NM-LEACH: A Novel Modified LEACH Protocol to Improve Performance in WSN

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Abstract: Saving energy and improving the lifetime of wireless sensor networks (WSNs) has remained as a key research challenge for some time. Low-energy adaptive clustering hierarchy (LEACH), a classical protocol is designed originally for the purpose of reducing and balancing the network's energy consumption. However, as the distances between the cluster head (CH) and the member nodes are not taken into consideration, it results in the uneven distribution of the clusters and uneven consumption of the energy in the network. Choosing the CHs with no distinction is an issue as well. Based on the original algorithm, a novel modified LEACH (NM-LEACH) has been proposed, considering critical problems that exist in the network. NM-LEACH protocol is capable of reasonably solving the number of the CHs in each round and takes the energy as a factor of weight under consideration in selecting the CH. The proposed protocol enhances performance by extending the WSN lifecycle, which results in increasing the balance of the energy consumption in the network, and improving the efficiency of the network.

Keywords: Cluster head selection, energy consumption, LEACH, network life-cycle, number of nodes.

1. Introduction

Wireless Sensor Networks (WSNs) can be described as a distributed sensor network [1] - it is a very influential technology worldwide, in the 21-st century. A typical WSN contains a large number of the sensor nodes and a minimum of one base station (BS) node [2]. Sensor nodes are often tiny in size with drawbacks of a limited carrying energy and hard to be supplemented once more (once deployed) [3]. Energy consumption issue in the WSNs has to be resolved for the purpose of prolonging the network's lifecycle to make it possible to deploy the WSNs in the wider areas. Low-energy adaptive clustering hierarchy (LEACH) protocol is a very early hierarchical protocol of routing [4], where the "*round*" concept is suggested. Each of the rounds includes the cluster establishment process and the phase of stable data transmission [5].

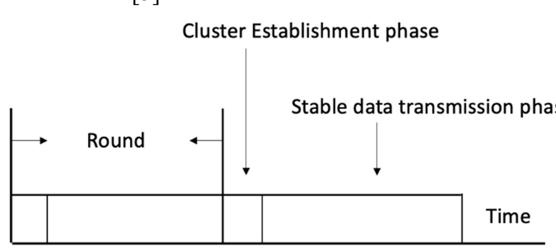


Figure 1. LEACH algorithm running process.

The intent of this proposed protocol in this paper is to reduce and balance the network's energy consumption, as a result, leading to extending the network's service life. The LEACH running process has been illustrated in Figure 1. The steady-state phase is the phase of the announcement packets of CHs (as shown in Figure 2).

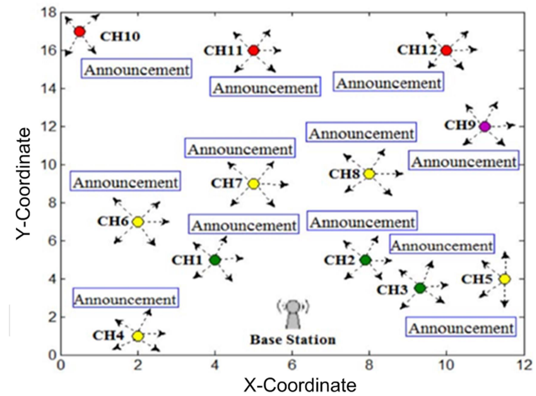


Figure 2. The announcement packets of CHs.

In set up phase, a random number is chosen between 0 to 1 to determine whether or not the node becomes CH. If the number is below the threshold, the node will become CH in this round based on the following equation:

$$T(n) = \frac{probability}{1-probability*(R\bmod p^{-1})}, \quad \forall n \in G \qquad (1)$$

$T(n) = 0, \forall n \notin G$ where G is the set of nodes that were not been CHs in previous iteration.
Another way,

$$T(n) = General\ probability + present\ probability \qquad (2)$$

Present probability can be written as

$$C_P = \left(\frac{C_N}{I_E}\right) * M \qquad (3)$$

where C_N is the current node energy, I_E denotes initial energy, M is the cluster percentage, and K is the number of bits in a transmission. General probability can be given as,

$$General\ probability = \frac{K}{N-K*(r\bmod M)} \qquad (4)$$

If N is the number in the range (0, 1), and P is the probability of CH, then,

$$K = N * P \qquad (5)$$

Therefore, eqn. (2) can be written using eqn. (3-5) as:

$$T(n) = \frac{P}{1-p*(r\bmod(1/p))} + \frac{Cn}{Ie} * M \quad (6)$$

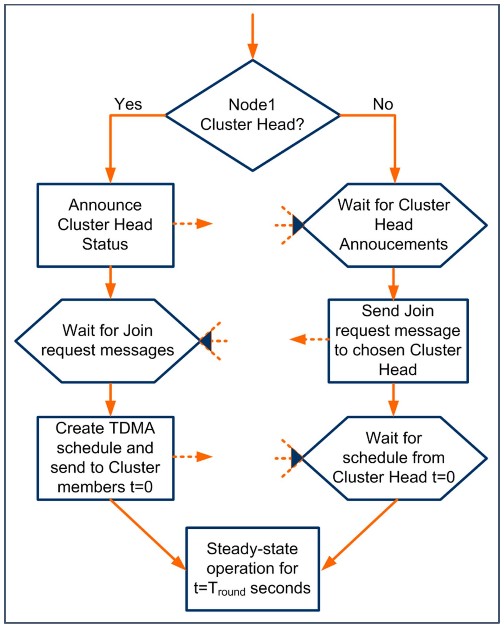


Figure 3. Set-up phase flowchart.

Set-up phase flowchart is presented in Figure 3. The decision is taken by remaining nodes about their CH (cluster head) for the first iteration according to the received signal strength of the announcement message. Time division multiple access (TDMA) is applied on all nodes in the cluster group to transmit messages to the CH, and then to the base station. When the CH is chosen for a region, the steady-state phase period will begin. Based on this setting, in this paper, a novel modified LEACH (NM-LEACH) is proposed. The NM-LEACH protocol is capable of selecting a reasonable amount of CHs in each of the rounds, and it considers energy as a factor of weight when determining the CH. The suggested protocol improves performance by prolonging the WSN lifespan, resulting in a more balanced energy consumption in the network and increased network efficiency.
The rest of the paper has been structured as follows: Section 2 describes related work. Section 3 presents the NM-LEACH protocol. Section 4 provides the simulation results. Section 5 concludes the paper with some future directions for research.

