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Enhancing QoS and Residual Energy by Using of Grid-Size Clustering, K-Means, and TSP Algorithms With MDC in LEACH Protocol

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ABSTRACT Some recent researches have shown that the energy consumption problem caused by data collection in a wireless sensor network (WSN) based on a static data collector is a main threat to the network lifetime. However, with the progress of the mobile terminal technology, the implementation of mobile data collectors (MDCs) has become more popular in large-scale WSNs, but it remains a big problem to improve the Quality of Service (QoS) criteria and minimize the energy consumption at the same time. However, most existing systems based on MDCs do not successfully strike a balance between routing energy consumption and QoS. In addition, most WSN protocols fail to maintain their impact when the network topology changes. Thus, for a dynamic WSN, it is important to support an intelligent MDC to continue data propagation despite the inevitable changes in the WSN topology. Considering all the above challenges, we propose a new intelligent MDC based on the traveling salesman problem (TSP) to determine the optimal path traveled by the MDC for energy efficiency and latency. Specifically, our proposed Mobile Data Collectors-Traveling Salesman Problem-Low Energy Adaptive Clustering Hierarchy-K-Means (MDC-TSP-LEACH-K) protocol uses K-Means and Grid clustering algorithm to decrease energy consumption in the cluster head (CH) election phase. Additionally, MDC is utilized as an intermediate between CH and the sink to further enhance the QoS of WSNs, to reduce delays while collecting data, and improve the transmission phase of the LEACH protocol.

INDEX TERMS Energy consumption, large-scale wireless sensor networks, optimal path, QoS.

I. INTRODUCTION

Most recently, studies have demonstrated that introducing mobile data collectors (MDCs) can significantly enhance the performance of wireless sensor networks (WSNs). But there are important design issues, such as how to determine the location of the nodes, the number of sensor nodes (SNs), and the design of an optimal MDC path. Therefore, new WSN protocols have been proposed to deal with media access control, routing protocols, data aggregation, etc. Although much research has focused on reducing the energy consumption of routing protocols, only a few have addressed other quality of service (QoS) criteria, such as node throughput and latency. Therefore, in this paper, we propose a routing protocol that considers energy consumption, throughput, latency, and stability of nodes in terms of QoS. In WSNs, clustering has been considered as an important data mining technique to solve problems such as data aggregation, network lifetime, load balancing, energy consumption, stability, and scalability [1]. For many advantages, aggregation is recommended in WSN [2], [3] data operation. In addition, clustering is an important element of network organization, which has an impact on network efficiency anyway. The process of clustering divides a WSN into groups called "clusters," each cluster has an elected leader among the SNs who is called "cluster head" (CH). All data flows are transferred by the WSNs and aggregated by their CHs into a cluster. After that, data streams are transmitted by the CHs to the base station (BS). Transmitting data continuously in a wireless network using multi-hop communication to reach the BS consumes

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the energy at the nodes, and therefore, reduces the network lifetime. Clustering algorithms in WSNs consist of rounds. The clustering algorithms of WSNs are executed in rounds. The rounds involve cluster creation, CH election, and data transmission [4]. WSN clustering algorithms running data streams are divided into two main steps, the clustering phase, and the data transmission phase. Using the grid clustering algorithm [5], each cluster is formed according to the size of each grid in WSN. In particular, this method fixes the size and location of clusters. In addition, other Machine Learning clustering algorithms have been proposed in the research literature, such as the K-Means algorithm. The latter divides the dataset into K clusters using the mean Euclidean distance, which allows for the optimization of intra-cluster similarity [1], [6].

Our research focuses on combining the MDC with the traveling salesman problem (TSP) during the transmission phase of our protocol, which is implemented by a company in the USA in order to find a solution to the path problem by utilizing linear programming. The TSP is a specific case of the vehicle touring problem. However, the problem of how to select the best travel route and not to miss each landscape has become a problem that needs to be considered in recent years. This current example exactly mirrors problems common in mathematics-TSP problem, in which a businessman visits n city and then goes back to the starting city, with the assumption that a city can be visited only once to determine the fastest [6], [7].

This study proposes a new protocol called Mobile Data Collectors-Traveling Salesman Problem-Low Energy Adaptive Clustering Hierarchy-K-Means (MDC-TSP-LEACH-K), which is a combination of the LEACH protocol and the TSP-based MDC approach. It uses K-Means and Grid clustering algorithms to decrease the energy consumption of the CH election phase and to improve the CH election and a new intelligent MDC based on the TSP to determine the optimal MDC path for an efficient latency. More precisely, the contribution of this paper is as follows:

1) This work proposes a new routing protocol called MDC-TSP-LEACH-K. The proposed algorithm first applies the Grid algorithm to divide the network into equal size regions, then the K-Means algorithm is applied to each grid cluster to determine the CH. Assigned each CH to the SN having the minimum distance to the centroid of each grid cluster. The CH can broadcast data to MDC when MDC visits its lineup. MDC completes its collection and finally delivers the data to the BS.
2) This work integrates TSP to the proposed solution to determine the MDC optimal path.
3) This work compares the proposed protocol to existing solutions and proves its higher performance.

The remaining of this paper is organized as below. Literature review on clustering protocol using the K-Means algorithm, Grid algorithm, and TSP in MDC are provided in section II. An explanation of the proposed clustering protocol is provided in section III. The analysis and simulation results are presented in section IV. Finally, conclusions are provided in Section V.

II. RELATED WORK

Many studies have been conducted to evaluate the effect of K-Means on the LEACH protocol performance in WSN [1], [8]–[13]. Other studies, apply the Grid-sizes clustering on LEACH to enhance the WSNs performances as in [5], [8], [14], [15]. Several other studies have been carried out to develop MDC routing protocols [16]–[20] in which they have concentrated on increasing the lifetime of the WSN. Some research studies implement the MDC in the LEACH protocol, while others apply the K-Means and Grid-sizes Clustering in the LEACH protocol. Other studies, on the other hand, apply the TSP algorithm, on LEACH to enhance the WSNs performances as in [21]–[26]. Table 1 summarizes some literature works.

As noted above, some works integrate the Grid, and K-Means algorithm into the LEACH protocol, while others implement the TSP algorithm in this protocol. Note that both Grid and K-Means algorithms have similar philosophies but are used separately, as stand-alone algorithms, to reduce energy consumption in LEACH. However, only a few works integrate both algorithms (Grid, K-Means) to improve the QoS of the LEACH protocol. To our knowledge, no work has combined the K-Means, Grid and TSP algorithms in the MDC of the LEACH protocol. This work aims to integrate the K-means and Grid algorithms in a clustering setup phase where the TSP approach is used in the transmission phase of the LEACH protocol to improve QoS measurements. In the following section, our MDC-TSP-LEACH-K clustering algorithm will be discussed.

III. PROPOSED APPROACH

A. MDC-TSP-LEACH-K

Our proposed protocol MDC-TSP-LEACH-K is an extension of the basic principle of LEACH [4], [31] and convergence of wireless mobile communication technologies and enhanced sensor technology. This work uses the K-Means and Grid algorithm to improve the LEACH protocol before CHs election and the MDC as an interface between the CHs and the BS. The whole WSN area is divided into a logical grid of a defined size (i.e, 4×4 grid, as shown in Fig. 1). Every grid is a rectangle (with *(d)* units on each side) of size *(d×d)*. Therefore, the size of the grid is determined according to the nominal radio range *(R)*. For a large value of R, the grid includes a large number of nodes. Once the grid is configured and all nodes are placed, the K-Means algorithm is applied for each cluster in the grid to reduce the intra-cluster communication distance and to provide the centroid coordinates. The choice of the CH is made according to the distance from the centroid. Let us assume that the number of the nodes designated by (n_i) is subdivided into K groups $\{G_1, G_2, G_3, G_4, \ldots, G_K\}$. Let centroid−K

TABLE 1. Comparative study of the literature.

