New Hierarchical Routing Protocol Based on K-Means Clustering with Exploiting Free Time Slot for Wireless Sensor Networks

Hassan Echoukairi[✉], Abdellah Idrissi, Fouzia Omary
Computer Science Department, Faculty of Sciences,
Mohammed V University, Rabat, Morocco
h.echoukairi@um5r.ac.ma

Abstract—The operation time of LEACH protocol is divided into several frames. Each frame consists of a number of equal time slots where the selection of cluster heads and the re-establishment of clusters are periodic. Each member of the cluster exploits its own time slot to transmit the data, then it turns off its radio to reduce energy consumption. Here, the clusters generated are not uniformly distributed and the time slots of the dead member nodes are not allocated. We propose an improved version, which is based simultaneously on the integration of the clustering approach K-Means and the exploitation of the free time slot in favor of cluster head in the transmission phase. The results show that the proposed protocol allowed us to achieve increased throughput, improved reliability of the packet delivery ratio, low routing load and an effective reduction in energy consumption for low node density in WSNs.

Keywords—wireless sensor networks, hierarchical protocols, LEACH, K-means, clustering, time slot, throughput, NS-2.34

1 Introduction

The Wireless Sensor Networks (WSNs) are widely used in order to collect and monitor information about a phenomenon or event such as ecology and environment (temperature or pressure), agriculture, smart city, medical health and smart traffic system in a geographical area. The WSN consists of a range of sensor nodes, including one or more base stations (BS), as well as a router node. The number of nodes also influences the network's density and traffic. In addition, the area in which the nodes are deployed depends on its shape, the position of the base station and the number of included sensors. In this type of network, data is sent through intermediate nodes in multi-hop communications from source nodes to the BS [1] [2]. Nevertheless, in several communications, the energy of sensor nodes can be more particularly consumed which involves the researchers to suggest clustering solutions. In this context, several types of centralized, distributed or hybrid clustering protocols have been proposed with the aim of generating better clusters and achieving energy efficiency, which leads to an extension of the lifetime network [3] [4] [5] [6]. Due to its flexibility and efficiency,

LEACH (Low Energy Adaptive Clustering Hierarchy) is one of the most widely used routing protocols for clustering wireless networks. The LEACH process is happening in the rounds. Each round is triggered by a set-up stage in which clustering occurs and a steady phase where data transmission happens only during the time slot allocated to each node [7] [8].

Although some works have been done to improve the LEACH protocol [9] [10] [11], there are few studies to examine simultaneously the restatement of unused time slot at each round and the impact of the non-perfect cluster formation during the steady phase on the effectiveness of LEACH protocol. This paper focuses on solving this problem by introducing a new improved protocol based on the K-Means clustering scheme in order to rebuild clusters whose Cluster Heads (CHs) are approximately positioned at the centroid of the members of each cluster and on the assignment the time slots of dead nodes to each CH. As indicated by the simulation results, the new protocol presents better performance than the current LEACH protocol. In terms of throughput, the proposed approach avoids collision problems and reduces network traffic. It also illustrates better packet delivery ratio and energy consumption for low node densities with better overhead routing efficiency.

The rest of this paper is organized as follows: Section 2 covers the overview of clustering-based hierarchical routing protocols, the time slot allocation in LEACH protocol for wireless sensor networks and the problem formulation. Section 3 presents our proposed routing protocol. In section 4, the performance analyzed of the proposed protocol is evaluated through simulations. Lastly, section 5 concludes the paper.

2   Related work

The challenge imposed facing the routing protocols in wireless sensor networks is to find the best technique for communication between nodes that guarantees (ensures) better performances with less energy consumption. To do so, many routing protocols using clustering techniques have been proposed such as: LEACH [7], LEACH-C [8], K-Means [27] [28] [29].

In 2000, Heinzelman et al. [7] proposed a cluster-based routing protocol, called Low-Energy Adaptive Clustering Hierarchy (LEACH) as shown in the Figure 1. LEACH is a hierarchical routing protocol that operates in rounds. Each round is triggered by a set-up phase for clustering and a steady phase for data transmission. During the set-up phase, the clusters are created and the cluster heads (CHs) are selected.

At the beginning, all nodes have the same amount of energy and the same probability of being CH. To do so, each node selects a random number between 0 and 1. If this number is less than the threshold value T(n), the node becomes a CH for current round and broadcasts a message advertising its CH status. The probability of being a CH is given by the following T(n) threshold equation:

$$T(n) = \begin{cases} \dfrac{p}{1 - p * \left(r \bmod \dfrac{1}{p} \right)}; & \text{if } n \in G \\ 0; \text{otherwise} \end{cases} \tag{1}$$

where:

- p denotes the desired percentage of CH in that specific round.
- G is the list of regular nodes that did not become CHs during the previous 1/p rounds
- r is the current round number.

