DE-PSO Fuzzy Controller for QoS-based self-adaptive system

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Abstract

The key idea of this article is to apply self-adaptive systems approach deployed on the distributed network ”smart” controllers installed at the oil wells in order to provide smooth data collection and transmission with minimum lost and meeting quality of service requirements. One of the new approaches for self-adaptation is to use self-organizing systems, where adaptation is entirely dependent on the decision taken at the local level, i.e at the level of system components. However, these systems are difficult to prove global properties of adaptation. In our work, we propose the control strategy based on the principles of self-organizing systems deployed over fuzzy logic controllers in a hybrid of the principle of differential evolution and particle swarm optimization (DE-PSO).

1. Introduction

The reliability of automated technology based on sensor networks and intelligent hardware and software has increased over the last decade. It can be observed especially in the area of oil and gas industry. An automation of the oil extracting monitoring processes realized by intelligent sensor networks can significantly improve production rate of the oil. The stipulations of undelayed data collection and transmission pre-determine a choice of the best solutions of optimal production and forecast accuracy. In order to establish a reliable network transmission of sensor data to the data center it is essential to implement 'smart' technologies to ensure quality of service of the large distributed system. This kind of systems traditionally consists of integrated subsystems such as monitoring, data collection and processing.

From practical point of view, it is critical to establish the real time data management framework to guarantee network Quality of Service (QoS) such as: high reliability, performance and capacity. However, it is quite often when control of quality of service attributes in real time is ambitious as there are abundant calculations needed to prepare data for transmission and obtain them. Moreover, it is crucial that the accuracy of data processing affects the future load of the system.

The key idea of this paper is to apply self-adaptive systems approach deployed on the network controllers which is capable to provide minimum delays while transmitting and processing data and meeting desirable quality of service requirements. The principle of self-adaptivity is often know as the ability of the system to optimally adjust its behavior in response to the environment changes [1].

The main advantage of self-adaptivity for the real time control systems is that it makes the system resistant and can keep its performance in case of emergent situations or long delays. This sustainability typically can be obtained via adjusting the system structural configuration and switching links between nodes of the system. Thus, the self-adaptation can be considered as a problem of finding the best system architectural configuration to meet changing environmental conditions and QoS requirements. In mathematical terms of view, it can represented by formulating and solving appropriate optimization problem that is minimization (maximization) of some objective function and subject constraints. This can expanded to the best algorithm selection problem which will successfully treat data transmission and processing flows control. There are two main approaches in designing self-adaptive systems control frameworks: centralized and decentralized [2].

The centralized self-adaptive control system usually is managed by a central controller with equipped predefined policies to meet QoS requirements and there is a behavior evaluation subsystem while system sends a feedback of the chosen configuration coping with the current environment state. Therefore, the adaptation happens only when monitor-ing and data analysis obligate reconfiguration of the system. Suppose we consider the wireless sensor network system where each node has to read data every three minute from more than sixty sensors and send them to the remote data center. The main challenge here is to design the run-time data management framework for the tremendous and heavy loaded distributed system. This kind of systems is related to the decentralized control pattern of the self-adaptivity. In decentralized systems there is no central control, and, as a rule, such systems consist of a large number of "equal" components that interact to each other in accordance with certain links switching criterion determined locally and globally for the whole system. The global behavior of the system emerges from those local refinements.

The paper addresses the problem of decentralized control framework for real time distributed system design and specif-ically focuses on the performance and reliability issues at run-time. A series of publications introduce different ways of decentralization for self-adaptive systems [3], [4], [5], [6], [7]. However, there are still open questions that are about templates application in various type of the control problems [8], [7] including: degree of applicability; completeness; quality of analysis.

One of the new approaches in self-adaptation mecha-nisms handles self-organization where adaptation is entirely dependent on the decision made at the local level, i.e at the level of system components [9]. However, these systems are problematic in view of proving global properties of adaptation.

In our work, we propose a management strategy based on the principles of self-organizing systems, it employs a fuzzy logic controller together with Differential Evolution-Particle Swarm Optimization (DE-PSO) engine having benefits from both methods. This paper is organized as follows: in Section 1 we consider an infrastructure of the self-adaptive control framework for the real time data monitoring and transmission from the network of distributed sensors to the data center where the decentralized control is implemented with the help of intelligent controllers. The second section provides a multi-layer hybrid approach decentralized control system built on the principle of fuzzy controller and DE-PSO engine. Related work section discusses advantages and limitations of the proposed approach. Conclusion summarizes the presented idea.

