Smart Mobile Data Collectors to Enhance quality of service in Wireless Sensor Networks

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Abstract

This paper proposes a new intelligent mobile data collector (MDC) using the traveling salesman problem (TSP) in order to find the optimal path traversed by the MDC for efficiency of energy and quality of service (QoS). Specifically, our proposed MDC-TSP protocol uses K-Means and grid clustering algorithm to reduce the consumption of energy during the cluster head (CH) election step. Furthermore, MDC is used as an interface between CH and sink to improve Wireless Sensor Network (WSN) QoS to enhance the MDC-K protocol transmission phase. Experimental results show that MDC-TSP improves on various improvements of the low energy adaptive clustering (LEACH) protocol like MDC-K.

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1 Introduction

More studies have demonstrated that the implementation of mobile data collector (MDC) can enhance wireless sensor network (WSN) performances. Some important design issues, in particular, how how to locate the sensor nodes (SNs), SNs amount, and best MDC path design, have been identified. Thus, new approaches have been developed for WSNs to manage clustering protocols, media access control, etc. However, many studies have concentrated on minimizing the energy consumption of routing protocols, but most of them did not address the other quality of service (QoS), like stability... This motivates us to propose a routing protocol that addresses the QoS node energy consumption,

throughput, latency-time, and stability. In WSNs and internet of things (IoT) [1, 2], clustering emerged as a major technique for data-mining to address problems such as lifetime of the network, stability, aggregation of data, reduction of energy consumption, and reliability [3]. For many benefits, aggregation is recommended in the exploitation of WSNs data. Moreover, clusters are a major part of WSN organization, impacting the efficiency of the network anyway. Clustering is the process of dividing a WSN into groups known as " clusters ", every cluster has a leader elected among the SNs that are called CH. The data streams are transmitted from the SNs and subsequently aggregated via their CH in a cluster. Then CHs send the data to the base station (BS). WSNs clustered protocols consist of rounds. Each round implies cluster creation, the CH election, and data transmission [4]. The WSNs clustered algorithms executing data streams composed of 2 main stages, namely clustering phase and transmission phase of the data. The Grid algorithm is regarded as a cluster of clusters, where the elementary clusters are not dynamic. Specifically, this approach fixes the size and location of the clusters[5, 6]. Furthermore, there are some other clustering algorithms have been suggested in the literature, like K-Means algorithm. It splits the SNs into k clusters by using the Euclidian distance mean, resulting in optimizing intracluster likeness [7].
This research suggests a new protocol named (MDC-TSP), which is a combination of MDC-K [8] approach and the traveling salesman problem (TSP) based MDC method. MDC-TSP utilizes the K-Means and the Grid clustering algorithms to reduce the CH election phase energy consumption and to improve the election of CH and a new intelligent MDC, which uses TSP to find the MDC optimal path for efficient latency time. In particular, our proposed protocol aims to extend the network lifetime and to improve its QoS criteria. Our contribution is presented below:

- First, a Grid algorithm is applied to divide the area-network in equally sized areas, and then the K-Means algorithm is implemented on every grid cluster to find the CH. To do this, each CH is assigned by the SN having the least distance to the centroid of every grid cluster.
- During the transmission phase, we use TSP to find the optimal MDC path (in which MDC acts as an intermediary between the CH and the BS).
- Finally, a comparative study of the proposed protocol with existing solutions was conducted and found to be more effective.

This paper is organized as follows. Section 2 presents a literature review of the clustering protocol using K-Means algorithm, Grid algorithm, and TSP in MDC. Section 3 presents K-Means algorithm protocol. Section 4 presentsthe proposed clustering protoco. The simulation results and analyses are presented in Section 5. Finally, Section 6 presents the conclusions.

