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Application of fuzzy logic for IoT node elimination and selection in opportunistic networks: performance evaluation of two fuzzy-based systems

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Abstract

Opportunistic Networks (OppNets) are a sub-class of DTN, designed as a specialized ad hoc network suitable for applications such as emergency responses. Unlike traditional networks, in OppNets communication opportunities are intermittent, so an end-to-end path between the source and the destination may never exist. Existing networks have already brought connectivity to a broad range of devices, such as hand held devices, laptops, tablets, PC, etc. The Internet of Things (IoT) will extend the connectivity to devices beyond just mobile phones and laptops, but to buildings, wearable devices, cars, different things and objects. One of the issues for these networks is the selection of the IoT nodes to carry out a task in OppNets. In this work, we implement two Fuzzy-Based Systems: Node Elimination System (NES) and Node Selection System (NSS) for IoT node elimination and selection in OppNets. We use three input parameters for NES: Node's Distance to Event (NDE), Node's Battery Level (NBL), Node's Free Buffer Space (NFBS) and four input parameters for NSS: Node's Number of Past Encounters (NNPE), Node's Unique Encounters (NUE), Node Inter Contact Time (NICT), Node Contact Duration (NCD). The output parameter is IoT Node Selection Possibility (NSP). The results show that the proposed systems make a proper elimination and selection decision for IoT nodes in OppNets.

Keywords Internet of things · Opportunistic network · Delay tolerant networks · Fuzzy logic · IoT node elimination · IoT node selection

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1 Introduction

The addition of thousands of heterogeneous nodes with various networking technologies interconnected with the aim to provide users with ubiquitous access to information, is making communication systems increasingly complex. The Opportunistic Networks (OppNets) can provide an alternative way to support the diffusion of information in special locations within a city, particularly in crowded spaces where current wireless technologies can exhibit congestion issues. However, sparse connectivity, no infrastructure and limited resources further complicate the situation [3, 16].

Due to the lack of a continuous path between source and destination, OppNets use different routing schemes for message delivery which utilize node mobility by having nodes carry messages and wait for an opportunity to transfer messages to the destination or the next relay node rather than transmitting them over a fixed path [1]. Hence, the challenges for routing in OppNets are very different from the traditional wireless networks and their utility and potential for scalability makes them a huge success.

Internet of Things (IoT), refers to the billions of devices equipped with various types of intelligent sensors which collect and exchange data. Each IoT device is equipped with a Unique Identifier (UID) and sensors, which will collect data and share it through an IoT gateway to other edge devices where data is locally analyzed or sent to the cloud for analytics. IoT will benefit companies by automating processes, providing beneficial services and making daily life more convenient. Due to its widespread area of application, IoT will probably become one of the most popular networking concepts that has the potential to bring out many benefits [2, 10].

The Fuzzy Logic (FL) is unique approach that is able to simultaneously handle numerical data and linguistic knowledge. The fuzzy logic works on the levels of possibilities of input to achieve the definite output.

In this paper, we propose and implement two Fuzzy-based systems: Node Elimination System (NES) and Node Selection System (NSS) for IoT node elimination and selection in OppNets, respectively. We use three parameters for NES: Node's Distance to Event (NDE), Node's Battery Level (NBL), Node's Free Buffer Space (NFBS) and four input parameters for NSS: Node's Number of Past Encounters (NNPE), Node's Unique Encounters (NUE), Node Inter Contact Time (NICT), Node Contact Duration (NCD). We evaluate both systems and present the simulation results for different values of input parameters.

The remainder of the paper is organized as follows. In the Section 2, we present the problem description. In Section 3, we introduce the design of fuzzy-based simulation systems. The simulation results are shown in Section 4. Finally, conclusions and future work are given in Section 5.

