Application of Fuzzy Inference Systems in the Transmission of Wireless Sensor Networks

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Keywords: Fuzzy Logic Systems, Artificial Intelligence Applications, Node Routing, Wireless Sensor Networks.

Abstract: The purpose of this paper is to apply fuzzy logic techniques for determining the data transmission path in wireless sensor networks. Wireless sensor networks are used in many applications and require efficient operation with speedy transmission of information and long lifespan. For suitable sensor transmission, a fuzzy system is defined considering as the goal to minimize the information transmission distance and maximize the battery lifespan of the network routers. Case studies simulations were carried out and the results indicate satisfactory performance of the method.

1 INTRODUCTION

Industrial wireless sensor networks are an emerging class of wireless sensor networks that faces specific constraints linked to the peculiarities of the industrial production. (Akyildiz et al., 2002).

The main advantages of wireless networks are reduction of devices installation time, no need for cabling structure, savings in the cost of projects and infrastructure, flexibility of devices configuration, savings in assembly costs, flexibility in changing architectures and the possibility of installing sensors in places that are difficult to reach.

However, industrial wireless sensor networks face several challenges such as the reliability and robustness in harsh environments, as well as the ability to properly execute and achieve the goal in parallel with all the other industrial processes. Besides, industrial wireless sensor networks solutions should be versatile, simple to use and install, long lifespan and low-cost devices – as a matter of fact, the combination of requirements hard to meet (Matin, 2012).

The deployment and the setup of wireless sensor are overwhelmingly challenging tasks that become even more challenging in industrial applications. The environment where industrial wireless sensor networks are deployed is extremely dynamic, it can depend on the specific product, the phase of life of the product and the kind of service provision considered. Indeed, each kind of product or phase of life has different requirements and imposes on the monitoring system different constraints. One of the challenges to face is the impact of the propagation environment. When the industrial wireless sensor network is deployed inside a factory to assess the production process quality, one has to tackle the interference and the radio environment produced by the production machines. For that matter, such network has to be deployed and calibrated not only to guarantee the correct assessment of the production process, but above all not to interfere with the production process. The same logic holds for networks used to monitor electricity, water and gas consumption (Kumari and Prachi, 2015).

The environment in which sensors will be deployed needs to be considered in order to find the optimal locations for sensors. Operation lifetime, due the power management policy, is one of the key issues in all the wireless sensor network applications, including industrial applications. Many industrial wireless sensor networks applications, particularly in the field of environmental monitoring, require the autonomous power supply from alternative power sources, such as wind or solar power. Even though it is possible to have a constant power supply in some industrial environments, sensors tend to be battery powered in order to keep the monitoring non-intrusive. But, in most cases, batteries are not expected to be reloaded or changed. So, energy

Coelho, P., Amaral, J., Almeida, N., Fonseca, A. and Guimarães, K.
Application of Fuzzy Inference Systems in the Transmission of Wireless Sensor Networks.
DOI: 10.5220/0006338406180624
In *Proceedings of the 19th International Conference on Enterprise Information Systems (ICEIS 2017) - Volume 1*, pages 618-624
ISBN: 978-989-758-247-9
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should be saved. There are many ways to obtain that, both in software and hardware.

The hardware solution requires to carefully choosing the components. These latter should be low energy consuming while providing the needed capacity. In some particular applications, energy harvesting modules can be envisioned, like solar cells or kinematic sensors, etc., but their usage is still marginal.

The software solution focuses energy preservation by controlling the number of messages to be sent and the range. As a matter of fact, radio activities, such as sending and receiving data are the activities that consume more energy in wireless sensor networks compared with processing and sensing activities. Therefore, it is of paramount importance to monitor carefully the amount of data to send and the frequency at which it is sent, i.e. the number and size of messages, while preserving the quality of service expected by the application. Similarly, the further the messages are sent the more the energy needed and the more the interferences generated. Thus, it is important to monitor the transmission range based on the target to reach (Lonare and Wahane, 2013).

