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A comparison study of two fuzzy-based systems for selection of actor node in wireless sensor actor networks

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Abstract In wireless sensor and actor networks, sensors and actors collaborate 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. In this work, we implement and compare two Fuzzy-Based Systems (FBS1 and FBS2) for actor selection problem. These systems decide whether the actor will be selected for the required job or not, based on data supplied by sensors and actual actor condition. For FBS1, we use three input parameters: job type (JT), remaining energy of actor (REA) and distance of actor from job place (DAJP). The output parameter is actor selection decision (ASD). The simulation results show that the FBS1 decides the actor selection in order to have short delays, low energy consumption, and proper task assignment. For FBS2, we consider four input parameters: JT, REA, DAJP and actor node speed (ANS). The output parameter is the ASD. Comparing complexity of FBS1 and FBS2, the FBS2 is more complex than FBS1. However, it also considers mobility of actor nodes. Thus, the FBS2 is more flexible system than FBS1.

Keywords Wireless networks · WSAN · Fuzzy logic · Actor mobility · Intelligent systems

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 (Akyildiz et al. 2002; Chen et al. 2013).

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 (Akyildiz and Kasimoglu 2004). 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.

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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 analyze 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 (Haider et al. 2013; Abbasi et al. (2009), reliable service (Li et al. 2011), quality of service (QoS) (Akkaya and Younis 2006; Kakarla and Majhi 2013) and so on.

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, we implement and compare two fuzzy-based systems (FBS1 and FBS2) for actor selection problem. These systems decide whether the actor will be selected for the required job or not, based on data supplied by sensors and actual actor condition.

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 proposed systems. 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 (Akbas and Turgut 2011; Akbas et al. 2010).
– *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 (Melodia et al. 2007).

– *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 (Gungor et al. 2008).
– *Coordination* In order to provide effective sensing and acting, a distributed local coordination mechanism is necessary among sensors and actors (Melodia et al. 2007).
– *Power management* WSAN protocols should be designed with minimized energy consumption for both sensors and actors (Selvaradjou et al. 2010).
– *Mobility* Protocols developed for WSANs should support the mobility of nodes, (Abbasi et al. 2009; Nakayama et al. 2011), 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 (Akbas et al. 2010; Nakayama et al. 2011).

2.2 WSAN architectures

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
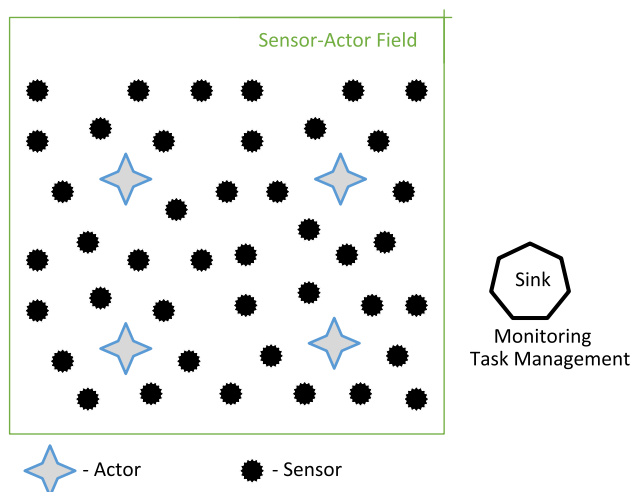

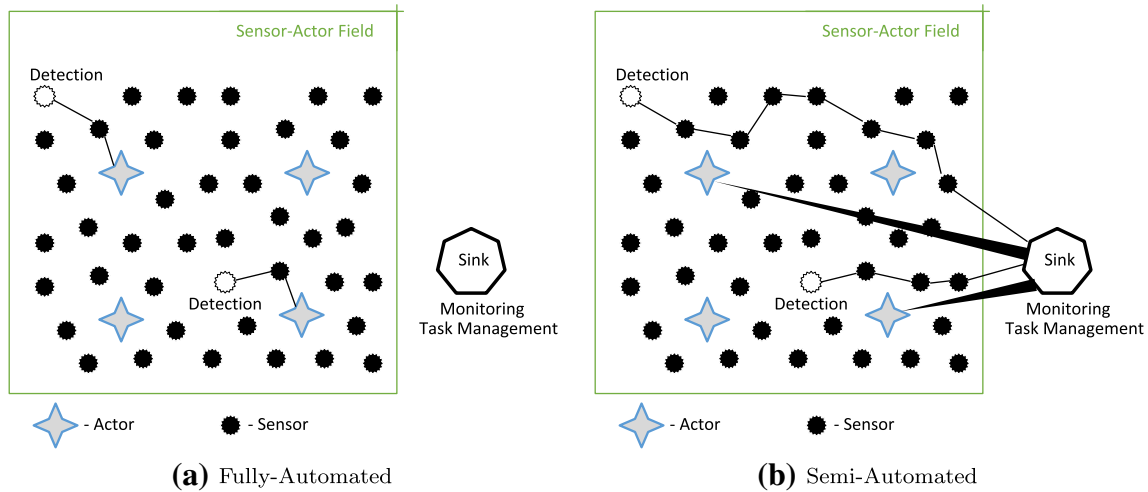**Fig. 1** Wireless sensor actor network (WSAN)

