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Selection of Actor Nodes in Wireless Sensor and Actor Networks: A Fuzzy-based Approach Considering Number of Obstacles as New Parameter

Donald Elmazi*, **Miralda Cuka***, **Kevin Bylykbashi**†, **Evjola Spaho**†, **Makoto Ikeda**‡ **and Leonard Barolli**‡

*Graduate School of Engineering
Fukuoka Institute of Technology (FIT)
3-30-1 Wajiro-Higashi, Higashi-Ku, Fukuoka 811-0295, Japan
Email: donald.elmazi@gmail.com, mcuka91@gmail.com

†Department of Electronics and Telecommunication
Polytechnic University of Tirana (PUT)
Bul. "Deshmoret e Kombit", "Mother Theresa" Square, Nr. 4, Tirana, Albania
Email: kevini_95@hotmail.com, evjolaspaho@hotmail.com

‡Department of Information and Communication Engineering
Fukuoka Institute of Technology (FIT)
3-30-1 Wajiro-Higashi, Higashi-Ku, Fukuoka 811–0295, Japan
Email: makoto.ikd@acm.org, barolli@fit.ac.jp

***Abstract*—Wireless Sensor and Actor Network (WSAN) is formed by the collaboration of micro-sensor and actor nodes. Whenever there is any special event i.e., fire, earthquake, flood or enemy attack in the network, sensor nodes have responsibility to sense it and send information towards an actor node. The actor node is responsible to take prompt decision and react accordingly. 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 Number of Obstacles (NO) 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. The simulation results show that ASD is decrased 23% and 40%, by increasing NO and DE, respectively.**

***Keywords*-WSAN, IoT, Intelligent Systems, Fuzzy-logic, JT, DE, RE, NO.**

I. INTRODUCTION

Recent technological advances have lead to the emergence of distributed Wireless Sensor and Actor Networks (WSANs) wich are capable of observing the physical world, processing the data, making decisions based on the observations and performing appropriate actions [1].

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 [2], [3].

In WSAN, the 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. Actor nodes are equipped with two radio transmitters, a low data rate transmitter to communicate with the sensor and a high data rate interface for actor-actor communication. 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 [4].

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 [5], [6], reliable service [7], Quality of Service (QoS) [8], [9] and so on.

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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. Obstacles such as walls, buildings, blockhouses exist in an outdoor environment. These obstacles significantly impact the performance of WSAN.

In this paper, different from our previous work [10], we propose and implement a simulation system which considers also the Number of Obstacle (NO) 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 II, we describe the basics of WSANs including research challenges and architecture. In Section III, we describe the system model and its implementation. Simulation results are shown in Section IV. Finally, conclusions and future work are given in Section V.

II. WSAN

A. 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 [11], [12].
- *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 [13].
- *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 [14].
- *Coordination:* In order to provide effective sensing and acting, a distributed local coordination mechanism is necessary among sensors and actors [13].
- *Power Management:* WSAN protocols should be designed with minimized energy consumption for both sensors and actors [15].
- *Mobility:* Protocols developed for WSANs should support the mobility of nodes [6], [16], 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 [12], [16].

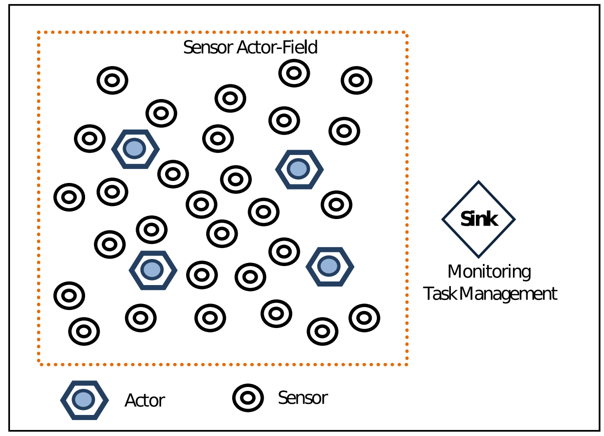


Figure 1. Wireless Sensor Actor Network (WSAN).