2 Problem description

2.1 IoT node elimination and selection process

In order to make a more robust decision when selecting IoT nodes, a big pool of parameters must be selected and combined for multiple nodes. This redundancy of parameters, although covers a large space of possible combinations, decreases the performance by increasing overhead and computational time. The process of deciding how many parameters to use in a system for the selection process is limited by each node's computational capabilities.

Parameter selection is vital in achieving an optimal selection of IoT nodes and to identify the proper parameters for each system, OppNets challenges were considered.

In this work we have used two systems implemented in FL; NES and NSS. By using two systems, one for node elimination and one for selection, we eliminate redundant nodes from participating in the selection process, maximizing resource usage in the heterogeneous OppNet. The most important challenge for OppNets is to tolerate connection disruptions and avoid loss of data during disconnections by using persistent storage to store it (bundle layer). Since most of the nodes are mobile devices with limited resources, battery level and storage will determine how long will the IoT node operate. Battery level indicates whether an IoT node can participate in an event and possibly stay on until it is completed. No matter how many rich resources one node has, low battery levels make it useless to the network. Furthermore, a long distance puts a strain to other resources such as battery, so we have selected it as one of the parameters for the first system. After each IoT node takes part in the elimination process, a second system is used to select the nodes which will benefit the task more. Selection process is used to determine the best qualifying candidates from a pool of nodes which have met the minimum qualifications and were selected for specific tasks. IoT nodes must meet the minimum requirements in order to be applicable for the selection process. In this way, we are able to eliminate nodes that do not have the basic resources for participating in events.

In an OppNet, nodes are continuously detected and evaluated for their usability and resource availability. However, to preserve these resources as much as possible we used NES as a system for eliminating nodes that do not fulfill the basic criteria for participating in task completion. Finding which nodes to remove from the selection process is an NP-Hard problem. That is why our proposed systems are based on FL. We will first evaluate the nodes based on the three most fundamental parameters battery, storage and distance to task. After we have assessed which nodes are less likely to be selected since they do not have the minimum resources, we eliminate them from participating in the selection process as shown in Figure 1. Once the elimination process is completed, the second system NSS will evaluate

