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Application of Fuzzy Logic for Selection of Actor Nodes in WSANs —Implementation of Two Fuzzy-Based Systems and a Testbed †

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Abstract: The development of sensor networks and the importance of smart devices in the physical world has brought attention to Wireless Sensor and Actor Networks (WSANs). They consist of a large number of static sensors and also a few other smart devices, such as different types of robots. Sensor nodes have responsibility for sensing and sending information towards an actor node any time there is an event that needs immediate intervention such as natural disasters or malicious attacks in the network. The actor node is responsible for processing and taking prompt action accordingly. But in order to select an appropriate actor to do one task, we need to consider different parameters, which make the problem NP-hard. For this reason, we consider Fuzzy Logic and propose two Fuzzy Based Simulation Systems (FBSS). FBSS1 has three input parameters such as Number of Sensors per Actor (NSA), Remaining Energy (RE) and Distance to Event (DE). On the other hand, FBSS2 has one new parameter—Transmission Range (TR)—and for this reason it is more complex. We will explain in detail the differences between these two systems. We also implement a testbed and compare simulation results with experimental results.

Keywords: WSANs; intelligent systems; intelligent algorithms; fuzzy logic; transmission range; load balancing; testbed

1. Introduction

Wireless Sensor Networks (WSNs) can be defined as a group of tiny wireless self-programmable devices, easily adaptable, which randomly connect to each other without needing any centralized authority, therefore dynamically sending the data to the intended recipient about the monitored phenomenon [1–3].

The development in sensor networks and the importance of smart devices in the physical world has brought attention to Wireless Sensor and Actor Networks (WSANs). They consist of a large number of static sensors and also a few other smart devices, such as different types of robots. WSANs have greatly enhanced the existing wireless sensor networks (WSNs) by its heterogeneous node structure. WSANs monitor their surroundings, process the gathered data, make a proper decision based on these data and complete different tasks when needed.
They can be applied in emergency scenarios such as fire situations, natural disasters and so forth. For example when a fire happens, sensors detect data such as the position and intensity of the fire and forward it to actors who coordinate with each other to decide what will extinguish it in time. Actors are different from each other, and some are more suitable for the specific disaster situation. To better illustrate this, let us take into consideration a fire happening on the higher floors of a building and in order to deal with this as soon as possible, a flying type robot will be selected [4,5].

In conventional WSNs, there are two main devices—sensors and sinks. Any changes in the environment will be sensed by the sensors immediately. At a certain time, a task which needs an action happens within the sensing range of the sensors, and they will forward this data to the sink. The sink is a collecting and processing device. Therefore the sink placement has a great impact on the performance of the network. Different from WSNs, where sensors forward all the data to the sink by multi-hop communication, in WSANs, two new interaction types are introduced. After the event is sensed, the actor in the proximity of this sensor will get, collect and then process these data before taking action upon the event. This is the scenario of sensor–actor interaction. In the above situation, before the actor takes action, it will first check if any other actor is better suited for taking over the task to ensure better resource management in the network. This is called actor–actor interaction, which is not only important during task fulfillment, but also during a network’s self-healing situations, that is, connectivity establishment [6,7], reliable services [8], Quality of Service (QoS) [9–11] and so on.

For selecting a proper actor to carry out a job we consider different parameters such as transmission range, load balancing, remaining energy and distance to event.

Since the actor and sensors are distributed in an arbitrary way, the main issues include coverage and communication, because of the different obstacles encountered. In general, this reflects how good the coverage is of the nodes in an area. So, to have better and clearer communication, we need to have an average transmission range in order not to affect the energy of the nodes and also to have better quality for communication.

The role of Load Balancing in WSANs is to provide a reliable service. Load balancing identifies the optimal load on nodes of the network to increase the network efficiency.

To have a better network efficiency and also to increase the network lifetime we have considered the parameter of the Remaining Energy (RE). As the devices are active and deployed in many scenarios, they perform tasks and exchange data between them. Due to this and due to their characteristics, some devices may have a lot of energy remaining in them and some others may have less. So, in order to increase the lifetime of the network, our system uses the actor nodes that are closer to the event.

The number of the actors in WSANs is smaller than the number of sensors. Thus, when an actor is called to action to perform a task, their distance to the event differs for every actor. Depending on the distance levels, our system takes decisions on the availability of each actor node.

