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IMPLEMENTATION AND EVALUATION OF A FUZZY-BASED CLUSTER-HEAD SELECTION SYSTEM FOR WIRELESS SENSOR NETWORKS CONSIDERING NETWORK TRAFFIC

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There are many fundamental problems that Wireless Sensor Networks (WSNs) research will have to address in order to ensure a reasonable degree of cost and system quality. Some of these problems include sensor node clustering, Cluster Head (CH) selection and energy dissipation. Cluster formation and CH selection are important problems in WSNs applications and can drastically affect the WSNs energy. However, selecting of the CH is not easy in different environments which may have different characteristics. In order to deal with this problem, in our previous work, we have proposed a power reduction algorithm for WNSs based on fuzzy logic and number of neighbor nodes. In this paper, we propose a new fuzzy-based CH selection system considering network traffic to improve the performance of the previous system. We evaluate the proposed system by simulations and show that it has a good CH selection.

Keywords: Wireless Sensor Networks, Cluster-Head, Network Traffic, Fuzzy Logic

1 Introduction

Recent developments in technologies such as wireless communication and microelectronics have enabled Wireless Sensor Network (WSN) applications to be deployed for many applications such as battlefield surveillance and environment monitoring. An important aspect of such networks is that the nodes are unattended, resource-constrained, their energy cannot be replenished and network topology is unknown. The resource-constrained limitations make it essential for these sensor nodes to conserve energy to increase life-time of the sensor network [1, 2, 3, 4].

Recently, there are lot of research efforts towards the optimization of standard communication paradigms for such networks. In fact, the traditional Wireless Network (WN) design has never paid attention to constraints such as the limited or scarce energy of nodes and their computational power. Also, in WSN paths can change over time, because of time-varying characteristics of links, local contention level and nodes reliability. These problems are important especially in a multi-hop scenario, where nodes accomplish also at the routing of other nodes' packets [4].

There are many fundamental problems that sensor networks research will have to address in order to ensure a reasonable degree of cost and system quality. Some of these problems include sensor node clustering, Cluster Head (CH) selection and energy dissipation. There are many research works that deal with these challenges [5, 6, 7, 8, 9, 10, 11, 12, 13].

The cluster based algorithms could be used for partitioning the sensor nodes into subgroups for task subdivision or energy management. Cluster formation is one of most important problems in sensor network applications and can drastically affect the network's communication energy dissipation. Clustering is performed by assigning each sensor node to a specific CH. All communication to (from) each sensor node is carried out through its corresponding CH node. Obviously one would like to have each sensor to communicate with the closest CH node to conserve its energy, however CH nodes can usually handle a specific number of communication channels. Therefore, there is a maximum number of sensors that each CH node can handle. This does not allow each sensor to communicate to its closest CH node, because the CH node might have already reached its service capacity. CHs can fuse data from sensors to minimize the amount of data to be sent to the sink. When network size increases, clusters can also be organized hierarchically.

In the conventional cluster architecture, clusters are formed statically at the time of network deployment. The attributes of each cluster, such as the size of a cluster, the area it covers, and the members it possesses, are static.

When a sensor with sufficient battery and computational power detects (with a high Signal-to-Noise Ratio: SNR) signals of interest, it volunteers to act as a CH. This is a simple method, because no explicit leader (CH) election is required and, hence, no excessive message exchanges are incurred. However, selecting of the CH in this way is not easy in different environments which may have different characteristics such as error rate, SNR, throughput and so on.

The heuristic approaches based on Fuzzy Logic (FL) and Genetic Algorithms (GA) can prove to be efficient for traffic control in wireless networks [14, 15, 16].

In our previous work [17], we proposed a fuzzy-based cluster selection method for wireless sensor networks, which uses 3 parameters for CH selection: Distance of Cluster Centroid (DCC), Remaining Power of Sensor (RPS) and Degree Number of Neighbor Nodes (D3N). We compared the performance with a previous method. The performance of our method was better than the previous method. But, we found that for CH selection also Network Traffic (NT) is very important. For this reason, we propose and implement a new CH system using FL, which together with these 3 parameters also considers NT.

The paper is organized as follows. In Section 2, we discuss the related work. In Section 3, we introduce the proposed system. In Section 4, we present the simulation results. Conclusions are given in Section 5.