Usually, mesh or tree topologies are used to minimize these interference effects on the transmission system. Mesh or tree topologies transmit the message from one node to another using other nodes (sensor and repeaters), which act as intermediate routers, directing messages to the others until it reaches its destination (gateway or manager node), as shown in figure 1.

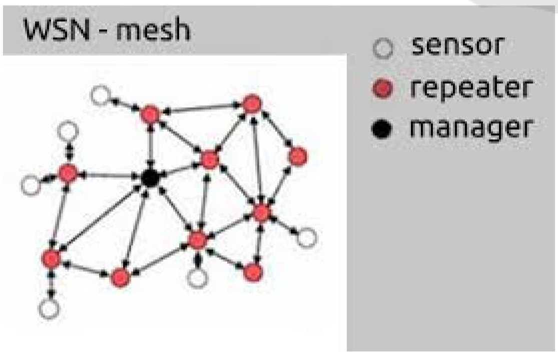

Figure 1: Mesh network characteristics.

The importance of data transmission in wireless networks motivates research works for improvement in routing algorithms. Some studies have already been carried out, such as in (Alshawi et al., 2012) in which it is proposed to include fuzzy logic techniques to the gossip algorithm with the purpose of reducing energy waste in data transmission. Other researchers (Shah et al., 2015) propose a fuzzy logic algorithm in which the main goal is to achieve fast real-time communication. An algorithm that performs routing through clusters and search for the best cluster-head to maximize the number of transmitted information is presented in (Amri et al., 2014). The present work uses a fuzzy system to find an efficient route for transmission between a sensor and the gateway in order to obtain the shortest possible time, avoid transmission failures in case there is an inactive router, and save the battery consumption of the routers and thus increase their lifespan. The article is organized in six sections. Section 2 presents a brief description of wireless sensor networks. Section 3 does a brief discussion to routers energy management. Section 4 describes the proposed method. In section 5 a case study is described and section 6 presents conclusions and future developments.

2 WIRELESS SENSOR NETS

A Wireless Sensor Network (WSN) is an autonomous network of smart sensors with a high degree of cooperation among them. It is responsible for monitoring a process or an environment, processing the collected information, classifying the degree of importance of the information, and spreading it to the other sensors or routers closest to the gateway. The sensor network consists of the elements: sensor, observer, phenomenon, router and gateway, as shown in figure 2.

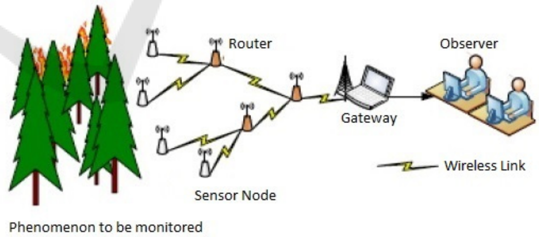

Figure 2: Elements of a wireless sensor networks.

The sensors measure the physical quantities and generate measurement reports by means of signal diffusion. For each type of phenomenon, there is a different type of sensor, which has a specific physical characteristic of the process. The observer is a user, or multiple users, who receive and request, when necessary, the information of the phenomena collected by the sensors, and broadcast by the wireless sensor net. The phenomenon is the process that will be monitored by the sensor element, and diffused by the wireless sensor network for the final evaluation of the observer.