(a) Fully-Automated
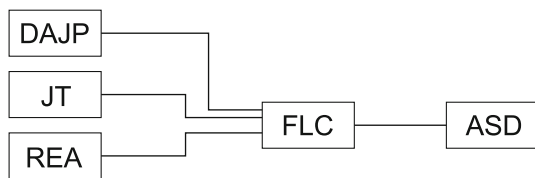

(b) Semi-Automated

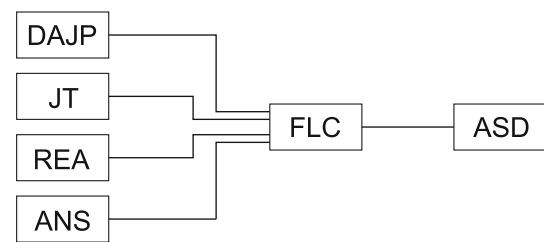**Fig. 2** WSAN architectures

Fig. 3 Structure of implemented FBS1

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* (Akyildiz and Kasimoglu 2004), *higher local position accuracy*, *higher reliability* and so on.

3 Proposed systems

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).

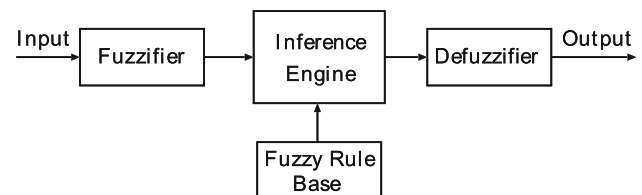

Fig. 4 Structure of implemented FBS2
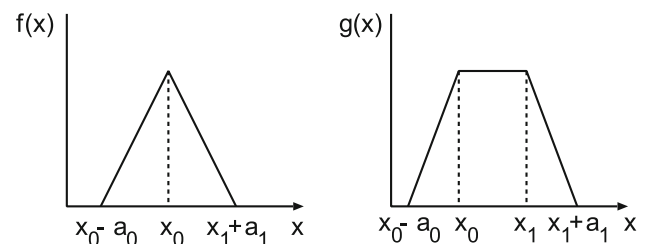

Fig. 5 FLC structure

Fig. 6 Triangular and trapezoidal membership functions

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

Table 1 Parameters and their term sets

Parameters	Term sets
Job type (JT)	Very easy (Ve), easy (E), medium (Mid), hard (H), very hard (VH)
Remaining energy of actor (REA)	Low (Lo), medium (Md), high (Hi)
Distance of actor from job place (DAJP)	Near (ne), middle (mi), far (fa)
Actor node speed (ANS)	Slow (S), medium (M), fast (F)
Actor selection decision (ASD)	Strong not select (StNS), not select (NS), select not select (Sens), select (S), strong select (SS)

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 two fuzzy-based systems in order to select an 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

