Selection of Actor Nodes in Wireless Sensor and Actor Networks Considering Actor-Sensor Coordination Quality Parameter

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Abstract. In Wireless Sensor and Actor Networks (WSANs), sensors and actors collaborate together to 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. The degree of errors encountered during data transmission over a communication is different. The higher the error rate, the less reliable the connection or data transfer will be. In this work, we consider the actor node selection problem and propose a fuzzy-based system that based on data provided by sensors and actors selects an appropriate actor node. We use 4 input parameters: Job Type (JT), Distance to Event (DE), Remaining Energy (RE) and different from our previous work we consider the Actor-Sensor Coordination Quality (ASCQ) parameter. The output parameter is Actor Selection Decision (ASD). Based on these parameters, the simulation results show that the proposed system makes a proper selection of actor nodes.

1 Introduction

Wireless Sensor Networks (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. WSNs are comprised of multiple sensors which are connected to each other in order to perform collaborative or cooperative functions. These nodes are typically connected as a multi-hop mesh network [1–3].

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Wireless Sensor and Actor Networks (WSANs), have emerged as a variation of WSNs. WSANs are capable of monitoring physical phenomenons, processing sensed data, making decisions based on the sensed data and completing appropriate tasks when needed. WSAN devices deployed in the environment are sensors able to sense environmental data, actors able to react by affecting the environment or have both functions integrated [4]. 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 [5].

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, it 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 [6,7], reliable service [8], Quality of Service (QoS) [9,10] 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 data packets follow to reach it. Among other challenges, when designing SA coordination, care must be taken in considering energy minimization because sensors, which have limited energy supplies, are the most active nodes in this process. On the other hand, Actor-Actor (AA) coordination helps actors to choose 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 [11], we propose and implement a simulation system which considers also the Actor-Sensor Coordination (ASCQ) 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 Sect. 2, we describe the basics of WSANs including research challenges and architecture. In Sect. 3, we describe the system model and its implementation. Simulation results are shown in Sect. 4. Finally, conclusions and future work are given in Sect. 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 [12,13].
- *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 [14].
- *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 [15].
- *Coordination:* In order to provide effective sensing and acting, a distributed local coordination mechanism is necessary among sensors and actors [14].
- *Power Management:* WSAN protocols should be designed with minimized energy consumption for both sensors and actors [16].
- *Mobility:* Protocols developed for WSANs should support the mobility of nodes [7,17], 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 [13,17].

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

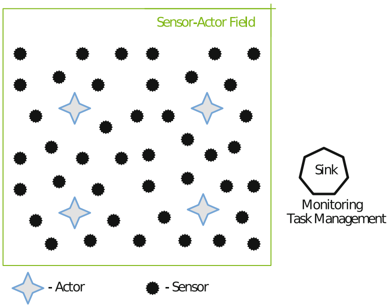
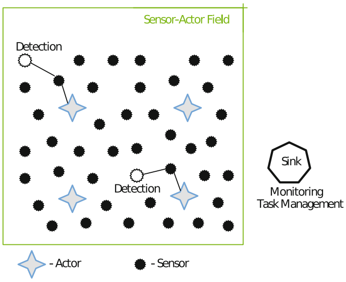
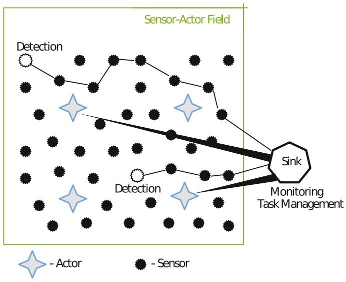


Fig. 1. Wireless Sensor Actor Network (WSAN).



(a) Fully-Automated



(b) Semi-Automated

Fig. 2. WSAN architectures.

(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* [4], *higher local position accuracy*, *higher reliability* and so on.

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

Actor-Sensor Coordination Quality (ASCQ): In order to provide effective sensing and acting, a distributed local coordination mechanism is necessary among sensors and actors. When the coordination quality between sensors and actors is high, then the probability of an actor to be selected is also high.

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 [18–31]. In this work, we use fuzzy logic to implement the proposed system.

The structure of the proposed system is shown in Fig. 3. It consists of one Fuzzy Logic Controller (FLC), which is the main part of our system and its basic elements are shown in Fig. 4. 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 [32]. 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

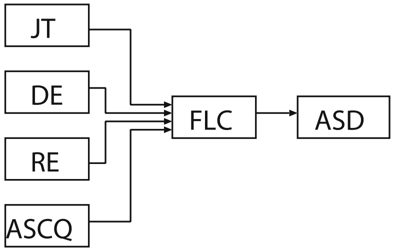


Fig. 3. Proposed System.