2. Real-time data monitoring and transmission as a decentralized distributed system

We propose an infrastructure of the self-adaptive control framework with integrated logic that can monitor QoS requirements and adjust the system when those requirements are violated. As a practical example, we consider an oilfield which consists of a allocated oil wells distributed over large territory and each well is equipped by set of sensors measuring various parameters. The complete and accurate information from sensors obtained in real time allows making decision clearly and, therefore, maximizing well productivity depending on changing behavior of the reservoir. In particular, the use of permanent sensors provide deep scan productive zones that maintain this support and get clear analysis of current state of the oil production. Data transmitted from the network of sensors can also be used for continuous improvement and updating of mining models and forecasting.

Thus, it is necessary to arrange the decentralized control of the undelayed transmission of data read from sensors installed in the wells. In practice, this kind of systems have certain complexity related to organizing sending a large amounts of data from a far distributed number of nodes. For instance, in case of loss of communications with the server, it is necessary to continuously transfer data using an alternative method or, in other words, to guarantee certain level of reliability. Tradition-ally, the data transmission in the oilfields often utilizes wire-less technologies, including radio or satellite communication system. However, due exploiting such communications, there are needs in additional devices such as gateways, routers and repeaters for amplifying the signal and data routing. In order to reduce these expenses, the self-adaptive systems control framework, particularly those ones that are designed according to principles of self-organizing networks, can be more efficient.

We have developed a device, an intelligent controller (IC), that is able to collect data from the network of sensors (one can simultaneously connect up to eighteen sensors) and send readings to the server while controlling the network load and reliability requirement.

We introduce the concept node in the network of ICs and its attributes as well as cluster of nodes:

– Each oil well has installed intelligent controller (for collection and transmission of data measured by sensors).

– Each group of wells is set up by intelligent controller (coordinator) (for collection and transmission of data received from other nodes).

– We refer intelligent controller as a node of considered network.

– Each IC (node) has a number of parameters:

– Each node has the same technical specifications including processor that can perform data (Out) and low level computations and, consequently, received data packed and queued while waiting their processing.

– Each node receives data from several sensors and from neighboring nodes.

The node can be in two modes: active or passive: when it activate the IC is involved in the packets transmission and routing data received from neighbors; when node is in a passive state it can "sleep", measure network parameters and store data in a local memory of IC, therefore, the IC does not route the message or, in other words, there is no communication with neighboring nodes and the server.

– Each node knows how many neighbors (sources) sur-rounded it and it is able to locally measure the number of packets received from neighbors. Each source has a fair bit of buffer space in a queue. That is each source has own "channel" not available to other sources.

– Each node adds a sequence number (sequence num-ber) in each packet which allows to determine packet loss.

– Each node estimates of its neighbors availability: neighbor loss threshold (NLT) = 1 - 1 / N (where N is a number of neighbors detected in the previous cycle).

– The value of neighbor threshold (NT) determines an average level of network connectivity.

– The ratio Tp / Ts (passive / sleep timers) determines the cost of energy and the system response to the dynamic changes.

– Each node has the same logic, transmission and storage of data based on the principle of a hybrid fuzzy controller and DE-PSO. This approach will be presented in the next section.

Thus, this type of ICs network provides data transferring even if the connection to the main server was lost.

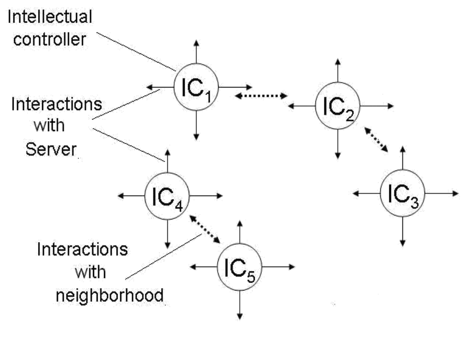

Figure 1. The scheme of the ICs interactions

Moreover, in passive mode when no controllers available to transmit data, the intelligent controller stores all the measured data on a dedicated built-in memory unit that keeps them in a matter of weeks. It grants the operator an opportunity to come and copy all stored information in IC and try to troubleshooting. The scheme of the ICs network interactions as a decentralized system control showed in Figure 1).

Figure 1 presents several types of interactions between intelligent controllers: with a server, neighboring nodes and a nearby cluster or group of nodes. We have selected decentralized control system as it owns such positive features as: good scalability of transmission and computation depending on the degree of communication between nodes and node clusters. For this type of the control framework an adaptation of the system may be performed through local interactions and, therefore, the overhead is limited by interaction with neighboring nodes. In addition, the computational load is distributed across the nodes. Decentralization can also improve reliability, as there is no central point of failure. However, due to the fact that increasing number of interactions an achieving of good scalability becomes harder. The calculations to obtain consensus on the appropriate system reconfiguration might be tremendous in terms of time and capacity. Decentralized control can often lead to a local optimum pattern of adaptation that may not be optimal solution for the overall system. In the next section we present decentralized approach that solves these problems.