2 Related Work

In this section, we review related work in clustering algorithms. Several clustering methods such as weighted clustering [5], hierarchal clustering [6] and dynamic clustering [7] algorithms have been proposed to organize nodes as a cluster. Most algorithms elect leaders based on certain weights or iteratively optimize a cost function or use heuristic to generate minimum number of clusters. The Distributed Clustering Algorithm (DCA) [8] assumes quasi-stationary nodes with real-valued weights. The Weighted Clustering Algorithm [5] elects a node based on the number of neighbors, transmission power and so on. The Max-Min d-Clustering Algorithm [9] generates d-hop clusters with a run time of O(d) rounds. This algorithm does not minimize the communicating complexity of sending information to the information center.

The hierarchal clustering scheme [6] uses spanning tree-based approach to produce cluster with certain properties. However, energy efficiency is not addressed in this work. In [10], the authors have proposed an emergent algorithm that iteratively tries to achieve high packing efficiency, however negotiation among nodes to be CH and join cluster based on degree and proximity leads to high amount of communication overhead, thus wastage energy.

LEACH [11], [12] uses two-layered architecture for data dissemination. In this scheme, sensors periodically elect themselves as CHs with some probability and broadcast an invitation message for nearby nodes to join the cluster. The nodes that do not intend to be CHs join the cluster based on the proximity of CH, thus minimizing the communicating cost. However, LEACH and PEGASIS [13] require the apriory knowledge of the network topology.

In [18], the authors propose a self-reconfiguring protocol for Wireless Personal Area Networks (WPAN) using an unsupervised clustering method. A fuzzy logic system is used to select the master/controller for each cluster. In our previous work [17], we had shown by simulation results that the selection surface of our system was better than the system in [18]. But, we found that for CH selection the number of neighbor nodes is very important. For this reason, we proposed and implemented a CH system using FL and number of neighbor nodes [19, 20].

3 Proposed System

3.1 Structure of Proposed Simulation System

The structure of the proposed system is shown in Fig. 1. We explain in details the design of FCS in following.

3.2 FCS System

The Fuzzy Logic Controller (FLC) is the main part of FCS and its basic elements are shown in Fig. 2. They are the fuzzifier, inference engine, Fuzzy Rule Base (FRB) and defuzzifier.

As shown in Fig. 3, as membership functions we use triangular and trapezoidal membership functions because they are suitable for real-time operation [21]. 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.

In our previous system, we found that the number of the neighbour nodes is very important for the selection of the CH. To explain this effect let us consider a small network model with 14 nodes as shown in Fig. 4. In this figure, the node number 1 has 6 neighbour nodes, for this reason is selected as a CH. After that, 2 other sets of nodes remain, but node 2 has

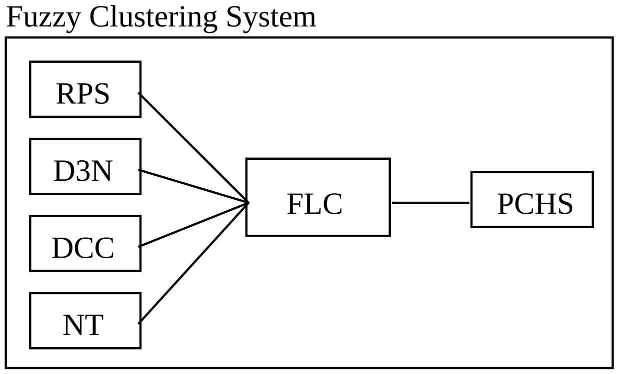

Fig. 1. Proposed simulation system.

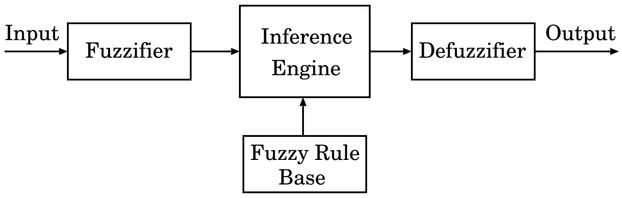

Fig. 2. FLC structure.

more neighbour nodes that nodes 3 and 7, thus node 2 is selected as CH. Finally, if we see 2 other remained nodes (node 3 and node 7), they have the same neighbour nodes that are not included in other clusters. In this case, the node with higher ID number is selected as CH. For this reason, node 7 is selected as CH and the procedure of CH selection is finished.

However, we think that also network traffic should be considered for CH selection. In the proposed FCS, we use 4 input parameters:

- Remaining Battery Power of Sensor (RPS);
- Degree of Number of Neighbour Nodes (D3N);
- Distance from Cluster Centroid (DCC);
- Network Traffic (NT).