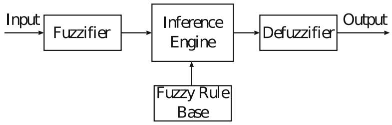


Fig. 4. FLC structure.

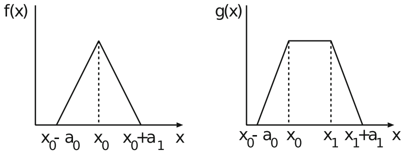


Fig. 5. Triangular and trapezoidal membership functions.

Table 1. Parameters and their term sets for FLC.

Parameters	Term sets
Job Type (JT)	Easy (Ea), Moderate (Mo), Hard (Hd)
Distance to Event (DE)	Near (Ne), Middle (Md), Far (Fa)
Remaining Energy (RE)	Low (Lo), Medium (Mdm), High (Hi)
Actor-Sensor Coordination Quality (ASCQ)	Low (Lw), Medium (Me), High (Hg)
Actor Selection Decision (ASD)	VLSP, LSP, MSP, HSP, VHSP

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);
- Actor-Sensor Coordination Quality (ASCQ).

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).

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 $|T(JT)| \times |T(DE)| \times |T(RE)| \times |T(ASCQ)|$, 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”.

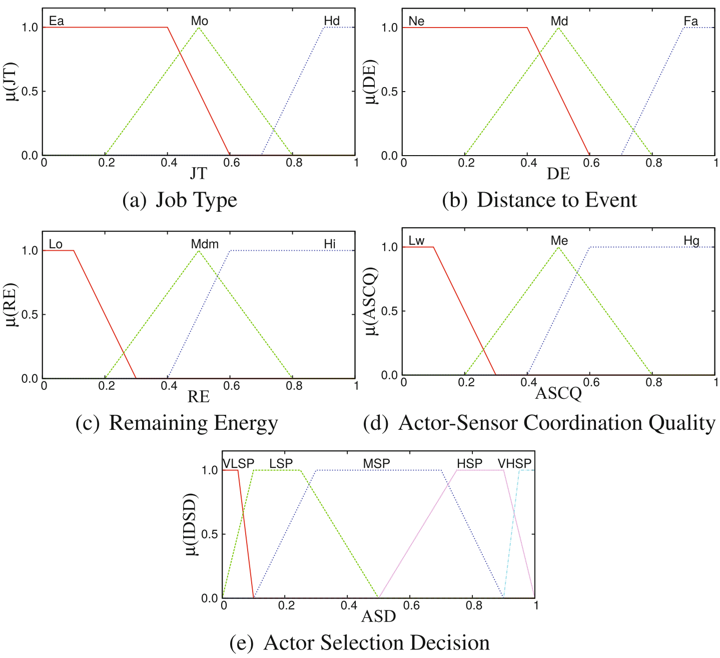
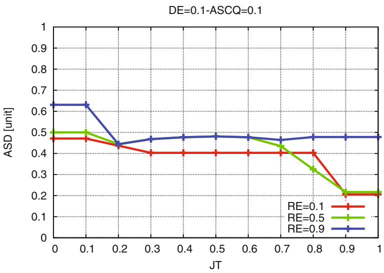


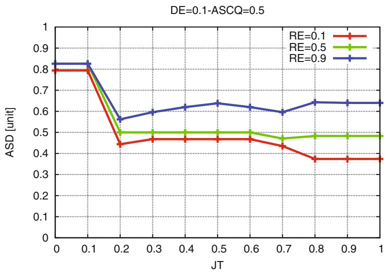
Fig. 6. Fuzzy membership functions.

Table 2. FRB of proposed fuzzy-based system.