Fig. 7 Fuzzy membership functions

(a) Job Type

(b) Remaining Energy of Actor

(c) Distance of Actor from Job Place

(d) Actor Node Speed

(e) Actor Selection Decision
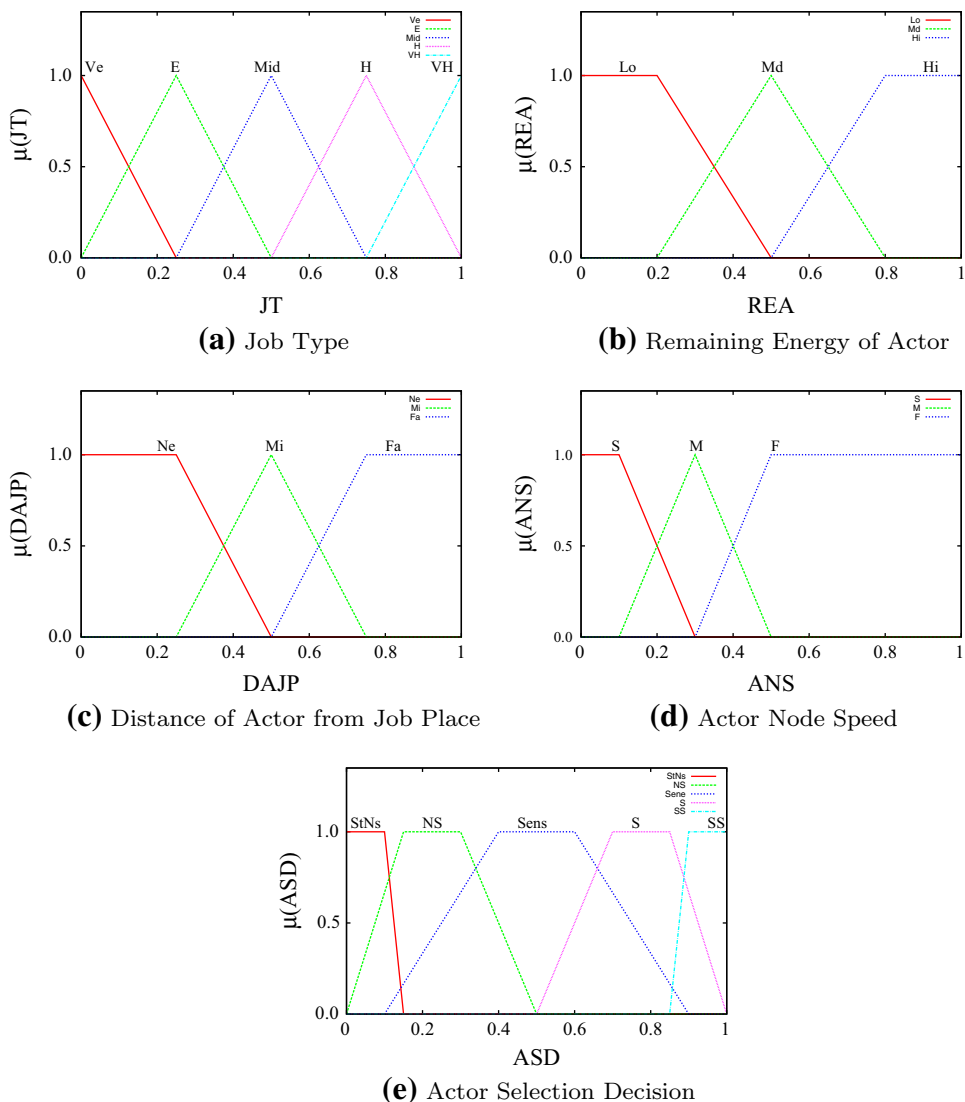
Table 2 FRB of FBS1

Rule	JT	REA	DAJP	ASD
1	Ve	Lo	Ne	Sens
2	E	Lo	Ne	Sens
3	Mid	Lo	Ne	S
4	H	Lo	Ne	S
5	VH	Lo	Ne	SS
6	Ve	Md	Ne	S
7	E	Md	Ne	S
8	Mid	Md	Ne	SS
9	H	Md	Ne	SS
10	VH	Md	Ne	SS
11	Ve	Hi	Ne	SS
12	E	Hi	Ne	SS
13	Mid	Hi	Ne	SS
14	H	Hi	Ne	SS
15	VH	Hi	Ne	SS
16	Ve	Lo	Mi	NS
17	E	Lo	Mi	Sens
18	Mid	Lo	Mi	Sens
19	H	Lo	Mi	Sens
20	VH	Lo	Mi	S
21	Ve	Md	Mi	Sens
22	E	Md	Mi	Sens
23	Mid	Md	Mi	S
24	H	Md	Mi	SS
25	VH	Md	Mi	SS
26	Ve	Hi	Mi	S
27	E	Hi	Mi	SS
28	Mid	Hi	Mi	SS
29	H	Hi	Mi	SS
30	VH	Hi	Mi	SS
31	Ve	Lo	Fa	StNs
32	E	Lo	Fa	StNs
33	Mid	Lo	Fa	NS
34	H	Lo	Fa	Sens
35	VH	Lo	Fa	Sens
36	Ve	Md	Fa	NS
37	E	Md	Fa	Sens
38	Mid	Md	Fa	Sens
39	H	Md	Fa	S
40	VH	Md	Fa	S
41	Ve	Hi	Fa	Sens
42	E	Hi	Fa	S
43	Mid	Hi	Fa	S
44	H	Hi	Fa	SS
45	VH	Hi	Fa	SS

system TRA is defined by five levels of difficulty. The hardest the task, the more likely an actor is to be selected.

Distance of actor from job place (DAJP) 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 of actor (REA) 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 node speed (ANS) It is obvious that in a heterogeneous WSAN, actors are of different types and may operate in different environments. So, in order to judge the mobility degree of an actor, the system uses the speed of an actor.

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:

– Strong not select: It is not worth assigning the task to this actor.
– Not select: There might be other actors which can do the job better.
– Select not select: The Actor is ready to be assigned a task, but is not the "chosen" one.
– Select: The actor takes responsibility of completing the task.
– Strong select: Actor has almost all required information and potential and takes full responsibility.

3.3 Systems implementation

Fuzzy sets and fuzzy logic (Zadeh 1994) 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. In this work, we use fuzzy logic to implement proposed systems.

The structure of the proposed Fuzzy-Based Systems (FBS1 and FBS2) are shown in Figs. 3, 4 respectively. It consists of one Fuzzy Logic Controller (FLC), which is the main part of our system and its basic elements are shown in Fig. 5. They are the fuzzifier, inference engine, Fuzzy Rule Base (FRB) and defuzzifier.