2. Related Work

Following the initial proposal of LEACH, numerous enhanced versions of the algorithm have been suggested. In [6], the authors have proposed the idea of secondary CH, playing the role of CH in the case where the original one fails. This process is similar to LEACH, selecting the CH in the 1st round and selecting a node with higher energy as secondary CH in subsequent rounds for the purpose of ensuring normal transmissions of the messages to the entire cluster in the case where the CH dies.
In [7], the authors presented the proposal of the TL-LEACH as well as its enhanced algorithm. In this algorithm, CH node does not need to be substituted in each round. In case where the CH's energy is higher than the energy of the rest of the cluster nodes, it would keep to be chosen as the CH. As a result, the overhead of the control energy of every round would be considerably reduced. The work in [8] includes an additional enhancement of the LEACH protocol through the use of the cache nodes and choosing of CHs based on the energy and the distance. CH aggregates the data to buffer node having the minimal distance from CH node or minimal time of transmission.
In [9], the authors have enhanced the mode of the data transmission between the CHs and the members in a cluster. In the case where the distance from the node to the CH is lower than the distance between the node and the BS, data transmission is performed based on the LEACH protocol. Nonetheless, in the case where distance between node and CH is larger compared to distance between the node and the BS, the node communicates in a direct way with BS without the need to pass through CH. This approach results in the reduction of energy loss of node and of the CH. In [10], the authors optimized the approach of the selection and the approach of the clustering of the member nodes. However, the relay nodes are added for the purpose of improving data transmission approach, effectively reducing the level of the energy consumption.
The abovementioned methods have reduced the network's consumption of energy and prolonged the life-cycle in various degrees, however, they paid no attention to balanced energy consumption in network. Why is this important? Because, imbalanced energy consumption may cut off or disconnect a portion of the network while some other parts would have relatively higher energy. Also, dying out of nodes (due to exhaustion of energy) in the critical area of deployment can even disconnect a strongly running portion of the network with high average energy. The proposed algorithm in the present study balances the consumption of the energy based on the reduction of energy consumption, as a result, improving the entire network's efficiency (in a balanced way).

3. NM-LEACH Protocol

NM-LEACH can be defined as an enhanced algorithm, which is based on the conventional LEACH considering two aspects. At first, it obtains optimum number of the CHs for the improvement of the efficiency of the network. Second, it considers the energy weight in the case of choosing the CHs. In the present study, the algorithm has been enhanced for the purpose of obtaining the Modified LEACH, which reduces energy consumption for signal transmission and receiving. The formula for the transmission and receiving of data has been analyzed in [11]. The energy is consumed by transceiver electric circuit in the processing of 1 bit of the data which can be noted as,

$$E_{\text{elec}} = \frac{50nj}{bit}$$

(7)

The consumption of the energy for the transmission of 1bit to a unit area is:

$$\varepsilon_{amp} = \frac{100pj}{\frac{bit}{m^2}} \quad (8)$$

The entire energy that has been spent in the transmissions is represented by:

$$T_{ex}(k,d) = E_{elec}k + \varepsilon_{anp}kd^2$$
(9)

where distance is represented by d and signal by k bits. The overall energy that has been consumed in the case of receiving a message can be expressed as:

$$R_{ex} = E_{\text{elec}} \times k$$
(10)

From the eqn. (9) and eqn. (10), it may be observed that the two aspects: the amount of the transmitted data and distance of the transmission, have higher impacts upon the consumption of the energy. Therefore, it is sufficient to improve the algorithm's performance from the perspectives of these two aspects.

3.1 Improving the Number of Cluster Heads (CHs)

In the case where the CH number is very small, distances between the CHs and the member nodes would be increased and the costs of the consumption of energy would be increased as well. In the case where this number is too large, the processing load of the redundant data would be increased, which in turn would reduce of network efficiency. That is why, a reasonable number of CHs may result in ensuring optimal distance from the CHs to their member nodes, thereby, resulting in the improvement of the algorithm's efficiency. With this idea, let us assume that there are N number of the nodes in an area, MxM. The nodes are split into n clusters, with $N/(n-1)$ member nodes (on an average) and 1 CH in every single cluster. The CH's consumption of energy in every frame could be express as [12]:

$$E_{CH} = k \times E_{\text{elec}} \times (N/\text{n} - 1) + EDA \times N/\text{n} + k \times E_{\text{elec}} + k \times \varepsilon_{\text{amp}} \times d^2_{\text{CHtoSink}} \quad (11)$$

where the EDA represents total energy that is needed for the compression and fusion of the data, k represents the amount of the bits that are included in each data transmission, d^2_{CHtoSink} represents distance between CH and BS [13].
The energy that is consumed by every node member in each frame can be written as:

$$E_{men} = k \times E_{elec} + k \times \varepsilon_{amp} \times d^2_{toCH} \quad (12)$$

where d^2_{toCH} represents distance between CH and member node. It can be seen from Eqn. (12) that the node's consumption of the energy is not directly associated with the number of CHs for n. The area of the entire network can be represented by M^2, the area of each cluster can be represented by M^2/n, density of the node (ρ) can be represented by n/M^2 in a cluster, and the mathematical expectations from the member nodes to CH can be written as:

$$E(d^2_{toCH}) = \int x^2 + y^2 \, \rho \text{d}x\text{d}y \quad (13)$$

For the purpose of facilitating the integrations, it is assumed that MxM represents circular area and the clusters are dispersed in an even way. Then, the equation of the radius for every cluster is $r = \sqrt{M^2/n\pi}$, eqn. (13) then can be reduced to:

$$E(d^2_{toCH}) = \int_0^{2\pi} \int_0^{\sqrt{M^2/n\pi}} \rho r^3 dr d\theta \quad (14)$$

and, the formula below may be obtained:

$$E(d^2_{toCH}) = M^2/2\pi n \quad (15)$$

Using eqn. (15) and eqn. (12), the correlation between the consumption of the energy of the member nodes and number of the CHs is calculate as:

$$E_{men} = k \times \varepsilon_{amp} \times M^2/2\pi n + k \times E_{\text{elec}} \quad (16)$$