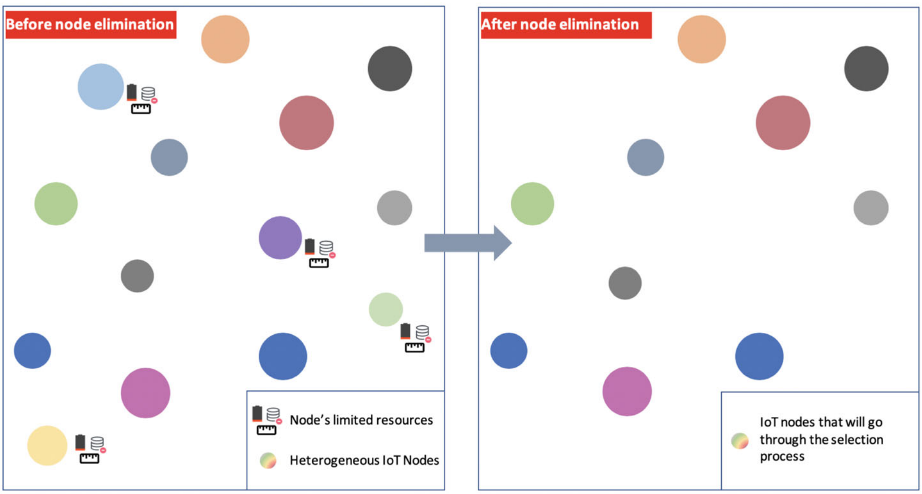

Figure 1 Node elimination

Table 1 Parameters and their term sets for FLC

Systems	Parameter	Term Sets
NES	Node's Distance to Event (NDE)	Near (Ne), Middle (Mi), Far (Fa)
	Node's Battery Level (NBL)	Low (Lw), Medium (Med), High (Hi)
	Node's Free Buffer Space (NFBS)	Small (Sm), Medium (Md), Big (Bg)
NSS	Node's Number of Past Encounters (NNPE)	Rarely (Ra), Sometime (Smt), Frequently (Frq)
	Node's Unique Encounters (NUE)	Few (Fe), Several (Sv), Many (Mn)
	Node Inter Contact Time (NICT)	Short (Sh), Medium (Mdm), Long (Ln)
	Node Contact Duration (NCD)	Short (Sho), Sufficient (Sf), Long (Lng)
Output	Node Selection Possibility (NSP)	Extremely Low Selection Possibility (ELSP), Very Low Selection Possibility (VLSP), Low Selection Possibility (LSP), Medium Selection Possibility (MSP), High Selection Possibility (HSP), Very High Selection Possibility (VHSP), Extremely High Selection Possibility (EHSP)

nodes for their usefulness as potential candidates to execute diverse tasks. Parameters chosen for the second system differ depending on the type of system and the task at hand. If the node satisfies the criteria for completing a task, it is integrated into the OppNet as a helper. This node selection process is continued until enough nodes are found to complete the task.

3 Design of Fuzzy-based simulation systems

Our proposed systems are implemented in FL. FL and Fuzzy sets 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 [4–9, 11–14, 17–19].

There are four steps to design a system based on FL: 1) Defining the fuzzy controller inputs and outputs, 2) Assigning each input and output linguistic variable and their term sets based on the level of aggregation (shown in Table 1), 3) Choosing the appropriate Fuzzy Membership Functions (FMFs) types based on the inputs and output selected and the problem specifics, 4) Building the Fuzzy Rule Base (FRB).

Our proposed systems consist of one Fuzzy Logic Controller (FLC), which is the main part of our system and its basic elements as shown in Figure 2. The proposed systems for node elimination and selection are shown in Figures 3 and 4. Parameters represented from numerical inputs to linguistic variables build the FRB. The control rules which are shown in Table 2 for NES and Table 3 for NSS have the form: *IF "conditions", THEN "control action"*. In Table 2 some rules are highlighted in red for the IoT nodes that do not fulfill the minimum requirements and are excluded from participating in the selection process, thus

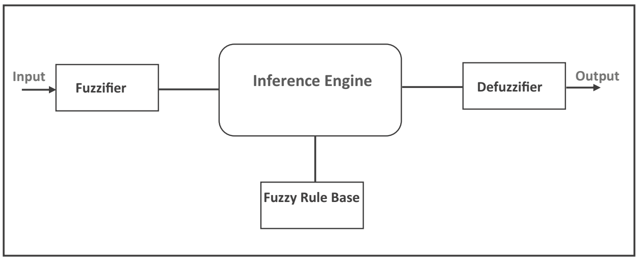

Figure 2 FLC structure

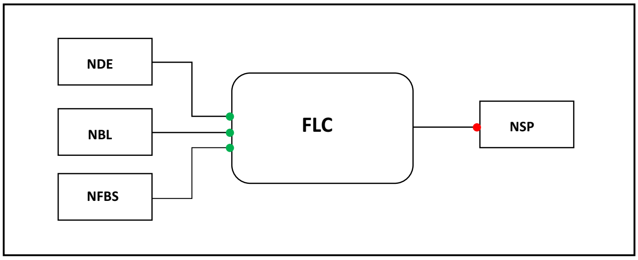

Figure 3 Proposed system NES

eliminated. The FMFs for each system are shown in Figures 5 and 6 for NES and NSS, respectively.

Due to their simplicity and computational efficiency, we have decided to use triangular and trapezoidal FMFs [15]. However, the overlap triangle-to-triangle and trapezoid-to-triangle fuzzy regions can not be addressed by any rule. It depends on the parameters and the specifics of their applications.

3.1 Parameters selection and description

We have considered the following parameters for implementation of our proposed systems.

