A Fuzzy-Based Simulation System for Actor Selection in Wireless Sensor and Actor Networks Considering as a New Parameter Density of Actor Nodes

Donald Elmazi, Tetsuya Oda, Evjola Spaho, Elis Kulla, Makoto Ikeda, Leonard Barolli

Abstract Wireless Sensor and Actor Networks (WSANs), refers to a group of sensors and actors that get the information about the physical environment and perform appropriate actions. In order to provide effective sensing and acting, a distributed local coordination mechanism is necessary among sensors and actors. In this work, we propose a fuzzy-based system for selection in WSANs. Our system uses four input parameters. Different from our previous work, we consider also the Density of Actor (DOA) parameter. The system output is Actor Selection Decision (ASD). The simulation results show that the proposed system has a good behaviour and makes a proper selection of actor nodes.

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1 Introduction

Wireless Sensor and Actor Networks (WSANs), have emerged as a variation of WSNs. WSNs can be defined as a collection of wireless self-configuring programmable multi-hop tiny devices, which can bind to each other in an arbitrary manner, without the aid of any centralized administration, thereby dynamically sending the sensed data to the intended recipient about the monitored phenomenon [1].

WSANs are capable of monitoring physical phenomenons, processing sensed data, making decisions based on the sensed data and completing appropriate tasks when needed [2]. For example, in the case of a fire, sensors relay the exact origin and intensity of the fire to actors so that they can extinguish it before spreading in the whole building or in a more complex scenario, to save people who may be trapped by fire.

Unlike WSNs, where the sensor nodes tend to communicate all the sensed data to the sink by sensor-sensor communication, in WSANs, two new communication types may take place. They are called sensor-actor and actor-actor communications. Sensed data is sent to the actors in the network through sensor-actor communication. After the actors analyse the data, they communicate with each other in order to assign and complete tasks. To provide effective operation of WSAN, is very important that sensors and actors coordinate in what are called sensor-actor and actor-actor coordination. Coordination is not only important during task conduction, but also during network's self-improvement operations, i.e. connectivity restoration [3, 4], reliable service [5], Quality of Service (QoS) [6, 7] and so on.

Sensor-Actor (SA) coordination defines the way sensors communicate with actors, which actor is accessed by each sensor and which route should be selected to transmit data packets. Among other challenges, when designing SA coordination, the energy minimization should be considered. On the other hand, by Actor-Actor (AA) coordination can be selected which actor will lead performing the task (actor selection), how many actors should perform and how they will perform. Actor selection is not a trivial task, because it needs to be solved in real time, considering different factors. It becomes more complicated when the actors are moving, due to dynamic topology of the network.

In this paper, different from our previous work [8], we propose and implement a simulation system which considers also the Density of Actor nodes (DOA) parameter.

The system is based on fuzzy logic and considers four input parameters for actor selection. We show the simulation results for different values of parameters.

The remainder of the paper is organized as follows. In Section 2, we describe the basics of WSANs including research challenges and architecture. In Section 3, we describe the system model and its implementation. Simulation results are shown in Section 4. Finally, conclusions and future work are given in Section 5.

2 WSAN

2.1 WSAN Challenges

Some of the key challenges in WSAN are related to the presence of actors and their functionalities.

- *Deployment and Positioning:* At the moment of node deployment, algorithms must consider to optimize the number of sensors and actors and their initial positions based on applications [9, 10].
- *Architecture:* When important data has to be transmitted (an event occurred), sensors may transmit their data back to the sink, which will control the actors' tasks from distance or transmit their data to actors, which can perform actions independently from the sink node [11].
- *Real-Time:* There are a lot of applications that have strict real-time requirements. In order to fulfill them, real-time limitations must be clearly defined for each application and system [12].
- *Coordination:* In order to provide effective sensing and acting, a distributed local coordination mechanism is necessary among sensors and actors [11].
- *Power Management:* WSAN protocols should be designed with minimized energy consumption for both sensors and actors [13].
- *Mobility:* Protocols developed for WSANs should support the mobility of nodes [4, 14], where dynamic topology changes, unstable routes and network isolations are present.
- *Scalability:* Smart Cities are emerging fast and WSAN, as a key technology will continue to grow together with cities. In order to keep the functionality of WSAN applicable, scalability should be considered when designing WSAN protocols and algorithms [10, 14].