All the consumption of energy in cluster can be calculated from:

$$E_{\text{all}} = n \times \left[E_{CH} + \left(\frac{N}{n} - 1\right) \times E_{\text{men}}\right] \approx 2kE_{\text{elec}} + nkEDA + nk\varepsilon_{\text{amp}} + Nk\varepsilon_{\text{anp}} M^2/2\pi n + kNEDA \quad (17)$$

and, n's derivative can be calculated as:

$$n = \sqrt{N/2\pi} \times M/d_{\text{CHtosink}} \quad (18)$$

3.2 Improving the Approach of Head Selection

CH selection process in each round can be described as: the node performs the generation of an arbitrary number of 0~1. In the case where the number is lower than the value of the threshold $T(n)$, it turns into a CH, or else it will become a non-CH. The calculation of the threshold $T(n)$ of CH election is as in eqn. 19 [14] :

$$T(n) = \begin{cases} p/1 - p^*[Rmod(1/p)], n \in G \\ 0 \end{cases} \quad (19)$$

R represents the number of the rounds that are in progress currently, G is a group of the nodes that were not chosen as CH in the round R, and p represents the proportion of the CHs to all the other nodes.
The ultimate enhancement of T(n) can be given as,

$$T(n) = \frac{p}{1 - p \times [rmod(1/p)]} \times \frac{E_{\text{keep}}}{E_{\text{ave}}} \times \frac{E_{\text{pre\_consume}}}{E_{\text{consume}}} \quad (20)$$

where E_{keep} represents the energy that a node has prior to the beginning of a following round. E_{consume} represents energy that nodes have consumed in the preceding round. $E_{\text{pre\_consume}}$ represents mean value of the consumption of energy of the final network round. E_{ave} represents the mean value of consumption of energy by the whole network prior to the beginning of the following round. This model makes the factor of energy be the election probability weight factor. The CH selection probability is directly proportionate to energy that is maintained by actual node and inversely proportionate to the value of the energy that has been spent in the preceding round. These measures result in avoiding the early CH death and result in prolonging [15], [16] the network's life-cycle.

4. Simulation Results

In this section, the classical LEACH and NM-LEACH are fundamentally compared based on the entire network's consumption of energy, its lifecycle and proportion of the CHs. We chose the classic version to compare even though it is the first one in this area because showing better performance against the classic algorithm could prove the point of enhancement first and then, other recent works can be compared. Simulation is conducted in MATLAB. The parameters used in simulation are shown in Table 1. The simulation scenario is shown in Figure 4. The network includes 180 nodes, which are distributed in a random manner in a 900x900 m^2 square area.

Table 1. Simulation parameters.

Parameter	Value
Sensing area (W×L)	$900 \times 900\ m^2$
Number of nodes (N)	180
Initial energy of nodes (E0)	2.0 j
Desired percentage of cluster heads	0.18
Position of BS	X = 450, Y = 450
Packet size for cluster head per round	6,400 bits
Max Number of simulated rounds	200
The energy of free space model amplifier	0.3400e−9 j
Energy for transmitting and receiving one bit	50×10 ^ (−9) j
Amount of energy spent by the amplifier to transmit the bits	100×10 ^ (−12) j
Data aggregation energy	5×10 ^ (−9) j

4.1 Comparison Between LEACH and NM-LEACH

The efficiency of the NM-LEACH protocol is evaluated based on the period of network stability, network throughput, and network lifetime and energy dissipation. All nodes simulated were distributed randomly in a 900×900 m^2 area, and the BS resides in the center at the (450, 450) coordinate, as is shown in Figure 4. This simulation was then run for 1,300 rounds to observe the effectiveness of the NM-LEACH protocol.

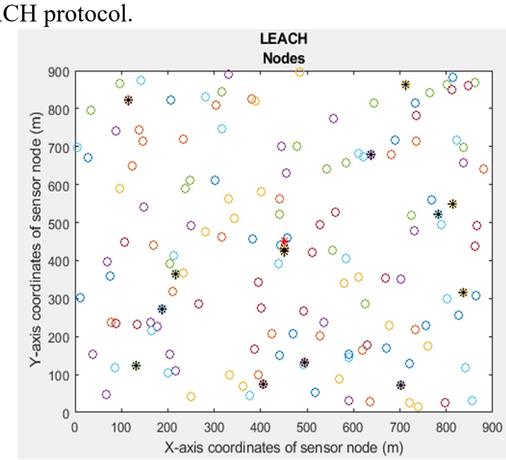


Figure 4. Node distribution in the WSN using the NM-LEACH protocol.

Lifetime of the Network - The network's lifetime represents the interval of time from the start of communication to the sensor node's death. Following 1,090 rounds of the NM-LEACH protocol and 590 rounds of the LEACH protocol, 20 nodes remained alive. This is demonstrated in Figure 5.

Energy - The performance of the WSN improved drastically with the NM-LEACH protocol when compared with the traditional LEACH protocol. The average residual energy was 300 J after completing 290 rounds in the traditional protocol, while it was 300 J in round 530 for the NM-LEACH protocol. This is shown in Figure 6.

Throughput of the Network - The simulation results demonstrated that the proposed NM-LEACH algorithm outperformed the original LEACH protocol concerning the throughput of the network, as is shown in Figure 7. Under the LEACH protocol, the number of packets was 4.2×10^6 in round 1,110. With the NM-LEACH protocol, the number of packets was 9.1×10^6 in the same round.