In this step, the time division multiple access (TDMA) schedule is enhanced by better investment of the TDMA time slot. If the sensor node has no data to send, the associated TDMA slot will not be lost but will be allocated to another active node in the current round. After a round, new CHs are randomly chosen on the basis of the nodes that were never selected as CH or so that they have minimum times for becoming a cluster head. Thereafter, the cluster head receives the data from the nodes of the cluster, aggregates and transmits it them to the base station [32].
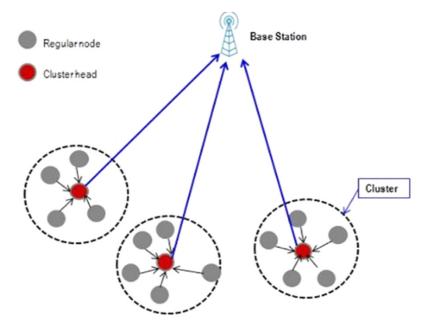

Fig. 1. Architecture of LEACH protocol

However, the distributed clustering algorithm used by LEACH forms adaptive clusters during a given round, which does not guarantee the equitable distribution of CHs in the network.

In order to address the limits of the LEACH protocol, a updated version called LEACH-Centralized (LEACH-C) were proposed in [8]. During LEACH-C's setup phase, this protocol uses the centralized clustering algorithm where the base station collects information about its current location and energy level from each node. The BS determines the cluster heads, constructs the clusters using the simulated annealing algorithm for solving the NP-hard problem which consists in discovering k optimal clusters. Once the CHs and associated clusters are located, the BS sends the cluster

header ID for each node. A node is considered to be a cluster head when the cluster head ID fits its own ID. Otherwise, the node decides its TDMA slot and goes to sleep until the data transmission time is reached. The steady-state LEACH-C process is the same as that of LEACH.

In [14], the Genetic Algorithm based Energy Efficient Clustering Hierarchy (GAECH) has been proposed considering a novel fitness function. It uses different kinds of metrics such as First Node Die (FND), Half Node Die (HND) and Last Node Die (LND) for maximizing the lifetime of the network. In [15], Chamam et al. have proposed a scheduling algorithm to maximize the lifetime of WSN. It determines the optimum coverage of a subset of sensor nodes for each time slot during the operating cycle when only those nodes are enabled and the other nodes are put to sleep. In [16], the authors re-established the node time slots by assigning the free time of the dead nodes to other alive nodes on each round. In the first step, it's attributed to the first node in the list. It will be granted to the last node in the second. It is reserved for a cluster member node in the last step. The main objective is to make the average throughput of data reception more efficient and thus to maximize the lifetime of the network. In [17], the proposed technique scheme dynamically allocates time slots to each node in the Wireless Body Area Networks using fuzzy logic. This assignment uses input parameters such as the remaining node energy, the buffer rate, and the packet arrival rate. The results reveal that this scheme is capable of improving the delivery of packets and reducing end-to-end delays. In [18], the authors have proposed for Wireless Sensor Network a novel centralized clustering approach by combining two clustering algorithms of k-means and LEACH-C protocol in order to create a new cluster scheme and lengthen the lifetime of the sensor network. The parameters have considered are average end-to-end delay, packet delivery ratio, average energy consumption, average throughput and control routing overhead. The results obtained by the approach called LEACH-Ckmeans can effectively and hugely reduce the overhead and give no loss of packets to the destination. The authors of [42] have applied K-Means on LEACH routing protocol before selecting CH and they investigated the effects of this technique on a variety of service quality measures. As a result, they've reduced energy consumption and latency times while improving stability, lifetime of the network and throughput. Bouakkaz et al. have adapted the LEACH protocol in the clustering phase based on the number of clusters and their CHs using the K-Means clustering method in their work [43]. According to simulation results, this decreased power consumption, enhanced network lifetime, and increased node survivability and data transmission to the base station. In [19] [39], the authors have proposed a hybrid clustered routing approach based on k-Means algorithm and LEACH protocol for WSN. A series of simulations using different clusters number were carried out to determine the experimental optimum value of the number of classified clusters capable of providing energy efficiency in the sensor network. The result of their approach minimizes the energy consumption and enhances the network's lifetime of sensor nodes. In [20], the authors have proposed a improved scheme in order to generate an equilibrate energy consumption on the cluster and maximize the network lifetime by using the k-means algorithm. Also, they used the Gauss algorithms to choose the cluster head and Davies Bouldin index (DBI) to find the optimal number of clusters k. The results obtained made it possible to minimize the energy consumption and to reduce the computation time. In another work [21], the authors explore how to extend

the lifetime of WSN and increase its throughput by configuring a fair round time. This work deduced the functions of lifetime and throughput that are correlated with the appropriate number of frames in a LEACH round to extend the lifetime and increase the performance [33]. In [38], the authors have developed a protocol that optimizes the cluster size so that each CH serves approximately the same number of sensor nodes by proposing a new Dynamic Re-clustering. The results reveal that the proposed protocol extends the lifetime of the network while reducing overall energy consumption. Much research carried out in this study has motivated the researchers to propose various protocols linked to the clustering technique in order to collect a maximum of data with the least amount of energy and to exploit the time slot of nodes to maximize the lifetime of the network [36] [37]. In [41], others authors have developed an efficient protocol that includes grid-based mobile communication network formation to select the shortest route from source node to target node for data transmission.