For NES we have used three input parameters:

1) **Node's Distance to Event (NDE):** The distance of a node from the event is an important parameter as our system makes decisions based on the availability of the IoT node. An IoT node closer to the event will have a higher possibility to be selected.
2) **Node's Battery Level (NBL):** Active IoT nodes can perform tasks and exchange data in different ways from each other. Consequently, in case of an event, some IoT nodes may have a lot of remaining battery while others may have very little. An IoT node with short battery life will be rendered useless, causing limitations for IoT nodes since their lifetime in the network is directly affected by it.
3) **Node's Free Buffer Space (NFBS):** The problem with the growth of IoT is the amount of data generated by each node. In an OppNet scenario, IoT nodes do not always have an Internet connection, therefore can not access cloud storage and are solely depended on their local storage. Also, some nodes may be busier than others and their buffer may overflow due to high amount of traffic affecting the average throughput and increasing the dropping ratio.

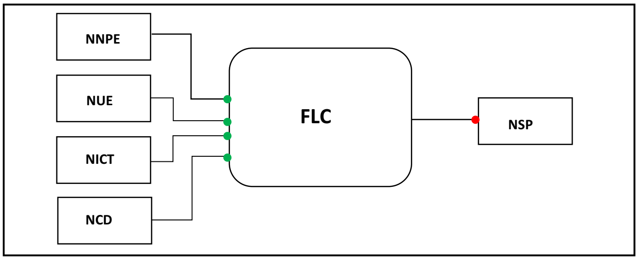

Figure 4 Proposed system NSS

Table 2 FRB for the 3 parameters system

No.	NDE	NBL	NFBS	NSP
1	Ne	Lw	Sm	VLSP
2	Ne	Lw	Md	MSP
3	Ne	Lw	Bg	VHSP
4	Ne	Med	Sm	LSP
5	Ne	Med	Md	HSP
6	Ne	Med	Bg	EHSP
7	Ne	Hi	Sm	VHSP
8	Ne	Hi	Md	EHSP
9	Ne	Hi	Bg	EHSP
10	Mi	Lw	Sm	ELSP
11	Mi	Lw	Md	VLSP
12	Mi	Lw	Bg	MSP
13	Mi	Med	Sm	VLSP
14	Mi	Med	Md	LSP
15	Mi	Med	Bg	HSP
16	Mi	Hi	Sm	LSP
17	Mi	Hi	Md	HSP
18	Mi	Hi	Bg	EHSP
19	Fa	Lw	Sm	ELSP
20	Fa	Lw	Md	ELSP
21	Fa	Lw	Bg	LSP
22	Fa	Med	Sm	ELSP
23	Fa	Med	Md	VLSP
24	Fa	Med	Bg	MSP
25	Fa	Hi	Sm	VLSP
26	Fa	Hi	Md	MSP
27	Fa	Hi	Bg	VHSP

For the NSS, we have used four parameters:

1) **Node's Number of Past Encounters (NNPE):** If one node has encountered another node more frequently than others, then it is more likely they will meet again in the future. Their mobility features such as habits and social features can be exploited for future contacts. However, sometimes due to security concerns, nodes are not allowed to exchange any explicit location updates, and the only local information available to a node about the network topology is the history of other nodes it has encountered in the past. History of past encounters plays a significant role in making a decision on node selection. This is because if a node has encountered other nodes in the past, then it is more likely to meet them again in the future.
2) **Node's Unique Encounters (NUE):** Unique encounters reflect the number of new nodes that one IoT node encounters. In some cases, IoT nodes can encounter the same nodes without making new contacts with other nodes. However, in order to expand the network and make new contacts, new encounters are preferred.
3) **Node Inter Contact Time (NICT):** The inter-contact time parameter measures the time between two consecutive contacts. It represents how long will it take for one IoT node to meet another. An increase in inter-contact time results in larger end-to-end delay.
4) **Node Contact Duration (NCD):** Contact duration between two IoT nodes is affected by their mobility and transmission range and it should be long enough so the whole message is transferred without interruption. Mobile nodes with high speed will create