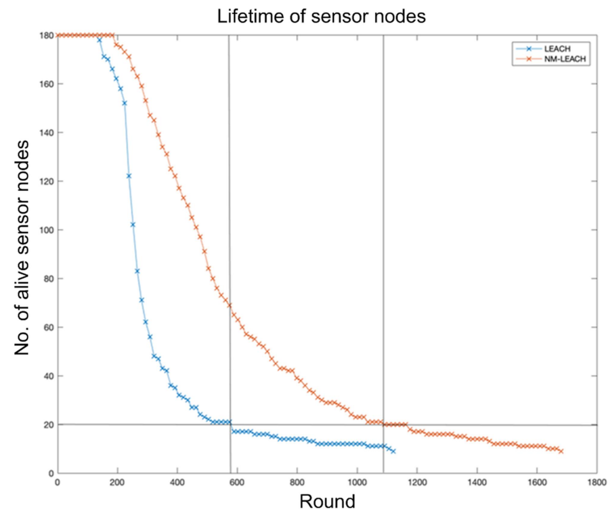


Figure 5. Lifetime of the sensor nodes.

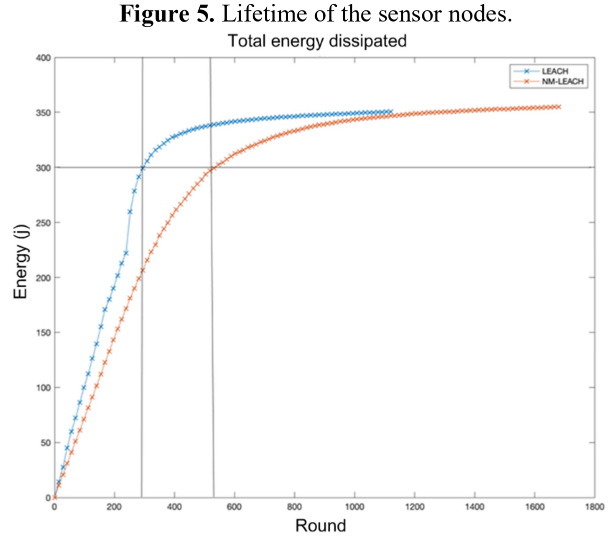


Figure 6. Total energy dissipation.

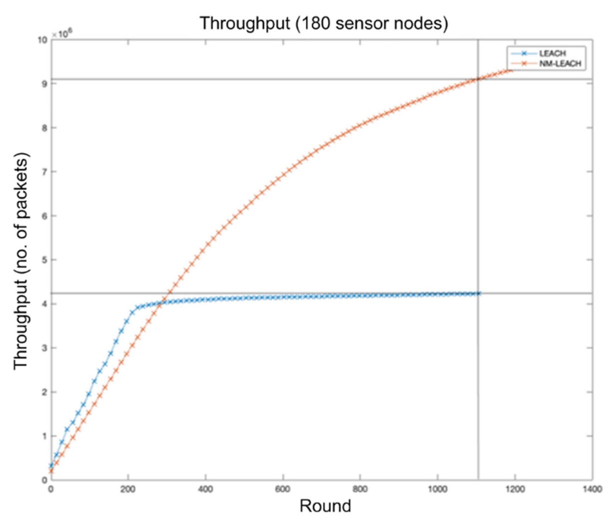


Figure 7. Throughput of the network.

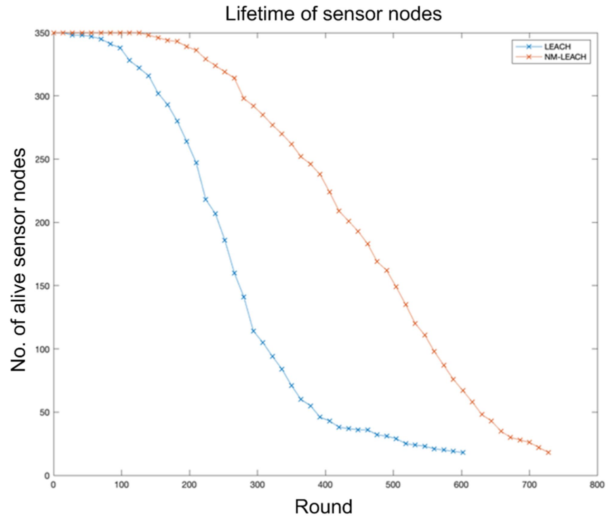
Table 2. Comparison of the five scenarios.

Scenario	Protocol	No of alive nodes	Round	Energy (joule)	Round	No. of packets	Round	Figure
Scenario 1 For 10 CHs	LEACH	250	210	600	260	2.75 x 10^6	400	Figure 8
	NM-LEACH		390		420	3.6 x 10^6		
	LEACH	100	315	400	120	2.80 x 10^6	600	
	NM-LEACH		560		250	4.75 x 10^6		
Scenario 2 For 20 CHs	LEACH	250	370	675	600	6.15x 10^6	750	Figure 9
	NM-LEACH		500		830	7.9 x 10^6		
	LEACH	100	510	500	370	6.1x 10^6	600	
	NM-LEACH		780		440	7.0 x 10^6		
Scenario 3 For 30 CHs	LEACH	150	385	600	385	6.4x 10^6	900	Figure 10
	NM-LEACH		700		700	11.7 x 10^6		
	LEACH	100	400	500	330	6.15 x 10^6	600	
	NM-LEACH		900		510	9.4 x 10^6		
Scenario 4 For 40 CHs	LEACH	90	380	650	450	6.15 x 10^6	1,150	Figure 11
	NM-LEACH		980		1080	15 x 10^6		
	LEACH	50	480	550	290	6.0 x 10^6	600	
	NM-LEACH		1400		600	11 x 10^6		
Scenario 5 For 50 CHs	LEACH	100	310	650	350	7.25x10^6	700	Figure 12
	NM-LEACH		700		900	14 x10^6		
	LEACH	50	420	500	200	7.2 x 10^6	500	
	NM-LEACH		1120		400	12 x 10^6		