2 Literature Study

Various studies are focused on the development of MDCs in routing protocols [8–10, 10, 11] in order to increase WSN lifetime. Several other studies have been carried out to assess the impact of K-Means on the performance of the clustering protocol performance in WSN [12–14]. Other works, Other works, on the other hand, implement grid clusters on LEACH to improve the efficiency of WSNs like in [7, 15, 16]. Some work in the research implements MDC in the clustering protocol, while others apply the K-Means and Grid-sizes clustering in the clustering protocol. The MDC was firstly oriented to the LEACH protocol.
The authors of [9] discuss and evaluate the LEACH-based MDC which is based on a multi-hop routing approach. This approach offers a major improvement of SN energy consumption, enhances network life, and is more efficient at collecting data at the sink than the LEACH protocol. More precisely, just forty SNs are employed, and the simulation area equals 1 km^2. Based on this work, reference [10] proposes an alternative approach, where MDC provides multi-hop communication from SNs to the MDC and then to BS. It allows decreasing the energy use for all network nodes. The MDC maximum residual energy approach [11] concentrates on multihop communication between SNs, the MDC, and the BS. In addition, it can be applied in a large area network. Simulation performance shows that this approach improves the performance compare to the LEACH protocol in terms of SN energy consumption and the network lifetime. However, it does not improve the QoS and the parameters of simulation were very limited as reported in [9].

In reference [8] MDC-K protocol, being a combination between LEACH-K and MDC protocol. More precisely, this approach utilizes K-means algorithm to decrease the energy consumption in the CH election step. Furthermore, MDC is employed to improve the WSN QoS, reduce latency in network data collection and prolong the network lifetime. The simulation results showed MDC-K has minimized energy consumption and improved QoS performance with reduced energy consumption, increased throughput, latency, and stability gains compared to LEACH, TEEN, LEACH-K, and the maximum residual energy LEACH protocols. Besides, several researchers investigate the effect of K-Means on WSNs. Several works investigate the effect of the K-Means approach on the energy consumption of SNs.[12] discusses the LEACH performance analysis using machine learning algorithms. These simulation results show a reduction in computation time by using K-Means and an increase in residual energy by using Gauss. The limitation of the study is that the proposed solution was run on a 100 SNs over a period of 200 rounds. The K-Means algorithm was applied in [13] in the election of the CH phase in LEACH protocol. Findings revealed that the suggested routing protocol decreased the energy consumption and latency time, increased stability time and throughput of the network. [14] studied the routing protocol and took the cluster routing point of view to study the LEACH protocol and to estimate its benefits and challenges. Therefore, a process of aggregation using K-Means algorithm is provided to achieve stable system operation and to transmit information while minimizing the energy consumption of the system. The basic concept of cluster-grid protocols consists in dividing the area into a set of quasi equal-sized grids where each grid is considered as an elementary cluster with one CH in each cluster [7, 15]. Different works use TSP to choose the optimal path of MDC. In this paper [17], the authors elaborate an alternative approach for collecting data in large-scale WSNs based on mobility in the network. In addition, in [18] a round follows the TSP path as the MDC moves through the SHDGP, the MDC may query the neighboring SNs one by one to collect data. Once a SN receives the query request, it simply uploads its data to the MDC in a single hop through one SN to the next.

As mentioned above, several works integrate the Grid and K-Means algorithm in LEACH protocol, whereas others apply the TSP algorithm in this protocol. It is worth mentioning that the two algorithms of Grid and K-Means have similar philosophies but are employed independently, as stand-alone algorithms, to decrease energy consumption in LEACH. Although, there are only a few studies that combine the two algorithms (Grid, K-Means) to enhance the QoS of the LEACH protocol. However, to the best of our awareness, almost no studies have integrated Grid, K-means, TSP algorithms and MDC in LEACH protocol. This paper focuses on integrating the K-means and Grid algorithms in a Clustering phase in which the TSP approach is utilized in the transmission step of LEACH protocol to enhance the QoS.

3 K-means algorithm

In the case of the k-Means algorithm, the selection of CHs is based mainly on Euclidean distances and depends on the residual energies of the SNs. Thus, here, the center node collects the identification, residual energy and position of all SNs and saves this in a list in the center node. After it collects this information from all the SNs, it starts running the K-Mean clustering algorithm [19, 20]. The K-Means algorithm is as follows:

Step1: Set the initial number of centroids K on random locations.

Step2: For each cluster, calculate the Euclidean distance from each SN to all centroids and assign it to the closest centroid and then the initial K clusters are created.