Table 3 FRB

No.	NNPE	NUE	NICT	NCD	**NSP**	No.	NNPE	NUE	NICT	NCD	**NSP**	No.	NNPE	NUE	NICT	NCD	**NSP**
1	Ra	Fe	Sh	Sho	ELSP	28	Smt	Fe	Sh	Sho	ELSP	55	Frq	Fe	Sh	Sho	VLSP
2	Ra	Fe	Sh	Sf	ELSP	29	Smt	Fe	Sh	Sf	VLSP	56	Frq	Fe	Sh	Sf	LSP
3	Ra	Fe	Sh	Lng	ELSP	30	Smt	Fe	Sh	Lng	ELSP	57	Frq	Fe	Sh	Lng	VLSP
4	Ra	Fe	Mdm	Sho	ELSP	31	Smt	Fe	Mdm	Sho	VLSP	58	Frq	Fe	Mdm	Sho	LSP
5	Ra	Fe	Mdm	Sf	LSP	32	Smt	Fe	Mdm	Sf	MSP	59	Frq	Fe	Mdm	Sf	VHSP
6	Ra	Fe	Mdm	Lng	ELSP	33	Smt	Fe	Mdm	Lng	VLSP	60	Frq	Fe	Mdm	Lng	MSP
7	Ra	Fe	Ln	Sho	VLSP	34	Smt	Fe	Ln	Sho	LSP	61	Frq	Fe	Ln	Sho	HSP
8	Ra	Fe	Ln	Sf	MSP	35	Smt	Fe	Ln	Sf	VHSP	62	Frq	Fe	Ln	Sf	EHSP
9	Ra	Fe	Ln	Lng	VLSP	36	Smt	Fe	Ln	Lng	LSP	63	Frq	Fe	Ln	Lng	HSP
10	Ra	Sv	Sh	Sho	ELSP	37	Smt	Sv	Sh	Sho	ELSP	64	Frq	Sv	Sh	Sho	LSP
11	Ra	Sv	Sh	Sf	VLSP	38	Smt	Sv	Sh	Sf	LSP	65	Frq	Sv	Sh	Sf	HSP
12	Ra	Sv	Sh	Lng	ELSP	39	Smt	Sv	Sh	Lng	ELSP	66	Frq	Sv	Sh	Lng	LSP
13	Ra	Sv	Mdm	Sho	VLSP	40	Smt	Sv	Mdm	Sho	LSP	67	Frq	Sv	Mdm	Sho	HSP
14	Ra	Sv	Mdm	Sf	MSP	41	Smt	Sv	Mdm	Sf	HSP	68	Frq	Sv	Mdm	Sf	EHSP
15	Ra	Sv	Mdm	Lng	VLSP	42	Smt	Sv	Mdm	Lng	LSP	69	Frq	Sv	Mdm	Lng	HSP
16	Ra	Sv	Ln	Sho	MSP	43	Smt	Sv	Ln	Sho	HSP	70	Frq	Sv	Ln	Sho	VHSP
17	Ra	Sv	Ln	Sf	VHSP	44	Smt	Sv	Ln	Sf	EHSP	71	Frq	Sv	Ln	Sf	EHSP
18	Ra	Sv	Ln	Lng	MSP	45	Smt	Sv	Ln	Lng	HSP	72	Frq	Sv	Ln	Lng	VHSP
19	Ra	Mn	Sh	Sho	VLSP	46	Smt	Mn	Sh	Sho	LSP	73	Frq	Mn	Sh	Sho	MSP
20	Ra	Mn	Sh	Sf	MSP	47	Smt	Mn	Sh	Sf	HSP	74	Frq	Mn	Sh	Sf	VHSP
21	Ra	Mn	Sh	Lng	VLSP	48	Smt	Mn	Sh	Lng	LSP	75	Frq	Mn	Sh	Lng	MSP
22	Ra	Mn	Mdm	Sho	MSP	49	Smt	Mn	Mdm	Sho	HSP	76	Frq	Mn	Mdm	Sho	VHSP
23	Ra	Mn	Mdm	Sf	VHSP	50	Smt	Mn	Mdm	Sf	EHSP	77	Frq	Mn	Mdm	Sf	EHSP
24	Ra	Mn	Mdm	Lng	MSP	51	Smt	Mn	Mdm	Lng	HSP	78	Frq	Mn	Mdm	Lng	EHSP
25	Ra	Mn	Ln	Sho	VHSP	52	Smt	Mn	Ln	Sho	VHSP	79	Frq	Mn	Ln	Sho	EHSP
26	Ra	Mn	Ln	Sf	EHSP	53	Smt	Mn	Ln	Sf	EHSP	80	Frq	Mn	Ln	Sf	EHSP
27	Ra	Mn	Ln	Lng	VHSP	54	Smt	Mn	Ln	Lng	VHSP	81	Frq	Mn	Ln	Lng	EHSP