In addition, we notice that the clusters produced by LEACH are unequal and the CH is not located at the center of the member nodes of the cluster. These clusters increase the distance of transmission between the sensor nodes and the CH. This means that more energy is consumed in intra-cluster communications. To address the issue of the non-perfect cluster formation, the CHs must be chosen nearer to the centroid cluster [30] [31] [33] [40].

In this context, it is clear that the k-means clustering technique appears to be the best approach optimizing the intra-cluster distance, producing balanced clusters and maximizing the lifetime of the entire WSN network.

On the one hand, in LEACH protocol, where the time is splitted into several rounds, the election of CHs and the re-establishment of clusters are periodic according to each round time. However, when transmitting data, some regular cluster nodes do not have the data they want to send or have died or are out of the coverage zone.

In addition, when the CH is dead, the collected data can no longer reach the BS. This induces an overload of the network with unnecessary traffic from member nodes, an excess consumption of energy that will not be exploited and loss of useful data due to the fact that the CH did not fulfill its role. As a consequence, the TDMA slot reserved for the dead nodes remains free throughout each round and not used which we can otherwise invest in its slot time.

To overcome all those problems, we have exploited this free time by allocating it to the special node CH under the effect of having a better optimization of the intra-clusters using the k-means clustering approach.

3 Proposed method: Leach protocol based on the K-means with investment of the free time slot

After integrating the centralized K-means clustering on LEACH Centralized protocol in [18], we present in this work our improved LEACH-KMEANS-FreeSlot contribution which is building jointly on LEACH protocol and K-means clustering with the best exploit of the free time slot relating to dead nodes in the network. In low-density network, the proposed protocol is proved to be more efficient than the existing protocol in terms of PDR, Average throughput, Normalized Routing Load (NRL), and energy consumption.

Thus, the associated algorithm is composed of many steps:

1. First, K initial centers are chosen arbitrarily. In LEACH, the optimal value of K is recommended to be 5% of nodes in the network [7] [8].
2. Calculate the Euclidean distance between every sensor node and the centers and attach them to the nearest centroids in order to form a cluster. Where the Euclidean distance can be calculated by the following equation:

$$d_{ij} = \sum_{j=1}^{K} \sum_{i=1}^{N} \sqrt{(x_j - x_i)^2 + (y_j - y_i)^2} \qquad (2)$$

d_{ij}: denote the Euclidean distance between sensor node S_i and the cluster center S_j
S_i: denote any sensor node in the cluster and (x_i, y_i) its coordinates.
S_j: denote the cluster center and (x_j, y_j) its coordinates

3. When all nodes have been assigned, recalculate the positions of centroid in each cluster.
4. Repeat Steps 2 and 3 until convergence. The convergence is obtained when there is no node that changes its cluster in successive iterations.
5. Second, the LEACH protocol is used to select the CH and its members in each cluster.

In setup phase:

6. The closest node to the cluster centroid which has more energy is selected as the cluster head with a certain probability determined according to the threshold T(n).
7. The elected CHs broadcast advertisement message that contains its identification number (ID) and advertisement to join the cluster (join ADV)
8. Each regular node listens to the advertising messages, chooses its CH with the strongest signal and informs the selected CH that becomes a member of its cluster with "join req" that contains its identifier (ID) using CSMA (Carrier Sense Multiple Access).
9. Each CH creates and communicates a TDMA (Time Division Multiple Access) slots for each node in the cluster to send the sensed data. The technique used here also allows the division of communication time into frames.

In steady phase:

10. Each regular node collects and transmits the sensed data to the CH in its own TDMA time slot.
11. After that, it turns off its contact interface outside the reserved slot time to save more energy.
12. In this step, when the sensor node is dead, its time interval is reserved for another node playing the role of CH. This adjusts the time slot synchronization between the nodes and provides more energy to CH.
13. Finally, each CH receives data from the nodes of the cluster, aggregates them, and transmits them to the base station.

In order to explain the relationship between the lifetime of the network and the time slot of the frame, the LEACH energy dissipation model [7] [8] [21] has been determined as follows:

$$E_{TX(L,d)} = \begin{cases} L \cdot E_{elec} + \epsilon_{fs} \cdot d^2, d < d_0 \\ L \cdot E_{elec} + \epsilon_{mp} \cdot d^4, d \geq d_0 \end{cases} \qquad (3)$$

$E_{TX(L,d)}$: Energy expended over a distance d for transmitting a L bit message.
E_{elec}: Electrical energy of the transmitter or receiver.

$\epsilon_{fs}, \epsilon_{mp}$: Energy expended on a crossover amplifier over a distance d_0, which $d_0 = \sqrt{\dfrac{\epsilon_{fs}}{\epsilon_{mp}}}$

By equation, the energy expended to obtain an L bit message is given (4):

$$E_{RX(L,d)} = L \times E_{elec} \qquad (4)$$

Here, we point out that this model takes into account three forms of energy during its operation which are: acquisition energy, communication energy, and processing energy. Nevertheless, the energy dissipation in the set-up phase is ignored because the number of CHs (k = 5) is chosen according to the same network configuration deployed in LEACH which proved optimal performance [8].