Table 3 FRB of FBS2

Rule	JT	REA	DAJP	ANS	ASD	Rule	JT	REA	DAJP	ANS	ASD	Rule	JT	REA	DAJP	ANS	ASD
1	Ve	Lo	Ne	S	Sens	46	Ve	Lo	Ne	M	NS	91	Ve	Lo	Ne	F	StNs
2	E	Lo	Ne	S	Sens	47	E	Lo	Ne	M	Sens	92	E	Lo	Ne	F	NS
3	Mid	Lo	Ne	S	S	48	Mid	Lo	Ne	M	S	93	Mid	Lo	Ne	F	Sens
4	H	Lo	Ne	S	SS	49	H	Lo	Ne	M	SS	94	H	Lo	Ne	F	S
5	VH	Lo	Ne	S	SS	50	VH	Lo	Ne	M	SS	95	VH	Lo	Ne	F	S
6	Ve	Md	Ne	S	S	51	Ve	Md	Ne	M	Sens	96	Ve	Md	Ne	F	Sens
7	E	Md	Ne	S	S	52	E	Md	Ne	M	S	97	E	Md	Ne	F	Sens
8	Mid	Md	Ne	S	SS	53	Mid	Md	Ne	M	SS	98	Mid	Md	Ne	F	S
9	H	Md	Ne	S	SS	54	H	Md	Ne	M	SS	99	H	Md	Ne	F	SS
10	VH	Md	Ne	S	SS	55	VH	Md	Ne	M	SS	100	VH	Md	Ne	F	SS
11	Ve	Hi	Ne	S	SS	56	Ve	Hi	Ne	M	S	101	Ve	Hi	Ne	F	S
12	E	Hi	Ne	S	SS	57	E	Hi	Ne	M	SS	102	E	Hi	Ne	F	S
13	Mid	Hi	Ne	S	SS	58	Mid	Hi	Ne	M	SS	103	Mid	Hi	Ne	F	SS
14	H	Hi	Ne	S	SS	59	H	Hi	Ne	M	SS	104	H	Hi	Ne	F	SS
15	VH	Hi	Ne	S	SS	60	VH	Hi	Ne	M	SS	105	VH	Hi	Ne	F	SS
16	Ve	Lo	Mi	S	NS	61	Ve	Lo	Mi	M	StNs	106	Ve	Lo	Mi	F	StNs
17	E	Lo	Mi	S	NS	62	E	Lo	Mi	M	NS	107	E	Lo	Mi	F	StNs
18	Mid	Lo	Mi	S	Sens	63	Mid	Lo	Mi	M	Sens	108	Mid	Lo	Mi	F	NS
19	H	Lo	Mi	S	S	64	H	Lo	Mi	M	S	109	H	Lo	Mi	F	Sens
20	VH	Lo	Mi	S	SS	65	VH	Lo	Mi	M	S	110	VH	Lo	Mi	F	S
21	Ve	Md	Mi	S	Sens	66	Ve	Md	Mi	M	NS	111	Ve	Md	Mi	F	NS
22	E	Md	Mi	S	Sens	67	E	Md	Mi	M	Sens	112	E	Md	Mi	F	NS
23	Mid	Md	Mi	S	S	68	Mid	Md	Mi	M	S	113	Mid	Md	Mi	F	Sens