2.2 WSAN Architecture

A WSAN is shown in Fig. 1. The main functionality of WSANs is to make actors perform appropriate actions in the environment, based on the data sensed from sensors and actors. When important data has to be transmitted (an event occurred), sensors may transmit their data back to the sink, which will control the actors' tasks from distance, or transmit their data to actors, which can perform actions independently from the sink node. Here, the former scheme is called Semi-Automated Architecture and the latter one Fully-Automated Architecture (see Fig. 2). Obviously, both architectures can be used in different applications. In the Fully-Automated Architecture are needed new sophisticated algorithms in order to provide appropriate coordination between nodes of WSAN. On the other hand, it has advantages, such as *low latency*, *low energy consumption*, *long network lifetime* [2], *higher local position accuracy*, *higher reliability* and so on.

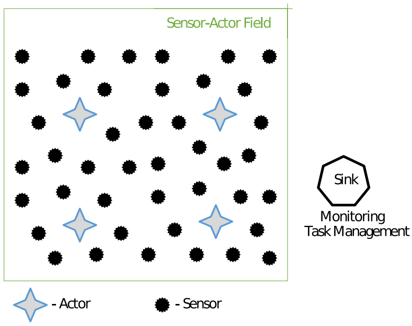
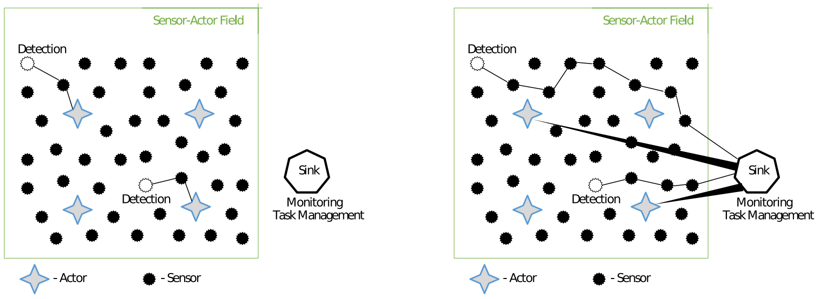


Fig. 1 Wireless Sensor Actor Network (WSAN).



(a) Fully-Automated (b) Semi-Automated

Fig. 2 WSAN architectures.

3 Proposed System Model

3.1 Problem Description

After data has been sensed from sensors, they are collected to the sink for semi-automated architecture or spread to the actors for fully-automated architecture. Then a task is assigned to actors. In general, one or more actors take responsibility and perform appropriate actions. Different actors may be chosen for acting, depending on their characteristics and conditions. For example, if an intervention is required in a building, a flying robot can go there faster and easier. While, if a kid is inside a room in fire, it is better to send a small robot. The issue here is which of the actors will be selected to respond to critical data collected from the field (actor selection). If WSAN uses semi-automated architecture, the sinks are used to collect data and control the actors. They may be supplied with detailed information about actors characteristics (size, ability etc.). If fully-automated architecture is being used, the collected data are processed only by actors, so they first have to decide whether they have the proper ability and right conditions to perform. Soon after that, actors coor-

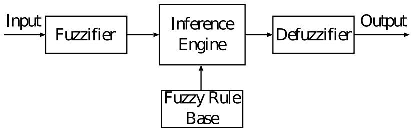


Fig. 3 FLC structure.

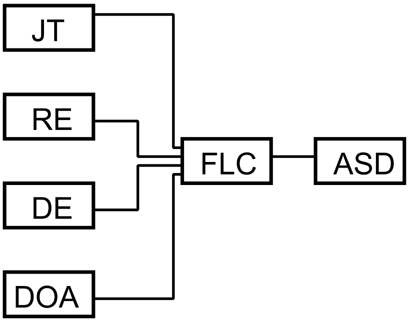


Fig. 4 Proposed System.

dinate with each-other, to decide more complicated procedures like acting multiple actors, or choosing the most appropriate one from several candidates. In this work, we propose a fuzzy-based system in order to select an appropriate actor node for a required task.