To better describe the energy dissipation and the division of the timeline during the steady phase, it is noted that the data transmission works in several frames (m) according to the following Figure 2.
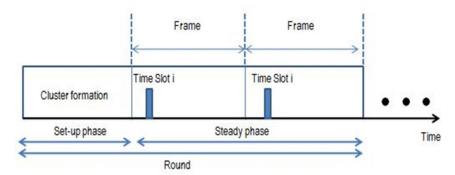

Fig. 2. Timeline of LEACH operation for steady phase (Heinzelman et al. [7])

In each frame, the energy dissipation of a cluster head and member sensor node is formulated as follows [8] [9] [21].

$$E_{Cluster-Steady\ phase} = E_{Cluster\ Head-Steady\ phase} + E_{Sensor\ member-Steady\ phase} \qquad (5)$$

where:

$E_{\text{Cluster−Steady phase}}$: is the energy dissipation of a cluster in steady phase of a round

$E_{\text{Cluster Head−Steady phase}}$: is the energy dissipation of a cluster head in a single frame.

$$E_{\text{Cluster Head−Steady phase}} = \left(\frac{N}{k}-1\right) \cdot L \cdot E_{elec} + \left(\frac{N}{k}-1\right) \cdot L \cdot E_{DA} \tag{6}$$
$$+ L \cdot E_{elec} + \in_{mp} \cdot d^4_{CH-BS}$$

with:

– N: represents the number of sensor nodes distributed in M×M area which includes k clusters

– $\frac{N}{k}$: is the average of sensor nodes in each cluster that includes one cluster head and $\left(\frac{N}{k}-1\right)$ member nodes.

– E_{elec}: is fixed to 50 *nJ/bit* $\tag{7}$

– E_{DA}: indicates the energy consumption for data aggregation, it is set to 5 nJ/bit/ signal.

– $\in_{mp}$: is fixed to 0.0013 *pJ/bit/m⁴* $\tag{8}$

– d_{CH-BS}: indicates the distance from CH to base station

– L: is the length of data message in bits over the distance d.

$E_{\text{Sensor member−Steady phase}}$: is the energy dissipation of a sensor member in a single frame.

$$E_{\text{Sensor member−Steady phase}} = L \cdot E_{elec} + \in_{fs} \cdot d^2_{Sensor\ member-CH}$$
$$= L \cdot E_{elec} + \in_{fs} \cdot \frac{1}{2\pi} \cdot \frac{M^2}{k} \tag{9}$$

with:

– $\in_{fs}$: is fixed to 10 *pJ/bit/m²* $\tag{10}$

– $d_{\text{Sensor member−CH}} = \frac{M}{\sqrt{2\pi k}}$ $\tag{11}$

$d_{\text{Sensor member–CH}}$: is the average distance between member sensors in a cluster and the cluster head. To simplify the study, we assume that the cluster area is a circle.

Therefore, the energy dissipation of a cluster head and member sensor node in steady phase for m frames is:

$$E_{\text{Cluster}-\text{Steady phase}} = m \cdot \left[E_{\text{Cluster head}-\text{Steady phase}} + \left(\frac{N}{k} - 1 \right) E_{\text{Sensor menber}-\text{Steady phase}} \right]$$

$$= m \left[\left(\frac{N}{k} - 1 \right) \cdot L \cdot E_{elec} + \left(\frac{N}{k} - 1 \right) \cdot L \cdot E_{DA} + L \cdot E_{elec} + \in_{mp} \cdot d_{CH-BS}^{4} \right]$$

$$+ m \cdot \left(\frac{N}{k} - 1 \right) \left[L \cdot E_{elec} + \in_{fs} \cdot \frac{1}{2\pi} \cdot \frac{M^2}{k} \right] \tag{12}$$

According to this equation (12) and [9], we can conclude that energy dissipation in the steady phase of a round is influenced by the time when the first sensor node dies and the time length of the number frames spread over each round.

4 Simulation and configuration

In this implementation, we use NS2 (Network Simulator, version 2) to simulate the wireless network environment, it is a discrete event network simulator developed by UC Berkeley. NS-2 is Open Source; it provides many versions [22] [23] [24] [25]. Here we choose 2.34 as the version, under the OS Ubuntu, to implement our approach called LEACH-KMEANS-FreeSlot. The main objective is to enhance the existing protocol LEACH in terms of PDR, throughput, overhead, and energy consumption for wireless sensor networks. With initial energy of 2 Joule, all the nodes used in this setting are homogeneous and distributed randomly. The number of nodes used for this network ranges from 25 to 125.

Table 1 displays the rest of the parameters used in this simulation to evaluate the performance of the routing protocols. The tool AWK scripts is used to calculate the performance metrics and analyze the Trace files. Finally, the obtained results are illustrated in figures using the Gnuplot.

Table 1. Summary of simulation parameters [22], [24]

Parameter	Value
Channel type	Channel/Wireless Channel
Radio-propagation model	Propagation/Two Ray Ground
Number of nodes	25, 50, 75, 100, 125
Simulation time	3600 s
Routing protocol	LEACH, LEACH-KMEANS-FreeSlot
Topology size	100 × 100 meters
Base Station Position	(50,175)
MAC Type	802.11
Link Layer Type	LL
Interface Type	Queue
Meta size in packet.h	5000 MB
Traffic Type	CBR

To validate our simulations, we estimated an average of 10 runs for each various test with different control parameters. In this simulation, the proposed LEACH-KMEANS-FreeSlot protocol is compared to the current LEACH protocol in terms of Packet Delivery Ratio (PDR), Average Throughput, Normalized Load Routing and Energy Consumption. The simulation metrics used allow to determine network performance needs that require upgrading for better performance. The protocol is said to be effective if it is capable of transmitting data with higher packet delivery rate, high throughput, low routing load and low energy consumption.

