IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received 26 December 2023, accepted 26 January 2024, date of publication 26 February 2024, date of current version 15 March 2024.

Digital Object Identifier 10.1109/ACCESS.2024.3370432

RESEARCH ARTICLE

Enhanced Network QoS in Large Scale and High Sensor Node Density Wireless Sensor Networks Using (IR-DV-Hop) Localization Algorithm and Mobile Data Collector (MDC)

RAHMA GANTASSI[1], (Member, IEEE), SANA MESSOUS[2], ZAKI MASOOD[1], (Member, IEEE), QUOTA ALIEF SIAS[1], AND YONGHOON CHOI[1], (Senior Member, IEEE)

[1]Department of Electrical Engineering, Chonnam National University, Gwangju 61186, South Korea

[2]Department of Electrical Engineering, Research Laboratory of Automatic Signal and Image Processing (LARATSI), National Engineering School of Monastir (ENIM), University of Monastir, Monastir 5019, Tunisia

Corresponding author: Yonghoon Choi (yh.choi@jnu.ac.kr)

This work was supported in part by the Ministry of Education of the Republic of Korea, and in part by the National Research Foundation of Korea under Grant NRF-2023S1A5C2A07096111.

ABSTRACT This paper poses new challenges, especially when designing routing protocols to improve the quality of service (QoS) criteria and the lifetime of large-scale wireless sensor networks (LS-WSNs) and high sensor node density WSNs (HSND-WSN). Some of these challenging problems for routing protocols are minimizing the distance between a base station (BS) and the cluster head (CH), latency in the transmission phase, power consumption in the clustering phase, and determining the precise SN location without error. Thus, for a dynamic WSN, it is important to support an intelligent mobile data collector (MDC) to continue data propagation despite the inevitable changes in the WSN topology. Considering these challenges, we propose a novel intelligent routing protocol based on the improved recursive distance vector-hop (IR-DV-Hop) localization algorithm to determine the accurate location of SNs without errors in LS-WSNs and determine the CHs and optimal route traversed by the MDC for energy efficiency, latency, and reliability. Specifically, the proposed mobile data collector-improved recursive distance vector-hop (MDC-IR-DV-Hop) protocol uses the MDC as an intermediate between the CH and BS to enhance the QoS of WSNs, reduce delays while collecting data, and improve the transmission phase of the routing protocol. Simulation results prove the performance of the proposed protocol compared with the energy-aware cluster based multi-hop (EACBM), tree clustering algorithm with mobile data collector (TCMDC), mobile data collector maximum residual energy low energy adaptive clustering hierarchy (MDC maximum residual energy leach), MDC minimum distance leach, mobile data collector-K-means (MDC-K), mobile data collector-traveling salesman problem-low energy adaptive clustering hierarchy-K-means (MDC-TSP-LEACH-K), a three-layer hierarchical architecture for optimized routing protocol based on clustering and the Khalimsky topology for mobile WSN (AMWSN), and node density-based clustering and mobile collection (NDCM) protocols. In addition, this article proposes a comparative analysis of the best clustering, CH election, localization and MDC by discussing and describing their functionalities, advantages, disadvantages and their main performance parameters.

INDEX TERMS High sensor-node density wireless sensor network (HSND-WSN), improved recursive distance vector-hop (IR-DV-Hop), large-scale wireless sensor network (LS-WSN), mobile data collector (MDC), quality of service (QoS), routing protocol.

The associate editor coordinating the review of this manuscript and approving it for publication was Zhangbing Zhou.

I. INTRODUCTION

The growth of wireless sensor networks (WSNs) has recently accelerated owing to their capability to sense and compute data efficiently. This rapid growth of WSNs has contributed to their wide use in many applications, such as telecommunications, smart homes, disaster management, agriculture, drone applications, military services, and medical applications. As WSNs comprise small and low-cost sensor nodes (SNs), they suffer limitations, such as limited battery capacity, low memory, and a lower communication distance [1]. Energy use in WSNs is continuous because it is used while sensing, collecting, and transmitting data. However, energy consumption in the data transmission phase is higher on average. Although WSNs are low-cost, easily deployed, flexible, and efficient, there are challenges in energy efficiency and quality of service (QoS). The energy efficiency problem has recently gained more attention, as it is not easy to change or recharge the battery for large-scale networks [2]. One of these problems involves clustering, election of the cluster head (CH), and data transmission in WSNs. Clustering in WSNs is the most reliable solution for the challenges, where SNs are grouped into a few clusters, and a CH is selected for data aggregation. However, many challenges still exist in energy efficiency when designing routing protocols, such as minimizing the distance between SNs and the CH and between the base station (BS) and CH in the clustering phase. The announcement of the nearest CH location to the BS is one of these challenges and is a central problem for any routing protocol. Although much research has focused on reducing the energy consumption of routing protocols, few researchers have addressed other QoS criteria, such as stability, and throughput.

