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Cooperative Game Theory Approach for Energy-Efficient Node Clustering in Wireless Sensor Network

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Abstract

Energy consumption is one of the critical challenges in designing wireless sensor network (WSN) since it is typically composed of resource-constrained devices. Many studies have been proposed clustering to deal with energy conservation in WSN. Due to its predominance in coordinating the behaviors of many players, game theory has been considered for improving energy efficiency in WSN. In this paper, we evaluate the performance of cooperative game theoretic clustering (CGC) algorithm which employs cooperative game theory in a form of 3-agent cost sharing game for energy-efficient clustering in WSN. Furthermore, we compared its performance to a well-known traditional clustering method, low-energy adaptive clustering hierarchy (LEACH), in terms of network lifetime and stability, and total residual energy. The simulation results show that CGC has better performance compared to LEACH due to the cooperation among cluster heads in coalition. CGC has higher alive nodes with stability improvement of first node dies (FND) by 65%, and the improvement by 52.4% for half node dies (HND). However, with the increasing of the number of nodes, the performance of LEACH is getting better compared to CGC.

Keywords: WSN clustering algorithm, CGC, LEACH, cooperative game theory, cost sharing game, Shapley value, FND, HND.

I. Introduction

A wireless sensor network (WSN) typically comprises a huge number of individual sensor nodes that have restricted resources, such as small processing capacity, memory and limited energy. These restricted resources need to be utilized efficiently to lengthen the network lifetime. Moreover, the network should also has self-organizing capability to achieve its tasks with a least cost. In consequence, increasing network lifetime through various energy-efficient mechanisms becomes a critical aspect when designing and deploying WSN.

Clustering is one of the effective approaches for conserving energy and maximizing network lifespan in WSN [1-5]. In clustering scheme, WSN nodes are divided up into clusters with cluster head (CH) as a node that coordinates other members of each cluster. CH is in charge for collecting, aggregating and passing collected data directly or in multi-hop fashion to the base station (BS). Clustering scheme reduces network energy consumption through these following [3]: 1) reduce the number of long-distance transmissions; 2) minimize each node activities; and 3) decrease the number of transmitted packets by aggregating the data in CH before the transmission, thereby result into saving of network energy consumption.

Low-energy adaptive clustering hierarchy (LEACH) is regarded as the most prominent traditional clustering algorithms for WSN applications [2], [6-8]. The basic procedures of LEACH are split into set up and steady state phase in every round. Clusters are formed in set up phase, then data are transmitted in steady state phase. The main issues of LEACH are uneven node energy consumption and high energy cost. Since CHs in LEACH are selected randomly based on the threshold function model, it is highly possible that CHs will distribute non-uniformly, regardless their position in monitored area. In consequence, CHs that located far for base station dissipated higher energy compared to the closed one. This leads to uneven energy consumption high energy cost.

In recent years, game theory (GT) has been broadly introduced for improving energy efficiency in WSN due to its predominance in coordinating the behaviors of many players. GT contributes in constructing mathematical models of distributed mechanisms for optimizing energy-efficient clustering in WSN. Generally, it classified into non-cooperative and cooperative game. In non-cooperative game, players individually attempt to maximize their own utility without regard to the utility achieved by other players. On the other hand, in cooperative game, players bargain with each other before the game is played.

Prior studies on game theory approach, particularly for WSN node clustering can be found in [9-13]. The studies in [9-11] utilized non-cooperative GT to achieve certain objectives in order to preserve energy. To balance the loads among coalitional heads, the study in [9] segmented the monitored area into squares clusters with the width determined by GT. The study in [10] specifies node's eligibility to participate in the clustering game based on a flexible weighted function. Profitable energy

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market game (PEMG) algorithm is proposed in [11] to energy consumption of sensors. Meanwhile, studies in [12-13] utilized cooperative GT framework to achieve efficient energy consumption. Cooperative game theoretic clustering (CGC) in [12-13] take into account number of cluster members, residual energy and transmission energy in cluster formation to maximizing network lifetime. Compared with non-cooperative GT, CGC considers not only individual cost but also incorporate network-wide cost which is the best match for group formation purposes in WSN.