However, having three or more parameters makes the problem NP-hard. There are different approaches and intelligent systems that can be used to deal with NP-hard problems. In our previous work, we considered Genetic Algorithms (GAs), Neural Networks (NNs), Particle Swarm Optimization (PSO), Hill Climbing (HC), Simulated Annealing (SA) and Tabu Search [12–15]. However, different intelligent algorithms have different efficiency for different problems. From our experience, the GAs provide good results for optimization and allocation problems. NNs provide good results for rule learning and recognition problems. While Fuzzy logic (FL) can be used for decision making and control problems. For this reason, we consider FL in this paper. Also, by using linguistic variables and a fuzzy rule base, it is easy to express previous knowledge and heuristics in the decision making process. We have proposed and implemented two decision-making systems, which consider uncertainty and vagueness of the data that cannot be computed by mathematical models. The core of Fuzzy Logic is Fuzzy Logic Controller (FLC), which is composed by four units such as the fuzzifier, inference engine, rule base and the defuzzifier. The crisp input value is fuzzified by the fuzzifier into a fuzzy value. By using this value and the rule base, the inference engine infers a fuzzy value, which is defuzzified by the defuzzifier and calculates a crisp value appropriate for control.
In our work, we consider three input linguistic parameters for FBSS1 and four input linguistic parameters for FBSS2. We performed simulations in order to evaluate the performance of the proposed systems. We also implemented a testbed and compared simulation results with experimental results. The comparison evaluation shows that experimental results are close to the simulation results, but there are some oscillations.

Different to our other published works [16–18], in this work we have added Number of Sensors per Actor (NSA) and Transmission Range (TR) to make the comparison between two fuzzy-based systems and also to evaluate the simulation results of one of the systems with the experimental results. The organization of the paper is as follows. The basics of WSANs including challenges and architecture are described in Section 2. The two systems and their implementation are described in Section 3. The experimental set up is explained in Section 4. Simulation and Experimental results are reported in Section 5. Finally, the paper is concluded in Section 6.

2. WSANs

2.1. WSANs Challenges

Some of the issues in WSANs related to the actors’ features are listed below.

- **Actor and Sensor Placement**: To avoid isolated islands being created and coverage only of secluded areas, a uniform deployment of sensors and actors is a major concern as the performance of the networks depends on it. By having a better spatially distributed network, we make better use of the collected data [19,20].

- **Real-Time**: WSANs are a distributed control system that requires a real-time reaction for the information gathered by the sensors. In case of an emergency situation the real-time response is crucial to guarantee immediate action [21].

- **Coordination**: Unlike WSNs, where the sink performs the functions of the gathered data, a new phenomena occurs in WSANs called sensor–actor and actor–actor coordination. This phenomenon provides the transmission of the event features from sensors to actors [22].

- **Energy Efficiency**: Each task, based on the difficulty, consumes power and drains the battery of the sensors. In order to increase the lifetime of the network, we should consider the energy of the sensors since they are power-constrained devices.

- **Scalability**: In a rapidly changing environment, it is a very big challenge for the network to meet scalability needs. A WSAN should have the capability to handle the growth of affecting the existing network [20,23].

2.2. WSAN Architecture

A WSAN is shown in Figure 1. In WSANs, the information of the physical environment is gathered by the sensors while the appropriate action upon the environment and the decision making is performed by the actors. The actor, besides being an acting device, is also an entity that performs network functionalities such as data receiving, processing and transmitting. After the sensors gather the data from the event, the action upon it depends on whether we have Semi-Automated or Fully-Automated architecture (see Figure 2). In the first case, the sensors forward the data to the sink. The sink is a resource-rich processing device, which collects the data and coordinates the devices.

In the Fully-Automated architecture, the sensors forward the data directly to the nearest actor. Afterward, the actors communicate with each other and coordinate to choose which of them will perform the task. This type of architecture is more complex as it needs sophisticated algorithms. Compared to the Semi-Automated architecture, it has some advantages such as long network lifetime, higher reliability, low energy consumption [4], low latency, and so on.
3. Proposed Fuzzy-Based Systems

After an event detection, the act upon this event depends on the present architecture type. These types of networks are characterized by the heterogeneity of the actors. This means that, based on the event type, we select the most suitable actor to perform this task.

3.1. System Parameters

Considering the challenges of WSANs, we have decided to use the following parameters for implementing our proposed system.

**Transmission Range (TR):** A well connected network is when all the devices are within the transmission range of each other. This parameter affects the network topology. A high range will achieve connection between nodes at the expense of high consumption of energy. A short range will use less energy to forward the data, but more hops are required to reach the destination. So, in our system we have considered an average transmission range.

**Distance to Event (DE):** Our system considers the availability of the actors when needed for action near an event. The distance of the actor to the event varies for different scenarios.

**Remaining Energy (RE):** These devices are power-constrained and one of the main issues is power consumption. Each task consumes different amounts of energy depending on its difficulty. Therefore, it is very important to utilize the remaining energy of each node efficiently.

**Number of Sensors per Actor (NSA):** It is important that all actors are within the sensing range of the sensors. In some situations the actors are secluded with a low number of sensors which decreases the chances of the event being detected. On the other hand, having too many sensors per actor isolates the network to a specific area. So it is better to have a balanced number of sensors within the range of an actor.
Actor Selection Decision (ASD): Based on the input parameters, our system makes a decision on which actor is to be selected to perform the task.

Parameters vary in different time steps depending on whether actors have or have not used their resources. With our simulation system, we aim to solve problems that are difficult for human reasoning. It should be noted that the problems with more than two unrelated parameter combinations are NP-Hard.