Study	Approach	Advantages	Challenges
		LEACH with KMeans	
[27]	This algorithm based on the self-organizing map (SOM) to form the clusters and the K-means algorithm is used to form different cluster sizes.	LEACH-SOM leads the LEACH protocol in minimum energy consumption and makes the network active for a long time.	This approach did not use the MDC and was TSP algorithm in the transmission phase and tested in LS-WSNs.
[1]	K-Means was applied on the CH election step of the LEACH protocol	Results showed that the proposed routing protocol decreased energy consumption, latency time, and increased network stability time, network lifetime, and throughput.	This approach did not use the MDC and TSP algorithm in the transmission phase. It did not improve the QoS of the network.
[8]	In this work, the K-Means approach was applied to WSNs.	One of its advantages is the increase of WSN residual energy.	This work is weak because it uses only a very limited number of parameters. The simulation phase, for example, focused on only two clusters of 10 nodes. This approach did not use the MDC and TSP algorithm in the transmission phase. It did not improve the QoS of the network.
[9]	In this paper, researchers implemented and discussed the K-Means algorithm and Gauss algorithms in LEACH.	The result decreased in terms of computing time using K-Means and increased energy residual using Gauss. This work was compared to LEACH and LEACH-C protocols for testing the performance of energy consumption.	The limitation of the study is that the proposed solution was run on a 100-node network over a period of 200 rounds. This approach did not use the MDC and TSP algorithm in the transmission phase and was tested in LS-WSN. It did not improve the QoS of the network.
[10]	The researchers introduced a K-Means approach in WSN.	The result reduced the viewpoint of energy consumption and improved QoS criteria.	This approach did not use the MDC and TSP algorithm in the transmission phase and was tested in LS-WSNs.
[11]	This work studied the routing protocol and took the cluster routing point of view in order to study the classical LEACH protocol and to estimate its advantages and challenges.	A process of aggregation based on the K-Means algorithm for dynamically adjusting the system in order to achieve a stable system operation and to transmit information by minimizing the energy consumption of the system, is provided.	This approach did not use the MDC and TSP algorithm in the transmission phase and was tested in LS-WSNs.
[12], [13]	The authors presented two hybrid clustering approaches K-Means Particle Swarm Optimization (KPSO) and K-Means Genetic Algorithms (KGAs) that show improvements over traditional LEACH.	Energy consumption was reduced.	This approach did not use the MDC and was TSP algorithm in the transmission phase and tested in LS-WSNs.
		LEACH with Grid fonction	
[28]	This paper proposes an adaptive network multi-mode LEACH protocol to address the QoS and energy efficiency requirements of the IoT/M2M communication system. The protocol provides an adaptive grid partitioning, considering three different transmission modes: node-to-gateway (CNG), node-to-base station (CN-BS), and node-to-cluster head (CH) and CH-to-base station (BS), with residual energy and inter-node distance taken into account for the CH selection.	Using the strategic implementation of the aforementioned multi-mode transmission with multi-parametric adaptive CH selection, timely and reliable transmission over a dense large-scale WSN was achieved. The M2M-LEACH protocol has improved energy efficiency, throughput and network lifetime. The protocol has also been shown to achieve higher node survival than the traditional LEACH and its enhanced variants, making it well suited for QOS and energy efficient IoT/M2M communication systems.	The limitation of the study is that the proposed solution does not use an intelligent MDC.
[29]	Grid-based clustering algorithms are used in routing protocol.	The result was improved in terms of energy efficiency, reducing cost and increasing network reliability.	This approach did not use the MDC and TSP algorithm in the transmission phase and tested in LS-WSNs.
[5]	In this paper, researchers implemented the Grid and K-Means algorithm in LEACH.	The proposed routing protocol decreased energy consumption and latency time, and increased network stability time, network lifetime, and throughput.	This approach did not use the MDC and TSP algorithm in the transmission phase and was tested in LS-WSNs.
[14], [15]	This approach is based on a shutdown timer. This is calculated based on the residual energy levels of each node in the network. The global energy of the given cluster, comprising the rest of the nodes and the CH, is kept during the process.	Cluster-grid protocols are employed to optimize the distribution of CH to reduce the cluster area.	This approach did not use the MDC and TSP algorithm in the transmission phase and was tested in LS-WSNs.

(To be Continued)

TABLE 1. ***(Continued.)*** **Comparative study of the literature.**

		LEACH with MDC	
[16]	In this paper, researchers implemented and discussed the K-Means and MDC in LEACH.	This routing protocol reduces energy consumption and latency, and increases network stability time, network lifetime and throughput. QoS optimization for LEACH in LWSN with MDC and K-Means.	The limitation of the study is that the proposed solution does not use an intelligent MDC.
[30]	This paper developed a JayaX approach with local search module based CH selection (JayaX-LSM-CHS) and a cluster formation method and adopted an ant colony optimization (ACO) based algorithm for efficient data collection.	From the experimental results, proposed framework (PF) is found to significantly improve the WSN lifetime.	This approach did not use the MDC and was TSP algorithm in the transmission phase and tested in LS-WSNs.
[17]	The authors propose, analyze and test the LEACH routing protocol-based MDC that is predicated on a multi-hop routing strategy.	This approach provides a significant reduction in SNs, energy consumption, improved network lifetime, and improved data collection compared to the LEACH protocol.	The simulation parameters are very restricted. Specifically, only 40 SNs are used, and the surface of simulation is equal to 1 km^2. This approach did not use the intelligent MDC and TSP algorithm in the transmission phase and was tested in LS-WSNs.
[18]	The authors report a comparison between the MDC's maximum residual energy routing protocol and LEACH multi-hop hybrid routing protocol. Reference [18] reports that the MDC moves to the nodes with the maximum energy.	The results of the simulation demonstrate the better performance of the "MDC Maximum Residual Energy" protocol compared to the LEACH protocol in terms of energy consumption of the SNs. These results also show a significant increase in network lifetime. In addition, the proposed scheme can be applied to LWSN.	This approach did not use the intelligent MDC and TSP algorithm in the transmission phase and tested in LS-WSNs and ameliorate the QoS.
[19]	In this paper, the MDC starts its data collection at the data BS by capturing the signal from the CH beacon, then collecting CH data, and finally conducting the data to the BS.	This method extends the life of the sensors since it is a reactive rather than proactive method.	This approach did not provide any simulation results confirming the claimed findings. This work did not use the intelligent MDC and TSP algorithm in the transmission phase and was tested in LS-WSNs.
[20]	The MDC maximum residual energy method focuses on multi-hop communication among SNs, the MDC, and the sink.	This approach is of nature to reduce the energy consumption of the network nodes. In addition, this approach can be implemented in a network covering large regions. Simulation results demonstrate that the proposed protocol outperforms the LEACH protocol in terms of sensor node power consumption and network lifetime.	This approach did not use the intelligent MDC and TSP algorithm in the transmission phase and was tested in LS-WSNs.
		Routing protocols with TSP	
[21]	Authors develop a new strategy for data collection in LS-WSN by using mobility in the network. In this paper, the problem of single-hop data collection (SHD) concentrates on reducing the time of each round of data collection.	The proposed scheme can be applied to LS-WSN.	This approach did not ameliorate the QoS and did not use the MDC in the transmission phase.
[23]	Typically, the round follows the path of the TSP. When MDC is traveling in the SHDGP, it can query neighboring SNs to gather data. When a sensor receives the polling message, it simply downloads the data to the MDC in a single hop from one sensor to another.	Results showed that the proposed routing protocol decreased energy consumption and latency time.	This approach did not ameliorate the QoS and did not use the MDC in the transmission phase.
[24]	Authors propose Multi-hop Simulated Annealing-LEACH (MhSA-LEACH) protocol based on intra-cluster multi-hop communication. The selection of intermediate nodes in the multi-hop protocol is done using Simulated Annealing algorithm on TSP.	The simulation results of this approach show the optimization of MhSA-LEACH on the number of packets received by the BS or the CH and the number of dead or alive nodes of the LEACH and Multi-Hop Advance Heterogeneity-aware Energy Efficient (MA-HEE) protocols.	This approach did not ameliorate the QoS and did not use the MDC in the transmission phase.
[25]	In this paper, the authors studied the LEACH routing protocol and its performance and proposed a new protocol, MA-LEACH. First, the mobile aggregator is introduced which represents the overhead of the CH. Furthermore, by using particle swarm optimization trajectory optimization is performed. Therefore, to determine the optimal trajectory that a mobile	The simulation results show that MA-LEACH surpasses LEACH with a fuzzy descriptor in network lifetime and energy consumption.	This approach did not ameliorate the QoS and did not use the MDC in the transmission phase.