Suppose there are N SNs where each of them belongs to D_R. To find the minimum variance grouping of these nodes into K clusters, the problem is to find the K centroids $[A_i]_{i=1}^{K}$ in D_R where:

$$(1/N)\times\sum\left\{mind^2(X_j,A_i)\right\}; \qquad for \quad j=1 \;\; to \;\; N \tag{1}$$

where:

d $(X_j\ ,\ A_i)$ refers to the Euclidean distance between X_j and A_i. The SNs $[i]_{j=1}^{K}$ are known as the centroid of cluster.

Step3: Recalculate the centroids locations within every cluster and verify the change in location from the last one.

Step4: If the position of a centroid changes, proceed to step 2. Otherwise the process of clustering is finished.
The process of K-Means algorithm is shown in in Fig. 1.

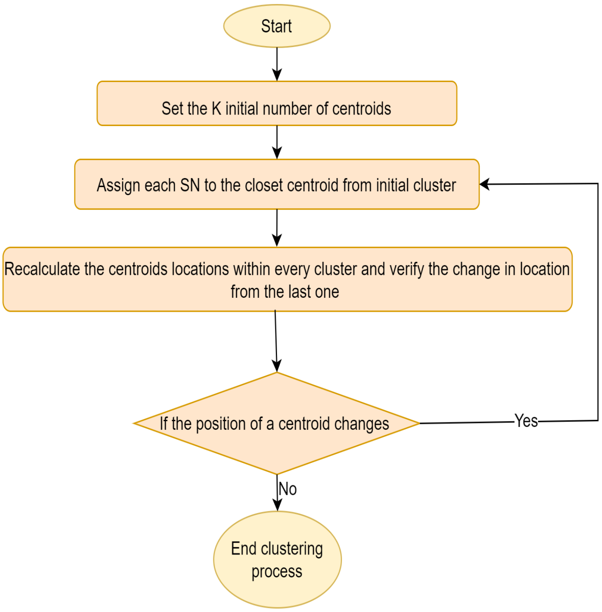

Fig. 1: The process of K-Means.

4 The proposed MDC-TSP protocol

Our assumption is that the WSN consists of 100 SNs from similar types deployed randomly. The geographical coordinates of each SN are known and allocated to them during the deployment phase. Each coordinate is used as an identifier of the given node. In addition, there is also the sink in the network, which is the BS. The latter is located outside the area network. Once the WSN deployment is completed, the process of building the network is launched based on their location. In our network model we assume:

- Homogeneous SN.
- The SNs are static and know their locations.
- Clustering is done through the Grid algorithm.
- CH is elected through the K-Means algorithm, the node having the minimum distance with centroid from each grid will be CH.
- BS gives the coordinates of all the CH to the MDC to use as input to the TSP algorithm.
- There is a single intelligent MDC.

4.1 MDC-TSP Model

MDC-TSP [8] extends the concept of MDC-K with the convergence of wireless mobile communication and improved WSN technology. We use the Grid and K-Means approach to improve the clustering phase and MDC as an interface between CHs and BS to improve the routing phase. The area of WSN is partitioned into grids of defined size (e.g., a 5 × 5 grid, as shown in Fig. 2). Each grid is a rectangular area of d × d. After the grid G is configured and all of the nodes are positioned, the K-Means algorithm is implemented on every grid cluster to minimize the intracluster communication distance and to deliver the centroid coordinates. The selection of the CH is based on the centroid distance. Suppose the number of nodes denoted by (N_i) is subdivided into$K$ clusters. Then the centroid c is chosen to be the centroid of the K clusters. The K-Means step, therefore, begins by calculating the positions of each grid centroids. Allocate every CH to the SN with the minimum distance to the centroid. Each SN belongs to the Grid(i) with coordinates $(x_i,\ y_i)$ then calculates the minimum distance as follows:

$$D\left(SN(j),c(i)\right)=min\left\{\sqrt{\left(x_c-\ x_i\right)^2+\left(y_c-y_i\right)^2}\right\};\ SN(j)\in G_c(i) \tag{2}$$

The CH is elected for each grid. Every CH broadcasts its position in its area of transmission to all nodes in its grid cluster via specially crafted packets containing its coordinates. The MDC makes its case intelligently by approaching only the CHs nearest to its borders. The MDC provides a dynamic trajectory using the TSP algorithm. TThe MDC collects data that is disseminated directly by the CH. However, the MDC completes the data collection and ultimately provides the data to the sink. Fig. 2 illustrates a straightforward MDC strategy in WSN and Fig. 3 illustrates a process of the MDC-TSP.