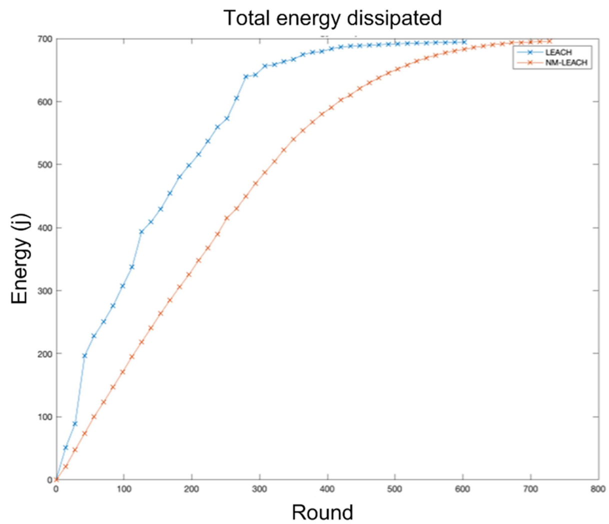
4.2 Correlation Between the Number of CHs and Network Lifetime

Five scenarios demonstrated the superiority of NM- LEACH Protocol compared with the original LEACH protocol. In total, 350 nodes were deployed in the network, under five different scenarios. The first scenario had ten CHs, the second had twenty CHs, the third had thirty CHs, the fourth had forty CHs, and the fifth scenario had fifty CHs. These scenarios are shown in Table 2, along with the comparisons between both protocols based on network lifetime and energy dissipation. When the network size increases, the number of CHs will increase. However, it will be proven that if the network size increases, the performance of the enhanced protocol also increases comparatively, and this means that it can be relied upon for a large network deployment.

energy dissipated, and (c) Throughput.



(a)



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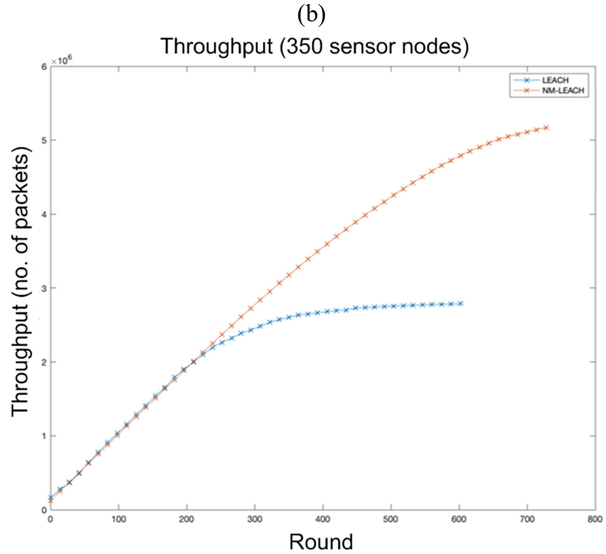
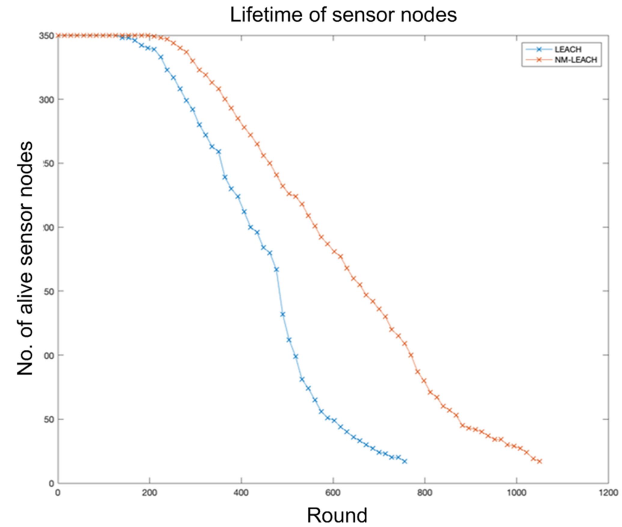
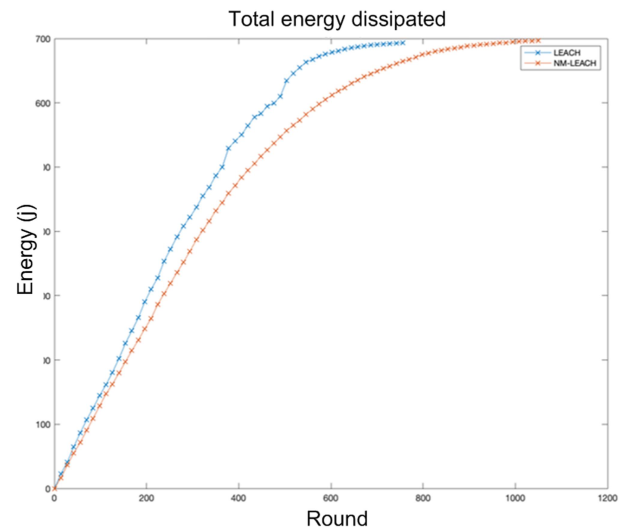


(c)

Figure 8. Scenario 1: (a) Number of alive nodes, (b) Total



(a)



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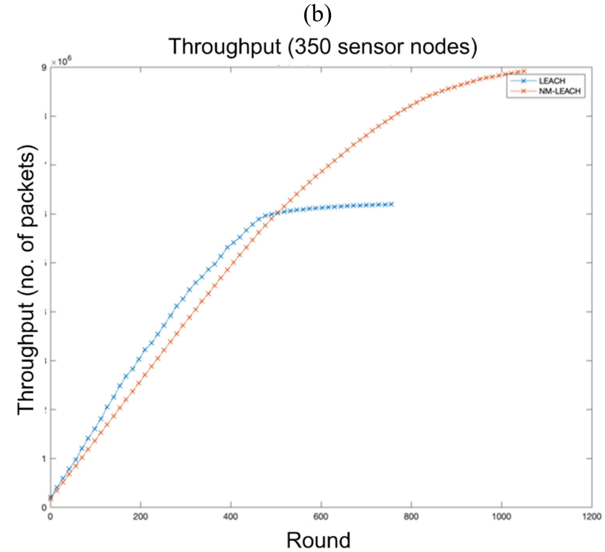
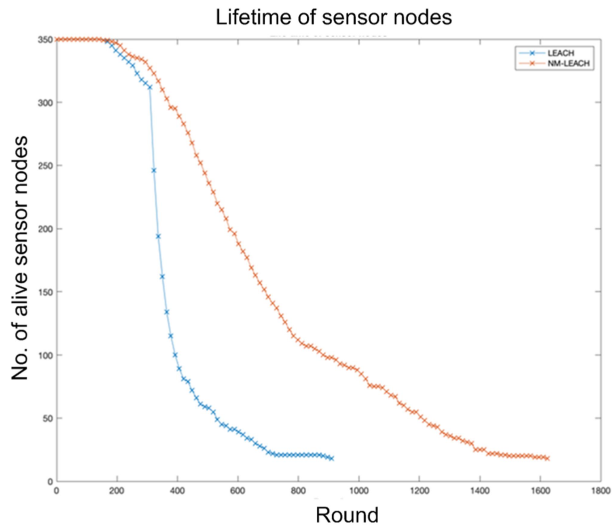