3.2. Implementation of Fuzzy Logic

We have implemented fuzzy logic in the area of actor selection for WSAN. Fuzzy logic uses an approximation approach for decision making [24–40].

The systems are implemented directly in the actors because they have high computational resources. Sensors are devices which detect, gather and distribute the data. In the case of Fully Automated Architecture, as mentioned above, the actors have the ability to communicate with each other for making the decision. On the other hand in the Semi-Automated Architecture, a centralized administration tool (Sink), analyzes and makes the decision.

Our proposed system is shown in Figure 3. The crisp input parameters (TR, NSA, RE, DE) are inserted on the fuzzy logic controller, which is shown in Figure 4.

We have implemented two systems based on Fuzzy theory, one with 3 input parameters and the other one with 4 input parameters. We have assigned 3 linguistic values for each parameter. This is because there are different scenarios and applications that require different parameters.

The membership functions measure the linguistic terms’ and maps’ non-fuzzy input to fuzzy and vice versa. There are different types of membership functions which are used for different applications. The types of membership functions we have used are shown in Figure 5. As can be seen from the figures, one value can be defined by more than one set and can have two different values at the same time.

![Figure 3. Proposed System.](image-url)

![Figure 4. Fuzzy Logic Controller.](image-url)
3.3. Description of FBSS1 and FBSS2

We use three input parameters for FBSS1:

- Distance to Event (DE);
- Remaining Energy (RE);
- Number of Sensors per Actor (NSA).

For FBSS2, we add a new parameter together with the FBSS1 parameters:

- Transmission Range (TR).

The term sets for each input linguistic parameter are defined respectively as shown in Table 1. Input and output membership functions are shown in Figure 6. After the input parameters are fuzzified, the fuzzy controller will decide which actor will be selected based on the membership functions and the fuzzy rule matrix of combinations number and input parameters. The table for FRB1 is shown in Table 2, and we have a total of twenty-seven rules. For the FRB2 we have eighty-one rules, as shown in Table 3, for four input parameters and three term sets each. The conditional statements of “IF–THEN” are used for the control rules.

Figure 6. Fuzzy membership functions. (a) Transmission Range. (b) Number of Sensors per Actor. (c) Remaining Energy. (d) Distance to Event. (e) Actor Selection Decision.
Table 1. Linguistic variables of input and output parameters.

| Parameters                  | Term Sets                                      |
|-----------------------------|-----------------------------------------------|
| Transmission Range (TR)     | Short (Sh), Middle (Mi), Long (Ln)            |
| Distance to Event (DE)      | Near (Ne), Moderate (Mo), Far (Fa)            |
| Remaining Energy (RE)       | Low (Lo), Medium (Mdm), High (Hi)             |
| Number of Sensors per Actor (NSA) | Few (Fw), Medium (Me), Many (My)            |
| Actor Selection Decision (ASD) | Very Low Selection Possibility (VLSP), Low Selection Possibility (LSP), Middle Selection Possibility (MSP), High Selection Possibility (HSP), Very High Selection Possibility (VHSP) |

Table 2. FRB1.

| No. | NSA | RE  | DE  | ASD  |
|-----|-----|-----|-----|------|
| 1   | Fw  | Lo  | Ne  | LSP  |
| 2   | Fw  | Lo  | Mo  | VLSP |
| 3   | Fw  | Lo  | Fa  | VLSP |
| 4   | Fw  | Mdm | Ne  | MSP  |
| 5   | Fw  | Mdm | Mo  | VLSP |
| 6   | Fw  | Mdm | Fa  | VLSP |
| 7   | Fw  | Hi  | Ne  | VHSP |
| 8   | Fw  | Hi  | Mo  | LSP  |
| 9   | Fw  | Hi  | Fa  | LSP  |
| 10  | Me  | Lo  | Ne  | MSP  |
| 11  | Me  | Lo  | Mo  | VLSP |
| 12  | Me  | Lo  | Fa  | VLSP |
| 13  | Me  | Mdm | Ne  | VHSP |
| 14  | Me  | Mdm | Mo  | LSP  |
| 15  | Me  | Mdm | Fa  | VLSP |
| 16  | Me  | Hi  | Ne  | VHSP |
| 17  | Me  | Hi  | Mo  | MSP  |
| 18  | Me  | Hi  | Fa  | LSP  |
| 19  | My  | Lo  | Ne  | LSP  |
| 20  | My  | Lo  | Mo  | VLSP |
| 21  | My  | Lo  | Fa  | VLSP |
| 22  | My  | Mdm | Ne  | MSP  |
| 23  | My  | Mdm | Mo  | VLSP |
| 24  | My  | Mdm | Fa  | VLSP |
| 25  | My  | Hi  | Ne  | VHSP |
| 26  | My  | Hi  | Mo  | LSP  |
| 27  | My  | Hi  | Fa  | LSP  |
### Table 3. FRB2.