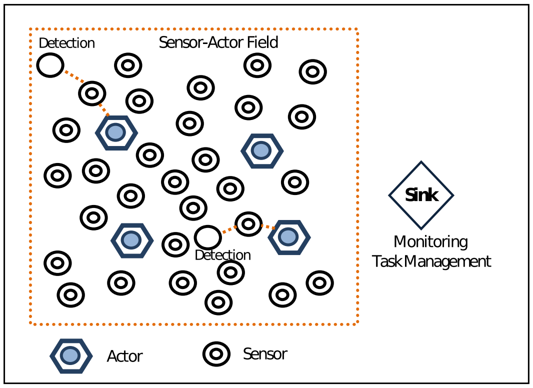
B. WSAN Architecture

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

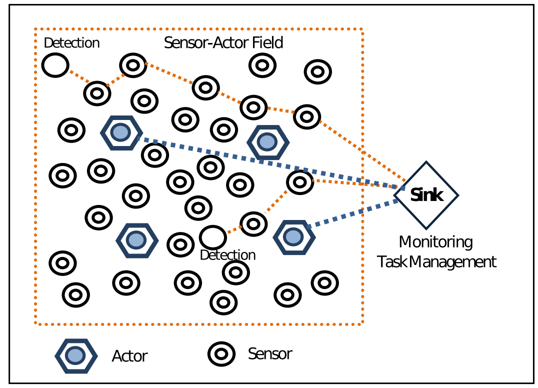
III. Proposed System Model

A. 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



(a) Fully-Automated



(b) Semi-Automated

Figure 2. WSAN architectures.

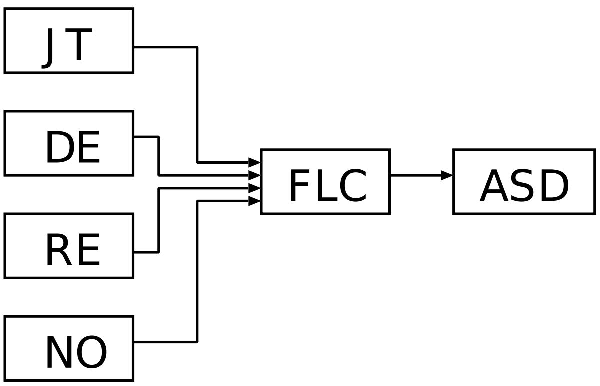


Figure 3. Proposed System.

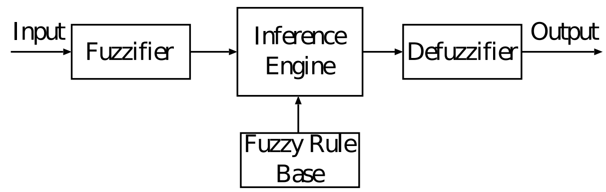


Figure 4. FLC structure.

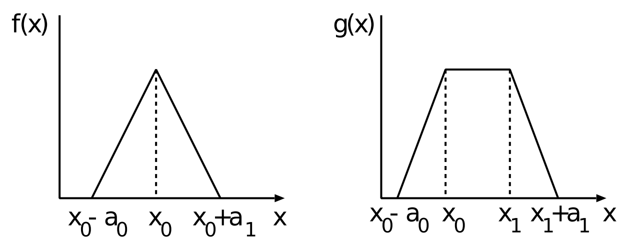


Figure 5. Triangular and trapezoidal membership functions.

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.

B. 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. 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 important because when the distance is longer, the actor will spend more energy. Thus, an actor which is close to an event, should be selected.

Remaining Energy (RE): As actors are active in the monitored field, they perform tasks and exchange data in different ways. Thus some actors may have a lot of remained power and other may have very little, when an event occurs.

Table I
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)
Number of Failure (NO)	Few (Fw), Some (So), Many (Mn)
Actor Selection Decision (ASD)	VLSP, LSP, MSP, HSP, VHSP

It is better that the actors which have more power are selected to carry out a task.