(c)

Figure 9. Scenario 2: (a) Number of alive nodes, (b) Total

energy dissipated, and (c) Throughput



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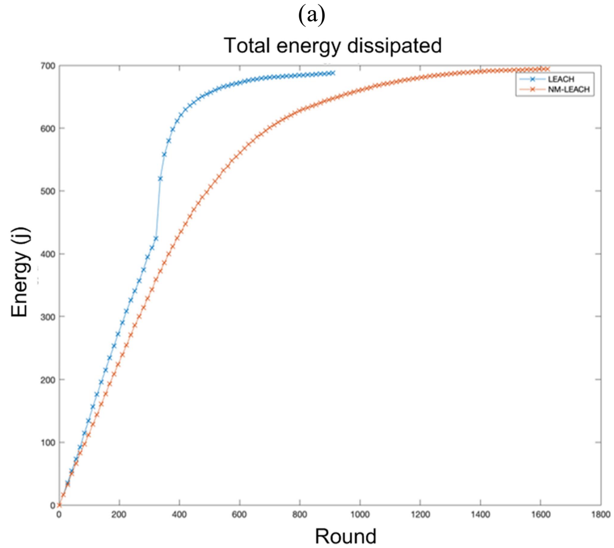

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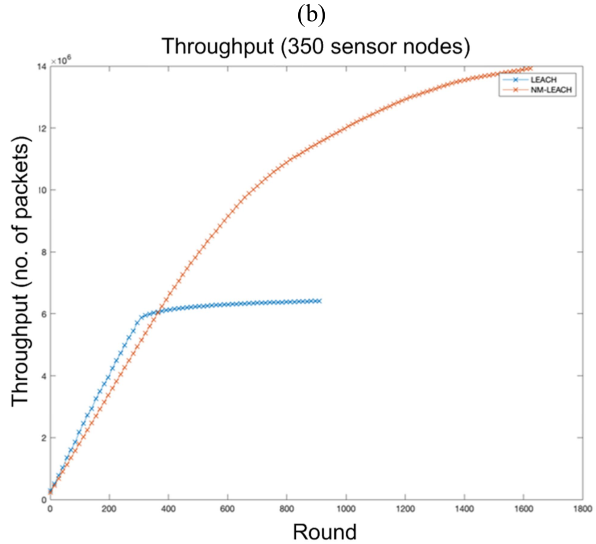
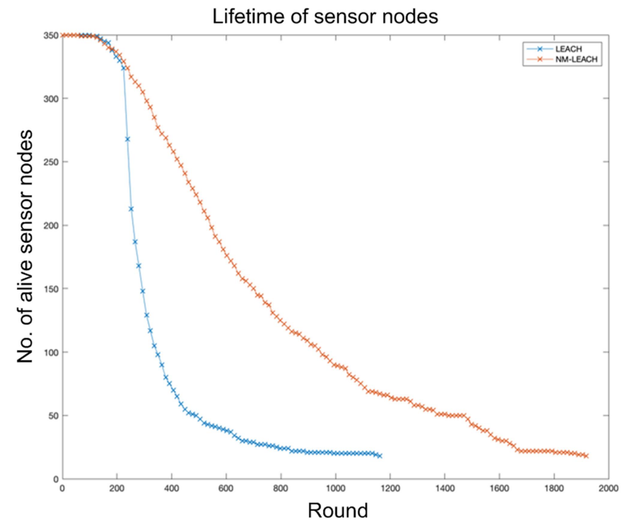


(c)

Figure 10. Scenario 3: (a) Number of alive nodes, (b) Total energy dissipated, and (c) throughput.



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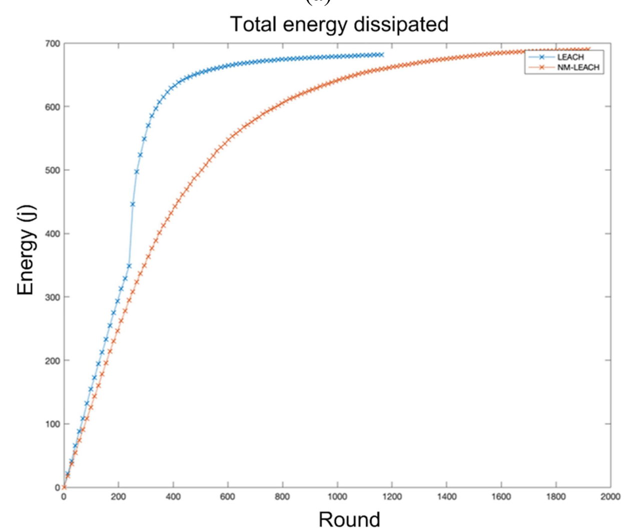