| No. | TR | DE | RE | NSA | ASD | No. | TR | DE | RE | NSA | ASD |
|-----|----|----|----|-----|-----|-----|----|----|----|-----|-----|
| 01  | Sh | Ne | Lo | Fw  | VLSP| 41  | Mi | Mo | Mdm | Me  | VHSP|
| 02  | Sh | Ne | Lo | Me  | HSP | 42  | Mi | Mo | Mdm | My  | HSP |
| 03  | Sh | Ne | Lo | My  | VLSP| 43  | Mi | Mo | Hi  | Fw  | VHSP|
| 04  | Sh | Ne | Mdm| Fw  | MSP | 44  | Mi | Mo | Hi  | Me  | VHSP|
| 05  | Sh | Ne | Mdm| Me  | VHSP| 45  | Mi | Mo | Hi  | My  | VHSP|
| 06  | Sh | Ne | Mdm| My  | MSP | 46  | Mi | Fa | Lo  | Fw  | VLSP|
| 07  | Sh | Ne | Hi | Fw  | HSP | 47  | Mi | Fa | Lo  | Me  | MSP |
| 08  | Sh | Ne | Hi | Me  | VHSP| 48  | Mi | Fa | Lo  | My  | VLSP|
| 09  | Sh | Ne | Hi | My  | VHSP| 49  | Mi | Fa | Mdm | Fw  | LSP |
| 10  | Sh | Mo | Lo | Fw  | VLSP| 50  | Mi | Fa | Mdm | Me  | VHSP|
| 11  | Sh | Mo | Lo | Me  | LSP | 51  | Mi | Fa | Mdm | My  | LSP |
| 12  | Sh | Mo | Lo | My  | VLSP| 52  | Mi | Fa | Hi  | Fw  | MSP |
| 13  | Sh | Mo | Mdm| Fw  | VLSP| 53  | Mi | Fa | Hi  | Me  | VHSP|
| 14  | Sh | Mo | Mdm| Me  | HSP | 54  | Mi | Fa | Hi  | My  | HSP |
| 15  | Sh | Mo | Mdm| My  | LSP | 55  | Ln | Ne | Lo  | Fw  | VLSP|
| 16  | Sh | Mo | Hi | Fw  | MSP | 56  | Ln | Ne | Lo  | Me  | HSP |
| 17  | Sh | Mo | Hi | Me  | VHSP| 57  | Ln | Ne | Lo  | My  | LSP |
| 18  | Sh | Mo | Hi | My  | MSP | 58  | Ln | Ne | Mdm | Fw  | MSP |
| 19  | Sh | Fa | Lo | Fw  | VLSP| 59  | Ln | Ne | Mdm | Me  | VHSP|
| 20  | Sh | Fa | Lo | Me  | VLSP| 60  | Ln | Ne | Mdm | My  | HSP |
| 21  | Sh | Fa | Lo | My  | VLSP| 61  | Ln | Ne | Hi  | Fw  | VHSP|
| 22  | Sh | Fa | Mdm| Fw  | VLSP| 62  | Ln | Ne | Hi  | Me  | VHSP|
| 23  | Sh | Fa | Mdm| Me  | MSP | 63  | Ln | Ne | Hi  | My  | VHSP|
| 24  | Sh | Fa | Mdm| My  | VLSP| 64  | Ln | Mo | Lo  | Fw  | VLSP|
| 25  | Sh | Fa | Hi | Fw  | VLSP| 65  | Ln | Mo | Lo  | Me  | MSP |
| 26  | Sh | Fa | Hi | Me  | HSP | 66  | Ln | Mo | Lo  | My  | VLSP|
| 27  | Sh | Fa | Hi | My  | LSP | 67  | Ln | Mo | Mdm | Fw  | LSP |
| 28  | Mi | Ne | Lo | Fw  | MSP | 68  | Ln | Mo | Mdm | Me  | VHSP|
| 29  | Mi | Ne | Lo | Me  | VHSP| 69  | Ln | Mo | Mdm | My  | LSP |
| 30  | Mi | Ne | Lo | My  | HSP | 70  | Ln | Mo | Hi  | Fw  | MSP |
| 31  | Mi | Ne | Mdm| Fw  | VHSP| 71  | Ln | Mo | Hi  | Me  | VHSP|
| 32  | Mi | Ne | Mdm| Me  | VHSP| 72  | Ln | Mo | Hi  | My  | HSP |
| 33  | Mi | Ne | Mdm| My  | VHSP| 73  | Ln | Fa | Lo  | Fw  | VLSP|
| 34  | Mi | Ne | Hi | Fw  | VHSP| 74  | Ln | Fa | Lo  | Me  | VLSP|
| 35  | Mi | Ne | Hi | Me  | VHSP| 75  | Ln | Fa | Lo  | My  | VLSP|
| 36  | Mi | Ne | Hi | My  | VHSP| 76  | Ln | Fa | Mdm | Fw  | VLSP|
| 37  | Mi | Mo | Lo | Fw  | LSP | 77  | Ln | Fa | Mdm | Me  | MSP |
| 38  | Mi | Mo | Lo | Me  | VHSP| 78  | Ln | Fa | Mdm | My  | VLSP|
| 39  | Mi | Mo | Lo | My  | LSP | 79  | Ln | Fa | Hi  | Fw  | LSP |
| 40  | Mi | Mo | Mdm| Fw  | HSP | 80  | Ln | Fa | Hi  | Me  | HSP |
|     |     |     |     |     |     | 81  | Ln | Fa | Hi  | My  | LSP |