Number of Obstacles (NO): WSAN are deployed in difficult and hostile environment such as disaster rescue operations, home automation, smart spaces. These applications are excpected to be fault tolerant and to have a low energy consumption. The presence of obstacles should be taken in consideration, where one or more sensors may abstain from the line of site of the actors, due to inserted obstacles in the area.

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.

C. 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 [17]–[30]. In this work, we use fuzzy logic to implementWe consider three levels of RP for actor selection.

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 [31]. The x_0 in $f(x)$ is the center of triangular function, $x_0(x_1)$ in $g(x)$ is the left (right) edgeWe consider three levels of RP for actor selection. 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.

D. Description of FLC

We use four input parameters for FLC:

- Job Type (JT);
- Number of Obstacles (NO);
- Distance to Event (DE);
- Remaining Energy (RE);

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

$$\begin{aligned}
T(JT) &= \{Easy(Ea), Moderate(Mo), Hard(Hd)\} \\
T(NO) &= \{Few(Fw), Some(So), Many(Mn)\} \\
T(DE) &= \{Near(Ne), Middle(Md), Far(Fa)\} \\
T(RE) &= \{Low(Lo), Medium(Mdm), High(Hi)\}
\end{aligned}$$

The membership functions for input parameters of FLC are defined as:

$$\begin{aligned}
\mu_{Ea}(JT) &= g(JT; Ea_0, Ea_1, Ea_{w0}, Ea_{w1}) \\
\mu_{Me}(JT) &= f(JT; Me_0, Me_{w0}, Me_{w1}) \\
\mu_{Hi}(JT) &= g(JT; Hd_0, Hd_1, Hd_{w0}, Hd_{w1}) \\
\mu_{Fw}(NO) &= g(NO; Fw_0, Fw_1, Fw_{w0}, Fw_{w1}) \\
\mu_{So}(NO) &= f(NO; So_0, So_{w0}, So_{w1}) \\
\mu_{Mn}(NO) &= g(NO; Mn_0, Mn_1, Mn_{w0}, Mn_{w1}) \\
\mu_{Ne}(DE) &= g(DE; Ne_0, Ne_1, Ne_{w0}, Ne_{w1}) \\
\mu_{Md}(DE) &= f(DE; Md_0, Md_{w0}, Md_{w1}) \\
\mu_{Fa}(DE) &= g(DE; Fa_0, Fa_1, Fa_{w0}, Fa_{w1}) \\
\mu_{Lo}(RE) &= g(RE; Lo_0, Lo_1, Lo_{w0}, Lo_{w1}) \\
\mu_{Mdm}(RE) &= f(RE; Mdm_0, Mdm_{w0}, Mdm_{w1}) \\
\mu_{Hi}(RE) &= g(RE; Hi_0, Hi_1, Hi_{w0}, Hi_{w1}).
\end{aligned}$$

The small letters *w0* and *w1* mean left width and right width, respectively.

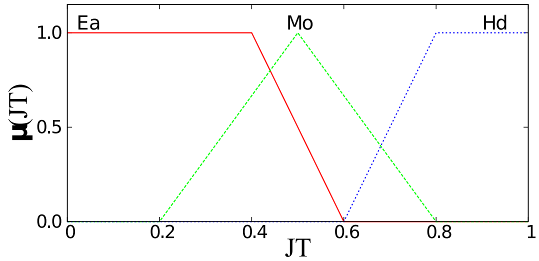
The output linguistic parameter is the Actor Selection Decision (ASD). We define the term set of ASD as:

$$\begin{aligned}
\{&Very\ Low\ Selection\ Possibility\ (VLSP), \\
&Low\ Selection\ Possibility\ (LSP), \\
&Middle\ Selection\ Possibility\ (MSP), \\
&High\ Selection\ Possibility\ (HSP), \\
&Very\ High\ Selection\ Possibility\ (VHSP)\}.
\end{aligned}$$