5 Results and analysis

In order to assess the efficiency and performance of the proposed system, we focus on the following performance metrics described as follows [34] [35]:

5.1 Average throughput

This metric is obtained by measuring the average of the successful delivery of data packets within a unit of time. The traffic corresponding to this metric can be injected from any of the source nodes into the network with the same quantity. Furthermore, the queue size at any node of the sensor is limited. The high value of this metric implies that there is a stronger network of WSN [26] [27].

Figure 3 shows the average throughput analysis of the proposed LEACH-KMEANS-FreeSlot with LEACH Protocol. The results show that the proposed protocol can successfully deliver data packets to BS from the sources rather than the current protocol. This can be clear because our proposed system prevents the collision problem and reduces network traffic. Therefore, the objective of LEACH-KMEANS-FreeSlot protocol is achieved.
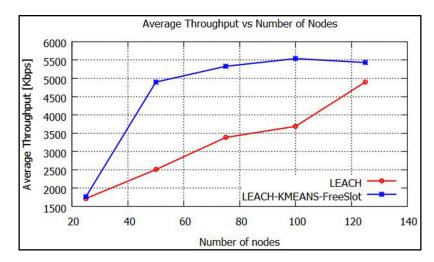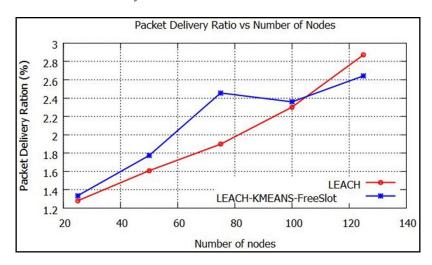

Fig. 3. Average throughput vs number of nodes

5.2   Packet Delivery Ratio (PDR)

This metric reflects the total number of packets received over the total number of packets generated on the network that reaches the base station. The higher the value of this metric is, the better performance and the reliability of the protocol is [26] [27].

Figure 4 provides an overview of the Packet Delivery Ratio of the proposed LEACH-KMEANS-FreeSlot with the existing LEACH protocol over various node numbers. As shown in Figure 4 and compared to the LEACH protocol, the proposed system's PDR value increases to a certain level (100 nodes) with increasing node density and then starts to decrease again. It can be clearly seen that with a lower node density, LEACH-KMEANS-FreeSlot records more PDRs than the LEACH protocol.

Therefore, it shows from the results that our proposed protocol exhibits better performance with lower density.

Fig. 4. Packet delivery ratio vs number of nodes

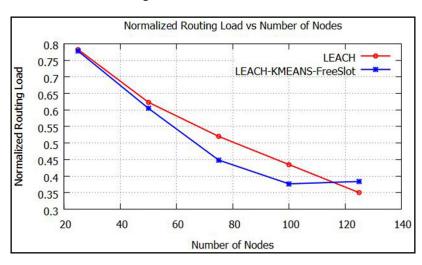## 5.3   Normalized Routing Load (NRL)

This metric is determined by measuring the number of routing packets transmitted per number of data packets received [27]. It is given by the formula:

NRL = Number of routing packets sent/Number of data packets received

When the routing load is higher, the network is overloaded with routing packets. This leads to the wireless sensors consuming excessive energy.

However, wireless sensor nodes are based on a small power source. A low routing load is therefore desirable in a wireless network, which contributes to improving the efficiency of the protocol.

Based on Figure 5, it is observed that the normalized routing load for the proposed protocol decreases as the number of nodes increases and produces low results compared to LEACH.

Therefore, we can conclude that LEACH-KMEANS-FreeSlot has better performance in the context of routing overhead because it has a lower NRL.

Fig. 5. Normalized routing load vs number of nodes

5.4 Energy consumption

The energy consumption remains a critical issue for wireless sensor networks.

Less energy consumption means that the related protocol is effective and therefore the WSN lifetime is longer. In this work, the two LEACH-KMEANS-FreeSlot and LEACH protocols are evaluated in terms of energy consumption for different nodes.

Figures: Figure 6 (a, b, c) shows the energy consumed for the number of nodes 25, 50, and 100 by the two protocols in a round. The first graph (Figure 6a) shows that during the simulation, the proposed LEACH-KMEANS-FreeSlot consumes less energy than LEACH for 25 nodes. In Figure 6b and for 50 nodes, the energy consumed by the LEACH-KMEANS-FreeSlot protocol is much lower than that of the LEACH until it almost exceeds 125 seconds. However, the energy expended increases throughout the remainder of the simulation for the LEACH protocol.