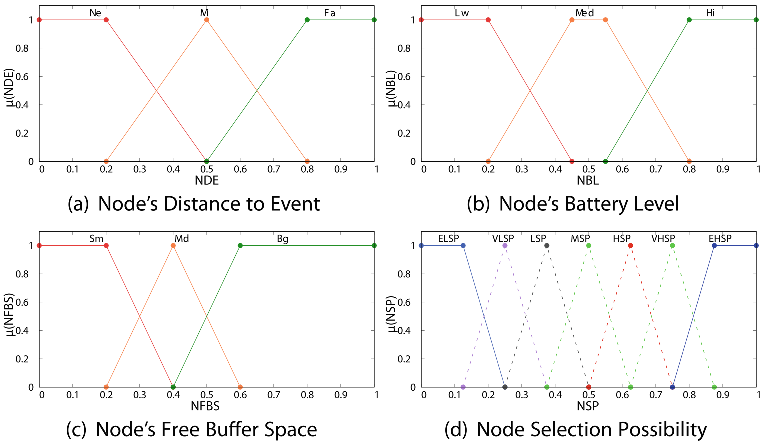

Figure 5 Fuzzy membership functions for NES

short durations and limit the amount of data that can be transmitted in one single contact, while less mobile nodes will stay in contact with each other for a longer time. For short durations, data replications techniques specific for DTN have to be applied to bypass the contact duration limitations. In this case, the opportunity for the whole message to be transmitted to the next node is increased, but the network mobility will be affected since it will be limited to a small confined area.