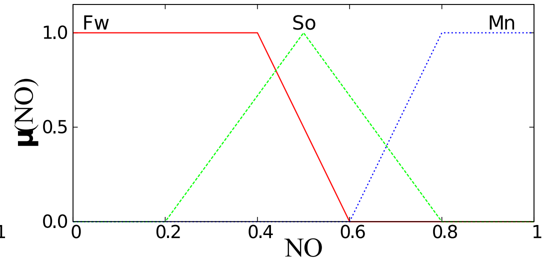
The membership functions for the output parameter *ASD* are defined as:

$$\begin{aligned}
\mu_{VLSP}(ASD) &= g(ASD; VLSP_0, VLSP_1, VLSP_{w0}, VLSP_{w1}) \\
\mu_{LSP}(ASD) &= g(ASD; LSP_0, LSP_1, LSP_{w0}, LSP_{w1}) \\
\mu_{MSP}(ASD) &= g(ASD; MSP_0, MSP_1, MSP_{w0}, MSP_{w1}) \\
\mu_{HSP}(ASD) &= g(ASD; HSP_0, HSP_1, HSP_{w0}, HSP_{w1}) \\
\mu_{VHSP}(ASD) &= g(ASD; VHSP_0, VHSP_1, VHSP_{w0}, VHSP_{w1}).
\end{aligned}$$

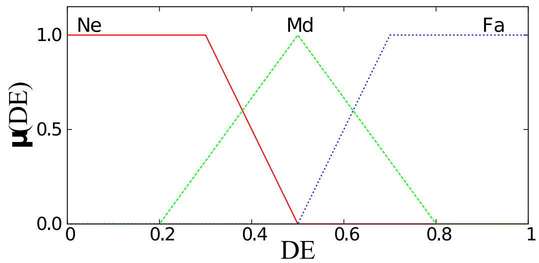
The membership functions are shown in Fig. 6 and the Fuzzy Rule Base (FRB) is shown in Table II. The FRB forms a fuzzy set of dimensions $|T(JT)| \times |T(DE)| \times |T(RE)| \times |T(NO)|$, where $|T(x)|$ is the number of terms on $T(x)$. The FRB has 81 rules. The control rules have the form: IF "conditions" THEN "control action".



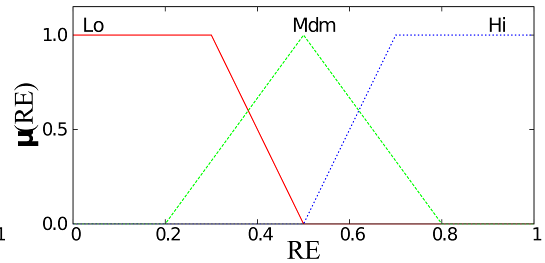
(a) Job Type



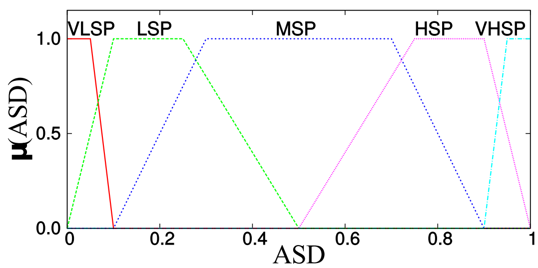
(b) Number of Obstacles



(c) Distance to Event



(d) Remaining Energy



(e) Actor Selection Decision

Figure 6. Fuzzy membership functions.

IV. Simulation Results

In our system, we decided the number of term sets by carrying out many simulations. We present the simulation results in Fig. 7, Fig. 8 and Fig. 9. From simulation results, we found that as JT becomes difficult, the ASD becomes higher, because actors are programmed for different jobs. In Fig. 7 are shown the simulation results for DE=0.1. We can see that in Fig. 7(a) for JT=0.7 when DE=0.1-NO=0.1 and Re=0.1 the ASD is 0.55. Comparing Fig. 7(b) with Fig. 7(a) we can see that for JT=0.7 the ASD is decreased 10%. Also comparing Fig. 7(c) with Fig. 7(a), the ASD for JT=0.7 is decreased 33%.