It is noted that for high density (Figure 6c) the LEACH-KMEANS-FreeSlot combined with free slot time reserved to CH and the LEACH protocol are evaluated at the same rate until almost time 200. After that, the proposed protocol diverges from the classic protocol. Because it's time for the nodes to begin depleting their resources, which produces the free time slots that will be reused by other nodes in the new LEACH. However, this is due to the traffic added by CH as soon as the node died as well as that of the kmeans re-clustering during the recreation of the clusters for the proposed protocol.

Therefore, we can conclude that the proposed protocol records better performance in the context of energy consumption than the existing LEACH for low density wireless sensor networks.
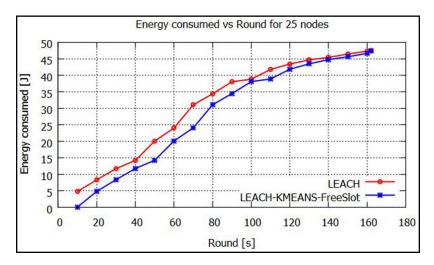
Fig. 6a. The energy consumption compared with the round for 25 nodes
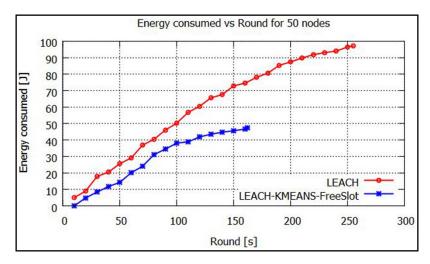

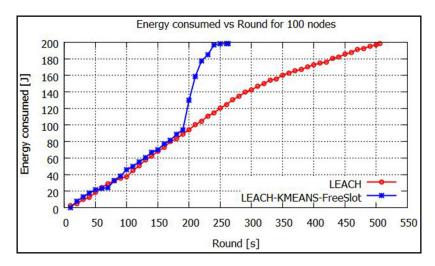**Fig. 6b.** The energy consumption compared with the round for 50 nodes

Fig. 6c. The energy consumption compared with the round for 100 nodes

6   Conclusion

In this paper, we presented an overview of related hierarchical protocols based on LEACH for wireless sensor networks and we try to demonstrate the influence of the time length of round on the energy dissipation in the network. Also, we proposed a novel improved clustering approach based on k-means with restatement of the time slots in order to generate equilibrated clusters and to allocate the time slot of dead nodes to the cluster heads. In addition, this work provided evaluation and comparisons between LEACH and the proposed protocol under varying density through the simulation NS2 platform. Experimental results reported that the proposed approach increases the throughput, improves the efficiency of PDR, reduces the routing load, and minimizes the energy consumption for low node density in WSNs. However, judging from the energy consumption at the high node density, it is completely consumed after 200 rounds of time, which is not ideal and severely limiting the application's scope. Future research will focus on overcoming the constraints of this approach and attempting to validate it in a real context.

7   References

[1] D. Miorandi, S. Sicari, F. D. Pellegrini, and I. Chlamtac. "Internet of Things: Vision, Applications and Research Challenges". In: Ad Hoc Networks, vol. 10, no. 7, (2012), pp. 1497–1516. ISSN: 1570–8705. https://doi.org/10.1016/j.adhoc.2012.02.016

[2] V. Çağrı Güngör and P. Gerhard. Hancke, "Industrial Wireless Sensor Networks: Applications, Protocols, and Standards", CRC Press, vol. 83, (2013), pp. 1027–40.

[3] A. Navarra, C. M. Pinotti, and A. Formisano. "Distributed Colorings for Collision-Free Routing in Sink-Centric Sensor Networks". In: J. Discrete Algorithms, vol. 14, (2012), pp. 232–247. https://doi.org/10.1016/j.jda.2011.12.007

[4] Ameer Ahmed Abbasi, Mohamed Younis, "A Survey on Clustering Algorithms for Wireless Sensor Networks", Computer Communications Journal (Elsevier), 2007, pp. 2826–2841. https://doi.org/10.1016/j.comcom.2007.05.024

[5] K. Akkaya and M. Younis, "A Survey on Routing Protocols for Wireless Sensor Networks", Ad Hoc Networks, vol. 3, no. 3, (2005), pp. 325–349. https://doi.org/10.1016/j.adhoc.2003.09.010

[6] A. Sarkar and T. S. Murugan. "Routing Protocols for Wireless Sensor Networks: What the Literature Says?" In: Alexandria Engineering Journal, vol. 55, no. 4, (2016), pp. 3173–3183. https://doi.org/10.1016/j.aej.2016.08.003

[7] W. Heinzelman, A. Chandrakasan, and H. Balakrishnan. "Energy-Efficient Communication Protocol for Wireless Microsensor Networks". 2000.

[8] W. B. Heinzelman, A. P. Chandrakasan, and H. Balakrishnan, "An Application-Specific Protocol Architecture for Wireless Microsensor Networks," in IEEE Transactions on Wireless Communications, vol. 1, no. 4, (2002), pp. 660–670. https://doi.org/10.1109/TWC.2002.804190

[9] Yun Li, Nan Yu, Weiyi Zhang, Weiliang Zhao, Xiaohu You and M. Daneshmand, "Enhancing the Performance of LEACH Protocol in Wireless Sensor Networks," 2011 IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS), Shanghai, 2011, pp. 223–228. https://doi.org/10.1109/INFCOMW.2011.5928813

[10] J. Hu, Y. Jin, and L. Dou, "A Time-based Cluster-Head Journal of Sensors for LEACH," IEEE Symposium on Computers and Communications, 2008, pp. 1172–1176.