(To be Continued)

TABLE 1. ***(Continued.)*** **Comparative study of the literature.**

	aggregator could travel to visit each CH in the network, the authors fit the TSP problem to their protocol.		
[25]	In the proposed protocol of this article, in PERLDA sensors do not send their data directly to CH for aggregation; rather each sensor sends its data to the nearest neighbor sensor. It receives data and aggregates it with its data. Then it sends the new information to another neighbor SN that is in line with CH. Therefore, data aggregation in PERLDA does not perform only in one sensor, rather it local data aggregation network. PERLDA protocol saves a lot of energy by selecting the shortest route for data transmission by TSP.	In the PERLDA protocol, to avoid data interference, the TDMA technique is used within each cluster. In fact, the combination of TDMA and the traveling salesman problem is quite unique. Each CHs energy is verified by the Neuro-Fuzzy network. Any CH possessing the lowest energy is detected, and the duration for which the CH can continue to do its job with the least energy is also estimated.	This approach did not ameliorate the QoS and did not use the MDC in the transmission phase and was tested in LS-WSNs.
[26]	In this paper, the authors proposed an anchor point with a clustering (APAC) algorithm in WSNs. It implemented TSP to find the shortest route.	The results showed that the latency is reduced compared to the only point substitution method.	This approach did not ameliorate the QoS and did not use the MDC in the transmission phase.

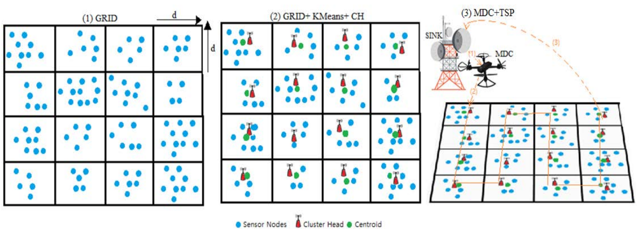


FIGURE 1. **MDC-LEACH-K architecture.**

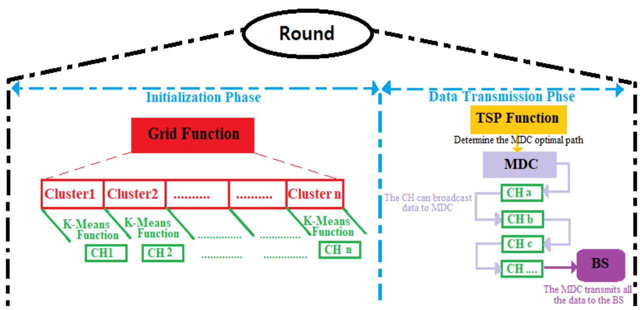


FIGURE 2. **The process of the MDC-TSP-LEACH-K.**

becomes the centroid of the G_K cluster groups. For example, $G_1 \cup G_2 \cup G_3 \cup G_4, \ldots \cup G_K = \{n_1, n_2, n_3 \ldots\}$.

The K-Means step is calculating the positions of the centroids of each grid. Then, assign each CH to the SN, which belongs to the grid (i) with coordinates (x_j, y_j), having the minimum distance to the centroid. The minimum distance is calculated as follows:

$$D((x, y), Grid_{Centroid}(i)) = min\{\sqrt{(x_{centroid} - x_j)^2 + (y_{centroid} - y_j)^2}\}; \quad (x_j, y_j) \in Grid_{Centroid}(i) \tag{1}$$

Consequently, the Grid-centroid coordinates, corresponding to the minimum distance to (x, y), are calculated. The CH is selected for the given grid. Each CH diffuses its location in its transmission area using a special packet containing its coordinates to all the nodes of each grid cluster. The MDC does its job in a smart way that it only approaches the CHs closest to its neighbors. The MDC collects the CH data. MDC collects the data that are broadcasted by the CH can broadcast data to MDC directly. Therefore, MDC completes the collection and finally delivers the data to the BS. Fig. 1 illustrates a straightforward MDC strategy in WSN.

The proposed scheme uses a Grid-cluster-based WSN. One of the SNs is selected as the CH of each Grid cluster, which TSP provides a dynamic trajectory to MDC. Since the CH are located almost very close to the centroid, the MDC moves on an almost linear trajectory starting from the first centroid of the first grid-cluster to the last grid column. Then it moves to the nearest centroid of the grid-cluster until the whole grid-cluster. Finally, it transmits all the data to the sink. The process of the MDC-TSP-LEACH-K Problems algorithm is shown in Fig. 2:

The MDC-TSP-LEACH-K process has the following advantages:

1) Less energy consumption.
2) Less Overheads
3) Less latency times.
4) More Robustness
5) Stability
6) Balancing of areas between groups
7) Scalability

The process of the MDC-TSP-LEACH-K is shown in Fig. 3:

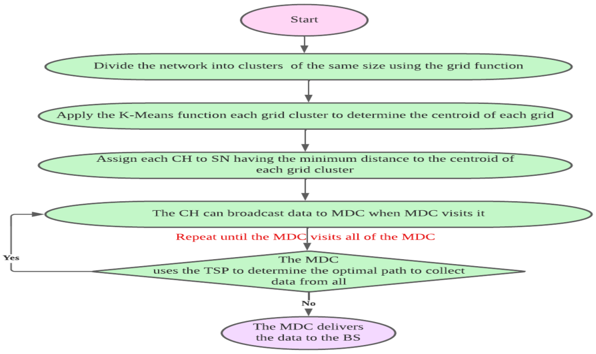


FIGURE 3. The process of the MDC-TSP-LEACH-K.

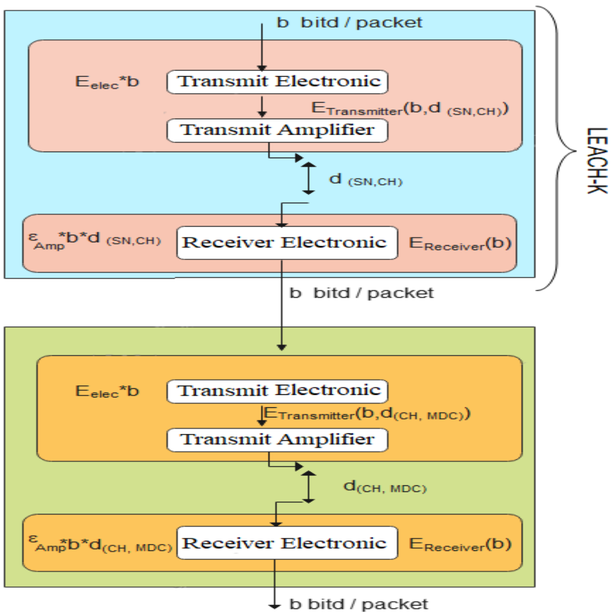


FIGURE 4. Radio modelof MDC-TSP-LEACH-K.

B. MDC-TSP-LEACH-K ENERGY MODEL

MDC-TSP-LEACH-K is an improvement of the LEACH-K protocol [1]. LEACH-K adapts the energy model of LEACH [4], as shown in Fig4.