3.2 System Parameters

Based on WSAN characteristics and challenges, we consider the following parameters for implementation of our proposed system.

Job Type (JT): A sensed event may be triggered by various causes, such as when water level passed a certain height of the dam. Similarly, for solving a problem, actors need to perform actions of different types. Actions may be classified regarding time duration, complexity, working force required etc., and then assign a priority to them, which will guide actors to make their decisions. In our system, JT is defined by five levels of difficulty. The hardest the task, the more likely an actor is to be selected.

Distance to Event (DE): The number of actors in a WSAN is smaller than the number of sensors. Thus, when an actor is called for action near an event, the distance from the actor to the event is different for different actors and events. Depending on three distance levels, our system takes decisions on the availability of the actor node.

Remaining Energy (RE): As actors are active in the monitored field, they perform tasks and exchange data in different ways from each other. Consequently, also based on their characteristics, some actors may have a lot of power remaining and

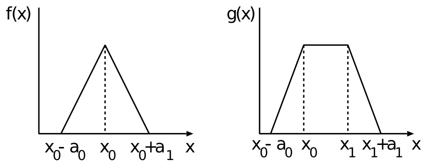


Fig. 5 Triangular and trapezoidal membership functions.

Table 1 Parameters and their term sets for FLC.

Parameters	Term Sets
Job Type (JT)	Easy (Ea), Medium (Me), Hard (Ha)
Distance to Event (DE)	Near (Ne), Middle (Mi), Far (Fa)
Remaining Energy (RE)	Low (L), Middle (M), High (H)
Density of Actors (DOA)	Spare (SP), Normal (Nrm), Dense (DN)
Actor Selection Decision (ASD)	VLSP, LSP, MSP, HSP, VHSP

other may have very little, when an event occurs. We consider three levels of RP for actor selection.

Density of Actors (DOA): The number of actor nodes can be different in various areas. When in an area we have spare actors, the probability to select an actor node is very high, otherwise if it is dense it has a low probability to be selected for carring out the task.

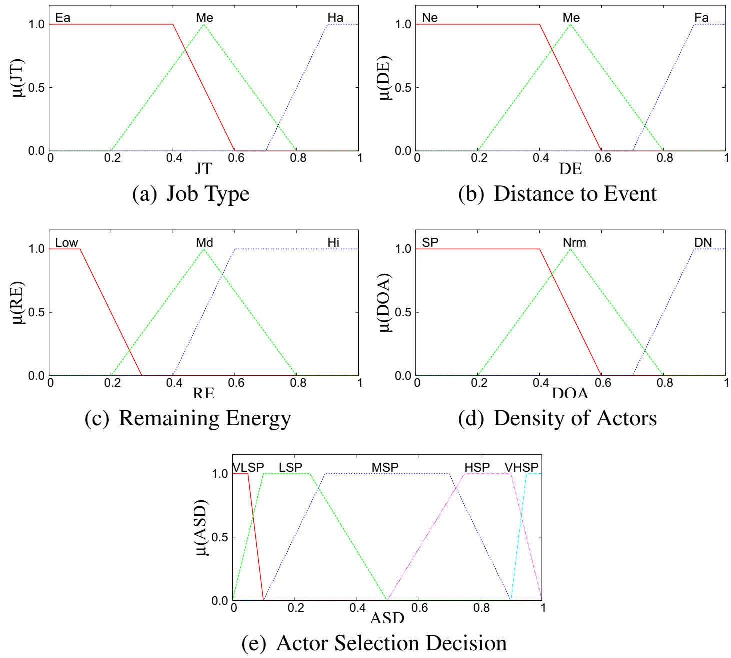
Actor Selection Decision (ASD): Our system is able to decide the willingness of an actor to be assigned a certain task at a certain time. The actors respond in five different levels, which can be interpreted as:

- Very Low Selection Possibility (VLSP) - It is not worth assigning the task to this actor.
- Low Selection Possibility (LSP) - There might be other actors which can do the job better.
- Middle Selection Possibility (MSP) - The Actor is ready to be assigned a task, but is not the “chosen” one.
- High Selection Possibility (HSP) - The actor takes responsibility of completing the task.
- Very High Selection Possibility (VHSP) - Actor has almost all required information and potential and takes full responsibility.