24	H	Md	Mi	S	SS	69	H	Md	Mi	M	SS	114	H	Md	Mi	F	S
25	VH	Md	Mi	S	SS	70	VH	Md	Mi	M	SS	115	VH	Md	Mi	F	SS
26	Ve	Hi	Mi	S	S	71	Ve	Hi	Mi	M	Sens	116	Ve	Hi	Mi	F	Sens
27	E	Hi	Mi	S	S	72	E	Hi	Mi	M	S	117	E	Hi	Mi	F	Sens
28	Mid	Hi	Mi	S	SS	73	Mid	Hi	Mi	M	SS	118	Mid	Hi	Mi	F	S
29	H	Hi	Mi	S	SS	74	H	Hi	Mi	M	SS	119	H	Hi	Mi	F	SS
30	VH	Hi	Mi	S	SS	75	VH	Hi	Mi	M	SS	120	VH	Hi	Mi	F	SS
31	Ve	Lo	Fa	S	NS	76	Ve	Lo	Fa	M	StNs	121	Ve	Lo	Fa	F	StNs
32	E	Lo	Fa	S	NS	77	E	Lo	Fa	M	NS	122	E	Lo	Fa	F	StNs
33	Mid	Lo	Fa	S	Sens	78	Mid	Lo	Fa	M	NS	123	Mid	Lo	Fa	F	StNs
34	H	Lo	Fa	S	Sens	79	H	Lo	Fa	M	Sens	124	H	Lo	Fa	F	NS
35	VH	Lo	Fa	S	S	80	VH	Lo	Fa	M	Sens	125	VH	Lo	Fa	F	Sens
36	Ve	Md	Fa	S	Sens	81	Ve	Md	Fa	M	NS	126	Ve	Md	Fa	F	StNs
37	E	Md	Fa	S	Sens	82	E	Md	Fa	M	Sens	127	E	Md	Fa	F	NS
38	Mid	Md	Fa	S	S	83	Mid	Md	Fa	M	Sens	128	Mid	Md	Fa	F	Sens
39	H	Md	Fa	S	S	84	H	Md	Fa	M	S	129	H	Md	Fa	F	Sens
40	VH	Md	Fa	S	SS	85	VH	Md	Fa	M	S	130	VH	Md	Fa	F	S
41	Ve	Hi	Fa	S	S	86	Ve	Hi	Fa	M	Sens	131	Ve	Hi	Fa	F	NS
42	E	Hi	Fa	S	S	87	E	Hi	Fa	M	S	132	E	Hi	Fa	F	Sens
43	Mid	Hi	Fa	S	S	88	Mid	Hi	Fa	M	S	133	Mid	Hi	Fa	F	S
44	H	Hi	Fa	S	SS	89	H	Hi	Fa	M	SS	134	H	Hi	Fa	F	S
45	VH	Hi	Fa	S	SS	90	VH	Hi	Fa	M	SS	135	VH	Hi	Fa	F	SS
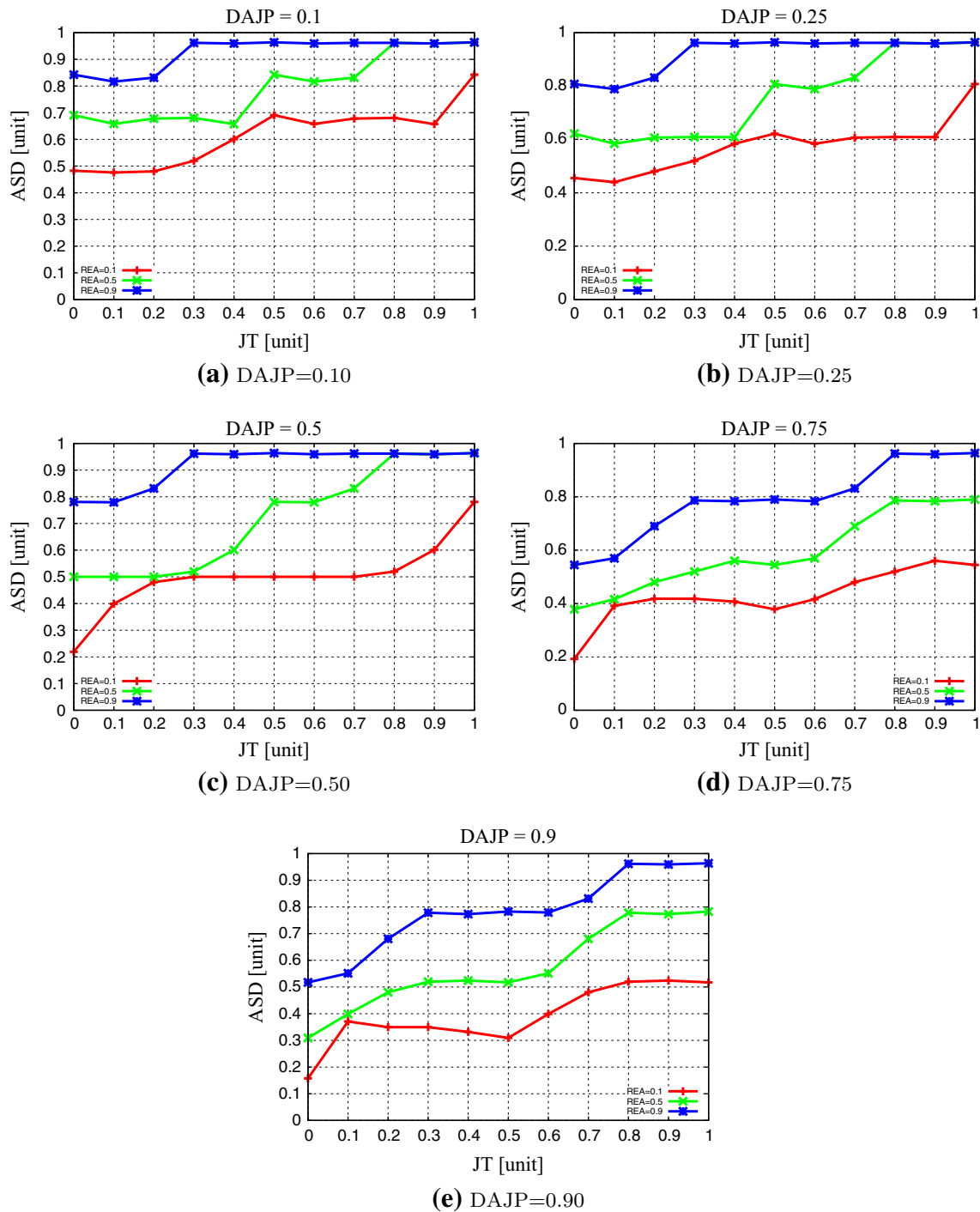
Fig. 8 Results for different values of DAJP (FBS1)