### 4. Testbed Description

An experiment was conducted to evaluate this simulation system. We selected an indoor environment and placed the sensors and actors randomly. Three different types of sensors (see Figure 7) were mounted on Arduino Uno (see Figure 8), which acted as actors. The event was also randomly deployed. The actors did different measures for different event positions. In order to move the actors freely, some of them were connected to a Raspberry Pi 3 B+, but in this scenario the battery consumption was higher than when we used a laptop as the processing unit.

- The transmission range of the actor.
- A power bank or laptop battery to check the levels of remained energy after each measurement.
- Distance sensor to measure the distance from actor to the event.
The experimental parameters are shown in the Table 4.

| Experimental Parameters                  |
|------------------------------------------|
| Operating System                         | MacOS, Ubuntu 18.04                      |
| Experiment Area                          | Indoor 2 × 2 (m²)                        |
| Number of Actors                         | 3 [Arduino Uno]                          |
| Number of Sensors                        | 3 [TR, Battery, Distance]                |
| Number of Events                         | 25                                       |
| IDE                                      | Arduino IDE v. 1.8.8, Processing v. 3.5.3|

5. Simulation and Experimental Results

In this section, we present the simulation results. The simulations are carried out in a Linux Ubuntu OS computer with these specifications—RAM (8 GB), CPU i5 (3.2 GHz × 4) and SSD (650 GB). For simulation, we used our implemented FuzzyC system. The FuzzyC is a simulation system written in C language and equipped with Fuzzy library.

5.1. Simulation Results

We have presented the simulation results of our system in Figure 9. In the networks where nodes are mobile, energy consumption is a main issue. In Figure 9a, TR is 0.1, DE is 0.2 and for RE from 0.1 to
0.5, ASD increases by 27% and when RE goes from 0.5 to 0.9, the ASD is increased by 31%. This means that the lifetime of the network will be longer if actors have a high amount of residual energy.

To see the effect of TR on actor selection we compare Figure 9c with Figure 9b, for RE = 0.1 and DE = 0.2. As expected, the ASD has decreased 29%, because TR is increased from 0.5 to 0.9. In Figure 9c, we observe the effect of DE. For RE = 0.1 and DE from 0.1 to 0.9, ASD has dropped by 49.5%.

The simulation results of FBSS2 are shown in Figures 10–12. Having these simulation results, we can say that while DE raises, the ASD declines, because for further distances of events actors have to move far and at the same time they spend a lot more energy. The increase of DE decreases ASD and we show this by comparing Figure 11a with Figure 11b,c. When NSA = 0.5, RE = 0.1 and TR = 0.5 for DE from 0.1 to 0.5 and from 0.1 to 0.9, ASD has decreased by 15% and 40%, respectively.

In WSANs, many clusters of actors and sensors are created, so it is essential to have a balanced distribution of sensors per actor. As shown in Figure 10a, we see the relationship between ASD and NSA, when TR = 0.1 and DE = 0.1. For three selected values of NSA, 0.2, 0.5 and 0.8, we see that NSA is increased by 27% from 0.2 to 0.5 unit and decreased by 15% from 0.5 to 0.8 unit.

Comparing Figure 11b with Figure 10b and Figure 12b with Figure 10b, by increasing TR from 0.1 to 0.5 and 0.9, the ASD is increased by 37% and decreased by 25%, respectively.

Hence, it is important to utilize the power of each actor with efficiency in order to have a longer network lifetime. If the TR is kept low, even when the energy will be consumed a little, the packets might not be able to reach the destination. On the other hand, if the TR is kept high, the energy will be consumed faster, but the coverage will be higher. So, in order to have an optimized network lifetime, an optimal value of TR needs to be chosen.

![Figure 9](image_url)

Figure 9. Results for different values of Transmission Range (TR). (a) TR = 0.1. (b) TR = 0.5. (c) TR = 0.9.
Figure 10. Results for TR = 0.1. (a) DE = 0.1. (b) DE = 0.5. (c) DE = 0.9.

Figure 11. Results for TR = 0.5. (a) DE = 0.1. (b) DE = 0.5. (c) DE = 0.9.
In this section, we describe the work towards solving the actors selection problem by setting up a testbed for evaluating the results of our system in a real life scenario. We present the experimental results in Figure 13. The three graphs belong to one of each linguistic variable of TR: Short, Middle and Long. The RE is represented with different color lines with blue being the High value, Medium is the green one and red is Low.

By analyzing the experimental results and simulation results, we observed that the curves follow a similar trend with some deviations. Experimental results show that the ASD is increased for higher RE, shorter DE and an average value of TR. The same phenomenon is also observed in the simulation results.