The term sets for each input linguistic parameter are defined respectively as:

$$\begin{aligned} T(RPS) &= \{Low(Lo), Middle(Mi), High(Hg)\}; \\ T(D3N) &= \{Few(Fw), Medium(Me), Many(Mn)\}; \\ T(DCC) &= \{Near(Nr), Moderate(Mo), Far(Fr)\}. \\ T(NT) &= \{Light(Lg), Moderate(Mr), Heavy(Hv)\}. \end{aligned}$$

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

$$\mu_{Lo}(RPS) = g(RPS; Lo_0, Lo_1, Lo_{w0}, Lo_{w1});$$

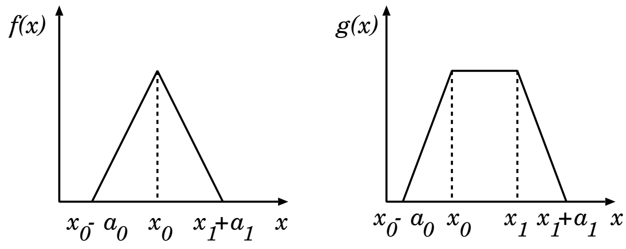

Fig. 3. Triangular and trapezoidal membership functions.

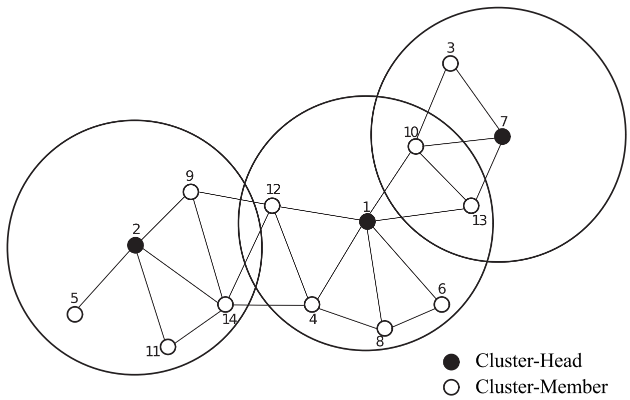

Fig. 4. CH selection process.

$$
\begin{aligned}
\mu_{Mi}(RPS) &= g(RPS; Mi_0, Mi_1, Mi_{w0}, Mi_{w1});\\
\mu_{Hg}(RPS) &= g(RPS; Hg_0, Hg_1, Hg_{w0}, Hg_{w1});\\
\mu_{Fw}(D3N) &= g(D3N; Fw_0, Fw_1, Fw_{w0}, Fw_{w1});\\
\mu_{Me}(D3N) &= f(D3N; Me_0, Me_{w0}, Me_{w1});\\
\mu_{Mn}(D3N) &= g(D3N; Mn_0, Mn_1, Mn_{w0}, Mn_{w1});\\
\mu_{Nr}(DCC) &= g(DCC; Nr_0, Nr_1, Nr_{w0}, Nr_{w1});\\
\mu_{Mo}(DCC) &= f(DCC; Mo_0, Mo_{w0}, Mo_{w1});\\
\mu_{Fr}(DCC) &= g(DCC; Fr_0, Fr_1, Fr_{w0}, Fr_{w1});\\
\mu_{Lg}(NT) &= g(NT; Lg_0, Lg_1, Lg_{w0}, Lg_{w1});\\
\mu_{Mr}(NT) &= g(NT; Mr_0, Mr_1, Mr_{w0}, Mr_{w1});\\
\mu_{Hv}(NT) &= g(NT; Hv_0, Hv_1, Hv_{w0}, Hv_{w1}).
\end{aligned}
$$

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

The output linguistic parameter is the Possibility of CH Selection ($PCHS$). We define the term set of $PCHS$ as: $\{Very\ Weak\ (VW),\ \ Weak\ (W),\ \ Little\ Weak\ (LW),$ $Medium\ (MD),\ Little\ Strong\ (LS),\ Strong\ (S),\ Very\ Strong\ (VS)\}$.