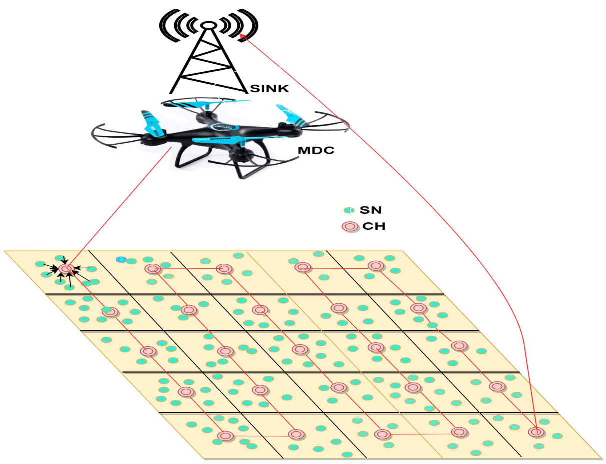

Fig. 2: MDC-TSP Architecture.

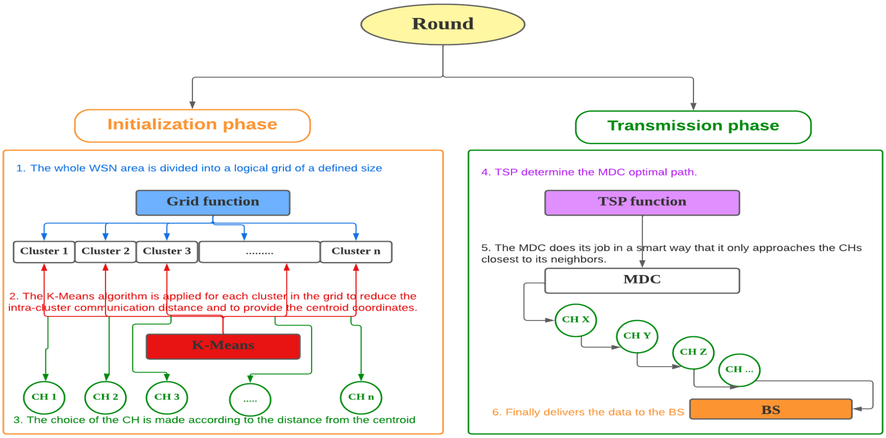

Fig. 3: The process of the MDC-TSP.

In this scheme, a WSN based on a grid of clusters is used in the proposed system. For each grid cluster (GC), one SN is elected as the CH, which operates as an aggregator. The CH is responsible for aggregating the data received from its SNs and sends them to the sink through the MDC. The resolution of the TSP gives the MDC a dynamic trajectory. Due to the fact that the CHs are nearly at the centroid, the MDC travels on a nearly linear path from the earliest centroid of the earliest GC to the final column of the GC. After that, it travels to the closest GC centroid to the entire GC. In the end, it transfers the full data to the sink. Therefore, energy and latency can be conserved by utilizing The TSP in MDC.

- We propose a smart routing clustering protocol consisting of two phases: an initialization phase and a transmission phase. This approach is an improvement of the MDC-K,LEACH-k protocols (which is an improvement of the LEACH protocol using the K-Means machine learning algorithm at the level of the initialization phase exactly the CH election phase and by integrating TSP at the MDC exactly at the level of the transmission phase).
- Using MDC the energy consumption and latency in the transmission phase reduces and the throughput is increased.
- However, to demonstrate the advantages of our protocol, we have compiled a comparison with the native LEACH protocol and its enhancements from 2008 to 2021 (LEACH, TEEN, LEACH-K, LEACH-C, Improved-LEACH, Stable-Improved-LEACH and MDC-maximum residual energy leach Protocol).