Each actor (A1, A2 and A3) parameters were measured for a total of 25 unrelated events (see Figure 14). In different moments, actors have different parameter values conditioned by the always changing topology. Comparing the values of each parameter for the three actors, only one is to be chosen for performing the task. So, we see that in event 3, A1 is selected to do the task. At event 15, A3 is selected and in event 24, A2 is suitable for carrying out the task.

Because there are three and four parameters for making decisions, the ASD values are different, so only one actor is selected.
Figure 13. Experimental results for different linguistic variables of TR. (a) TR = Short. (b) TR = Middle. (c) TR = Long.

Figure 14. Experimental results for different Events.

6. Conclusions and Future Work

The conclusions for our proposed systems and testbed are given below. With our systems, we expected actors to complete the task without wasting resources. We observed the effect of these parameters—TR, NSA, RE and DE—on ASD. The further away the actor, the less they are favored to be selected for the task. So an increase in DE results in a decrease in ASD. A higher level of residual energy keeps the actor in the network longer. As for the TR parameter to preserve energy and to limit the
number of hops, we saw that an average value is more preferable as it increases ASD. Comparing FBSS1 with FBSS2, the FBSS2 is more complex than FBSS1, but it makes a better selection of actor nodes. A drawback of implementing a testbed is that they are confined to the environment, where simulation results offer a broad range of scenarios. By analyzing the experimental results and simulation results, we observed that the curves follow a similar trend with some deviations.

For future work, we will implement other systems and propose new parameters for actor selection and will conduct extensive experiments and simulations to evaluate the systems.

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**References**

1. Akyildiz, I.; Su, W.; Sankarasubramaniam, Y.; Cayirci, E. Wireless sensor networks: A survey. *Comput. Netw.* 2002, 38, 393–422. [CrossRef]

2. Atassi, A.; Sayegh, N.; Elhajj, I.H.; Chehab, A.; Kayssi, A. Decentralised malicious node detection in WSN. *Int. J. Space Based Situated Comput.* 2014, 4, 15–25. [CrossRef]

3. Boyinbode, O.; Le, H.; Takizawa, M. A survey on clustering algorithms for wireless sensor networks. *Int. J. Space Based Situated Comput.* 2011, 1, 130–136. [CrossRef]

4. Akyildiz, I.F.; Kasimoglu, I.H. Wireless Sensor and Actor Networks: Research Challenges. *Ad Hoc Netw. J.* 2004, 2, 351–367. [CrossRef]

5. Bahrepour, M.; Meratnia, N.; Poel, M.; Taghikhaki, Z.; Havinga, P.J. Use of wireless sensor networks for distributed event detection in disaster management applications. *Int. J. Space Based Situated Comput.* 2012, 2, 58–69. [CrossRef]

6. Haider, N.; Imran, M.; Saad, N.; Zakariya, M. Performance analysis of reactive connectivity restoration algorithms for wireless sensor and actor networks. In Proceedings of the IEEE Malaysia International Conference on Communications (MICC-2013), Kuala Lumpur, Malaysia, 26–28 November 2013; pp. 490–495, doi:10.1109/MICC.2013.6805879. [CrossRef]

7. Abbasi, A.; Younis, M.; Akkaya, K. Movement-Assisted Connectivity Restoration in Wireless Sensor and Actor Networks. *IEEE Trans. Parallel Distrib. Syst.* 2009, 20, 1366–1379, doi:10.1109/TPDS.2008.246. [CrossRef]

8. Li, X.; Liang, X.; Lu, R.; He, S.; Chen, J.; Shen, X. Toward Reliable Actor Services in Wireless Sensor and Actor Networks. In Proceedings of the 2011 IEEE 8th International Conference on Mobile Adhoc and Sensor Systems (MASS), Valencia, Spain, 17–22 October 2011; pp. 351–360, doi:10.1109/MASS.2011.42. [CrossRef]

9. Akkaya, K.; Younis, M. COLA: A Coverage and Latency Aware Actor Placement for Wireless Sensor and Actor Networks. In Proceedings of the IEEE 64th Conference on Vehicular Technology (VTC-2006) Fall, Montreal, QC, Canada, 25–28 September 2006; pp. 1–5, doi:10.1109/VTCS.2006.544. [CrossRef]

10. Kakarla, J.; Majhi, B. A new optimal delay and energy efficient coordination algorithm for WSAN. In Proceedings of the 2013 IEEE International Conference on Advanced Networks and Telecommunications Systems (ANTS), Kattankulathur, India, 15–18 December 2013; pp. 1–6, doi:10.1109/ANTS.2013.6802871. [CrossRef]

11. Elmazi, D.; Cuka, M.; Bylykbashi, K.; Spaho, E.; Ikeda, M.; Barolli, L. Selection of Actor Nodes in Wireless Sensor and Actor Networks Considering Actor-Sensor Coordination Quality Parameter. In Proceedings of the International Conference on Broadband and Wireless Computing, Communication and Applications, Barcelona, Spain, 8–10 November 2017; pp. 87–99.