In this study, we analyze the performance of CGC algorithm compared to a well-known traditional clustering method, LEACH, regarding the metrics of network lifetime, stability, and total residual energy. In performance comparison of these protocols, the effect of wireless channel interference and signal collision are negligible.

II. System Model

In this study, we consider WSN composed of N stationary nodes that are distributed uniformly in monitored area of $M\times M$ m^2. Base station (BS) has no energy constrained and has fix location at the center of monitored area. Each CH performs data aggregation before forwarding data packets to BS directly.

A. Energy Consumption Model

For energy dissipation analysis, energy model applied in [1]-[3] is adopted as illustrated in Figure 1. At transmitter side, energy expenditure is including the radio electronics and the transmit amplifier circuitry. Meanwhile, the receiver only consumes radio electronics part. When transmitting the l-bit data to a distance d, the radio expends energy according to Eq. (1). E_{elec} denotes circuit depletion of transmitter or receiver. α is the propagation loss exponent which depends on the propagation model. Particularly, α is 2 for the free space model and increases to 4 for the two-ray ground reflection model. ε_{fs} and ε_{tr} represent amplifier coefficients of free-space and two-ray ground reflection model respectively. The crossover distance is denoted by $d_{\text{co}} = \sqrt{\frac{\varepsilon_{\text{fs}}}{\varepsilon_{\text{tr}}}}$ wherein the propagation model is switching from free space model to two-ray ground reflection model. To receive l-bit packet, energy expending is expressed in Eq. (2).

For a WSN with k number of CHs, the energy expenditure of each CH for a round is calculated by Eq. (3). n, E_{DA}, d_{toBS} are the number of each cluster members, the energy for data aggregation per bit and the distance of CH to BS respectively. Meanwhile, the energy spend by non-CH is calculated by Eq. (4). $d_{\text{toCH}} = \frac{M}{\sqrt{2k\pi}}$ denotes the average distance between sensor nodes in the cluster with their CH [14].

$$E_{Tx}(l,d) = l\left(E_{elec} + \varepsilon_{\text{amp}} \cdot d^{\alpha}\right) \tag{1}$$

$$= \begin{cases} l(E_{elec} + \varepsilon_{\text{fs}} d^2) & ; \text{d} < \text{d}_{\text{co}} \\ l(E_{elec} + \varepsilon_{\text{tr}} d^4) & ; \text{d} \geq \text{d}_{\text{co}} \end{cases}$$

$$E_{Rx}(l) = lE_{elec} \tag{2}$$

$$E_{CH} = l[(nE_{elec} + E_{DA}) + \varepsilon_{\text{tr}} d_{toBS}^4] \tag{3}$$

$$E_{Non-CH} = l(E_{elec} + \varepsilon_{\text{fs}} d_{toCH}^2) \tag{4}$$

B. Clustering Process

Clustering process in CGC [12-13] is as follows:

- At the start of round r, candidate CHs (CCHs) are chosen with the probability of P_{i} as expressed in Eq. (5). As seen in (1), CGC takes residual energy into account for CCH selection. Each CCH then broadcasts an advertisement message via CSMA protocol.

$$P_i = \frac{k}{N - k * \left(r \bmod \frac{N}{k}\right)} \frac{E_{residual}}{E_{initial}} \tag{5}$$

- After receiving an advertisement message, all non-CCH nodes decide which cluster to join according to the received signal strength. Following this, each of non-CCH node sends its join message to CCH containing information of node's ID, residual energy and distance from CCH.
- When all join messages of non-CCH nodes in the clusters reach CCH, it subsequently adjusts the final coalition.
- After CCHs are elected, they select two other capable nodes in each cluster to form cluster head coalitions. The cooperation among these nodes is formulated as a cost sharing game of 3 agents. The game consists of set of players, strategies and a cost function.