3.3 System Implementation

Fuzzy sets and fuzzy logic have been developed to manage vagueness and uncertainty in a reasoning process of an intelligent system such as a knowledge based system, an expert system or a logic control system [15–29]. In this work, we use fuzzy logic to implement the proposed system.

The structure of the proposed system is shown in Fig. 4. It consists of one Fuzzy Logic Controller (FLC), which is the main part of our system and its basic elements



(a) Job Type

(b) Distance to Event

(c) Remaining Energy

(d) Density of Actors

(e) Actor Selection Decision

Fig. 6 Fuzzy membership functions.

are shown in Fig. 3. They are the fuzzifier, inference engine, Fuzzy Rule Base (FRB) and defuzzifier.

As shown in Fig. 5, we use triangular and trapezoidal membership functions for FLC, because they are suitable for real-time operation [30]. The x_0 in $f(x)$ is the center of triangular function, $x_0(x_1)$ in $g(x)$ is the left (right) edge of trapezoidal function, and $a_0(a_1)$ is the left (right) width of the triangular or trapezoidal function. We explain in details the design of FLC in following.

3.4 Description of FLC

We use four input parameters for FLC:

- Job Type (JT);
- Distance to Event (DE);
- Remaining Energy (RE);
- Density of Actors (DOA);

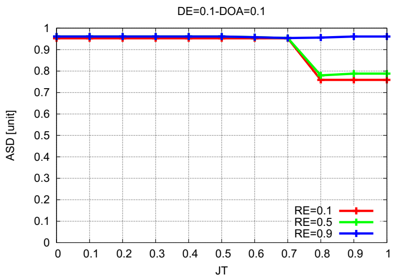
The term sets for each input linguistic parameter are defined respectively as shown in Table 1.

The output linguistic parameter is the Actor Selection Decision (ASD).

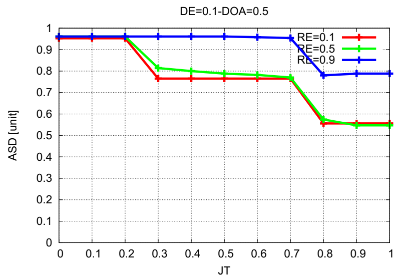
Table 2 FRB of proposed fuzzy-based system.