In Fig. 8 are shown the simulation results for DE=0.5. Comparing Fig. 8(b) with Fig. 8(a), for JT=0.7 when DE=0.5-NO=0.5 and RE=0.1, ASD is decreased 23%. In Fig. 8(c) compared to Fig. 8(a), for JT=0.7 when DE=0.5-NO=0.9 and Re=0.9, ASD is decreased 40%.

In Fig. 9, we can see the result for DE=0.9. Comparing Fig. 9(b) with Fig. 9(a), for JT=0.7, DE=0.9-NO=0.5 and RE=0.1, ASD is decreased 17%. Also comparing Fig. 9(c) with Fig. 9(a), for JT=0.7 and DE=0.9-NO=0.9, ASD is decreased 17%.

Comparing Fig. 8(b) with Fig. 7(b) and Fig. 9(b) with Fig. 7(b), for JT=0.7, NO=0.5, RE=0.9 and also different values of DE, the ASD is decrased 23% and 40%, respectively.

V. Conclusions and Future Work

We proposed and implemented a fuzzy-based simulation system for WSAN, wich is used for making the right actor selection for a required task in the network.

From simulation results, we conclude as follows.

- When JT and RE 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 and NO parameter are increased, the ASD parameter is decreased, so the probability that an actor node is selected for the required task is low.

Comparing Fig. 8(b) with Fig. 7(b) and Fig. 9(b) with Fig. 7(b), for JT=0.7, NO=0.5, RE=0.9 and also different values of DE, the ASD is decrased 23% and 40%, respectively.

Table II
FRB OF PROPOSED FUZZY-BASED SYSTEM.

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

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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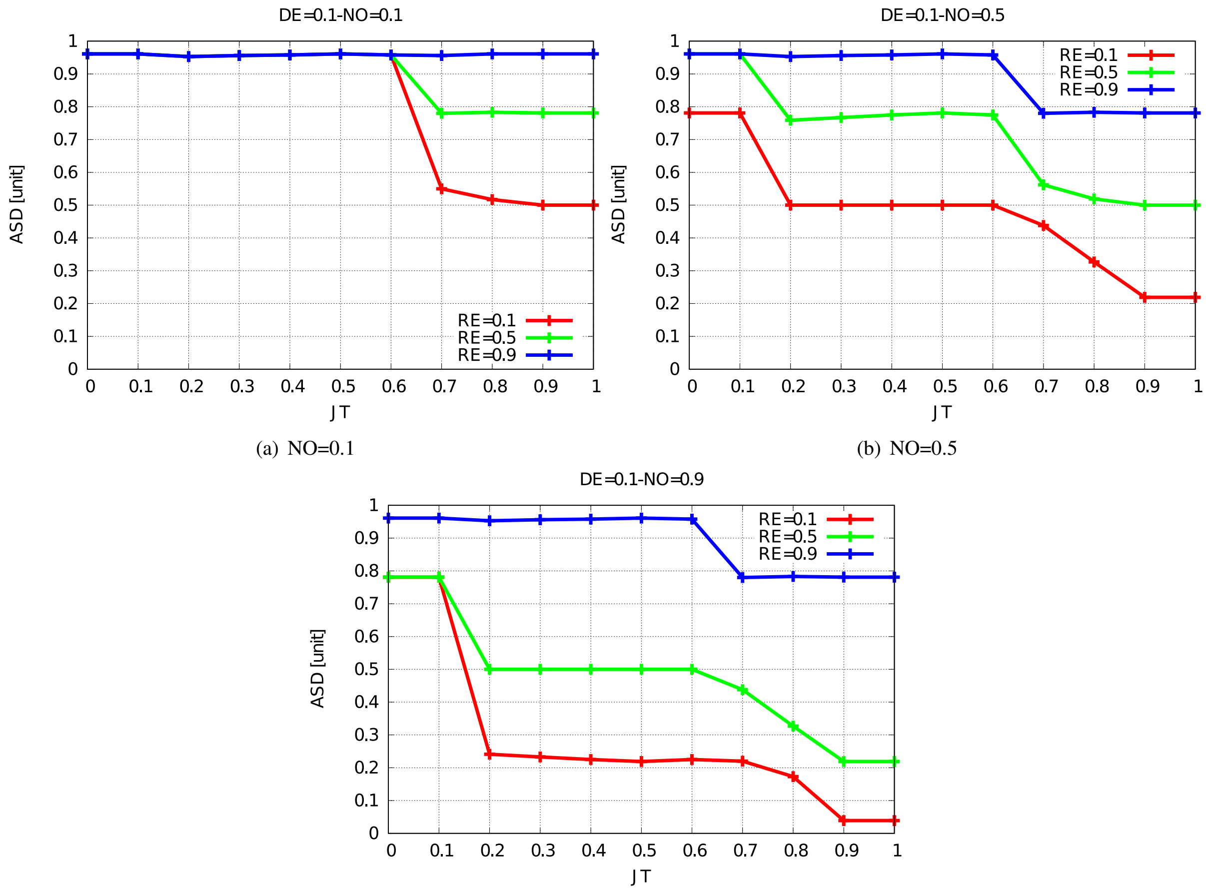