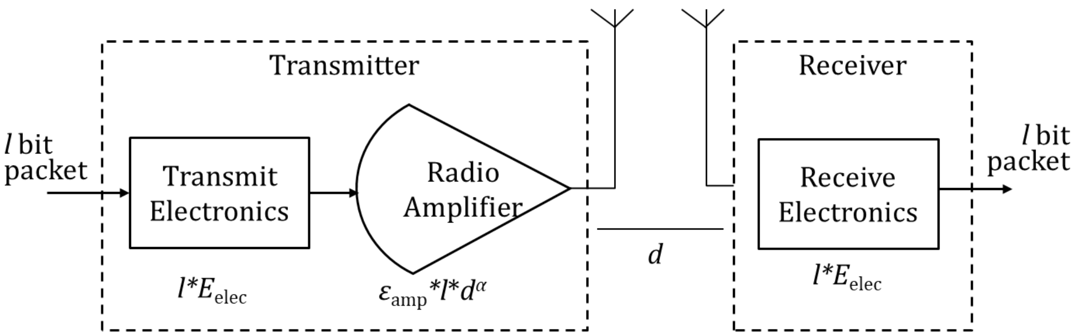


Figure 1. Radio energy model.

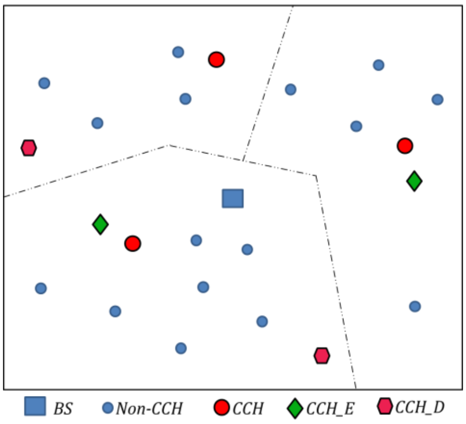


Figure 2. Cluster architecture of CGC.

The players are set of candidate cluster heads, $A = \{CCH, CCH\_D, CCH\_E\}$, where *CCH_D* is the farthest node in the cluster from CCH, while *CCH_E* is located closed to CCH with redundant energy. The cluster architecture for cooperation is depicted in Figure 2. The cost function of this coalition, *c*, is defined as the total energy consumption of all sensor nodes for data collection in one round involving β frames as stated in eq. (6). Shapley value is employed to provide solution by assigning a single cost allocation to cost sharing game. The Shapley value ϕ for each agent *i* on the cost function *c* is represented by eq. (10).

$$c(S) = \beta c_{CH}(S) + \beta c_{Non-CH}(S) + c_{red}(S) \quad (6)$$

$$c_{CH}(S) = sE_{CH}\left(\frac{n}{s}\right) \quad (7)$$

$$c_{NON-CH}(S) = \begin{cases} (n-s)E_{Non-CH}(d_{2k}) \\ \quad ; s > 1 \text{ and } CCH_D \in S \\ (n-s-1)E_{Non-CH}(d_k) + E_{Tx}(\ell, d) \\ \quad ; \text{otherwise} \end{cases} \quad (8)$$

$$c_{red}(S) = \begin{cases} -E_{red} & ; CCH\_E \in S \\ 0 & ; \text{otherwise} \end{cases} \quad (9)$$

$$\phi_i(c) = \sum_{S \subseteq A \setminus \{i\}} \frac{s!\,(n-1-s)!}{n!}\left(c(S \cup \{i\}) - c(S)\right) \quad (10)$$

where *S* denotes a coalition of CCHs. $c_{CH}(S), c_{Non-CH}(S), c_{red}(S)$ represent the energy consumption of all CHs, the energy consumption of all non-CHs when agents in S are as cluster heads, and the redundant energy of the *CCH_E* when $CCH\_E \in S$ respectively. $s = |S|$ is cardinality of *S*, and *n* is a number of agents (*A*). ϕ_i(c) is a solution that allots one cost allocation to cost sharing games, $S \subseteq A \setminus \{i\}$ denotes set of all coalitions *S* of *A* not containing agent *i*.