The membership functions for the output parameter $PCHS$ are defined as:

$$
\mu_{VW}(PCHS) = g(PCHS; VW_0, VW_1, VW_{w0}, VW_{w1});
$$

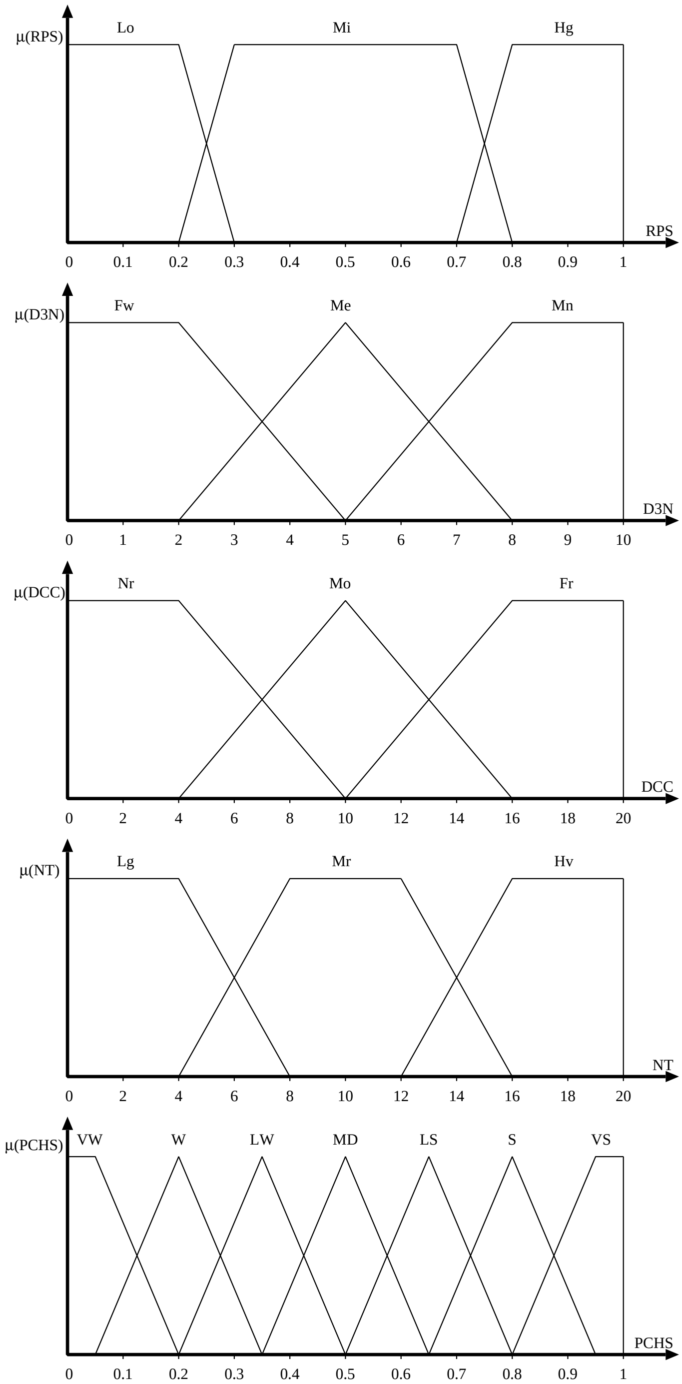

Fig. 5. Membership functions.

Table 1. Parameters and their term sets.

Parameters	Term Sets
Remaining Battery Power of Sensor (RPS)	Low, Middle, High
Degree of Number of Neighbour Nodes (D3N)	Few, Medium, Many
Distance from Cluster Centroid (DCC)	Near, Moderate, Far
Network Traffic (NT)	Light, Moderate, Heavy
Probability (Possibility) of CH Selection (PCHS)	Very Weak, Weak, Little Week, Medium, Little Strong, Strong, Very Strong

$$\begin{aligned}
\mu_W(PCHS) &= f(PCHS; W_0, W_{w0}, W_{w1});\\
\mu_{LW}(PCHS) &= f(PCHS; LW_0, LW_{w0}, LW_{w1});\\
\mu_{MD}(PCHS) &= f(PCHS; MD_0, MD_{w0}, MD_{w1});\\
\mu_{LS}(PCHS) &= f(PCHS; LS_0, LS_{w0}, LS_{w1});\\
\mu_S(PCHS) &= f(PCHS; S_0, S_{w0}, S_{w1});\\
\mu_{VS}(PCHS) &= g(PCHS; VS_0, VS_1, VS_{w0}, VS_{w1}).
\end{aligned}$$

The linguistic parameters and their term sets of proposed system are shown in Table 1. The fuzzy membership functions for input parameters are shown in Fig. 5.

The FRB is shown in Table 2 and forms a fuzzy set of dimensions $|T(RPS)| \times |T(D3N)| \times |T(DCC)| \times |T(NT)|$, 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".