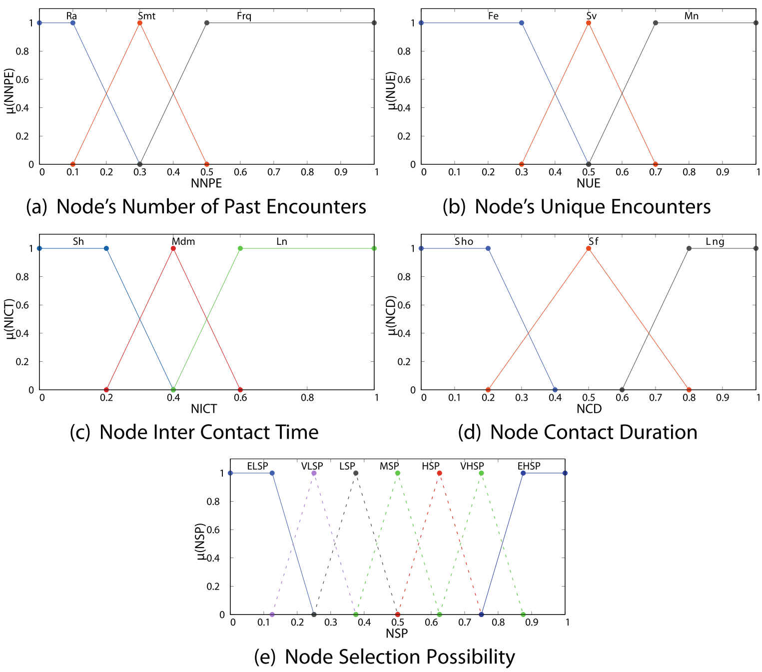

Figure 6 Fuzzy membership functions for NSS

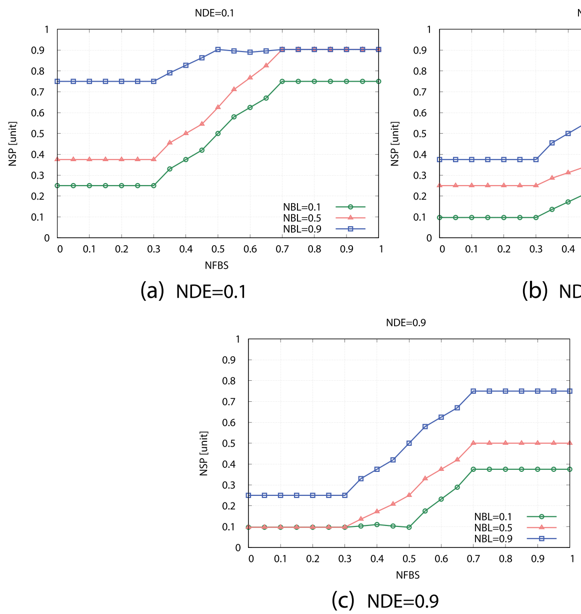

Figure 7 Simulation Results for NES

4 Simulation results

In this work we proposed two systems, NES and NSS. We used NES to show which IoT nodes do not have the basic resources such as sufficient battery, sufficient storage and good distance from the task considering OppNets characteristics. The simulation results of NES are shown in Figure 7. From this simulation results we gather which IoT nodes lack the necessary resources to participate in the selection system.

In realistic OppNet environments, some IoT nodes might roam the network with random mobility patterns exploiting contacts to communicate. Even though the node's contact information does not predict future encounters, keeping a set of information about node's contacts could help identify potential candidates and help choose the best next IoT node. It is important to study the properties of contacts made between nodes, that is why for NSS we have used parameters related to IoT node's contact characteristics. To evaluate the effect of the four input parameters as presented in Figure 8, simulation results where carried out.

Some encounters made between nodes are probabilistic which means that two nodes have met each other in the past or they follow a schedule which is known by both nodes. These two nodes which follow a scheduled route will probably meet again in the future. We have summarized this type of encounter as NNPE. When we compare Figure 8(a) with Figure 8(c) and Figure 8(c) with Figure 8(e), for NCD=0.6 and NICT=0.1, we see that NSP has increased 32% and 8%, respectively. Past encounters are probably a good estimate to determine the possibility of future encounters, thus the increase in NSP.

NUE shows whether or not one IoT node has established new connections with other nodes. Local IoT nodes, which are constricted to certain areas do not encounter new nodes very often. Comparing Figure 8(e) with Figure 8(f), for NICT=0.9 and NCD=0.5, NSD has increased 36%. Frequent new contacts are beneficial to an OppNet since they maximize end-to-end delivery.