The conditions for coalition are as follows:

i. Cooperate with *CCH_E*
$\phi_{CCH} + \phi_{CCH\_E} < c(\{CCH\})$

ii. Cooperate with *CCH_D*
$\phi_{CCH} + \phi_{CCH\_D} < c(\{CCH\})$

If there are no partners, the candidate cluster head is decided to accomplish data collection in the round by itself. At this time, the system energy consumption is $c(\{CCH\})$. As for *i*-th node, $E_{red\_i} = E_{residual\_i} - E_{residual\_CCH}$.

- Consequently, CCH broadcasts identifications of CHs while other nodes listen for the CH coalition message. When receive coalition message, an elected node notifies other nodes of this decision.
- Once coalitions are formed, data collection comes into act. Each node starts sensing then forwards the data to the respective CHs. Time-division multiple access (TDMA) schedule is allocated to each node within the cluster by CH, then it collects individual data, fuses the data and transmits them to BS. In this way, a round is completed.

As a reference for further analysis, we provide flowcharts of LEACH and CGC procedure in Figure 3.

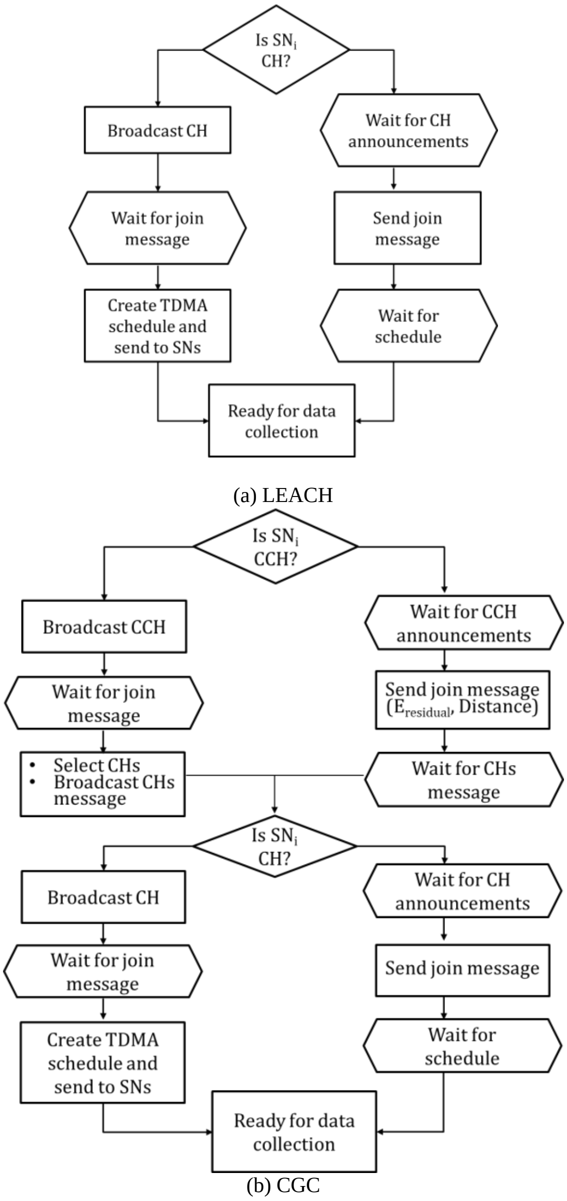


Figure 3. Flowcharts of LEACH and CGC procedure.