[11] H. Yang and B. Sikdar, "Optimal Cluster Head Selection in the LEACH Architecture", IEEE International Conference on Performance, Computing, and Communications, 2007, pp. 93–100. https://doi.org/10.1109/PCCC.2007.358883

[12] Chinchu T. Sony, C. P. Sangeetha, and C. D. Suriyakala. "Multi-hop LEACH Protocol with Modified Cluster Head Selection and TDMA Schedule for Wireless Sensor Networks." 2015 Global Conference on Communication Technologies (GCCT). IEEE, 2015. https://doi.org/10.1109/GCCT.2015.7342720

[13] N. Qubbaj, A. A. Taleb, and W. Salameh, "Review on LEACH Protocol," 2020 11th International Conference on Information and Communication Systems (ICICS), Irbid, Jordan, 2020, pp. 414–419. https://doi.org/10.1109/ICICS49469.2020.239516

[14] B. Baranidharan, B. Santhi, "GAECH: Genetic Algorithm Based Energy Efficient Clustering Hierarchy in Wireless Sensor Networks", Journal of Sensors, vol. 2015, Article ID 715740, 8 pages, 2015. https://doi.org/10.1155/2015/715740

[15] A. Chamam and S. Pierre, "Energy-Efficient State Scheduling for Maximizing Sensor Network Lifetime under Coverage Constraint", Wireless and Mobile Computing, Networking and Communications, 2007, pp. 63–63. https://doi.org/10.1109/WIMOB.2007.4390857

[16] Abedelhalim HNINI, Abdellah EZZATI, Mohammed FIHRI and Abdelmajid HAJAMI, "Time Slots Investment of a Dead Node in LEACH Protocol on Wireless Sensor Network" International Journal of Advanced Computer Science and Applications (IJACSA), Special Issue on Advances in Vehicular Ad Hoc Networking and Applications 2014, 2014. https://doi.org/10.14569/SpecialIssue.2014.040202

[17] S. Pushpan and B. Velusamy, Fuzzy-Based Dynamic Time Slot Allocation for Wireless Body Area Networks. Sensors, vol. 19, no. 9, (2019), p. 2112. https://doi.org/10.3390/s19092112

[18] H. Echoukairi, A. Kada, K. Bouragba, M. Ouzzif. A Novel Centralized Clustering Approach Based on K-Means Algorithm for Wireless Sensor Network. In Computing Conference 2017 (pp. 1259–1262). IEEE. https://doi.org/10.1109/SAI.2017.8252252

[19] A. Mahboub, M. Arioua and E. M. En-Naimi, "Energy-Efficient Hybrid K-Means Algorithm for Clustered Wireless Sensor Networks", International Journal of Electrical and Computer Engineering (IJECE), vol. 7, no. 4, (2017), pp. 2054–2060. https://doi.org/10.11591/ijece.v7i4.pp2054-2060

[20] R. ELkamel and A. Cherif, "Energy-Efficient Routing Protocol to Improve Energy Consumption in Wireless Sensors Networks," Int. J. Commun. Syst., vol. 30, no. 17, 2017, p. e3360. https://doi.org/10.1002/dac.3360

[21] Z. Zhang and X. Zhang, "Research of Improved Clustering Routing Algorithm Based on Load Balance in Wireless Sensor Networks", IET International Communication Conference on Wireless Mobile and Computing, 2009, pp. 661–664.

[22] The Network Simulator-ns2-Available from: http://www.isi.edu/nsnam/ns (Accessed on Nov 28, 2020).

[23] A. Nayyar and R. Singh. A Comprehensive Review of Simulation Tools for Wireless Sensor Networks (WSNs). Journal of Wireless Networking and Communications, vol. 5, no. 1, (2015), pp. 19–47.

[24] W. Heinzelman, "The MIT uAMPS ns Code Extensions, Version 1.0," MIT, August 2000.

[25] Kevin Fall, Kannan Varadhan, "The ns Manual" MIT, November 4, 2011.

[26] A. Hac, Wireless Sensor Network Design, John Wiley & Sons, New York, NY, USA, 2003.

[27] D. Culler, D. Estrin, M. Srivastava, Guest Editors' Introduction: Overview of Sensor Networks. Computer. vol. 37, no. 8, (2004), pp. 41–49. https://doi.org/10.1109/MC.2004.93

[28] TEKNOMO, Kardi. K-means clustering tutorial. Medicine, vol. 100, no 4, 2006, p. 3.

[29] J. MacQueen, Some Methods for Classification and Analysis of Multivariate Observations. In: Proceedings of the Fifth Berkeley Symposium on Mathematical Statistics and Probability. pp. 281–297. Berkeley, 1967.