No.	JT	DE	RE	DOA	ASD	No.	JT	DE	RE	DOA	ASD
1	Ea	Ne	L	DN	VLSP	41	Me	Mi	M	Nrm	MSP
2	Ea	Ne	L	Nrm	LSP	42	Me	Mi	M	SP	MSP
3	Ea	Ne	L	SP	LSP	43	Me	Mi	H	DN	HSP
4	Ea	Ne	M	DN	LSP	44	Me	Mi	H	Nrm	HSP
5	Ea	Ne	M	Nrm	MSP	45	Me	Mi	H	SP	HSP
6	Ea	Ne	M	SP	MSP	46	Me	Fa	L	DN	VLSP
7	Ea	Ne	H	DN	MSP	47	Me	Fa	L	Nrm	VLSP
8	Ea	Ne	H	Nrm	HSP	48	Me	Fa	L	SP	LSP
9	Ea	Ne	H	SP	HSP	49	Me	Fa	M	DN	LSP
10	Ea	Mi	L	DN	VLSP	50	Me	Fa	M	Nrm	LSP
11	Ea	Mi	L	Nrm	VLSP	51	Me	Fa	M	SP	MSP
12	Ea	Mi	L	SP	LSP	52	Me	Fa	H	DN	MSP
13	Ea	Mi	M	DN	LSP	53	Me	Fa	H	Nrm	MSP
14	Ea	Mi	M	Nrm	LSP	54	Me	Fa	H	SP	HSP
15	Ea	Mi	M	SP	MSP	55	Ha	Ne	L	DN	MSP
16	Ea	Mi	H	DN	MSP	56	Ha	Ne	L	Nrm	MSP
17	Ea	Mi	H	Nrm	MSP	57	Ha	Ne	L	SP	MSP
18	Ea	Mi	H	SP	HSP	58	Ha	Ne	M	DN	HSP
19	Ea	Fa	L	DN	VLSP	59	Ha	Ne	M	Nrm	HSP
20	Ea	Fa	L	Nrm	VLSP	60	Ha	Ne	M	SP	HSP
21	Ea	Fa	L	SP	VLSP	61	Ha	Ne	H	DN	VHSP
22	Ea	Fa	M	DN	VLSP	62	Ha	Ne	H	Nrm	VHSP
23	Ea	Fa	M	Nrm	LSP	63	Ha	Ne	H	SP	VHSP
24	Ea	Fa	M	SP	LSP	64	Ha	Mi	L	DN	LSP
25	Ea	Fa	H	DN	LSP	65	Ha	Mi	L	Nrm	MSP
26	Ea	Fa	H	Nrm	MSP	66	Ha	Mi	L	SP	MSP
27	Ea	Fa	H	SP	MSP	67	Ha	Mi	M	DN	MSP
28	Me	Ne	L	DN	LSP	68	Ha	Mi	M	Nrm	HSP
29	Me	Ne	L	Nrm	LSP	69	Ha	Mi	M	SP	HSP
30	Me	Ne	L	SP	MSP	70	Ha	Mi	H	DN	HSP
31	Me	Ne	M	DN	MSP	71	Ha	Mi	H	Nrm	VHSP
32	Me	Ne	M	Nrm	MSP	72	Ha	Mi	H	SP	VHSP
33	Me	Ne	M	SP	HSP	73	Ha	Fa	L	DN	LSP
34	Me	Ne	H	DN	HSP	74	Ha	Fa	L	Nrm	LSP
35	Me	Ne	H	Nrm	HSP	75	Ha	Fa	L	SP	LSP
36	Me	Ne	H	SP	VHSP	76	Ha	Fa	M	DN	MSP
37	Me	Mi	L	DN	LSP	77	Ha	Fa	M	Nrm	MSP
38	Me	Mi	L	Nrm	LSP	78	Ha	Fa	M	Sp	MSP
39	Me	Mi	L	SP	LSP	79	Ha	Fa	H	DN	HSP
40	Me	Mi	M	DN	MSP	80	Ha	Fa	H	Nrm	HSP
						81	Ha	Fa	H	SP	HSP

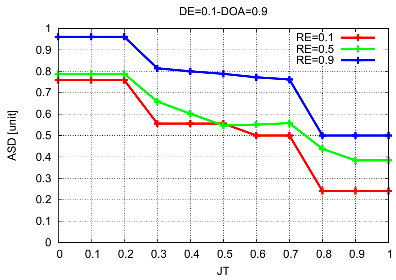
The membership functions are shown in Fig. 6 and the Fuzzy Rule Base (FRB) is shown in Table 2. The FRB forms a fuzzy set of dimensions $|T(JT)| \times |T(DE)| \times |T(RE)| \times |T(DOA)|$, where $|T(x)|$ is the number of terms on $T(x)$. The FRB has 81 rules. The control rules have the form: IF "conditions" THEN "control action".