If the distance is less than a threshold D, the free space model (d^2 power loss) is used; otherwise, the multi path model (d^4 power loss) is used. Or, for short distance transmission, such as intra-cluster communication, the energy consumed by a transmitting amplifier is proportional to d^2 and for long distance transmission, such as inter-cluster communication, the energy consumption is proportional to d^4. D is a threshold transmission distance where:

$$D = \sqrt{\epsilon_{fs}}/\sqrt{\epsilon_{Amp}}, \tag{2}$$

Thus, if the transmitter sends a message of b bits to the receiver until d distance, the required energy to transmit b bits of data is modeled by (3):

$$E_{Transmitting} = (E_{ele} \times b) + \epsilon_{Amp} \times b \times d^2, \tag{3}$$

where:

- Each SN is static and homogeneous.
- B is the number of transmitted bits.
- ϵ_{fs} is the power loss of free space.
- ϵ_{Amp} is the power multi path models.
- d is the distance between CH and MDC.
- E_{ele} is The parameter Eelec is the per bit energy dissipations for transmission and reception.

The required energy to get B bits of data is modeled by (4):

$$E_{Receiving}(B) = E_{ele} \times B, \tag{4}$$

where:

- E_{ele} is the energy required to operate electronic circuitry of receiver.

Energy consumed during a data collection cycle is calculated in (5).

$$E_{Round} = E_{Transmitting} + E_{Receiving}. \tag{5}$$

IV. SIMULATION RESULTS AND ANALYSIS

To evaluate the performance of the proposed approach, it is compared to various existing protocols that are based on QoS criteria such as throughput and energy consumption in the operate of CH as an aggregator. It aggregates the data received from its nodes and sends it to the BS via the MDC. The simulation of the proposed approach is done by using MATLAB simulators. We chose MATLAB due to the facility of its interface and the availability of the necessary functions programmed in advance such as the K-Means and grid functions. Furthermore, the implementation of our mathematical model is very easy on MATLAB because the MATLAB language is a matrix language allowing the most natural expression of computational mathematics.

Various parameters and factors are taken into consideration while performing the simulation to enhance the network performance. Our simulation is divided into two scenarios. In the first scenario, we have evaluated MDC-TSP-LEACH-K with hierarchical WSNs routing protocols such as LEACH-K, which is one of the proposed enhanced versions of LEACH. In particular, in this scenario, the position of the BS is outside the area (0, 1.25). In the second step, we have evaluated the simulation results of our proposed protocol MDC-TSP-LEACH-K with different protocols including threshold-sensitive energy-efficient sensor network (TEEN), LEACH, LEACH-K, LEACH-C, LEACH-G-K, Improved-LEACH, Stable-Improved-LEACH, MhSa-LEACH, MDC maximum residual energy leach and, MDC-K protocols, which used K-means, MDC, TSP or Grid function in LEACH for LS-WSNs. In particular, in this scenario, we have increased the size of the area from 100*100 to 1000*1000. Table 2 describes the simulation parameters to all scenarios.

1) FIRST SCENARIO

In these simulation scenarios, the SNs have 0.5 J battery energy. We evaluate the following parameters in the TENN,

TABLE 2. Simulation parameters.

Settings	Values
Electronic dissipation energy (sending, receiving)	E_{elec}= 50 nJ/bit
Energy for data aggregation	E_{DATA} = 5 nJ/bit/m^2
Transmit Amplifier if $d_{toBS} \leq d_0$	ϵ_{fs}= 10pJ/bit/m^2
Transmit Amplifier if $d_{toBS} \geq d_0$	ϵ_{Amp}= 0.0013 pJ/bit/m^4
Position of BS	(0 , 125)
Initial power	E= 0.5 J/node
Node distribution	Static
Simulation period	10000 rounds
Simulation Area	rom 100 m$^2 to 1500 m^2$

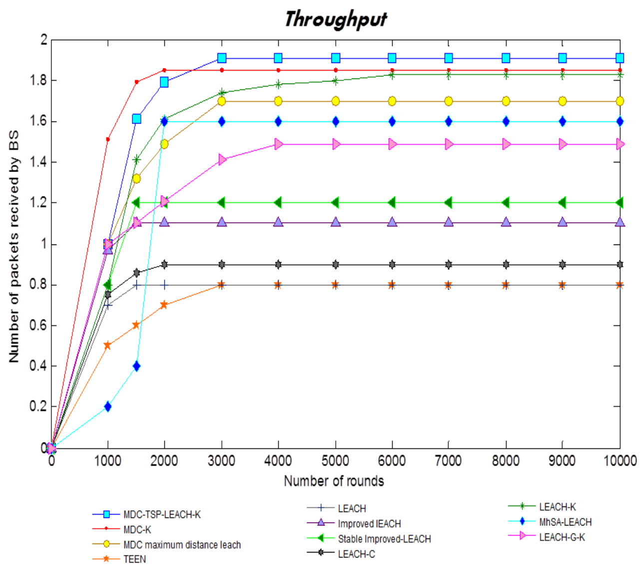


FIGURE 5. Simulation throughput results of TENN, LEACH, LEACH-K, LEACH-C, LEACH-G-K, Improved-LEACH, Stable-Improved-LEACH, MhSa-LEACH, MDC maximum residual energy leach, MDC-K, and MDC-TSP-LEACH-K protocols.

LEACH, LEACH-K, LEACH-C, LEACH-G-K, Improved-LEACH, Stable-Improved-LEACH, MhSa-LEACH, MDC maximum residual energy leach, MDC-K protocols, and our proposed protocol MDC-TSP-LEACH-K. In this section, we discuss the considered test scenario and the adopted performance metrics. We present the results of simulation scenarios. These results are analyzed to make a tradeoff between residual energy, throughput (packets received by the BS), and latency as a function of *K* variation over 10000 rounds. One hundred nodes were chosen to test the performance of their improvement method against the MDC-TSP-LEACH-K protocol. Fig. 5 shows the throughput in each round of LEACH, TENN, LEACH-K, LEACH-C, Improved-LEACH, Stable-Improved-LEACH, MDC maximum residual energy leach, MDC-K, MhSa-LEACH, LEACH-G-K protocols, and the proposed protocol MDC-TSP-LEACH-K.

Fig. 5 illustrates the throughput variations of the proposed MDC-TSP-LEACH-K protocol compared to the TENN, LEACH, LEACH-K, LEACH-C, LEACH-G-K, Improved-LEACH, Stable-Improved-LEACH, MhSa-LEACH, MDC maximum residual energy leach and, MDC-K protocols. The curves of Fig. 5 point out that integrating

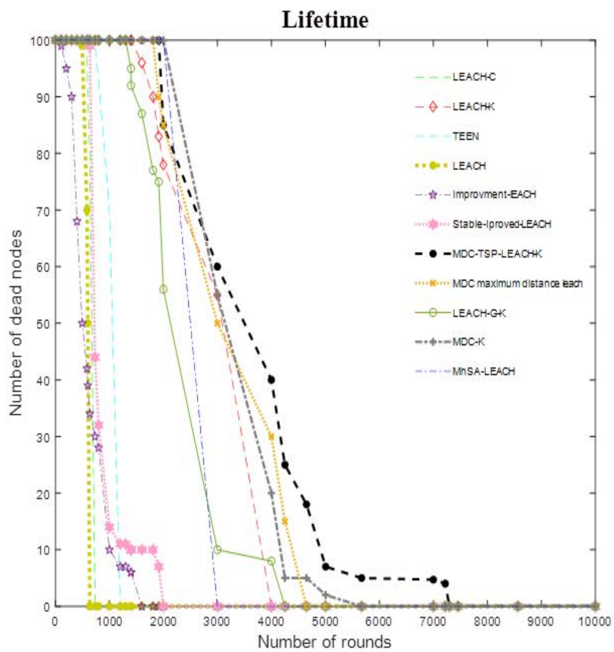


FIGURE 6. Simulation lifetime results of LEACH, TENN, LEACH-K, LEACH-C, Improved-LEACH, Stable-Improved-LEACH, MDC maximum distance leach, MDC-K, MhSa- LEACH, LEACH-G-K protocols, and MDC-TSP-LEACH-K.