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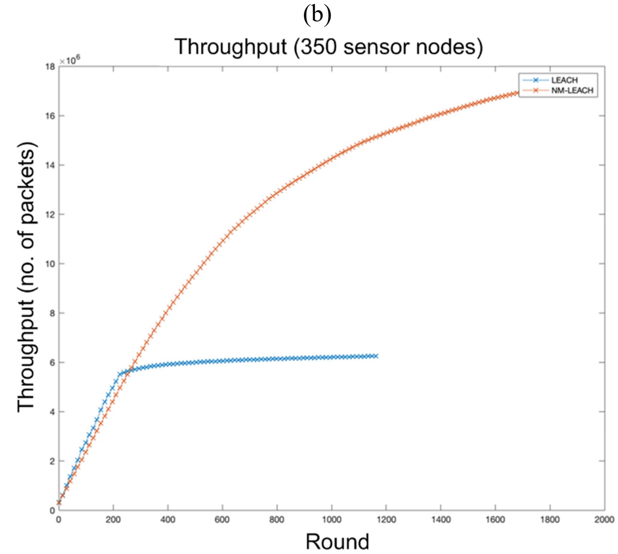
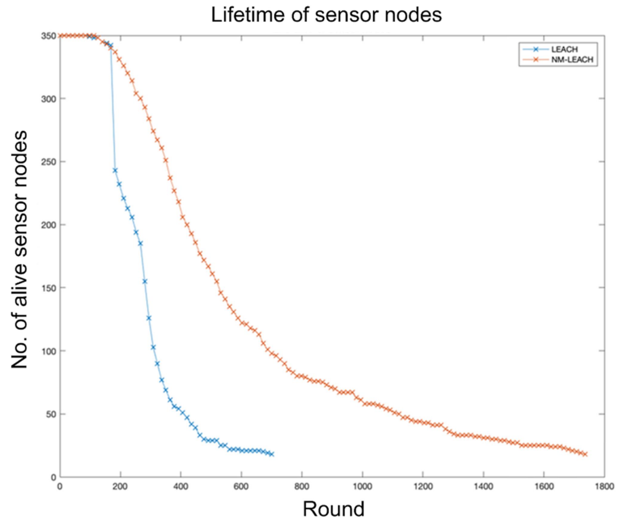
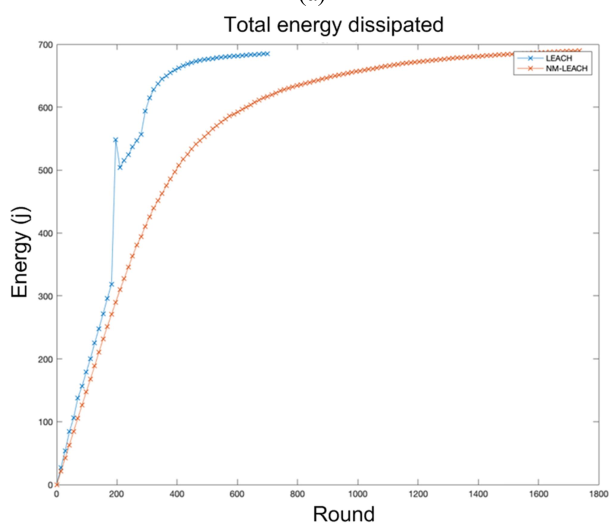


(c)

Figure 11. Scenario 4: (a) Number of alive nodes (b) Total energy dissipated, and (c) Throughput.



(a)



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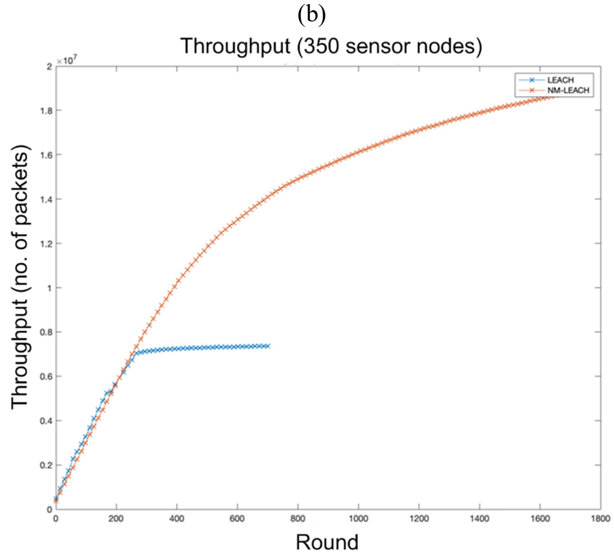

(c)

Figure 12. Scenario 5: (a) number of alive nodes, (b) total energy dissipated, and (c) throughput.

4.3 Performance Comparison of the Algorithms in Densely Deployed Networks

This section discusses a comparison of the performances of the LEACH, TL-LEACH, E-LEACH and NM-LEACH algorithms in dense and sparse networks. In addition, the performances of the protocols in terms of the data that has been received at the BS, the energy dissipated, and the network lifetime are discussed.

All simulations were performed in a 900×900m^2 network with 180 nodes, and the nodes were both uniformly and randomly placed. Figure 13 demonstrates that the NM-LEACH protocol consumes relatively lower energy when compared with the TL-LEACH, E-LEACH and original LEACH protocols. Figure 14 shows an improvement in network throughput with the NM-LEACH protocol when compared with the TL-LEACH, E-LEACH and original LEACH protocols. In Figure 15, the performance of the NM-LEACH protocol in terms of network lifetime and average delay is compared with the TL-LEACH, E-LEACH and original LEACH protocols.

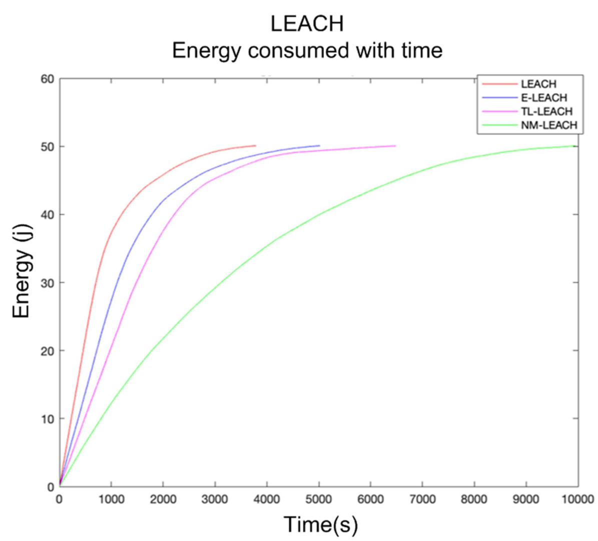

Figure 13. Energy consumption with time.