III. SIMULATION AND ANALYSIS

A. Simulation Setup

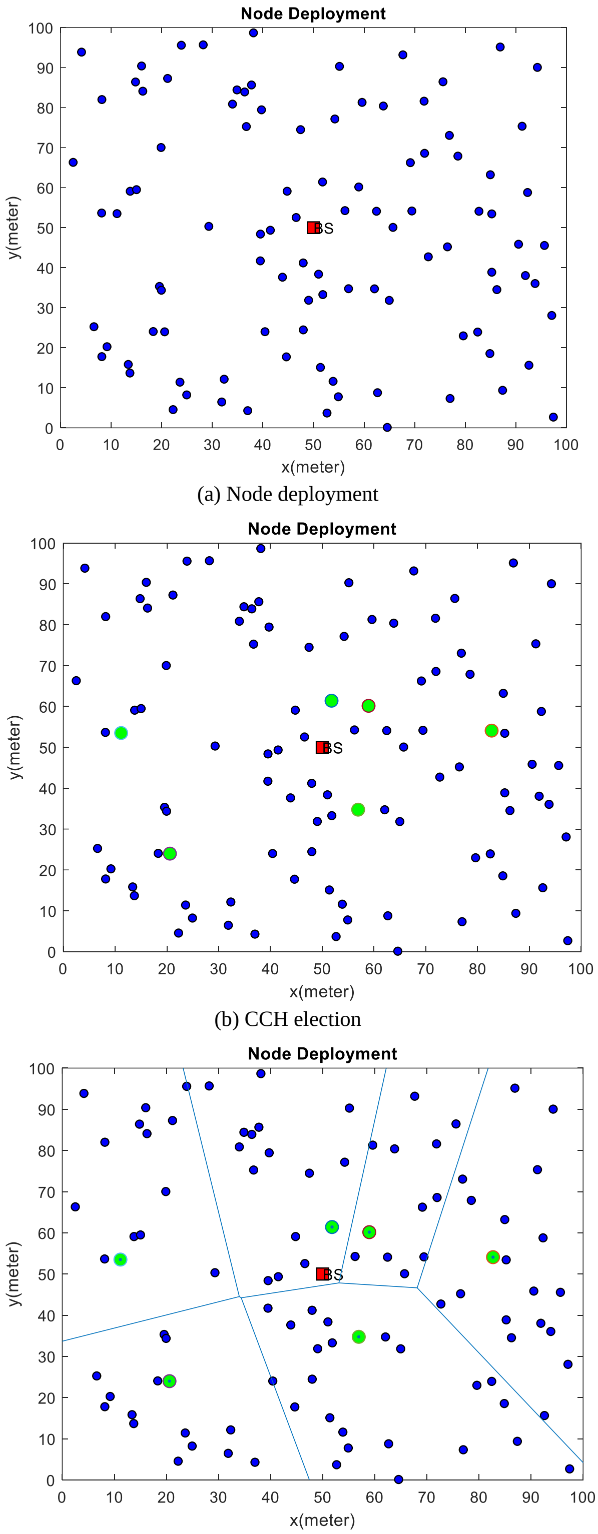
We conduct simulation using MATLAB software. The simulation considers the sensor network field size of 100 m × 100 m consists of 100 homogeneous sensor nodes scattered randomly. Figure 4(a) displays sensor nodes deployment on monitored area. The BS is located at the center of monitored area, specifically at (50, 50) as indicates by red square in Figure 4(a), while blue circles indicate deployed sensor nodes. Figures 4(b) and 4(c) visualize how the CCHs are elected and clusters formation respectively. Table 1 shows the simulation parameters.

IV. RESULTS ANALYSIS

The performance of CGC is evaluated in regard to network lifetime and stability as well as residual energy at different rounds of data transfer. Network lifetime is evaluated through number of nodes alive or dead. Meanwhile, the stability is defined as the time interval before the death of the first node, well known as first node dies (FND) metric [15]. Longer stability period is crucial in many WSN applications, since it indicates longer time to collect the data properly. In addition, we also provide half node dies (HND) metric which indicates time interval the death of half nodes. Another evaluation metric is total residual energy which indicates the difference of the initial energy and current energy of each sensor node.