5 Evaluation and simulation results

In order to assess our protocol's performance, it is compared with several other QoS-based protocols. We compared our MDC-TSP approach with LEACH and the ameliorated versions of LEACH [21] protocol namely TENN [21], LEACH-K [13] , LEACH-C [22], Improved-LEACH [23], Stable-Improved-LEACH [24], MDC maximum residual energy leach [25], and MDC-K [8] protocols in terms of residual energy, packet latency time, and throughput. Table 1 depicts the common simulation settings for all scenarios.

Table 1: Simulation Parameters.

Parameters	Values
Position of BS	$(0.5, 1.05)$
Electronic dissipation energy	E_{elec}= 50 nJ/bit
Data aggregation energy	$E_{DATA} = 5nJ/bit/m^2$
Transmit Amplifier $d_{toBS} \leq d_0$	$E_{Afs} = 10pJ/bit/m^2$
Transmit Amplifier $d_{toBS} \geq d_0$	$E_{Amp} = 0.0013pJ/bit/m^4$
Round duration	20 seconds
Lifetime	Round duration x Number of round of live nodes
Initial energy	$0.5J/node$

The test scenarios considered and the performance measures adopted are discussed in this section. The analysis of these results is performed in order to make a trade-off between residual energy, throughput (packets received by the sink) and network latency as a function of the variation of K over 10000 rounds. One hundred nodes have been chosen to test the performance of MDC-TSP protocol. Fig. 4 shows the throughput in each round of TENN, MDC maximum residual energy leach, LEACH-K, LEACH-C, LEACH, Improved-LEACH, Stable-Improved-LEACH, MDC -K protocols, and the proposed protocol MDC-TSP.

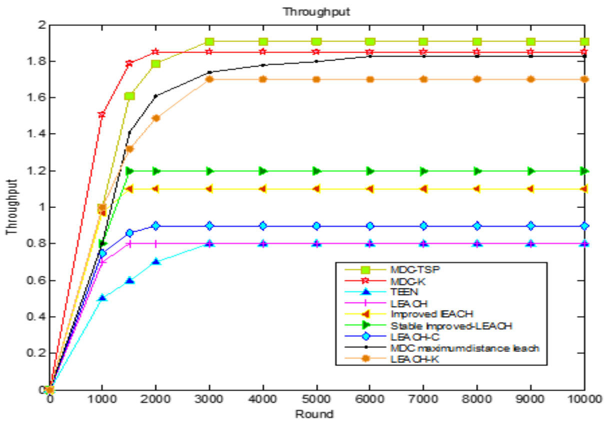

Fig. 4: Simulation throughput results of MDC-TSP, LEACH, TENN, LEACH-K, LEACH-C, Improved-LEACH, Stable-Improved-LEACH and MDC maximum residual energy leach Protocols.

Fig. 4 shows a variation of throughput of our proposed protocol as compared to Improved-LEACH, TENN, LEACH-K, LEACH-C, Improved-LEACH, Stable-Improved-LEACH, MDC-K, LEACH and MDC maximum residual energy leach protocols. The graphs in Fig. 4 show that the MDC implementation with TSP algorithm enhances a significant amount of throughput. We observed in the previous figure that the throughput of MDC-TSP in round 10000 is equal to 18910 packet/round compared to 18300 packet/round for MDC maximum residual energy leach protocol, 18110 packet/round of LEACH-K protocol, 11845 packet/round of Improved-LEACH protocol, 12009 packet/round of Stable-Improved-LEACH protocol, 8012 packet/round of TEEN protocol and 8001 packet/round of LEACH protocol. However, our proposal enhances the Throughput value by reducing the path distance between sink and CH using the K-Means algorithm and decreasing the latency time by utilizing TSP in MDC. Fig. 5 shows a comparison between MDC-TSP approach LEACH, TENN, LEACH-K, LEACH-C, Improved-LEACH, Stable-Improved-LEACH and MDC maximum residual energy leach protocol in terms of latency time.