(a) NO=0.1

(b) NO=0.5

(c) NO=0.9

Figure 7. Results for $DE = 0.1$.

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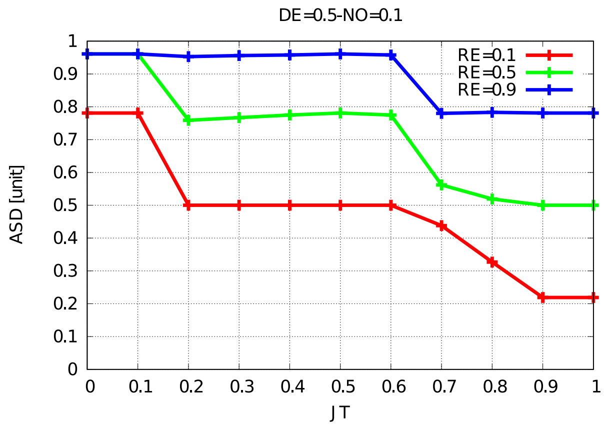
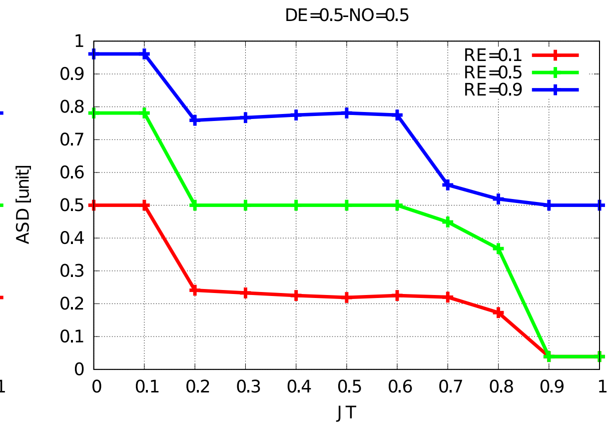
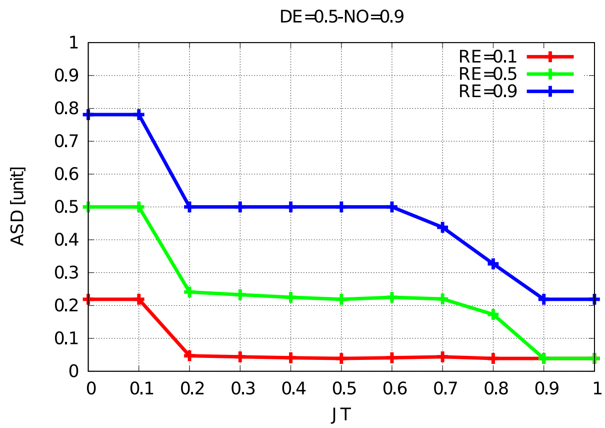