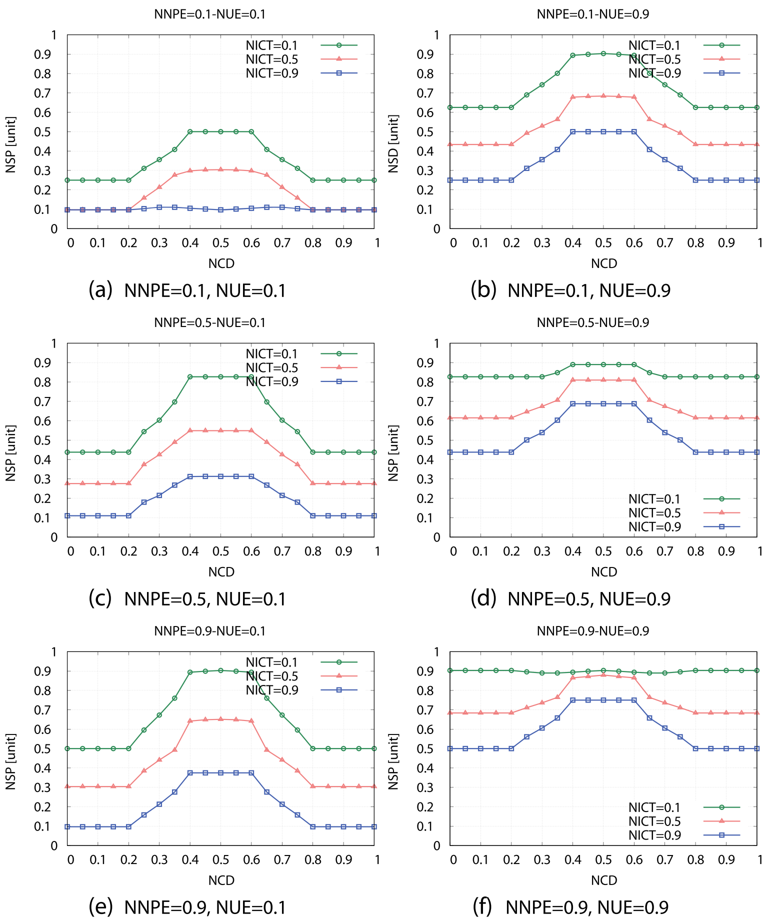

Figure 8 Simulation Results for NSS

IoT nodes that wander over long periods of time without coming in contact with new nodes will create less connections, thus the possibility that one IoT node gets selected, decreases with the increase of NICT. We can see the effect of NICT in NSP in Figure 8(a), for NCD=0.5. When NICT decreases from 0.9 to 0.5 NSP increases 20% and when NICT decreases from 0.9 to 0.1, NSP increases 40%.

Contact durations between IoT nodes are very short due to high node mobility. For example, high speed IoT nodes such as vehicles, create many contacts with very short durations. For these cases to compensate the high speed, IoT nodes communicate via long range communications media WiFi (802.11g). While hand-held devices communicate via Bluetooth, have shorter communication range, and fairly lower speeds than vehicles. When IoT nodes encounter each other, how long they stay in contact is determined by their transmission range or speed. However, contact duration must be long enough so that the message is transferred during a single contact. For example, in Figure 8(e), for NICT=0.1 when NCD increases from 0.2 to 0.4, NSD increases 40%. For NCD from 0.4 to 0.6, it is evident that NSD remains unaltered because all these values of NCD are considered equally good amounts of contact duration.

5 Conclusions and future work

In this paper, we proposed two fuzzy-based systems for IoT node elimination and selection in OppNets. NES makes the decision about which nodes should be excluded from the selection system while NSS makes the selection decision and chooses which IoT nodes from the remaining nodes are better suited for a certain task. From both systems we concluded the following:

- In NES, IoT nodes that did not fulfill the basic criteria for resource availability were eliminated from the selection process.
- In NES, we saw that IoT nodes that have sufficient basic resources are selected to go through the selection process for completing tasks.
- We used four parameters which provided the decision making system (NSS) with the essential information to determine which IoT nodes will be selected.
- For NSS, NSP increases with the increase of NNPE and NUE and decreases with the increase of NICT. However for NCD we need to find the optimal time required for a successful transmission of message.
- In addition, use of four parameters does not exclude that other parameters can be used to better evaluate each node on their specific characteristics.

In the future work, we will also consider other parameters for IoT node selection and make extensive simulations and experiments to evaluate the proposed systems.

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