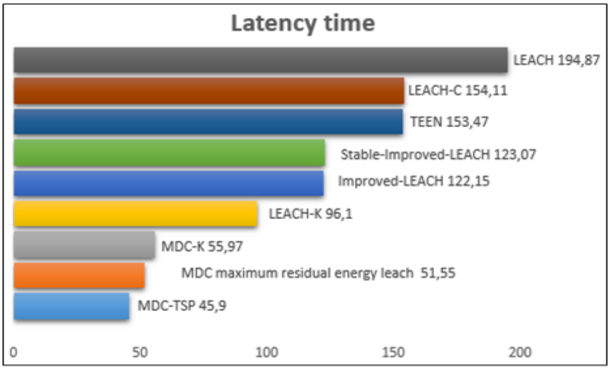

Fig. 5: Comparison between MDC-TSP, TENN, LEACH-K, LEACH-C, Improved-LEACH, Stable-Improved-LEACH, and MDC maximum residual energy leach protocols in terms of latency time.

As illustrated in Fig. 5, once using our protocol approach, also the latency decreases to 194.8 (ms) for the LEACH protocol, 154.11 (ms) for the LEACH-C protocol, 153.47 (ms) for the TEEN protocol, 123, 07 (ms) for the Stable-Improved-LEACH protocol, 122.12 (ms) for the Improved-LEACH protocol, 96.1602 (ms) for the LEACH-K protocol, 55.97 (ms) for the MDC-K protocol, and 51.551 (ms) for the MDC maximum residual energy leach protocol compared to 45.9 (ms) for the MDC-TSP protocol to 45.9 (ms). However, we find that our approach provides optimal latency reduction over the previous routing protocols. Fig. 6 compares MDC-TSP approach LEACH, TENN, LEACH-K, LEACH-C, Improved-LEACH, Stable-Improved-LEACH, MDC-K and MDC maximum residual energy leach protocols in terms of lifetime.

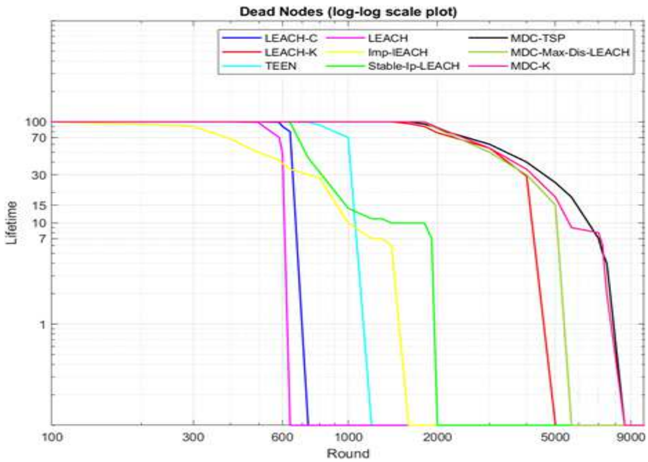

Fig. 6: Comparison between MDC-TSP, LEACH, TENN, LEACH-K, MDC-K, LEACH-C, Improved-LEACH, Stable-Improved-LEACH and MDC maximum residual energy leach protocols in terms of lifetime.

As illustrated in Fig. 6, our protocol MDC-TSP improves the lifetime of the network with higher efficiency in terms of stability than LEACH, TENN, LEACH-K, MDC-K, LEACH-C, Improved-LEACH, Stable-Improved-LEACH, but it is less stable than MDC.It improves the SNs residual energy as well. Results show that the proposed method is able to decrease the sensor nodes' energy consumption. Fig. 7 presents the stability of the proposed protocol compared to the MDC-TSP approach LEACH, TENN, LEACH-K, LEACH-C, Improved-LEACH, MDC-K, Stable-Improved-LEACH and MDC maximum residual energy leach protocol.

