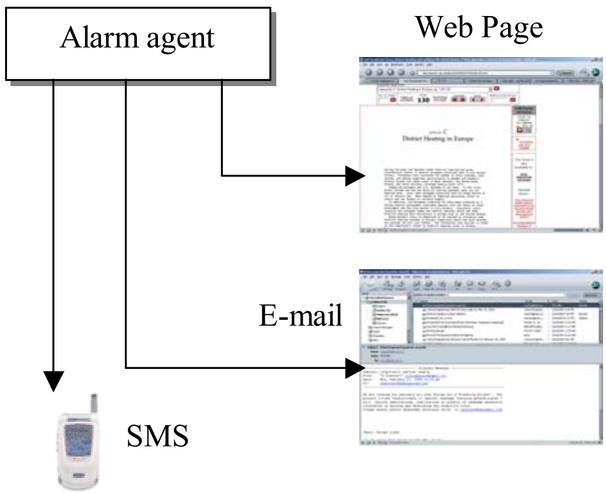

Figure 3. The Alarm agent

- *user interface a*gent: this type of agent interfaces to human users. *User interface agent* supports the user in creating a query or operation to perform on the system data. *User interface agent* manages also the information of the user and provides control functions to the user, such as parameter settings for their visualization tool;
- *security agent*: its main function is to enforce security over the information in DH system. *Security agent* is responsible for

authenticating and performing a validation check on the *user interface agent*. The *user interface agent* will be allocated an access permission level. Agents from registered users may use, and have access to more information resources than agents from unregistered users.

The integration of diverse detection algorithms into an overall diagnostic system by using one single interface challenges the generality of the interface itself. Such an interface allows the creation of an independent application diagnostic system to be successfully employed in treating a variety of characteristics pertaining to industrial units and processes.

Conclusions

The multi-agent system model seems to be the adequate framework for dealing with the design and development of an application which is flexible, adaptable to the environment, versatile and robust enough to supply the control of the district heating system with efficiency and reliability. The proposed project will adapt and introduce agent technology in an industrial application in which the use of leading edge information technology is currently very low. This action is difficult because it is necessary to correlate existing technologies with new domain elements (multi-agent systems). In order to do this, it is necessary to develop an efficient industrial infrastructure (wireless or not). The benefits are immediate: improved service quality and lower operational costs.

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