MDC by using the TSP algorithm increases throughput significantly. We noticed that the throughput value of MDC-TSP-LEACH-K in round 10000 is equal to 18910 packet/round compared to 18300 packet/round for MDC-K protocol, 18110 packet/round of LEACH-K protocol, 16271 packet/round of MDC maximum distance leach protocol, 16020 packet/round for MhSA-LEACH protocol, 15111packet/round of LEACH-G-K, 12046 packet/round of Stable-Improved-LEACH protocol, 11199 packet/round of Improved-LEACH protocol, 8747 packet/round of LEACH-C, 8012 packet/round of the TEEN protocol, and 8001 packet/round of LEACH protocol. The proposed protocol increases the throughput value by minimizing the distance between SB and CH with the K-Means algorithm and reducing the latency time by using TSP in MDC. Fig.5 shows that the number of packets received by the sink for LEACH is very less than other protocols. The comparison of MDC-LEACH-K-TSP and MDC-K showed that MDC-LEACH-K-TSP is better than MDC-K from 2500 rounds. At 2500 rounds, the number of packets received by the sink starts to deviate significantly from the previous round. Moreover, MDC-TSP-LEACH-K protocol can play a vital role to enhance reliability. Fig. 6 presents a comparison between the MDC-TSP approach TENN, LEACH, LEACH-K, LEACH-C, LEACH-G-K, Improved-LEACH, Stable-Improved-LEACH, MhSa-LEACH, MDC maximum residual energy leach, and MDC-K protocols in terms of lifetime.

As indicated in the above figures, our proposed solution of MDC-TSP-LEACH-K improves the network

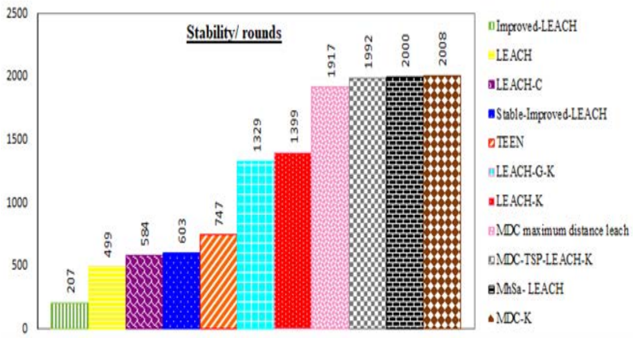


FIGURE 7. The stability of the proposed approach compared to LEACH, TENN, LEACH-K, LEACH-C, Improved-LEACH, Stable-Improved-LEACH, MDC maximum distance leach, MDC-K, MhSa- LEACH, and LEACH-G-K protocols.

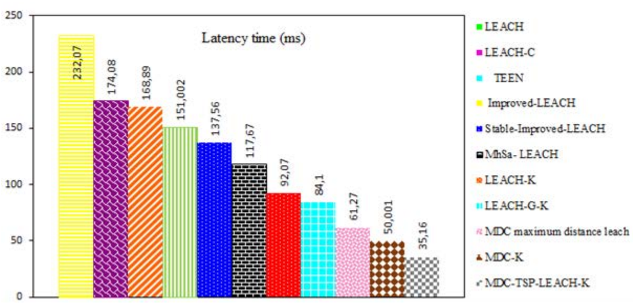
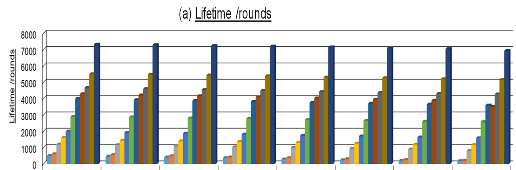


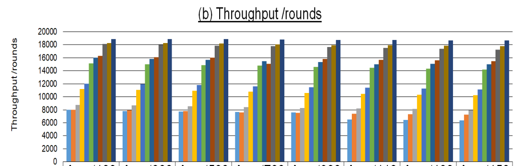
FIGURE 8. Comparison between MDC-TSP-LEACH-K LEACH, LEACH, TENN, LEACH-K, LEACH-C, Improved-LEACH, Stable-Improved-LEACH, MDC maximum distance leach, MDC-K, MhSa- LEACH, and LEACH-G-K protocols in terms of latency time.

lifetime with higher performances compared to LEACH, TENN, LEACH-K, LEACH-C, Improved-LEACH, Stable-Improved-LEACH, MDC maximum distance leach, LEACH-G-K but it is less stable than MDC-K and MhSa-LEACH protocols. It improves the sensor node's residual energy as well. Numerical results show that the proposed method is able to decrease the sensor node's energy consumption. Fig. 7 presents the stability of the proposed approach compared to LEACH, TENN, LEACH-K, LEACH-C, Improved-LEACH, Stable-Improved-LEACH, MDC maximum distance leach, LEACH-G-K but it is less stable than MDC-K and MhSa-LEACH protocols.

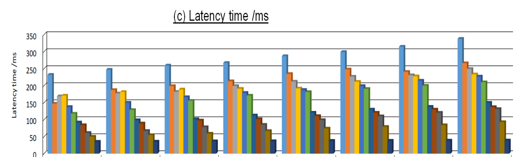
The stability slightly increases from 207(rounds) in Improved-LEACH to 499 (rounds) in LEACH to 584 (rounds) in LEACH-C to 603 (rounds) in Stable-Improved-LEACH to 747 (rounds) in TEEN to 1329 (rounds) in LEACH-G-K to 1399(rounds) in LEACH-K to 1917 (rounds) in MDC maximum distance leach to 1992(rounds) in MDC-TSP-LEACH-K to 2000 (rounds) in MhSa-LEACH to 2008 5rounds) to MDC-K. We notice that our protocol is less stable than MhSa-LEACH and MDC-K protocols. Fig. 8 presents a comparison between LEACH, TENN, LEACH-K, LEACH-C, Improved-LEACH, Stable-Improved-LEACH, and MDC maximum distance leach protocols in terms of latency time.



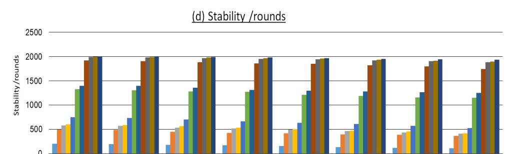
	Area(100, 100)	Area(300, 300)	Area(500, 500)	Area(700, 700)	Area(900, 900)	Area(1100 ,1100)	Area(1300 ,1300)	Area(1500 ,1500)
LEACH	503	461	410	366	290	240	206	188
LEACH-C	611	557	489	412	365	311	256	204
TEEN	1200	1167	1107	1037	1004	944	896	807
Improved-LEACH	1605	1439	1400	1367	1300	1255	1195	1174
Stable-Improved-LEACH	1995	1916	1873	1815	1744	1700	1640	1588
MhSa- LEACH	2897	2866	2802	2775	2702	2643	2600	2578
LEACH-K	4000	3922	3876	3811	3761	3702	3654	3593
LEACH-G-K	4286	4211	4159	4101	4030	3956	3888	3511
MDC maximum distance leach	4670	4600	4544	4489	4419	4367	4300	4275
MDC-K	5505	5476	5429	5380	5306	5265	5200	5156
MDC-TSP-LEACH-K	7321	7289	7236	7200	7150	7101	7046	6933



	Area(100 ,100)	Area(300 ,300)	Area(500 ,500)	Area(700 ,700)	Area(900 ,900)	Area(110 0,1100)	Area(130 0,1300)	Area(150 0,1500)
LEACH	8001	7777	7740	7666	7603	6540	6426	6376
TEEN	8012	7901	7809	7582	7505	7411	7336	7254
LEACH-C	8747	8667	8577	8437	8304	8219	8111	7907
Improved-LEACH	11199	11039	10900	10767	10610	10455	10333	10229
Stable-Improved-LEACH	12046	11933	11803	11605	11502	11390	11240	11107
MhSa- LEACH	15111	15000	14902	14796	14602	14443	14300	14187
LEACH-K	16020	15829	15676	15451	15333	15029	15101	15000
LEACH-G-K	16271	16113	16009	15091	15817	15714	15600	15450
MDC maximum distance leach	18110	18006	17843	17777	17622	17509	17378	17217
MDC-K	18300	18247	18176	18053	17940	17900	17833	17783
MDC-TSP-LEACH-K	18910	18880	18857	18807	18761	18717	18692	18667