TABLE 1 SIMULATION PARAMETERS

Parameter		Value
Monitored Area	M×M	100×100 m
Number of sensor nodes	N	100
Number of BS		1
Initial Energy	$E_{initial}$	0.02 J
	E_{elec}	50 pJ/bit
Amplifier coefficient of free-space model	ε_{fs}	10 pJ/bit/m^2
Amplifier coefficient of two-ray ground reflection model	ε_{tr}	0.0013 pJ/bit/m^4
Energy for data aggregation per bit	E_{DA}	5 pJ/bit/signal
Crossover distance	$d_{co} = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{tr}}}$	87.7
Data packet size		4000 bits
Cluster head probability		0.05
Maximum round	r_{max}	2000



(a) Node deployment

(b) CCH election

(c) Cluster formation

Figure 4. Node deployment and clustering process.

Figures 5 and 6 depict the comparison of CGC and LEACH pertaining the number of alive and dead nodes. It is noticeable that CGC demonstrates better performance with higher number of alive nodes or less number of dead nodes compared to LEACH. Detail information on FND and HND are summarize in Table 1. FND values can be further used to analyze network lifetime. It is show from Table 2 that FND occurs at round 103 and 170 for LEACH and CGC respectively. This indicates that CGC outperforms LEACH in terms of

FND with 65% improvement, and the improvement by 52.4% for HND. Since both CGC and LEACH need more than one sensor node to establish a cluster, LND) metric is not necessary.

Residual energy is another indicator to evaluate the performance of WSN. It visualizes overall energy consumption by the network at particular round. Figure 7 shows total residual energy over rounds of CGC compared with LEACH. Overall, CGC achieves higher residual energy than LEACH. In other words, CGC consume less energy than LEACH or more energy efficient.

To see the impact of different number of nodes on CGC and LEACH performance, we conduct simulations with number of nodes, N = 50, 100, 150. The result pertaining the number of dead nodes against rounds is depicted in Figure 8, while Table 3 shows FND and HND of each algorithm.

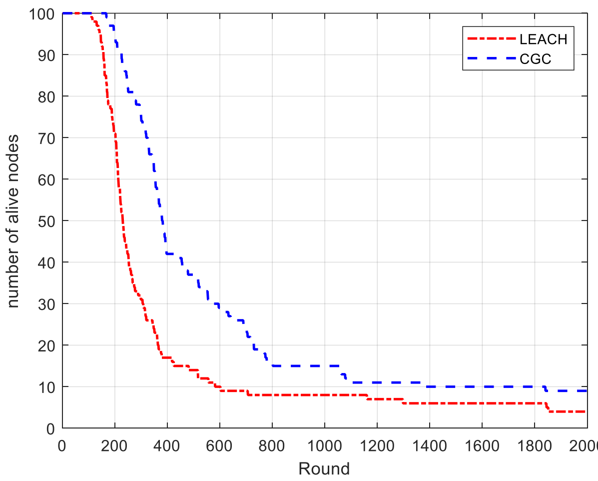


Figure 5. Number of alive nodes vs number of rounds.

TABLE 2. FND, HND

Algorithm	FND	HND
LEACH	103	246
CGC	170	375

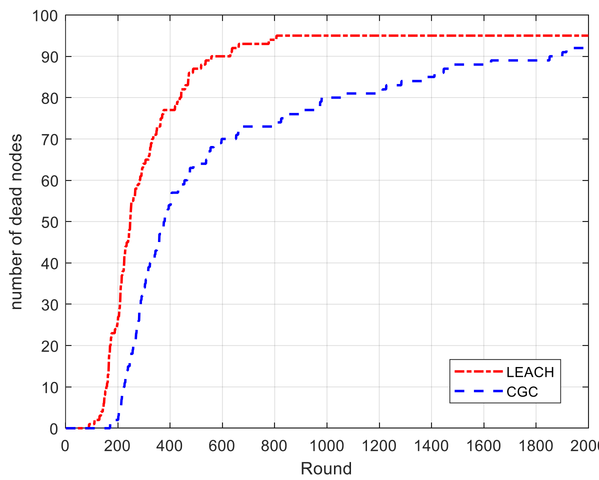


Figure 6. Number of dead nodes vs number of rounds.