As shown in Fig. 6, we use triangular and trapezoidal membership functions for FLC, because they are suitable for real-time operation (Mendel 1995; Esposito et al. 2015). 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 FBS1

We use three input parameters for FLC of FBS1:

– Job type (JT);
– Remaining energy of actor (REA);
– Distance of actor from job place (DAJP);
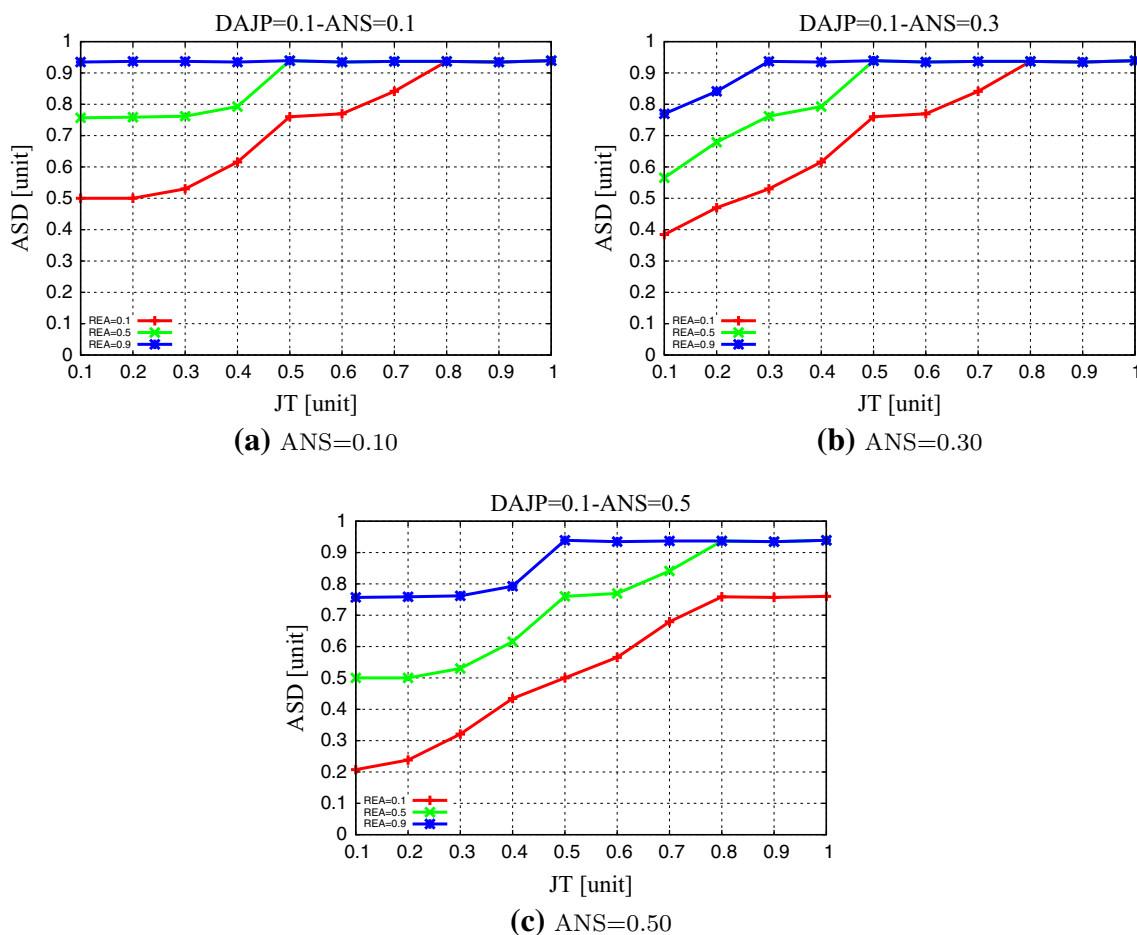
Fig. 9 Results for $DAJP = 0.1$ (FBS2)

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. 7 and the FRB of FBS1 is shown in Table 2. The FRB forms a fuzzy set of dimensions $|\mu(JT)| \times |\mu(REA)| \times |\mu(DAJP)|$, where $|\mu(x)|$ is the number of terms on $\mu(x)$. The FRB of FBS1 has 45 rules. The control rules have the form: IF "conditions" THEN "control action".

3.5 Description of FBS2

We consider four input parameters for FLC of FBS2:

– JT;
– REA;
– DAJP;

– Actor node speed (ANS).