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3 ENERGY MANAGEMENT

In recent years, the number of WSNs deployments for real-life applications has rapidly increased. However, the energy problem remains one of the main barriers limiting the full exploitation of this technology. Sensor nodes are usually powered by battery with limited capacity and even when there is possibility of obtaining additional energy from external environment, for example solar or piezo-electric, it remains a limited resource to be consumed judiciously. Among the characteristics of the WSNs, regardless of their application, the energy issue is the one that imposes the most restriction on the lifespan of the network. This causes several solutions to be presented as a way to maximize network durability without sacrificing the system reliability. Most of the sensor nodes have the characteristic of being disposable, because in certain applications of the network its maintenance is impracticable. The physical resources of the sensor nodes can be represented by an energy model, in the consumption and in the interaction level with a model of functions. Such energy model can be seen as an energy provider for consumer elements, through a battery with finite stored energy capacity. Each sensor informs the level of energy available to its provider, called an observer or sink. The energy model consists of the following elements: battery, radio (communication interface), processing and sensing unit. From the power model it is possible to obtain individual information from each sensor node of the network and perform a survey of the power map of the network, which in turn can be used to make decisions about what can and cannot be done to improve performance the network. It is important to highlight that in this energy model, the element that consumes the most energy is communication, mainly in the function of transmission and routing of the data collected by the sensing units. A sensor node is internally divided into four main units:

i) processing unit, consisting of a microprocessor or microcontroller;
ii) transmission unit (communication) consisting of a short-range radio for - wireless communication;
iii) sensing unit that connects the node to the physical world, and consists of a group of sensors and actuators;
iv) power unit.

It should be stressed that the path loss of the transmitted signal between two sensor nodes may be as high as the fourth order exponent of the distance between them, because the antennas of the sensor nodes are near to the ground (Akyildiz et al, 2002). Figure 3 shows the main components of a sensor structure.

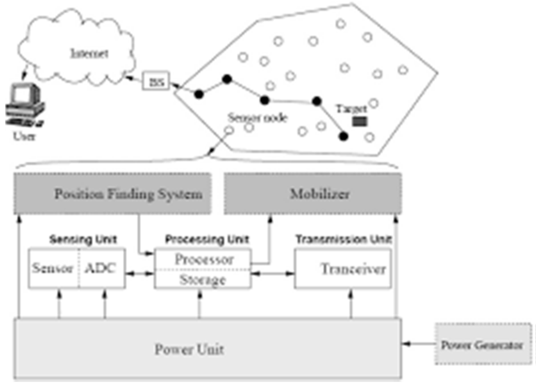

Figure 3: Sensor node structure of a WSN (Matin, 2012).

Due to the difficulty in having access to a dense WSN in full operation to carry out simulations regarding the energy consumption among the sensors, some proposals of models of energy dissipation for the sensor nodes are found in the literature. The main objective of these models is to characterize the energy consumption in each sensor node in a WSN. The common models used are: uniform dissipation model, hotspot based dissipation model and model based on four modes of operation. Among other authors, (Kashani and Ziafat, 2011), in addition to being concerned with Dynamic Power Management (DPM), present a new approach to energy management based on a centralized adaptive clustering protocol for self-organization of the sensor map through neural networks, which can group the sensor nodes based on several parameters: available energy level and coordinates of sensor nodes, in order to distribute the energy consumption between the sensor nodes and extend the lifetime of the network.

4 METHODOLOGY

For the sensors collected information be transmitted to the gateway, it is often necessary for it to pass through other sensors or routers until it reaches the sink or observer, which will take an action. If a sensor or router is not functioning properly, the information must find another path to go to the gateway. In addition, these sensors and routers are usually battery operated so they have a limited lifespan and it becomes impractical to frequently change their power source. To extend the period of use of the sensors it is interesting to optimize the data transfer in order to save the unnecessary use of routers and avoid transmission failures due to lack of power. One of the main goals in the transmission of information is to ensure that the data arrives at the gateway in the shortest possible time, since each additional router uses extra time. One way to minimize the delay time is to use a shorter, more efficient path in which a minimum number of routers are used to transmit information. In order to achieve that, a fuzzy inference system is implemented that will determine for each sensor or router what the next element to receive the information should be. For this, the system uses fuzzy inference rules that take into account the distance that the information will travel until it reaches the gateway and the state of conservation of the router, in other words, if it is in operation and has a good battery charge. The details of that modeling are found in the next section where a case study is elaborated to illustrate better the method.