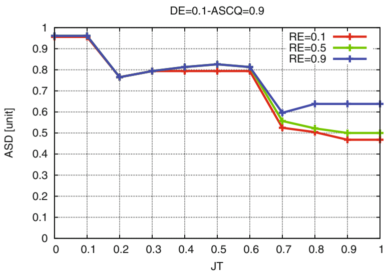
No.	JT	DE	RE	ASCQ	ASD	No.	JT	DE	RE	ASCQ	ASD
1	Ea	Ne	Lo	Lw	MSP	41	Mo	Md	Mdm	Md	MSP
2	Ea	Ne	Lo	Me	VHSP	42	Mo	Md	Mdm	Hg	HSP
3	Ea	Ne	Lo	Hg	VHSP	43	Mo	Md	Hi	Lw	MSP
4	Ea	Ne	Mdm	Lw	MSP	44	Mo	Md	Hi	Md	MSP
5	Ea	Ne	Mdm	Me	VHSP	45	Mo	Md	Hi	Hg	VHSP
6	Ea	Ne	Mdm	Hg	VHSP	46	Mo	Fa	Lo	Lw	VLSP
7	Ea	Ne	Hi	Lw	VHSP	47	Mo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



(a) ASCQ=0.1

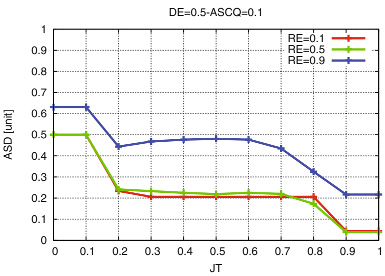


(b) ASCQ=0.5

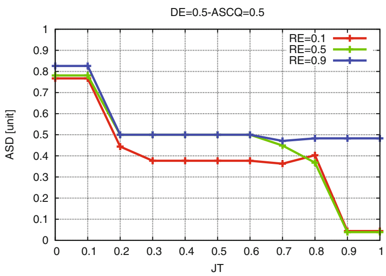


(c) ASCQ=0.9

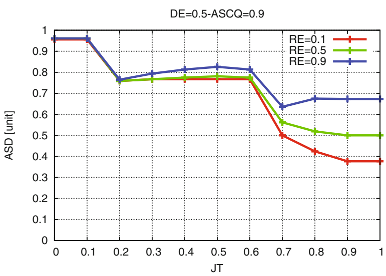
Fig. 7. Results for $DE = 0.1$.



(a) ASCQ=0.1



(b) ASCQ=0.5



(c) ASCQ=0.9

Fig. 8. Results for $DE = 0.5$.

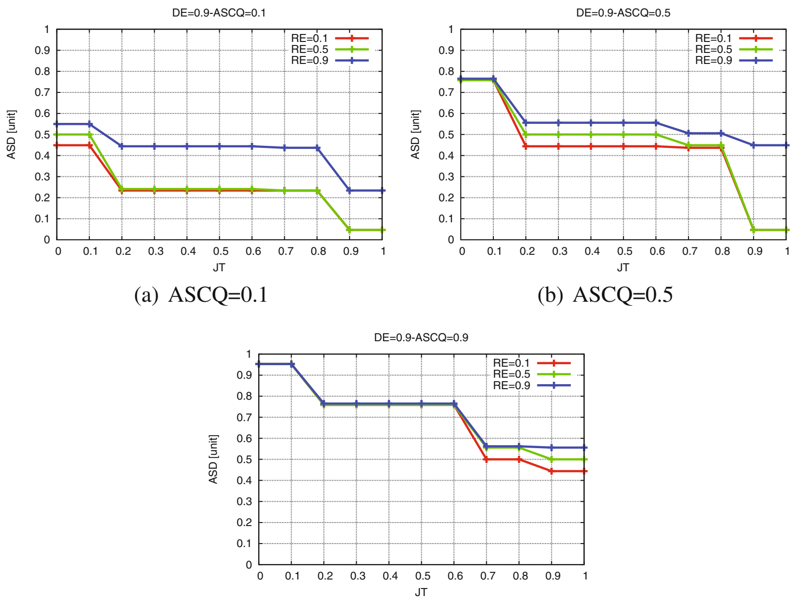
4 Simulation Results

We present the simulation results in Figs. 7, 8 and 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 decreased for different values of RE. When we increase the ASCQ parameter, the ASD is increased.

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.

In Fig. 8, we can see that the performance is lower than in Fig. 7, beacuse the DE is increased. Furthermore in Fig. 9, we can see that the performance is the lowest because DE is increased much more.

When RE is increased, the ASD is increased. Also, when ASCQ is increased the ASD is increased too and the actor node is selected for the required job.



(a) ASCQ=0.1

(b) ASCQ=0.5

(c) ASCQ=0.9

Fig. 9. Results for $DE = 0.9$.

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 ASCQ) and decides the actor selection for a required task in the network. From simulation results, we conclude as follows.

- When JT, RE and ASCQ parameters are increased, the ASD parameter is increased, so the probability that the system selects an actor node for the job is high.
- When the DE parameter is increased, the ASD parameter is decreased, so the probability that an actor node is selected for the required task is low.

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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