We added ANS input parameter to FBS1 in order to consider the mobility of actor node. The term sets for each input linguistic parameter are defined respectively as shown in Table 1. The output linguistic parameter is the ASD. The membership functions are shown in Fig. 7 and the FRB of FBS2 is shown in Table 3.

4 Simulation results

We present the simulation results of FBS1 in Fig. 8. In Fig. 8a, we display how the output parameter ASD is affected by JT value, for different values of REA and DAJP = 0.1. Then, we increase the value of DAJP and repeat the simulations.
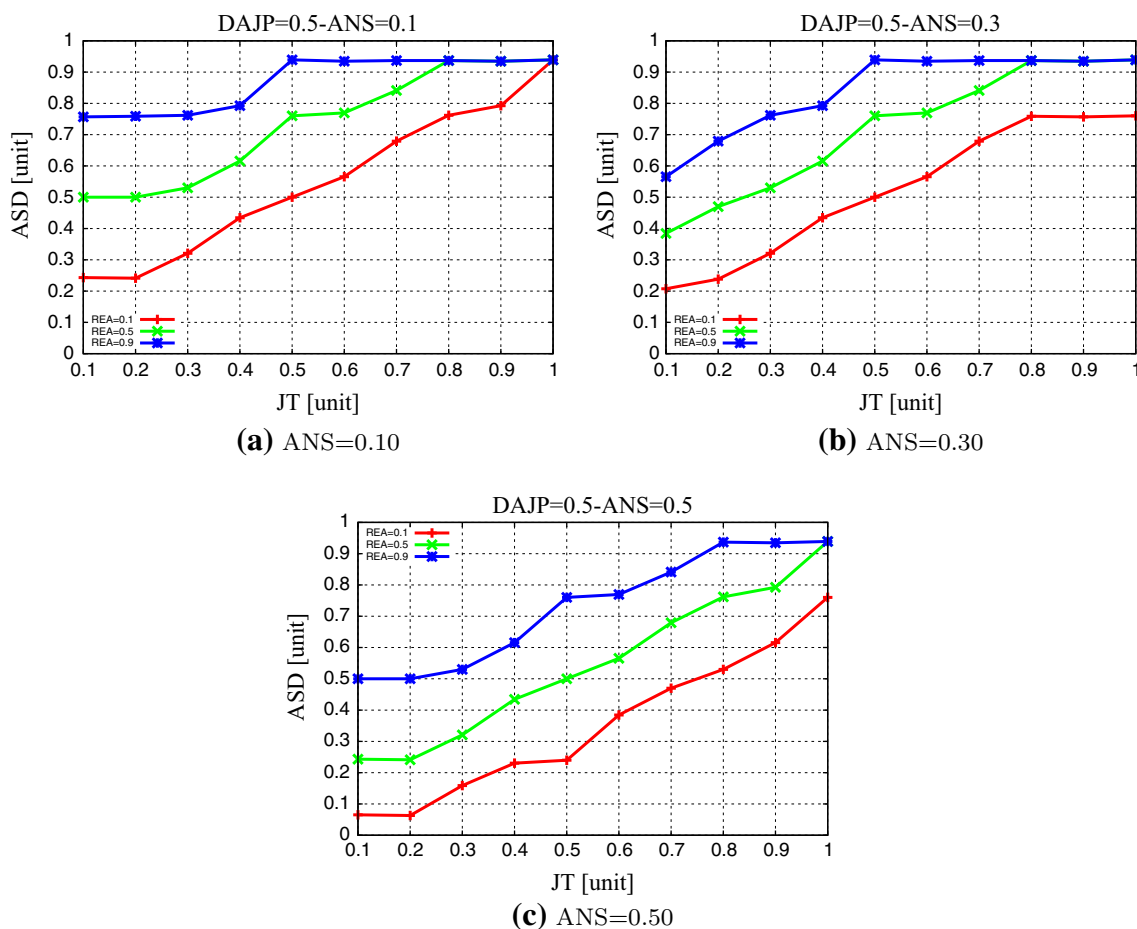
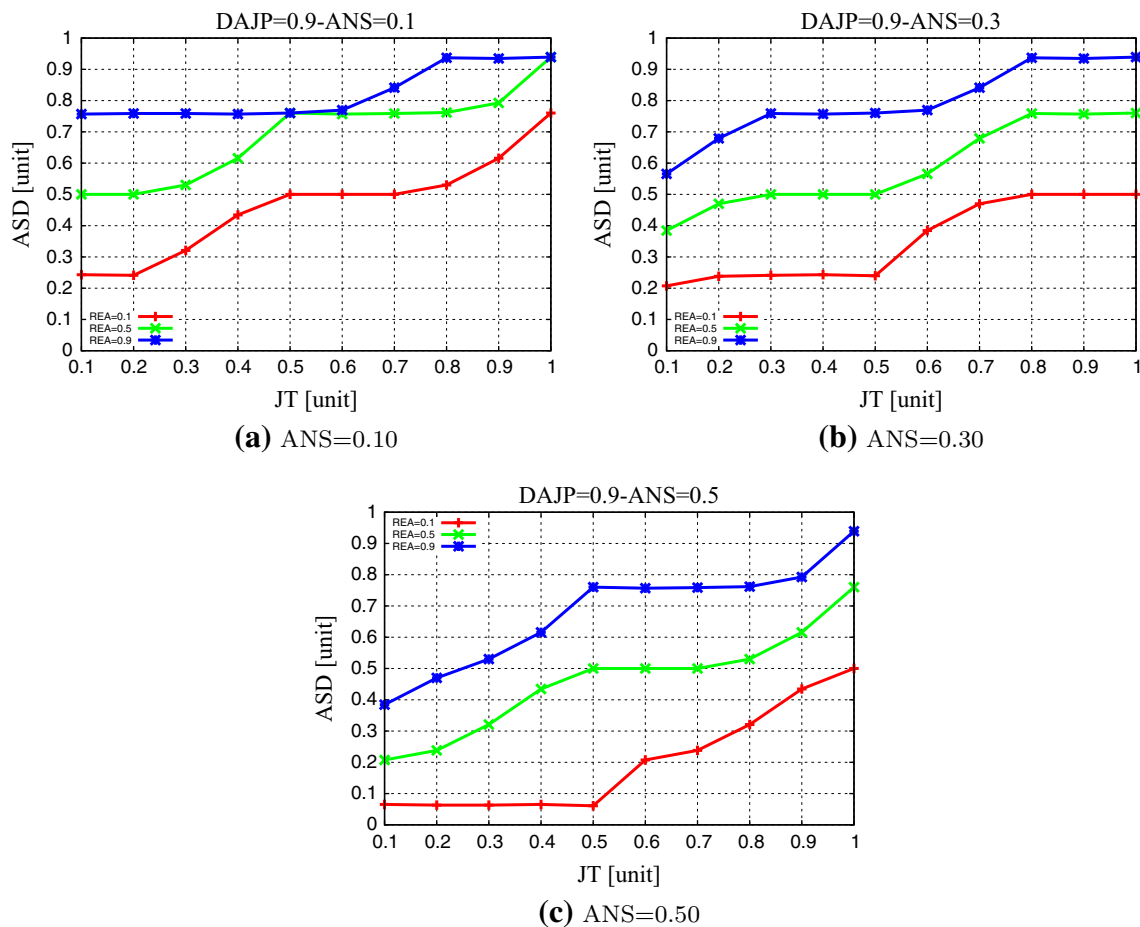**Fig. 10** Results for $DAJP = 0.5$ (FBS2)