	Area(100, 100)	Area(300, 300)	Area(500, 500)	Area(700, 700)	Area(900, 900)	Area(1100 ,1100)	Area(1300 ,1300)	Area(1500 ,1500)
LEACH	232,07	247,08	259,44	267,09	287,03	299,11	314,76	337,98
LEACH-C	147,08	187,33	198,99	213,17	234,66	247,84	240,65	266,22
TEEN	168,89	177,33	182,01	199,12	212,12	226,66	230,88	249,31
Improved-LEACH	170,84	181,55	189,03	191,03	191,88	211,55	227,64	233,33
Stable-Improved-LEACH	137,56	149,99	166,34	179,09	187,76	199,08	214,89	226,98
MhSa- LEACH	117,67	128,65	155,66	170,88	181,33	190,66	199,89	210,15
LEACH-K	92,07	98,65	101,55	112,52	120,77	129,88	137,99	149,88
LEACH-G-K	84,1	88,96	97,77	101,67	110,86	120,55	129,87	137,11
MDC maximum distance leach	61,27	67	78,08	85,03	98,99	110,15	120,48	131,55
MDC-K	50,001	54,66	59,09	66,78	74,09	78,99	84,003	92,97
MDC-TSP-LEACH-K	35,16	35,59	36,66	36,89	37,99	38,25	38,67	38,98



	Area(100, 100)	Area(300, 300)	Area(500, 500)	Area(700, 700)	Area(900, 900)	Area(110 0,1100)	Area(130 0,1300)	Area(150 0,1500)
Improved-LEACH	207	200	183	173	156	132	122	109
LEACH	499	486	451	430	421	400	389	363
LEACH-C	584	574	533	517	495	466	434	411
Stable-Improved-LEACH	603	589	566	537	504	476	455	421
TEEN	747	733	701	668	632	609	577	530
LEACH-G-K	1329	1302	1282	1271	1215	1186	1162	1149
LEACH-K	1399	1395	1360	1311	1300	1281	1265	1248
MDC maximum distance leach	1917	1901	1880	1860	1854	1822	1800	1740
MDC-TSP-LEACH-K	1992	1982	1967	1952	1944	1921	1903	1879
MhSa- LEACH	2000	1993	1981	1970	1959	1933	1911	1900
MDC-K	2008	2002	1991	1980	1970	1949	1940	1932

FIGURE 9. MDC-TSP-LEACH-K LEACH, LEACH, TENN, LEACH-K, LEACH-C, Improved-LEACH, Stable-Improved-LEACH, MDC maximum distance leach, MDC-K, MhSa-LEACH, and LEACH-G-K protocols in terms of stability, latency time, lifetime, and throughput in different area sizes.

TABLE 3. The comparison analysis of QoS criteria of our protocol and some similar protocols in the literature.

Protocols	Communcation Scheme	Lifetime	Stability	CH selection	Latency Time	Complexity	Load Balancing	Type of network	Scalability	Energy dissipation
LEACH [4]	Single-hop	Low	Poor	Random	High	Low	No	Homogeneous	Poor	les than all the amelioration of LEACH
TENN [32]	Single-hop	Low	Poor	Random	High	Low	No	Homogeneous	Poor	High than LEACH
LEACH-C [33]	Multi-hop	Low	Poor	Random	High	Low	No	Homogeneous	Poor	High than LEACH
LEACH-K [1]	Multi-hop	Low	High	Random	less	High	No	Homogeneous	High	High than LEACH, LEACH-C, TEEN, Improvement-LEACH, and Stable-Improved-LEACH
LEACH-G-K [5]	Multi-hop	High	High	Choose the node near the centroid of the cluster	Poor	High	No	Homogeneous	High	High than LEACH, LEACH-C, TEEN, Improvement-LEACH, Stable-Improved-LEACH, and LEACH-K
Improved-LEACH [34]	Multi-hop	High	Poor	According to the residual energy	High	Low	No	Homogeneous	High	High than LEACH, LEACH-C, and TEEN
Stable-Improved-LEACH [35]	Multi-hop	High	Medium	According to the residual energy	High	Medium	No	Homogeneous	High	High than LEACH, LEACH-C, TEEN, Improvement-LEACH, and LEACH-K
MhSa-LEACH [23]	Multi-hop	Medium	High	Choose node that has the highest energy and near BS	High	High	No	Homogeneous	High	High than LEACH, LEACH-C, TEEN, Improvement-LEACH, LEACH-K, and Stable-Improved-LEACH
MA-LEACH [24]	Multi-hop	Medium	High	Random	High	Medium	No	Homogeneous	High	High than LEACH, TEEN, and Fuzzy LEACH
Fuzzy LEACH [25]	Multi-hop	Medium	Medium	Random	High	Medium	No	Homogeneous	High	High than LEACH and TEEN
MDC maximum distance leach [36]	Multi-hop	High	Medium	Choose the node near the BS	less	Medium	No	Homogeneous	High	High than LEACH, LEACH-C, TEEN, Improvement-LEACH, LEACH-K, Stable-Improved-LEACH, MhSa-LEACH,

(To be Continued)

TABLE 3. *(Continued.)* **The comparison analysis of QoS criteria of our protocol and some similar protocols in the literature.**

										Fuzzy LEACH, and MA-LEACH
MDC-K [5]	Multi-hop	High	High	Choose the node near the centroid of the cluster	Poor	High	No	Homogeneous	High	High than LEACH, LEACH-C, TEEN, Improvement-LEACH, LEACH-K, Stable-Improved-LEACH, MhSa-LEACH, Fuzzy LEACH, MA-LEACH, LEACH-K, LEACH-G-K, and MDC maximum distance leach
MAHEE [23]	Multi-hop	Medium	Poor	According to remaining energy, location of the node	High	Medium	YES	Homogeneous	High	High than LEACH, TEEN, M-LEACH, SEP, DEEC
SEP [37]	Multi-hop	High	High	Choose node that has the highest energy	High	Low	No	Heterogeneous	Poor	High LEACH, LEACH-C, and TEEN
MDC-TSP-LEACH	Multi-hop	High	High	Choose the node near the centroid of the cluster	Poor	High	No	Homogeneous	High	High than LEACH, LEACH-C, TEEN, Improvement-LEACH, LEACH-K, Stable-Improved-LEACH, MhSa-LEACH, Fuzzy LEACH, MA-LEACH, LEACH-K, LEACH-G-K, SEP, MDC-K and MDC maximum distance leach

As shown in Fig. 8, when we used our approach, the latency time also increases to 35,16 (ms) from MDC-TSP-LEACH-K protocol compared to 232,07 (ms) in LEACH protocol, 174,08 (ms) from LEACH-C protocol, 151,002(ms) from TEEN protocol, 137,56(ms) from Stable-Improved-LEACH protocol, 117,67 (ms) from MhSa- LEACH protocol, 92,07 (ms) from LEACH-K protocol and 84,1 (ms) from LEACH-G-K protocol, 61,27 (ms) from MDC maximum distance leach, 50,001 (ms) from MDC-K. Based on the experimental results, we conclude that our MDC-TSP-LEACH-K protocol is the best solution to reduce the latency time compared to the LEACH protocol and their improvement.

2) SECOND SCENARIO

Since LS-WSNs are very developed nowadays, in the second scenario, the effectiveness of our proposed protocol TSP-LEACH-K in LS-WSNs is also tested. Specifically, we have evaluated the QoS criteria values in different area sizes. Fig.9 presents a comparison between MDC-TSP-LEACH-K LEACH, LEACH, TENN, LEACH-K, LEACH-C, Improved-LEACH, Stable-Improved-LEACH,

TABLE 4. The comparison analysis of reliability for cluster head election and clustering of our protocol and some clustering protocols in the literature.