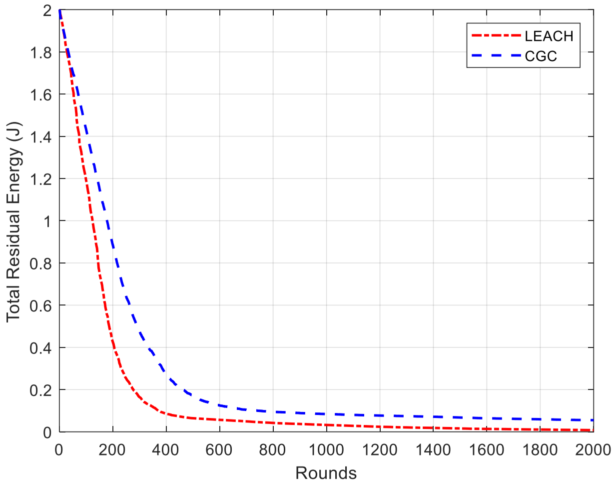


Figure 7. Residual energy over rounds of CGC and LEACH.

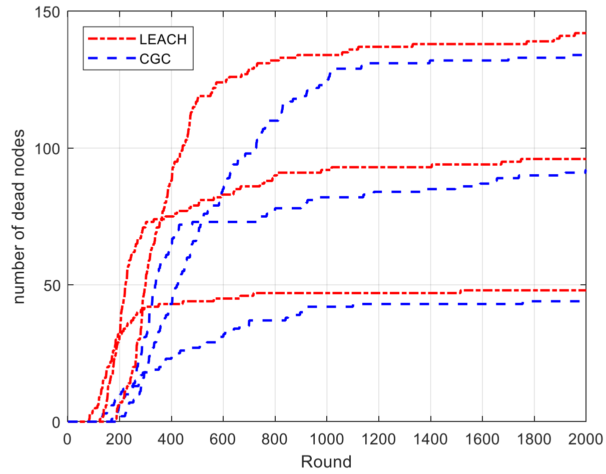


Figure 8. Number of alive nodes vs number of rounds N = 50, 100, 150.

TABLE 3. FND, HND WITH DIFFERENT NUMBER OF NODES (N)

Algorithm	FND			HND		
	N=50	N=100	N=150	N=50	N=100	N=150
LEACH	101	136	170	192	280	394
CGC	170	176	123	394	410	294
(%)	68.3	29.4	-(38.2)	105.2	46.4	-(34)

Overall, LEACH has a higher number of dead nodes compare to CGC. From Table 3, we can derive that as the number of nodes increases, the improvement of node stability in terms of FND decreases. At N=150, LEACH outperforms CGC with the improvement 38.2% of FND and 34% HND. This means that LEACH has a better performance than CGC at a higher number of nodes.

CONCLUSION

An efficient energy clustering is indispensable for prolong the lifetime of wireless sensor networks. In this paper, we conduct simulation on MATLAB to analyze CGC algorithm for node clustering. The performance is compared to a well-known LEACH algorithm. When the number of nodes is less, the simulation results indicate the dominant performance of CGC over LEACH.

However, as the number of node increases, the performance of LEACH is getting better.

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REFERENCES

[1] H. Park, J.H. Eom, T.M. Chung, “Energy-efficient distance based clustering routing scheme for wireless sensor networks,” in *Proc. International Conference on Computational Science and Its Applications*, Aug. 2007, pp. 195-206.