From simulation results of FBS1, we can observe that when the difficulty level of the job (JT) increases, ASD also increases. For different values of REA, the value of ASD differs in a way that actors with low battery are not involved in many task assignment. Thus, for lower values of REA, ASD decreases. In this way the network lifetime is increased. From Fig. 8a–e, the DAJP increases and ASD decreases. In this case, our system instructs actors that are near the event to be more active in task assignment, while for actors that are further away and need more time and energy to reach the event place not to be active. By doing this the response to emergency situations is improved and the energy management is better.

We present the simulation results of FBS2 in Figs. 9, 10, 11.

From simulation results of FBS2, as in general, we notice that as JT becomes difficult the ASD becomes higher because actors are programmed for different jobs, the same as FBS1. The DAJP defines the distance of the actor from the job place, so when DAJP is small, the ASD is higher. The actors closest to the job place use less energy to reach the job position. We also notice that for each value of DAJP, when the ANS increases the network topology is more dynamic. In this condition, the actor may loose connectivity and changes its condition (such as distance from job place) in a while, so it will be not reachable any more. However, when the actor is moving with higher speed, the response can be faster for emergency situations.

Comparing complexity of FBS1 and FBS2, the FBS2 is more complex than FBS1. However, it also considers mobility of actor nodes. Thus, the FBS2 is more flexible system than FBS1.

(a) ANS=0.10

(b) ANS=0.30

(c) ANS=0.50

Fig. 11 Results for $DAJP = 0.9$ (FBS2)

5 Conclusions and future work

The main challenges for WSANs have to do with node coordination, energy management and mobility. A WSAN can be implemented as semi-automated architecture (which is similar to WSN) and fully-automated architecture (which is the real challenge of embedded WSANs).

In this paper, we implemented and compared two fuzzy-based simulation systems for WSANs. The FBS1 has three input parameters and the FBS2 has four input parameters. The systems select the actor node in order to have short delays, low energy consumption and proper task assignment.

From simulation results, we found that the response of implemented system to emergency situations is improved and the energy management is better. Comparing complexity of FBS1 and FBS2, the FBS2 is more complex than FBS1. However, it considers also mobility of actor nodes. Thus, the FBS2 is more flexible system than FBS1.

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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