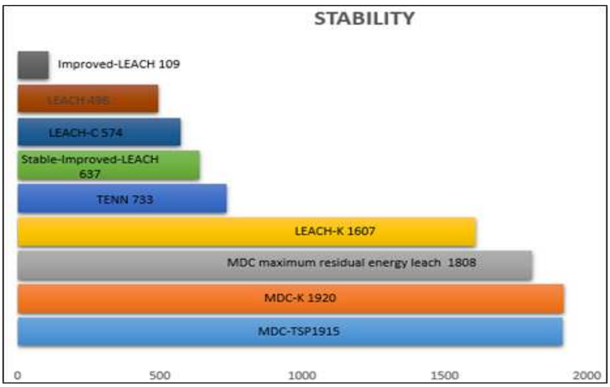

Fig. 7: Comparison between MDC-TSP, LEACH, TENN, LEACH-K, LEACH-C, Improved-LEACH, Stable-Improved-LEACH, MDC-K, MDC-K, and MDC maximum residual energy leach protocols in terms of stability.

Table 2: The comparison analysis of QoS criteria of our MDC-TSP and some LEACH protocol improvements in the literature

Protocols	Lifetime	Stability	CH selection	Latency Time	Complexity	Load Balancing	Scalability	Energy dissipation
LEACH	Low	Poor	Random	High	Low	No	Poor	les than all the amelioration of LEACH
TENN	Low	Poor	Random	High	Low	No	Poor	High than LEACH
LEACH-G-K	High	High	Choose the node near the centroid of the cluster	Poor	High	No	High	High than LEACH, LEACH-C, TEEN, Improvement-LEACH, Stable-Improved-LEACH, and LEACH-K
Improved-LEACH	High	Poor	According to the residual energy	High	Low	No	High	High than LEACH, LEACH-C, and TEEN
Stable-Improved-LEACH	High	Medium	According to the residual energy	High	Medium	No	High	High than LEACH, LEACH-C, TEEN, Improvement-LEACH, and LEACH-K
MDC maximum distance	High	Medium	Choose the node near the BS	less	Medium	No	High	High than LEACH, LEACH-C, TEEN, Improvement-LEACH, LEACH-K, and Stable-Improved-LEACH
MDC-K	High	High	Choose the node near the centroid of the cluster	Poor	High	No	High	High than LEACH, LEACH-C, TEEN, Improvement-LEACH, LEACH-K, Stable-Improved-LEACH, LEACH-K, LEACH-G-K, and MDC maximum distance leach
MDC-TSP	High	High	Choose the node near the centroid of the cluster	Poor	High	No	High	High than LEACH, LEACH-C, TEEN, Improvement-LEACH, LEACH-K, Stable-Improved-LEACH, LEACH-K, LEACH-G-K, MDC-K and MDC maximum distance leach

The stability improves slightly from 109(rounds) in Improved-LEACH to 496 (rounds) in LEACH to (574) in LEACH-C to (637) in Stable-Improved-LEACH to 733 (rounds) in TEEN to 1607 (rounds) in LEACH-K to 1915(rounds) in MDC-TSP to 1808 in MDC maximum residual energy leach to 1920 (rounds) MDC-K. We observe that the MDC (Maximum residual energy leach) protocol is more stable than our protocol.To assess the effectiveness of our MDC-K protocol in improving the QoS of the routing protocol,236 Table 2 summarizes a comparison of our protocol and some similar protocols in the literature.

6 Conclusion

MDC represents one of the emerging technologies for diverse applications of WSNs. The main focus of these networks are latency time, throughput, lifetime, stability and energy efficiency. This paper proposes the MDC-TSP protocol, which is a combination of the MDC-K protocol and the TSP to improve the transmission phase of MDC-K protocol. To be more precise in our approach an MDC is employed as an interface between the CH and the BS to improve the QoS of WSN, to decrease delay during data collection, and to increase the lifespan of WSN. The simulation results showed that MDC-TSP had a significant impact on energy consumption and QoS than LEACH, TENN, LEACH-K, LEACH-C, Improved-LEACH, Stable-Improved-LEACH, MDC maximum residual energy leach and MDC-K protocols.

Declarations

Author Contributions. Rahma Gantassi: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing original draft, Visualization. Zaki Masood : Software, Validation, Data curation, Visualization. Yonghoon Choi: Validation, Resources, Writing review and editing, Supervision, Project administration, Funding acquisition.

Confict of interest. The authors have no competing interests to declare that are relevant to the content of this article.

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Ethical Approval. This article does not contain any studies with human participants or animals performed by any of the authors.

Availability of data and materials. not applicable

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