Research / Year	Contributions Already Provided	Validations Already Done
[38] / 2022	A clustered routing scheme for heterogeneous network (CRSH) has been proposed in this paper to carry out the clustering of SNs and network data aggregation.	As a result, an simulation of the proposed scheme is performed in MATLAB simulator. By using various performance parameters, a comparison is made between the proposed scheme and the existing protocols to measure its efficiency in order to provide more reliability and extend the lifetime for the low power consumption protocols.
[39] / 2022	In this paper, A novel CH selection protocol has been proposed based on the firefly algorithm (FA) and hesitant fuzzy. It utilizes three SN parameters in order to calculate the score of each node and find the best CHs.	The assessment of the performance included various factors related to the energy efficiency and the lifetime and not the reliability of the system.
[40] / 2018	This paper proposes a novel extended LEACH-based clustering algorithm to improve WSN performance in terms of reliability, energy efficiency, and lifetime. This algorithm, EM-LEACH, firstly takes on new rules for CH selection and the calculation of round time based on the remaining energy. On the other hand, EM-LEACH improves the communication model from a single hop to a multi-hop between CHs and the sink using two operational processes: leveling and generic multi-hop routing.	The evaluation of performance focused on various aspects related to the network's reliability, energy efficiency and lifetime.
MDC-TSP-LEACH-K	Our paper proposed a new clustering algorithm based on extended LEACH to improve the performance of WSN in terms of QoS, and lifetime. First, our protocol, MDC-TSP-LEACH-K, supports new rules for CH selection and Clustring using Grid and KMeans function.	MDC-TSP improves QoS, reduces and balances energy consumption and introduces more reliability in packet delivery to the sink through the use of smart MDC.

MDC maximum distance leach, MDC-K, MhSa-LEACH, and LEACH-G-K protocols in terms of stability, latency time, lifetime, and throughput in different area sizes.

It is shown in Fig. 9 that when the area size increased, the lifetime, throughput, and stability decreased slightly, which indicates that the benefits of our protocol stay almost stable with a large area. For example, the latency also increases from 35.16 (ms) in an area size (100, 100) to 38.98 (m) in an area size (1500, 1500). The throughput decreases from 18910 (packets/ rounds) in a (100, 100) size area to 18667 (packets/ rounds) in a (1500, 1500) size area. The lifetime decreases from 7321 (rounds) in a (100, 100) size area to 6933 (rounds) in a (1500, 1500) size area. The throughput decreases from 18910 (packets/ rounds) in a (100, 100) size area to 18667 (packets/ rounds) in a (1500, 1500) size area. The stability decreases from 2008 (rounds) in a (100, 100) size area to 1932 (rounds) in a (1500, 1500) size area. According to its results, we conclude that our MDC-TSP-LEACH-K is the better solution for LS-WSN.

To assess the effectiveness of our MDC-TSP-LEACH-K protocol in improving the QoS of the routing protocol, Table 3 provides a comparison of our protocol and some similar protocols in the literature.

As illustrated in Table 3, several protocols have been proposed to improve the LEACH protocol. For example, LEACH-G-K, LEACH-K, and MDC-K protocols are proposed to improve all QoS metrics. In addition, MDC-TSP-LEACH-K also improved the lifetime, latency, stability, and throughput. However, LEACH-G-K and LEACH-K was not useful for LS-WSNs. Our protocol is better than LEACH-G-K, MDC-K, MDC maximum residual energy leach, and Stable-Improved-LEACH because it improves all QoS criteria for LWSNs. The combination of K-Means, Grid, TSP, and MDC approaches improves all QoS criteria of LEACH, LEACH-G-K, and LEACH-K protocols LS-WSNs.

In our approach, we have chosen the SN where its position is close to the centroid i.e. the center of each grid cluster and therefore the distance between the CH and the SNs is very small and therefore the CH does not consume a lot of energy and therefore the communication between the CH and the SNs is very reliable. Otherwise all CHs will be moved on the same trajectory of all K-Means cluster which facilitates the movement of MDC also via TSP the MDC will be chosen the CH closest to their position. so less movement and less energy consumption is required and the risk of falling the CH battery failure is low and subsequently we can say that our approach is very reliable.

To assess the effectiveness of our MDC-TSP-LEACH-K protocol in improving the reliability of the routing protocol,table 4 provides a comparison of our protocol and some similar protocols in the literature.

V. CONCLUSION

In this paper, a new hybrid protocol called MDC-TSP-LEACH-K, which is a combination of LEACH-G-K, TSP, and MDC approach, had been proposed to improve LEACH protocol aggregation. To be more precise, MDC-TSP-LEACH-K used the grid, and K-Means algorithms to minimize the energy consumption during the CH election phase. Furthermore, MDC was used as the intermediary between CH and sink in order to improve the QoS criteria of LS-WSNs again, reduce the latency during data collection, and prolong the network lifetime in the LS-WSNs. Our simulation results showed that MDC-TSP-LEACH-K had a significant impact on QoS metrics, and energy consumption. Specifically, this protocol provided considerable enhancement in terms of residual energy, throughput, latency, and stability gains more than LEACH, TENN, LEACH-K, LEACH-C, Improved-LEACH, Stable-Improved-LEACH, MDC maximum distance leach, LEACH-G-K but it is less stable than MDC-K and MhSa- LEACH protocols.

REFERENCES

[1] R. Gantassi, B. B. Gouissem, and J. B. Othmen, "Routing protocol LEACH-K using K-means algorithm in wireless sensor network," in *Proc. Workshops Int. Conf. Adv. Inf. Netw. Appl.* Springer, 2020, pp. 299–309.

[2] S. Y. K. Nagesh and S. P. Kumar, "Reputation-based energy efficient opportunistic routing for wireless sensor network," *J. Telecommun., Elec. Comput. Eng. (JTEC)*, vol. 9, nos. 3–6, pp. 29–33, 2017.

[3] J. Liu, L. Liu, Z. Liu, Y. Lai, H. Qin, and S. Luo, "WSN node access authentication protocol based on trusted computing," *Simul. Model. Pract. Theory*, vol. 117, May 2022, Art. no. 102522.

[4] W. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan, "Energy-efficient communication protocol for wireless microsensor networks," in *Proc. 33rd Annu. Hawaii Int. Conf. Syst. Sci.*, 2000, p. 10.

[5] R. Gantassi, B. B. Gouissem, and J. B. Othman, "Combination of MDC and K-Means to improve LEACH," in *Proc. IEEE Int. Conf. Commun. (ICC)*, Jun. 2021, pp. 1–5.

[6] G. Devi, S. Swain, and R. S. Bal, "The K-means clustering used in wireless sensor network," *Int. J. Comput. Sci. Eng.*, vol. 8, no. 4, pp. 106–111, 2016.

[7] D. M. Lin, D. Wang, and Y. Li, "Two-level degradation hybrid algorithm for multiple traveling salesman problem," *Appl. Res. Comput.*, vol. 28, pp. 2876–2879, 2011.

[8] E. Rabiaa, B. Noura, and C. Adnene, "Improvements in LEACH based on K-means and Gauss algorithms," *Proc. Comput. Sci.*, vol. 73, pp. 460–467, Jan. 2015.

[9] S. Randhawa and S. Jain, "Performance analysis of LEACH with machine learning algorithms in wireless sensor networks," *Int. J. Comput. Appl.*, vol. 147, no. 2, pp. 7–12, Aug. 2016.

[10] Y. Feng, S. Zhao, and H. Liu, "Analysis of network coverage optimization based on feedback K-Means clustering and artificial fish swarm algorithm," *IEEE Access*, vol. 8, pp. 42864–42876, 2020.