12. Barolli, A.; Sakamoto, S.; Durre, H.; Ohara, S.; Barolli, L.; Takizawa, M. A Comparison Study of Constriction and Linearly Decreasing Vmax Replacement Methods for Wireless Mesh Networks by WNN-PSOHC-DGA Simulation System. In Proceedings of the International Conference on P2P, Parallel, Grid, Cloud and Internet Computing, Antwerp, Belgium, 7–9 November 2019; pp. 26–34.
13. Ishitaki, T.; Elmazi, D.; Liu, Y.; Oda, T.; Barolli, L.; Uchida, K. Application of neural networks for intrusion
detection in tor networks. In Proceedings of the 2015 IEEE 29th International Conference on Advanced
Information Networking and Applications Workshops, Gwangju, Korea, 24–27 March 2015; pp. 67–72.
14. Sakamoto, S.; Kulla, E.; Oda, T.; Ikeda, M.; Barolli, L.; Xhafa, F. A Comparison Study of Simulated Annealing
and Genetic Algorithm for Node Placement Problem in Wireless Mesh Networks. J. Mob. Multimed. 2013,
9, 101–110.
15. Oda, T.; Elmazi, D.; Lala, A.; Kolici, V.; Barolli, L.; Xhafa, F. Analysis of node placement in wireless mesh
networks using Friedman test: A comparison study for Tabu Search and hill climbing. In Proceedings of the
2015 9th International Conference on Innovative Mobile and Internet Services in Ubiquitous Computing,
Blumenau, Brazil, 8–10 May 2015; pp. 133–140.
16. Elmazi, D.; Cuka, M.; Ikeda, M.; Barolli, L. A Fuzzy-Based System for Actor Node Selection in WSANs
for Improving Network Connectivity and Increasing Number of Covered Sensors. In Proceedings of the
International Conference on Network-Based Information Systems, Bratislava, Slovakia, 5–7 September 2018;
pp. 3–15.
17. Elmazi, D.; Cuka, M.; Ikeda, M.; Barolli, L. Effect of Size of Giant Component for actor node selection in
WSANs: A comparison study. Concurr. Comput. Pract. Exp. 2019, e5106, doi:10.1002/cpe.5106. [CrossRef]
18. Elmazi, D.; Cuka, M.; Ikeda, M.; Matsuo, K.; Barolli, L. A Fuzzy-Based System for Actor Node Selection in
WSANS: Simulation and Experimental Results. In Proceedings of the International Conference on Innovative
Mobile and Internet Services in Ubiquitous Computing, Sydney, NSW, Australia, 3–5 July 2019; pp. 11–24.
19. Akbas, M.; Turgut, D. APAWSAN: Actor positioning for aerial wireless sensor and actor networks. In Proceedings of the 2011 IEEE 36th Conference on Local Computer Networks (LCN), Bonn, Germany,
4–7 October 2011; pp. 563–570, doi:10.1109/LCN.2011.6115518. [CrossRef]
20. Akbas, M.; Brust, M.; Turgut, D. Local positioning for environmental monitoring in wireless sensor and actor
networks. In Proceedings of the 2010 IEEE 35th Conference on Local Computer Networks (LCN), Denver,
CO, USA, 10–14 October 2010; pp. 806–813, doi:10.1109/LCN.2010.5735815. [CrossRef]
21. Gungor, V.; Akan, O.; Akyildiz, I. A Real-Time and Reliable Transport (RT2) Protocol for Wireless Sensor
and Actor Networks. IEEE/ACM Trans. Netw. 2008, 16, 359–370, doi:10.1109/TNET.2007.900413. [CrossRef]
22. Melodia, T.; Pompili, D.; Gungor, V.; AkyildizZX, I. Communication and Coordination in Wireless Sensor
and Actor Networks. IEEE Trans. Mob. Comput. 2007, 6, 1126–1129. [CrossRef]
23. Nakayama, H.; Fadlullah, Z.; Ansari, N.; Kato, N. A Novel Scheme for WSAN Sink Mobility Based
on Clustering and Set Packing Techniques. IEEE Trans. Autom. Control. 2011, 56, 2381–2389,
doi:10.1109/TAC.2011.2163872. [CrossRef]
24. Kulla, E.; Ikeda, M.; Leonard, B. A Fuzzy Approach to Actor Selection in Wireless Sensor and Actor Networks.
In Proceedings of the 17th International Conference on Network-Based Information Systems (NBiS-2014),
Salerno, Italy, 10–12 September 2014; pp. 244–248.
25. Inaba, T.; Sakamoto, S.; Kolici, V.; Mino, G.; Barolli, L. A CAC Scheme Based on Fuzzy Logic for Cellular
Networks Considering Security and Priority Parameters. In Proceedings of the 9th International Conference
on Broadband and Wireless Computing, Communication and Applications (BWCCA-2014), Guangdong,
China, 8–10 November 2014; pp. 340–346.
26. Spaho, E.; Sakamoto, S.; Barolli, L.; Xhafa, F.; Barolli, V.; Iwashige, J. A Fuzzy-Based System for Peer Reliability
in JXTA-Overlay P2P Considering Number of Interactions. In Proceedings of the 16th International
Conference on Network-Based Information Systems (NBiS-2013), Gwangju, Korea, 4–6 September 2013;
pp. 156–161.
27. Matsuo, K.; Elmazi, D.; Liu, Y.; Sakamoto, S.; Mino, G.; Barolli, L. FACS-MP: A fuzzy admission control
system with many priorities for wireless cellular networks and its performance evaluation. J. High Speed Netw.
2015, 21, 1–14. [CrossRef]
28. Grabisch, M. The Application of Fuzzy Integrals in Multicriteria Decision Making. Eur. J. Oper. Res. 1996,
89, 445–456. [CrossRef]
29. Inaba, T.; Elmazi, D.; Liu, Y.; Sakamoto, S.; Barolli, L.; Uchida, K. Integrating Wireless Cellular and
Ad-Hoc Networks Using Fuzzy Logic Considering Node Mobility and Security. In Proceedings of the
29th IEEE International Conference on Advanced Information Networking and Applications Workshops
(WAINA-2015), Gwangju, Korea, 24–27 March 2015; pp. 54–60.
30. Kulla, E.; Mino, G.; Sakamoto, S.; Ikeda, M.; Caballé, S.; Barolli, L. FBMIS: A Fuzzy-Based Multi-interface System for Cellular and Ad Hoc Networks. In Proceedings of the International Conference on Advanced Information Networking and Applications (AINA-2014), Victoria, BC, Canada, 13–16 May 2014; pp. 180–185.