[30] S. Peryasamy, S. Khara, S. Thangavelu, "Balance Cluster Head Selection Based on Modified K-Means in a Distributed Wireless Sensor Network", International Journal of Distributed Sensor Network, 2016, pp. 1–11. https://doi.org/10.1155/2016/5040475

[31] Anindita Ray, Debasis De, "Energy Efficient Clustering Protocol Based on K-Means (EECPK-means)-Midpoint Algorithm for Enhanced Network Lifetime in Wireless Sensor Network", IET Wireless Sensors System, vol. 6, 2016, pp. 181–191. https://doi.org/10.1049/iet-wss.2015.0087

[32] A. Boukerche, M. Ahmad, B. Turgut, D. Turgut, A Taxonomy of Routing Protocols in Sensor Networks, in: A. Boukerche (Ed.), Algorithms and Protocols for Wireless Sensor Networks, Wiley, 2008, pp. 129–160 (Chapter 6). https://doi.org/10.1002/9780470396360.ch6

[33] A. O., Abu Salem, N. Shudifat, Enhanced LEACH protocol for increasing a lifetime of WSNs. Pers Ubiquit Comput 23, 901–907 (2019). https://doi.org/10.1007/s00779-019-01205-4

[34] L. Alazzawi, A. Elkateeb, "Performance Evaluation of the WSN Routing Protocols Scalability", Journal of Computer Networks and Communications, vol. 2008, Article ID 481046, 9 pages, 2008. https://doi.org/10.1155/2008/481046

[35] Subhrananda Goswami, Subhankar Joardar, Chandan Bikash Das, Samarajit Kar and Dibyendu Kumar Pal (May 11th 2017). Performance Analysis of Three Routing Protocols in MANET Using the NS-2 and ANOVA Test with Varying Speed of Nodes, Ad Hoc Networks, Jesus Hamilton Ortiz and Alvaro Pachon de la Cruz, IntechOpen, Available from: https://www.intechopen.com/books/ad-hoc-networks/performance-analysis-of-three-routing-protocols-in-manet-using-the-ns-2-and-anova-test-with-varying-; https://doi.org/10.5772/66521

[36] M. Haque, T. Ahmad, M. Imran, Review of Hierarchical Routing Protocols for Wireless Sensor Networks. In Intelligent Communication and Computational Technologies; Springer: Singapore, 2018, pp. 237–246. https://doi.org/10.1007/978-981-10-5523-2_22

[37] A. S. Rostami, M. Badkoobe, F. Mohanna, H. Keshavarz, A. A. R. Hosseinabadi, A. K. Sangaiah, Survey on Clustering in Heterogeneous and Homogeneous Wireless Sensor Networks. J. Supercomput. vol. 74, (2018), 277–323. https://doi.org/10.1007/s11227-017-2128-1

[38] Parvinder Singh, Rajeshwar Singh, "Energy-Efficient QoS-Aware Intelligent Hybrid Clustered Routing Protocol for Wireless Sensor Networks", Journal of Sensors, vol. 2019, Article ID 8691878, 12 pages, 2019. https://doi.org/10.1155/2019/8691878

[39] A. Y. Prasad and R. Balakrishna, TELKOMNIKA; Yogyakarta vol. 17, no. 4, (2019), pp. 1758–1766. https://doi.org/10.12928/telkomnika.v17i4.12004

[40] T. Mu and T. Minghao. (2010). LEACH-B: An Improved LEACH Protocol for Wireless Sensor Network. https://doi.org/10.1109/WICOM.2010.5601113

[41] S. V. Manikanthan and T. Padmapriya. An Efficient Cluster Head Selection and Routing in Mobile WSN. International Journal of Interactive Mobile Technologies (iJIM), vol. 13, no. 10, (2019), pp. 56–70. https://doi.org/10.3991/ijim.v13i10.11303

[42] R. Gantassi, B. B. Gouissem, J. B. Othmen, (2020). Routing Protocol LEACH-K Using K-Means Algorithm in Wireless Sensor Network. In: Barolli L., Amato F., Moscato F., Enokido T., Takizawa M. (eds) Web, Artificial Intelligence and Network Applications. WAINA 2020. Advances in Intelligent Systems and Computing, vol. 1150. Springer, Cham. https://doi.org/10.1007/978-3-030-44038-1_27

[43] B. Fatima, A. Wided, G. Sabrina, and D. Makhlouf, "K-Means Efficient Energy Routing Protocol for Maximizing Vitality of WSNs", in Computational Optimization Techniques and Applications. London, United Kingdom: IntechOpen, 2021 [Online]. Available: https://www.intechopen.com/chapters/75722; https://doi.org/10.5772/intechopen.96567

8   Authors

Hassan Echoukairi is a professor at the Faculty of Sciences, Mohammed V University in Rabat, Morocco. His research interests are in networking, routing protocols, wireless sensor networks and IoT. E-mail: h.echoukairi@um5r.ac.ma

Abdellah Idrissi is Full Professor in Computer Science, speciality Artificial Intelligence at the Faculty of Sciences, Mohammed V University in Rabat. His research domains include modeling, solving and optimization of intelligent and complex systems. E-mail: a.idrissi@um5r.ac.ma

Fouzia Omary is a Full Professor at the Faculty of Sciences, Mohammed V University in Rabat. Her fields of research interest are cryptography, complexity, genetic algorithms, Blockchain and Security. E-mail: f.omary@um5r.ac.ma