[2] V. Gupta, R. Pandey, “An improved energy aware distributed unequal clustering protocol for heterogeneous wireless sensor networks,” *Engineering Science and Technology, an International Journal*, vol. 19, no. 2, pp. 1050-1058, 2016, doi: https://doi.org/10.1016/j.jestch.2015.12.015.

[3] B. Jan, H. Farman, H. Javed, B. Montrucchio, M. Khan, S. Ali, “Energy efficient hierarchical clustering approaches in wireless sensor networks: A survey,” *Wireless Communications and Mobile Computing*, 2017, doi: https://doi.org/10.1155/2017/6457942.

[4] A. Karmaker, M.S. Alam, M.M. Hasan, A. Craig, “An energy-efficient and balanced clustering approach for improving throughput of wireless sensor networks,” *International Journal of Communication Systems*, vol. 33, no. 3, e4195, 2020, doi: https://doi.org/10.1002/dac.4195.

[5] R. Sinde, F. Begum, K. Njau, S. Kaijage, “Refining network lifetime of wireless sensor network using energy-efficient clustering and DRL-based sleep scheduling,” *Sensors*, 20(5), p. 1540, 2020, doi: https://doi.org/10.3390/s20051540.

[6] W. Akkari, B. Bouhdid, A. Belghith, “LEATCH: Low Energy Adaptive Tier Clustering Hierarchy,” *InANT/SEIT*, Jan. 2015, pp. 365-372, doi: 10.1109/DISTRA.2018.8600921.

[7] W. Abidi, T. Ezzedine, “New approach for selecting cluster head based on LEACH protocol for wireless sensor networks,” in *Proc. International Conference on Evaluation of Novel Approaches to Software Engineering*, vol. 2, 2017, pp. 114-120 .

[8] G.M. Tamilselvan, K. Gandhimathi, “Network coding based energy efficent LEACH protocol for WSN,” Journal of applied research and technology, vol. 17, no. 1, pp. 1-7, 2019.

[9] Y. Yang, C. Lai, L. Wang, X. Wang, “A energy-aware clustering algorithm via game theory for wireless sensor networks,” in *Proc. 12th International Conference on Control, Automation and Systems*, Oct. 2012, pp. 261-266,

[10] A. Attiah, M. Chatterjee, C.C. Zou, “A game theoretic approach for energy-efficient clustering in wireless sensor networks,” in Proc. 2017 IEEE Wireless Communications and Networking Conference (WCNC), Mar. 2017, pp. 1-6, doi: 10.1109/WCNC.2017.7925668.

[11] S. Kassan, J. Gaber, P. Lorenz, “Game theory based distributed clustering approach to maximize wireless sensors network lifetime,” *Journal of Network and Computer Applications*, vol. 123, pp.80-88, 2018, doi: https://doi.org/10.1016/j.jnca.2018.09.004.

[12] H. Jing, H. Aida, “A cooperative game theoretic approach to clustering algorithms for wireless sensor networks,” in *Proc. 2009 IEEE Pacific Rim Conference on Communications, Computers and Signal Processing*, Aug. 2009, pp. 140-145, doi: 10.1109/PACRIM.2009.5291382.

[13] H. Jing, H. Aida, “Cooperative Clustering Algorithms for Wireless Sensor Networks,” in *Smart Wireless Sensor Networks*, H.D. Chinh, Y.K. Tan, Ed., Rijeka, Croatia: InTech, 2010, pp. 157-172.

[14] Z. Beiranvand, A. Patooghy, M. Fazeli, “I-LEACH: an efficient routing algorithm to improve performance & to reduce energy consumption in wireless sensor networks,” in *Proc. The 5th Conference on Information and Knowledge Technology*, 2013, pp. 13-18, doi: 10.1109/IKT.2013.6620030

[15] C. Vimalarani, R. Subramanian, S.N. Sivanandam, “An enhanced PSO-based clustering energy optimization algorithm for wireless sensor network,” *The Scientific World Journal*, 2016, doi: http://dx.doi.org/10.1155/2016/8658760.