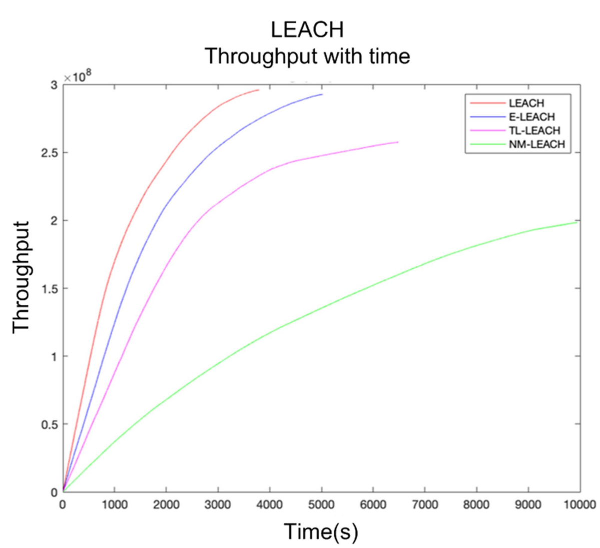

Figure 14. Throughput with time.

4.4 Period of Network Stability

The period of network stability is represented by the First Dead Node (FDN): the number of rounds where the first sensor node's death occurs according to the time(s) [17], [18]. The simulation results demonstrate that the NM-LEACH protocol has higher stability compared to the E-LEACH, TL-LEACH and original LEACH protocols.

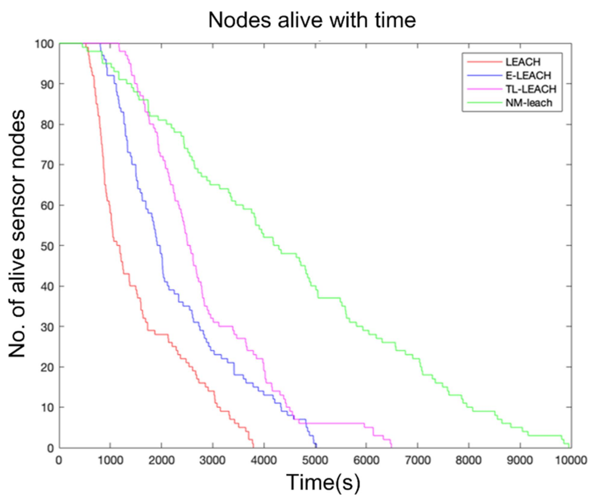

Figure 15. Number of alive nodes with time.

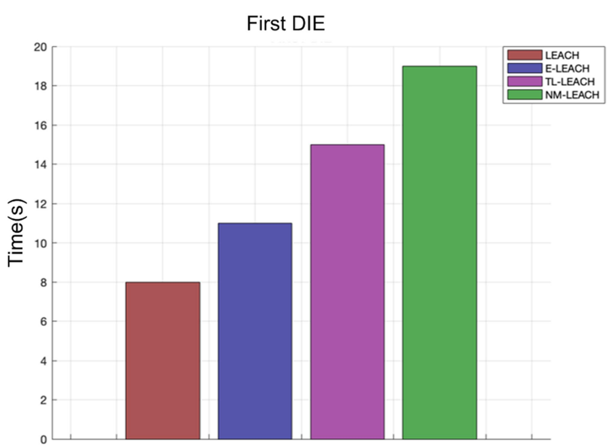

Figure 16. First Dead Node (FDN) with time.

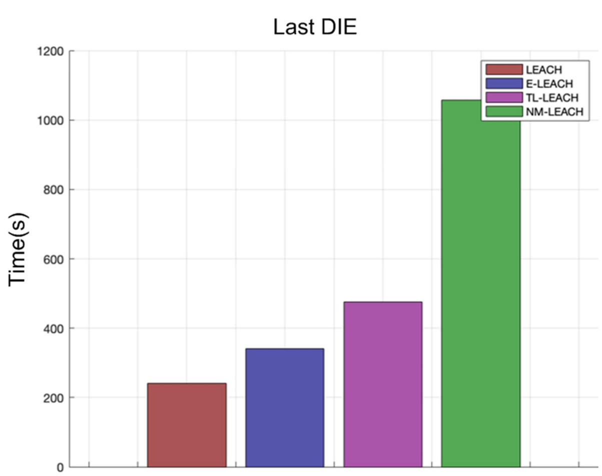

Figure 17. Last dead node with time.

As is shown in Figure 16, after several simulation runs, the FDN appears for the LEACH protocol at 8 second. The FDN for the E-LEACH protocol occurs at 11 seconds, for the TL-LEACH protocol, it occurs at 15 second, and the FDN for the NM-LEACH protocol occurs at 19 seconds.

As clearly could be observed in Figure 17, the last dead node under the original LEACH protocol occurred at 250 seconds. The last dead node under the E-LEACH protocol occurred at 350 seconds and under the TL-LEACH protocol, at 480 seconds. The last dead node [19], [20] with NM- LEACH protocol did not appear until 1060 seconds.

5. Conclusions and Future Work

Improving the lifetime and saving energy of WSNs is a research challenge because the sensors are powered by a tiny, non-replaceable battery. The NM-LEACH routing protocol is proposed in this paper for extending the lifetime of sensor nodes by considering their residual energy and their distance from the BS. Moreover, the NM-LEACH protocol has improved the network's stability. CH selection is an essential subject in cluster formation that influences network lifetime and throughput. The proposed NM-LEACH protocol ensures evenly distributed CH selection across the network. This protocol gives higher chance of becoming Cluster Heads to those nodes that are with relatively higher residual energy and a shorter distance from the BS.

Simulation results demonstrated that the proposed NM-LEACH protocol can overcome the limitations of the original LEACH protocol in terms of network energy, throughput and network lifetime. The NM-LEACH protocol improves energy exhaustion by approximately 49% and productivity by approximately 50% for a setting of 180 nodes. The rationale for main comparison against the classical protocol is to show its efficiency within its mechanism while other results prove its superiority given various scenarios. In the future, more features like security, Quality of Service (QoS), fair scheduling, and other directions can be investigated.

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