4 Simulation Results

In this section, we present the simulation results for FCS system. In our system, we decided the number of term sets by carrying out many simulations. These simulation results were carried out in MATLAB.

We show the performance of our previous system [22] in Fig. 6 and performance of FCS in Fig. 7, Fig. 8 and Fig. 9. In these figures, we show the relation between the probability of a sensor to be selected as a CH versus the DCC, D3N, NT and RPS. We consider DCC and D3N as constants and change the values of NT and RPS. We clearly distinguish 3 zones. When, the RPS is less than 0.2 units the probability of a node to be selected as CH is very small. A middle zone (more than 0.2 units but less than 0.8 units), where the CH selection possibility increases slowly with increase of the RPS. A third zone (more than 0.8 units), where the possibility of a node to be CH is high.

In Fig. 6, when the RPS is smaller than 2 units, the D3N is 10 units. This means that when the present CH has more neighbours nodes and has a small remained power, it can ask neighbour nodes to be as CH. As shown by this figure, the probability of a node to be CH decreases with the increase of D3N parameter.

Comparing Fig. 9 with Fig. 6, we can see that FCS has a more acurate estimation of CH selection, which results in better control of the energy, thus increasing network life time.

Table 2. FRB.

Rule	RPS	D3N	DCC	NT	PCHS	Rule	RPS	D3N	DCC	NT	PCHS
1	Lo	Fw	Fr	Lg	W	42	Mi	Me	Mo	Hv	LS
2	Lo	Fw	Fr	Mr	W	43	Mi	Me	Nr	Lg	MD
3	Lo	Fw	Fr	Hv	LW	44	Mi	Me	Nr	Mr	MD
4	Lo	Fw	Mo	Lg	W	45	Mi	Me	Nr	Hv	LS
5	Lo	Fw	Mo	Mr	W	46	Mi	Mn	Fr	Lg	MD
6	Lo	Fw	Mo	Hv	LW	47	Mi	Mn	Fr	Mr	LS
7	Lo	Fw	Nr	Lg	W	48	Mi	Mn	Fr	Hv	LS
8	Lo	Fw	Nr	Mr	W	49	Mi	Mn	Mo	Lg	MD
9	Lo	Fw	Nr	Hv	W	50	Mi	Mn	Mo	Mr	LS
10	Lo	Me	Fr	Lg	VW	51	Mi	Mn	Mo	Hv	S
11	Lo	Me	Fr	Mr	W	52	Mi	Mn	Nr	Lg	LS
12	Lo	Me	Fr	Hv	W	53	Mi	Mn	Nr	Mr	S
13	Lo	Me	Mo	Lg	VW	54	Mi	Mn	Nr	Hv	VS
14	Lo	Me	Mo	Mr	W	55	Hg	Fw	Fr	Lg	MD
15	Lo	Me	Mo	Hv	W	56	Hg	Fw	Fr	Mr	MD
16	Lo	Me	Nr	Lg	VW	57	Hg	Fw	Fr	Hv	LS
17	Lo	Me	Nr	Mr	W	58	Hg	Fw	Mo	Lg	MD
18	Lo	Me	Nr	Hv	W	59	Hg	Fw	Mo	Mr	MD
19	Lo	Mn	Fr	Lg	VW	60	Hg	Fw	Mo	Hv	LS
20	Lo	Mn	Fr	Mr	VW	61	Hg	Fw	Nr	Lg	MD
21	Lo	Mn	Fr	Hv	VW	62	Hg	Fw	Nr	Mr	LS
22	Lo	Mn	Mo	Lg	VW	63	Hg	Fw	Nr	Hv	S
23	Lo	Mn	Mo	Mr	VW	64	Hg	Me	Fr	Lg	MD
24	Lo	Mn	Mo	Hv	VW	65	Hg	Me	Fr	Mr	LS
25	Lo	Mn	Nr	Lg	VW	66	Hg	Me	Fr	Hv	S
26	Lo	Mn	Nr	Mr	VW	67	Hg	Me	Mo	Lg	LS
27	Lo	Mn	Nr	Hv	VW	68	Hg	Me	Mo	Mr	LS
28	Mi	Fw	Fr	Lg	LW	69	Hg	Me	Mo	Hv	S
29	Mi	Fw	Fr	Mr	MD	70	Hg	Me	Nr	Lg	LS
30	Mi	Fw	Fr	Hv	LS	71	Hg	Me	Nr	Mr	S
31	Mi	Fw	Mo	Lg	MD	72	Hg	Me	Nr	Hv	VS
32	Mi	Fw	Mo	Mr	MD	73	Hg	Mn	Fr	Lg	MD
33	Mi	Fw	Mo	Hv	MD	74	Hg	Mn	Fr	Mr	LS
34	Mi	Fw	Nr	Lg	LW	75	Hg	Mn	Fr	Hv	VS
35	Mi	Fw	Nr	Mr	MD	76	Hg	Mn	Mo	Lg	S
36	Mi	Fw	Nr	Hv	LS	77	Hg	Mn	Mo	Mr	VS
37	Mi	Me	Fr	Lg	MD	78	Hg	Mn	Mo	Hv	VS
38	Mi	Me	Fr	Mr	MD	79	Hg	Mn	Nr	Lg	VS
39	Mi	Me	Fr	Hv	LS	80	Hg	Mn	Nr	Mr	VS
40	Mi	Me	Mo	Lg	MD	81	Hg	Mn	Nr	Hv	VS
41	Mi	Me	Mo	Mr	MD						