5 CASE STUDY

In this section the simulation of a wireless routing system is elaborated, in which the sensors measure the physical quantities and transmit the collected data to the gateway through a network of routers and sensors. We used the MATLAB software and the Fuzzy Logic toolbox as a tool to illustrate the method for a case study. Initially an algorithm was developed capable of generating a configuration simulating the location of sensors / routers in an industrial area. The sensors monitor various physical quantities such as temperature, pressure and flow. We consider that all sensors are also routers, so all points can be used for routing. One hundred nodes were distributed in a square area with 1km² and the gateway was placed in the center of the environment in order to avoid great distances between it and some routers. The transmission range of each router was defined as 200m. At first we calculate which nodes can be reached by each of the mesh sensors / routers. This information will be used to define which of them will be evaluated by the fuzzy system. The choice of nodes to be used in the transmission of the information collected by the sensors is performed by the fuzzy system and is done based on the battery level and the distance between the nodes that are within its range and the gateway. We set the node closest to the gateway and with the highest battery level as the priority. Thus, we will be preventing transmission failure due to lack of energy, while at the same time, a minimum number of components in the process will be used in the transmission of information. The fuzzy system has as inputs the distance between the sensors / routers and the gateway, only those that can receive the information, i. e. the routers that are within reach of the transmitter sensor, and the battery level of these. The output of the system is a classification of the quality of the node to receive the information. After executing the fuzzy system, the node with the highest grade is chosen to carry out the transmission. Membership functions with triangular and trapezoidal format were used, and the linguistic variables are:

i) Distance: near / reasonable / far;

ii) Battery: low / medium / high;

iii) Output: poor / fair / good.

The membership function for an input variable is shown in figure 4 and the membership function for an output variable is shown in figure 5.

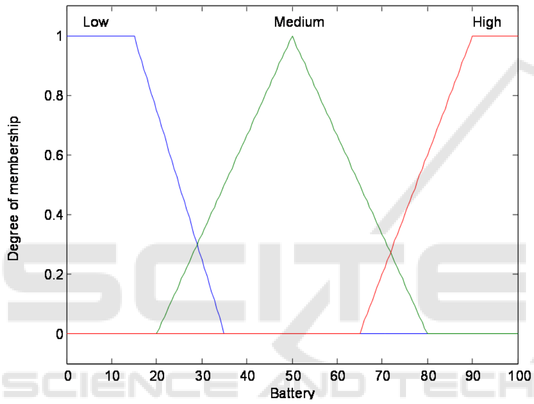

Figure 4: Membership function for input variable.

The rule matrix of the implemented fuzzy system is presented in Table 1.

Table 1: Fuzzy matrix.

Battery / Distance	Low	Medium	High
Near	Fair	Good	Good
Reasonable	Poor	Fair	Fair
Far	Poor	Poor	Fair

In order to verify the effectiveness of the proposed fuzzy system, some simulations were performed. Initially the sensor node where the information would be sent from is defined. Then the fuzzy system was executed to choose the node to which the information would be directed. The node with the best classification was chosen and the information transmitted to it. After this, the fuzzy system is executed again, using now the information regarding this new router. This process is repeated successively until the gateway is reached. In a first

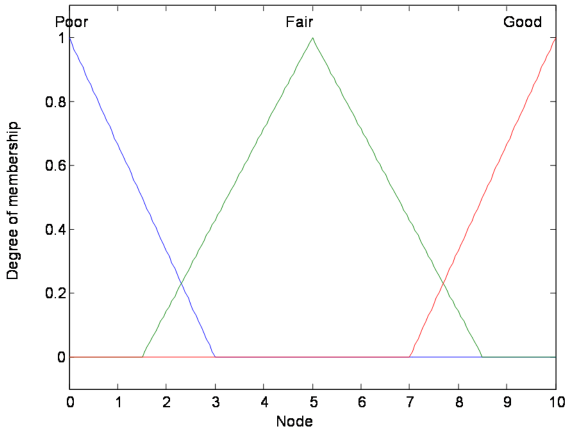

Figure 5: Membership function for output variable.

simulation, a sensor was chosen to the left of the gateway. The path traveled and the amount of battery existing in the used routers can be seen in figure 6.