(a) DOA=0.1



(b) DOA=0.5

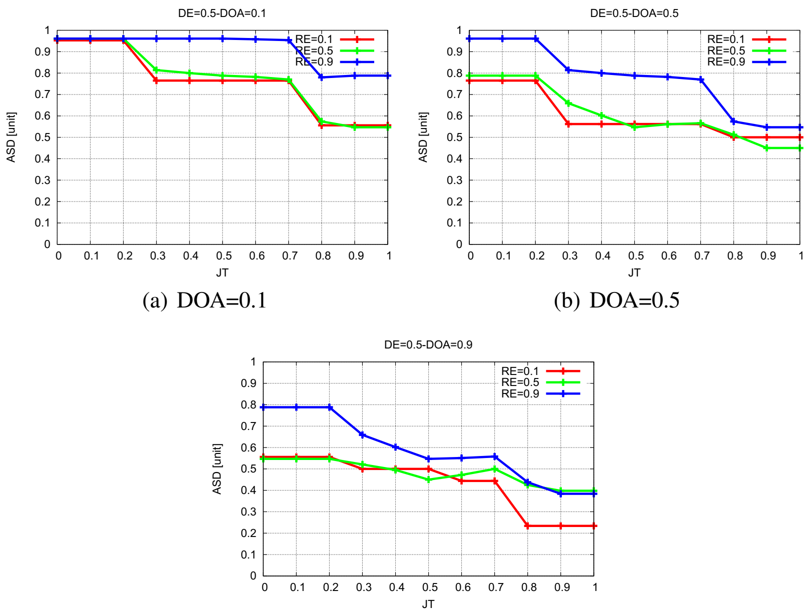


(c) DOA=0.9

Fig. 7 Results for $DE = 0.1$.

4 Simulation Results

The simulation results are presented in Fig. 7, Fig. 8 and Fig. 9. From results, we found that as JT becomes difficult the ASD becomes higher because actors are programmed for different jobs. As we can see the performance is constant from 0 to 0.7 unit and after that is decrased for different values of RE. When the number of actor nodes in an area is small our system selects the present the best actor node to perform the task. When there are many actors in the area, the present actor is not selected and the energy can be saved. In Fig. 8, we can see that the performance is lower than in the previous graphics beacuse of the increase of DE and DOA parameters. Furthermore in Fig. 9 we can see that the performance is the lowest because DE and DOA have maximum value and affect the system in a negative way. The DE defines the distance of the actor from the job place, so when DE is small, the ASD is higher. The actors closest to the job place use less energy to reach the job position. When RE is increased, the ASD is increased. However, when DOA is increased, the actor node is not selected for the required job.



(a) DOA=0.1

(b) DOA=0.5

(c) DOA=0.9

Fig. 8 Results for $DE = 0.5$.

5 Conclusions and Future Work

In this paper, we proposed and implemented a fuzzy-based simulation system for WSAN, which takes into account four input parameters, including DOA and decides the actor selection for a required task in the network.

The simulation results show that our system has a good performance.

In the future work, we will consider also other parameters for actor selection and make extensive simulations to evaluate the proposed system.

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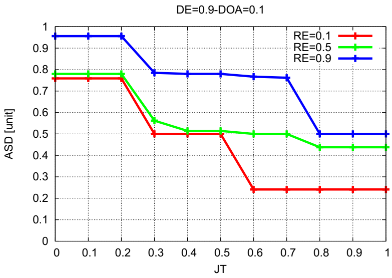
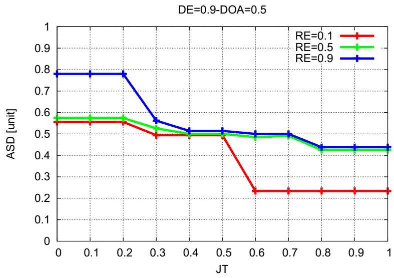
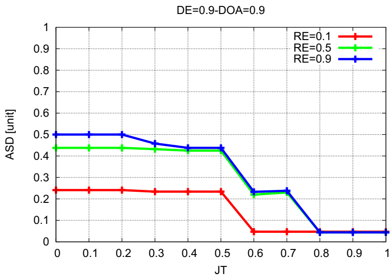


(a) DOA=0.1



(b) DOA=0.5



(c) DOA=0.9

Fig. 9 Results for $DE = 0.9$.

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