5 Conclusions

The power conservation in WSN is a very important issue. Conserving power prolongs the lifetime of a node and also the lifetime of the whole network. Clustering is one of the energy-efficient techniques for extending the lifetime of a sensor network. Clustering techniques organize the nodes into clusters where some nodes work as CHs and collect the data from other nodes in the clusters. However, CH selection is very difficult when many parameters are used for making the decision.

In our previous work, in order to select the CH, we proposed a power reduction algorithm for WSNs based on fuzzy logic. In this paper, we implement a new simulation system for clustering algorithms in WSNs considering NT parameter. From the simulation results, we found that the probability of a node to be selected as CH is increased with increase of number

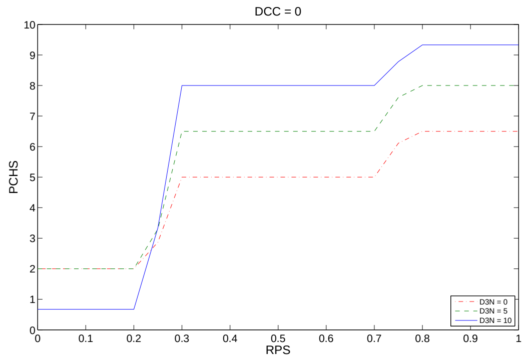

Fig. 6. Previous system results.

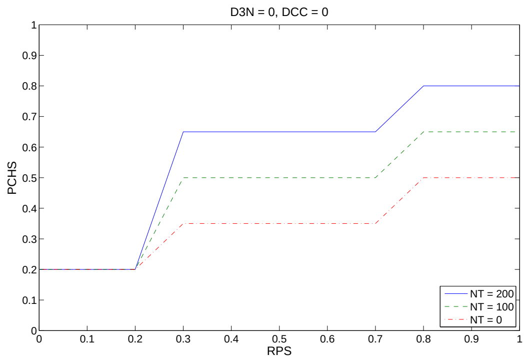

Fig. 7. FCS system results (case 1).

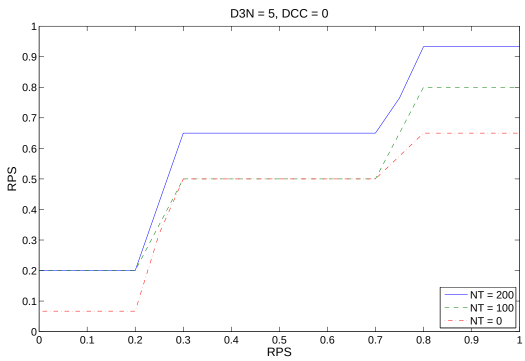

Fig. 8. FCS system results (case 2).

of neighbour nodes, network traffic and remained battery power but decrease with increase of distance from the cluster centroid.

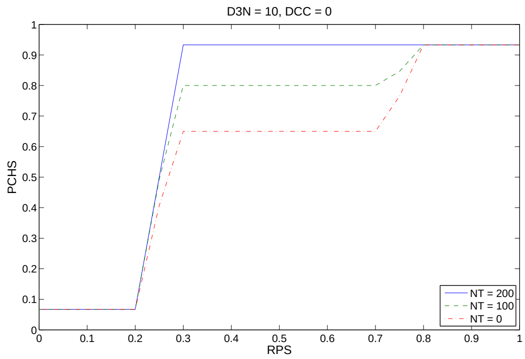

Fig. 9. FCS system results (case 3).

In our future work, we will consider other parameters and also will carry out extensive simulations to evaluate the proposed system.

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