(a) NO=0.1



(b) NO=0.5



(c) NO=0.9

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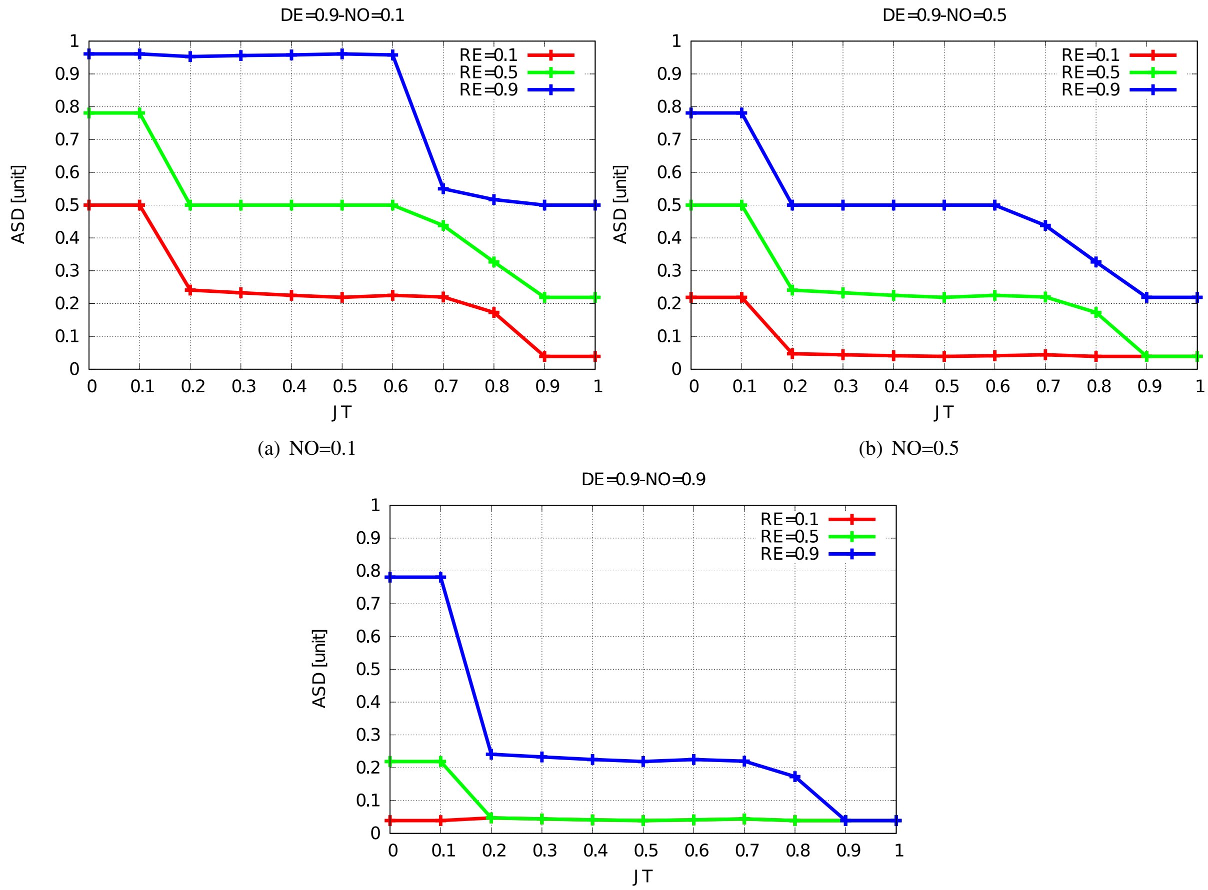

(a) NO=0.1

(b) NO=0.5

(c) NO=0.9

Figure 9. Results for $DE = 0.9$.

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