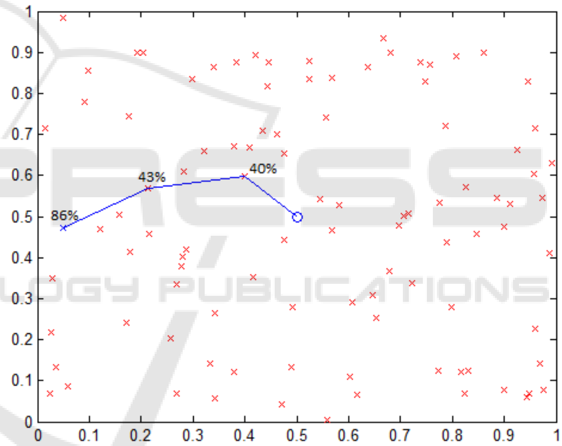

Figure 6: Path followed by information collected from a sensor on the left of the gateway.

In a second simulation a sensor was chosen in the lower right corner. The path obtained for transmission is shown in figure 7. The amount of battery in the nearby routers is also indicated.

In this simulation it was observed that the information passed through four nodes of the environment until reaching the gateway. It is also observed that the third chosen node was the one with the highest level of battery among the nearby nodes.

A new simulation was performed in which the same source sensor was maintained, but the battery of the third node traveled in the previous path was modified. Initially it had the value of 53% and in this simulation a very low value of 5% was used. The

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new transmission path obtained can be seen in figure 8.

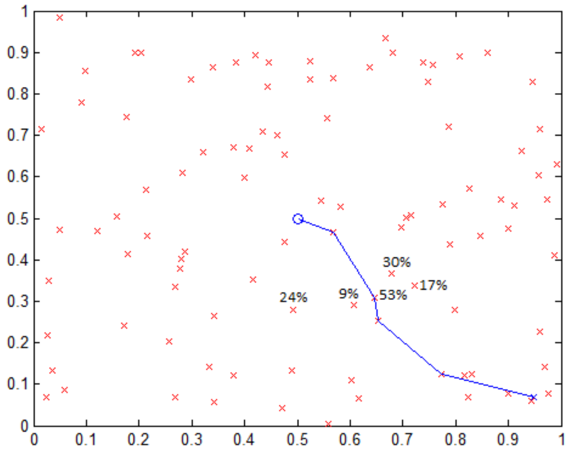

Figure 7: Path covered by information collected from a sensor in the lower right corner of the gateway.

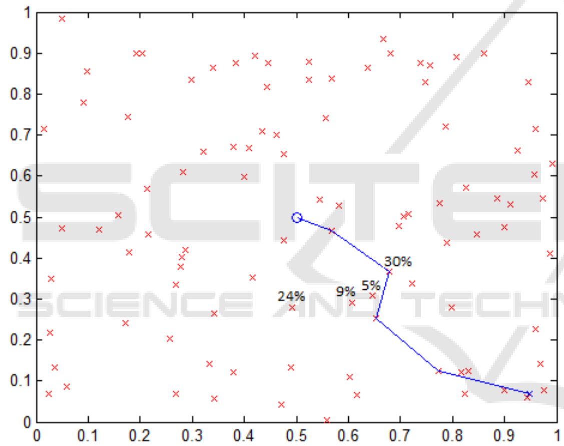

Figure 8: New path covered by information in the simulation shown in figure 7 after changes carried out.