31. Elmazi, D.; Kulla, E.; Oda, T.; Spaho, E.; Sakamoto, S.; Barolli, L. A comparison study of two fuzzy-based systems for selection of actor node in wireless sensor actor networks. *J. Ambient. Intell. Humaniz. Comput.* 2015, 6, 635–645. [CrossRef]

32. Zadeh, L. Fuzzy Logic, Neural Networks, and Soft Computing. *Commun. ACM* 1994, 37, 77–84. [CrossRef]

33. Spaho, E.; Sakamoto, S.; Barolli, L.; Xhafa, F.; Ikeda, M. Trustworthiness in P2P: Performance Behaviour of Two Fuzzy-based Systems for JXTA-overlay Platform. *Soft Comput.* 2014, 18, 1783–1793. [CrossRef]

34. Inaba, T.; Sakamoto, S.; Kulla, E.; Caballe, S.; Ikeda, M.; Barolli, L. An Integrated System for Wireless Cellular and Ad-Hoc Networks Using Fuzzy Logic. In Proceedings of the International Conference on Intelligent Networking and Collaborative Systems (INCoS-2014), Salerno, Italy, 10–12 September 2014; pp. 157–162.

35. Matsuo, K.; Elmazi, D.; Liu, Y.; Sakamoto, S.; Barolli, L. A multi-modal simulation system for wireless sensor networks: A comparison study considering stationary and mobile sink and event. *J. Ambient. Intell. Humaniz. Comput.* 2015, 6, 519–529. [CrossRef]

36. Kolici, V.; Inaba, T.; Lala, A.; Mino, G.; Sakamoto, S.; Barolli, L. A Fuzzy-Based CAC Scheme for Cellular Networks Considering Security. In Proceedings of the International Conference on Network-Based Information Systems (NBIoS-2014), Salerno, Italy, 10–12 September 2014; pp. 368–373.

37. Liu, Y.; Sakamoto, S.; Matsuo, K.; Ikeda, M.; Barolli, L.; Xhafa, F. A comparison study for two fuzzy-based systems: Improving reliability and security of JXTA-overlay P2P platform. *Soft Comput.* 2016, 20, 2677–2687. [CrossRef]

38. Elmazi, D.; Oda, T.; Spaho, E.; Kulla, E.; Ikeda, M.; Barolli, L. A Fuzzy-Based Simulation System for Actor Selection in Wireless Sensor and Actor Networks Considering as a New Parameter Density of Actor Nodes. In Proceedings of the International Conference on Broadband and Wireless Computing, Communication and Applications, Asan, Korea, 5–7 November 2016; pp. 163–174.

39. Elmazi, D.; Cuka, M.; Oda, T.; Kulla, E.; Ikeda, M.; Barolli, L. Effect of Packet Error Rate on Selection of Actor Nodes in WSANs: A Comparison Study of Two Fuzzy-Based Systems. In Proceedings of the International Conference on Network-Based Information Systems, Toronto, ON, Canada, 24–26 August 2017; pp. 114–126.

40. Cuka, M.; Elmazi, D.; Bylykbashi, K.; Spaho, E.; Ikeda, M.; Barolli, L. Effect of node centrality for IoT device selection in opportunistic networks: A comparison study. *Concurr. Comput. Pract. Exp.* 2018, 30, e4790. [CrossRef]

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