[11] B. F. Solaiman and A. Sheta, "Energy optimization in wireless sensor networks using a hybrid K-means PSO clustering algorithm," *Turkish J. Electr. Eng. Comput. Sci.*, vol. 24, pp. 2679–2695, Apr. 2016.

[12] S. Alaa and S. Basma, "Evolving a hybrid K-means clustering algorithm for wireless sensor network using pso and gas," *Int. J. Comput. Sci. Issues*, vol. 12, no. 1, p. 23, 2015.

[13] A.-R. N. H. Ismail and A.-S. B. Y. Mohsin, "Qualnet performances of grid-based clustering for WSN's routing protocols," *Indonesian J. Elect. Eng. Comput. Sci.*, vol. 17, no. 1, pp. 448–456, 2020.

[14] P. Sasikumar and S. Khara, "K-means clustering in wireless sensor networks," in *Proc. 4th Int. Conf. Comput. Intell. Commun. Netw.*, Nov. 2012, pp. 140–144.

[15] R. Gantassi, B. B. Gouissem, O. Cheikhrouhou, S. El Khediri, and S. Hasnaoui, "Optimizing quality of service of clustering protocols in large-scale wireless sensor networks with mobile data collector and machine learning," *Secur. Commun. Netw.*, vol. 2021, pp. 1–12, Mar. 2021.

[16] M. Arshad, "Mobile data collector based routing protocol for wireless sensor networks," *Scientific Res. Essays*, vol. 6, no. 29, pp. 6162–6175, Nov. 2011.

[17] M. Arshad, M. Y. Aalsalem, and F. A. Siddqui, "Energy efficient cluster based routing scheme for mobile wireless sensor networks," in *Proc. 5th Int. Conf. Intell. Adv. Syst. (ICIAS)*, Jun. 2014, pp. 1–6.

[18] M. K. D. Barma and S. Das, "Data gathering mechanism of mobile data collector in wireless sensor network," in *Proc. Int. Conf. Internet Things Appl. (IOTA)*, Jan. 2016, pp. 401–405.

[19] R. Vishnuvarthan, R. Sakthivel, V. Bhanumathi, and K. Muralitharan, "Energy-efficient data collection in strip-based wireless sensor networks with optimal speed mobile data collectors," *Comput. Netw.*, vol. 156, pp. 33–40, Jun. 2019.

[20] S. Trigui, O. Cheikhrouhou, A. Koubaa, A. Zarrad, and H. Youssef, "An analytical hierarchy process-based approach to solve the multi-objective multiple traveling salesman problem," *Intell. Service Robot.*, vol. 11, no. 4, pp. 355–369, Oct. 2018.

[21] A. Koubâa, O. Cheikhrouhou, H. Bennaceur, M.-F. Sriti, Y. Javed, and A. Ammar, "Move and improve: A market-based mechanism for the multiple depot multiple travelling salesmen problem," *J. Intell. Robot. Syst.*, vol. 85, no. 2, pp. 307–330, 2017.

[22] U. Sharma, C. R. Krishna, and T. P. Sharma, "An efficient mobile data collector based data aggregation scheme for wireless sensor networks," in *Proc. IEEE Int. Conf. Comput. Intell. Commun. Technol.*, Feb. 2015, pp. 292–298.

[23] A. S. Kirsan, U. H. Al Rasyid, I. Syarif, and D. N. Purnamasari, "Energy efficiency optimization for intermediate node selection using MhSA-LEACH: Multi-hop simulated annealing in wireless sensor network," *EMITTER Int. J. Eng. Technol.*, vol. 8, no. 1, pp. 1–18, Jun. 2020.

[24] A. Elsayed, M. Sharaf, and F. Elrefaai, "MA-LEACH: Energy efficient routing protocol for WSNs using particle swarm optimization and mobile aggregator," *J. Al-Azhar Univ. Eng. Sector*, vol. 12, no. 45, pp. 1401–1407, Oct. 2017.

[25] M. Zahra and K. Maryam, "Traveling salesman problem for routing in the clusters and estimated time for receiving information to BS by neuro-fuzzy," in *Proc. Symp. Adv. Sci. Technol.*, 2013, pp. 1–7.

[26] U. Hinal and M. Mala, "Improved APAC algorithm for minimizing delay in wireless sensor network with mobile sink," *Int. J. Adv. Comput. Res.*, vol. 7, no. 28, p. 23, 2017.

[27] P. Nayak, G. K. Swetha, P. Kaushal, and D. G. Padhan, "Cluster formation algorithm in WSNs to optimize the energy consumption using self-organizing map," in *IoT and Analytics for Sensor Networks*. Springer, 2022, pp. 11–22.

[28] S. K. Rani, "Network adaptive self-configuring multi-mode leach protocol for hierarchical WSN," in *Proc. 3rd Int. Conf. Commun., Comput. Elec. Syst.* Springer, 2022, pp. 673–684.

[29] Y. Zhuang, J. Pan, and G. Wu, "Energy-optimal grid-based clustering in wireless microsensor networks with data aggregation," *Int. J. Parallel, Emergent Distrib. Syst.*, vol. 25, no. 6, pp. 531–550, Dec. 2010.

[30] K. M. Chowdary and V. Kuppili, "Enhanced clustering and intelligent mobile sink path construction for an efficient data gathering in wireless sensor networks," *Arabian J. Sci. Eng.*, vol. 46, no. 9, pp. 8329–8344, Sep. 2021.

[31] R. Gantassi, A. B. Yagouta, and B. B. Gouissem, "Improvement of the LEACH protocol in load balancing and energy-association conservation," in *Proc. Int. Conf. Internet Things, Embedded Syst. Commun. (IINTEC)*, Oct. 2017, pp. 53–59.

[32] A. Manjeshwar and D. P. Agrawal, "TEEN: A routing protocol for enhanced efficiency in wireless sensor networks," in *Proc. 15th Int. Parallel Distrib. Process. Symp. (IPDPS)*, 2001, p. 189.

[33] W. Xinhua and W. Sheng, "Performance comparison of LEACH and LEACH-C protocols by NS2," in *Proc. 9th Int. Symp. Distrib. Comput. Appl. to Bus., Eng. Sci.*, Aug. 2010, pp. 254–258.

[34] N. Kumar and J. Kaur, "Improved LEACH protocol for wireless sensor networks," in *Proc. 7th Int. Conf. Wireless Commun., Netw. Mobile Comput.*, Sep. 2011, pp. 1–5.

[35] A. S. Al-Zubaidi, A. A. Ariffin, and A. K. Al-Qadhi, "Enhancing the stability of the improved-LEACH routing protocol for WSNs," *J. ICT Res. Appl.*, vol. 12, no. 1, pp. 1–13, Apr. 2018.

[36] F. A. Siddqui, M. Saeed, J. R. Khan, M. Arshad, and N. Touheed, "WSN multi-tier MDC grid based routing protocol to mitigate financial impact," *Int. J. Comput. Sci. Netw. Secur*, vol. 17, no. 11, pp. 20–27, 2017.

[37] T. Sharma, B. Kumar, and G. S. Tomar, "Performance comparision of LEACH, SEP and DEEC protocol in wireless sensor network," in *Proc. Int. Conf. Adv. Comput. Sci. Electron. Eng.*, 2012, pp. 1–6.

[38] P. Rawat and S. Chauhan, "A novel cluster head selection and data aggregation protocol for heterogeneous wireless sensor network," *Arabian J. Sci. Eng.*, vol. 47, no. 2, pp. 1971–1986, Feb. 2022.

[39] M. Rayenizadeh, M. K. Rafsanjani, and A. B. Saeid, "Cluster head selection using hesitant fuzzy and firefly algorithm in wireless sensor networks," *Evolving Syst.*, vol. 13, no. 1, pp. 65–84, Feb. 2022.

[40] S. Al-Sodairi and R. Ouni, "Reliable and energy-efficient multi-hop LEACH-based clustering protocol for wireless sensor networks," *Sustain. Comput., Inform. Syst.*, vol. 20, pp. 1–13, Dec. 2018.

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