Because the previously used battery node is now at a low level, it is preferable to save this router for cases where it needs to be used. It is observed that the new path used went through the node that had the highest level of battery still acceptable, that is, 30%, which was also close to the gateway. A new simulation was performed by changing the battery of this node, which was decreased to 10%. The result obtained is shown in figure 9.

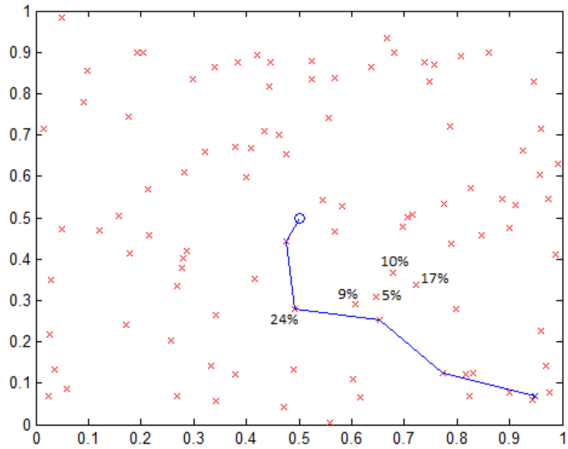

Figure 9: New path covered by information in the simulation shown in figure 8 after additional changes.

In this case, the nearest node with a higher battery level, 24%, was on the left and was chosen instead of the routes previously found. In a real system, this process would run simultaneously on several nodes according to the need of the plant. Therefore, the system was run again simulating five sensors transmitting information at the same time. The found trajectories can be seen in figure 10.

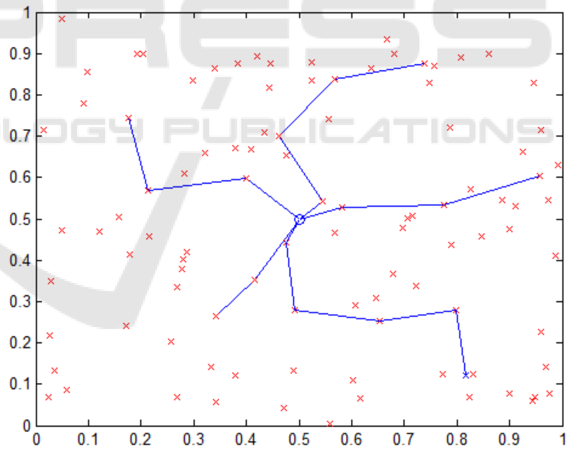

Figure 10: Path covered by information from five sensors transmitting concurrently.

The simulation was not performed with more sensors to allow a better visualization of the behavior at each node. Through the implemented simulations it is possible to observe the proper behavior of the proposed fuzzy system, which focused the choice of a shorter path to the gateway, but considered the amount of residual energy in each router in order to extend the useful life of the network.

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6 CONCLUSIONS

This paper proposed the use of fuzzy system techniques for use in wireless sensor networks focusing on shortest path and energy saving for the sensors in routing applications. Case studies of a wireless routing system was carried out, in which sensors measuring physical quantities were simulated, transmitting the data collected by them to the gateway through a network of routers and sensors. Five simulations were presented in the present paper in which favorable results were achieved. In the simulations, we performed the fuzzy inference system that determined the best route for routing taking into account the node's reach, the battery level of the possible nodes that could propagate the information and the distances among them and the gateway. The decision on which way to go was established based on the matrix of rules and functions of pertinence of the fuzzy inference system presented in this work. Through these simulations it was possible to illustrate the trajectory of a chosen path in the transmission of the information collected by a sensor until its reception, in the gateway. The results show that the fuzzy systems represent a suitable method for this application, presenting satisfactory results, since they chose a shorter path to the gateway considering the amount of energy in each router, extending the lifespan of the network. More complex networks involving new case studies are under way as well as a comprehensive comparison taking into account traditional techniques and algorithms. The huge amount of information and time needed to perform that task did not allow the authors to finish that task. There is sure a long way to go.

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