3. Data transmission control system based on a hybrid fuzzy controller and DE-PSO

In view of the above-mentioned weaknesses of decentralized control system for the ICs network, we equip the intelligent controller by a repository of knowledge which is shared for the entire system and built-in fuzzy logic controller in a hybrid with De-PSO engine. This type of hybrid method is able: to analyze the state of the system on the basis of publicly available global knowledge; to give an optimal solution for the whole system and the best decision to be taken in the event of a lack of communication with the server or with all neighboring nodes. Figure 2 shows the general structure of an intelligent controller that implements this approach.

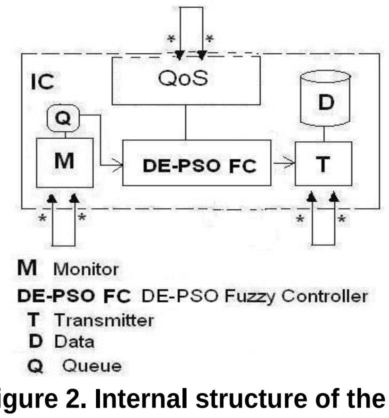

Figure 2. Internal structure of the IC

As shown in Figure 2, all data first are read from sensors and monitored by Monitor (M) which accepts all those data both from sensors connected to the IC and from neighborhoods ICs. Monitor forwards data to Queue (Q) at the processor and then they are transmitted to Differential Evolution and Particle Swarm Fuzzy Controller (DE-PSO FC) which makes deci-sion about best data allocation and transmission route. Fuzzy controller in this situation is an appropriate way to reduce amount of calculations whereas DE-PSO provides optimal solution in the decentralized control system [11]. We use DE-PSO algorithm which frames DE that generates trial vector that has a path to the target node and then checks whether this vector is better than the corresponding target path. This path is included in the population otherwise the algorithm runs PSO and gives a new candidate solution. All steps are repeated until the optimum value of the cost function introducing QoS performance is reached. PSO allows creating perturbation in the population providing maintaining diversity of the population and producing an optimal solution.
Moreover, this hybrid technique helps in predicting future load of the network and produce the best switching links between nodes. Finally, Transmitter (T) directly sends certain data to the appropriate nodes or to the server, or saves them into the built-in memory card (D).
Now we consider the mechanism of adaptation based on the proposed hybrid approach of fuzzy controller and DE-PSO shown in Figure 3.

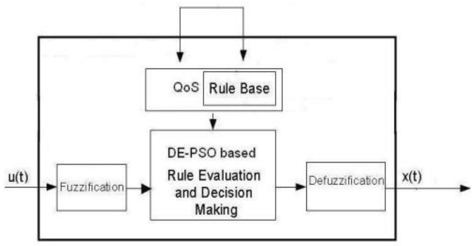

Figure 3. Fuzzy Controller structure of the IC

As can be seen from Figure 3, there are several stages to process signals. Fuzzyfication block converts crisp values measured by sensors into fuzzy ones that described by lin-guistic variables in the knowledge base. DE-PSO block helps to make decision under QoS rules and knowledge base using fuzzy set and produce new fuzzy outputs and actions which are also fuzzy. Defuzzification block converts those fuzzy data in to crisp values that are later used to send data to appropriate nodes which is executed by Transmitter. Block QoS is a set of rules that control reliability level, in particular, looking for the quality of transmitted signal.
It is essential to note that treatment of fuzzy controller has advantages in two cases: when a very complex systems whose behavior is not well understood has to be exploited, and in case when there is need to make decision quickly although the solution might be approximate [10]. There are two tradi-tional methods in designing fuzzy systems such as Mamdani and Takaki-Sugeno. Mamdani's method requires significant computational cost. On the other hand, Sugeno's method is computationally efficient and works well with optimization and adaptive techniques which makes it very attractive in building control systems, in particular, for non-linear dynamic systems.
Therefore, our approach is able to fully control all trans-missions of data on QoS requirements. Fuzzy Controller can sufficiently reduce calculations during making decision. DE-PSO engine allows to generate table of routing for each package of data through the network.

4. Conclusion

This paper offers the self-adaptive control framework with integrated logic that can monitor QoS requirements and adjust the system when those requirements are violated. We use decentralized control strategy which is implemented via DE-PSO Fuzzy Controller engine. As the main component of the proposed system we have developed the intelligent controller IC that has embedded DE-PSO FC logic. Therefore, the intelligent controller has a "self-aware" supported by the built-in logic to control the attributes of service quality computer network (Quality of Service) such as reliability. Intelligent controller is capable dynamically switch transmission of data the distributed system taking into account quality of service requirements and future changes.

5. References

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