The clustering mechanism hierarchically provides SN grouping and ensures efficiency, scalability, and collaboration in the network. As a promising approach, it reduces the required total transmissions to the BS and reduces cluster energy because CHs aggregate the data from their SNs and transmit them to the BS. In addition, the dynamic topology incurs maintenance costs when using the clustering technique. Typically, reconfiguration is performed at the level of the CH, which does not affect the other SNs in the cluster. In summary, clustering can achieve several objectives, such as improved scalability, uniform network energy, efficient resource use, and enhanced QoS [3], [4]. These clustering algorithms for WSNs executed on data streams are divided into two main steps: the clustering and data transmission phases. In the clustering phase, by employing the density-based clustering algorithm [5], each cluster is formed by the same number of SNs [6]. Furthermore, other transmission algorithms have been suggested in the literature, such as the distance vector-hop (DV-Hop) algorithm and its improvements [7], [8] that reduce the localization error. However, the battery energy in a WSN is a limited resource for SNs. Therefore, the energy consumption of SNs determines their and the network's lifetimes, which affects the network connectivity and coverage. A smart mobile data collector (MDC) can reduce energy consumption for data collection instead of transmitting multi-hop data to the BS. The MDC collects data from SNs and transfers it to the BS. Various MDC approaches have been explored for different assumptions and constraints [9], [10]. However, in all proposed models, the data latency is usually high due to the slow speed of the mobile nodes.

This paper proposes a new routing strategy based on clustering and a data collection mechanism based new model of MDC on wireless communication. Using clustering, IR-DV-Hop protocols and a MDC, we demonstrate that the delay can be reduced significantly without compromising the advantages of the MDC-based approach. Using extensive simulation studies, we analyzed the performance of the proposed approach and demonstrated that the packet delay was reduced by more than half compared to other existing approaches. Therefore, we propose a novel mobile routing protocol that minimizes significant data latency and improves several QoS criteria. This research focuses on combining the MDC and improved-recursive (IR) DV-Hop during in transmission phase using a combination of a novel equal-clustering-based round strategy and a wireless-based data collection mechanism, where the IR-DV-Hop protocol is an improvement of the original DV-Hop algorithm and updates the recursive least squares solution. We apply a recursive method for the SN localization process to help the BS determine the precise SN locations, elect the optimal CH, and determine the optimal MDC path to collect CH data. Thus, the proposed MDC-IR-DV-Hop-K protocol uses equal clustering to decrease energy consumption and the IR-DV-Hop algorithm to decrease the localization error, provide efficient reliability, and improve the CH election phase. It also uses a novel intelligent MDC based on the IR-DV-Hop results and a spiral path for efficient QoS. Specifically, the contribution of this paper is as follows:

- In this paper, We have proposed a new routing protocol called IR-DV-Hop-LEACH-K. We assume that the BS is not limited in energy and that the BS coordinates and field dimensions are known, at least in comparison to the energy of other SNs. We also assume that the SNs are uniformly distributed over the field and are not mobile. First, the BS applies the IR-DV-Hop algorithm in the WSN to determine the location of all SNs without error. Then, its fixed spiral is the MDC trajectory, beginning from the centroid of the area. After that, The BS assigns each CH to the SN that belongs to $spiral_{MDC}$. In addition, we propose a threshold that balances the number of member SNs of all clusters. Each CH accepts the SN as a member if the distance between itself and the SNs is less than or equal to the minimal distance. The CH accepts this SN as a member SN whose number of member SNs is less than or equal to the threshold. In addition, CHs collect and aggregate data received from their cluster members. The intelligent MDC is based on the spiral trajectory starting from the centroid area as an interface between the CHs and BSs.

- This protocol uses the IR-DV-Hop algorithm to decrease the localization error, provide efficient reliability, and improve the CH election phase. Thus, it uses a smart MDC as an intermediary between the BS and CH. The MDC uses a spiral trajectory to collect data from all CHs for large-scale WSNs (LS-WSNs) and high SN density (HSND) WSNs, decreasing the latency and energy consumption. We study the effect of the area variation (from 100 m^2 to 10000 m^2) on QoS criteria.
- The simulation phase is divided into two scenarios: in the first, we justified our choice of localization protocol. In the second, we tested our protocol in the LS-WSNs and HSND-WSNs cases and demonstrated its higher performance.

The article is organized into the following sections. Section II discusses the related work. Next, Section III describes the IR-DV-Hop mechanism. Then, Section IV explains the proposed routing protocol. Section V presents the simulation results of the MDC-IR-DV-Hop mechanism. Finally, Section VI provides the conclusions.

II. RELATED WORK

One of the main approaches to designing energy-efficient, robust, and highly scalable distributed networks is to organize WSNs into clustered architectures. In WSNs, the SNs are energy constrained. Therefore, CH selection among a cluster's coordinators is a major problem in these network applications and can severely affect the energy dissipation of a network. Many studies have been conducted to evaluate the clustering algorithm to increase the lifetime of the WSN. The clustering in WSNs involves dividing the SNs into groups according to certain characteristics. Clustering can be formed based on the network topology, location, and residual energy. In each cluster, there is an SN that takes on more responsibilities, which is called the CH. The techniques of forming the CH are two-fold (distributed or centralized) in WSNs. In the former technique, each SN broadcasts information, such as residual energy, to its neighbor at a hop, and finally, the SN with the highest value becomes the CH. In the second technique, each SN is responsible for sending the information to the BS, which performs the calculation and selects CHs in the network. Subsequently, the BS notifies all nodes about their respective CHs. The clustering process consists of three steps (i.e., CH selection, cluster formation, and data transmission; Fig. 1).

Several research studies have been performed to elect the CH in clustering protocols, focusing on minimizing the energy consumption of WSNs, whereas other research studies have evaluated the effect of various machine learning algorithms on clustering performance in WSNs. Table 1 summarizes some of the literature.

The clustering process and cluster number are very important factors in clustering protocols. The number of exchanged messages during the formation of clusters must

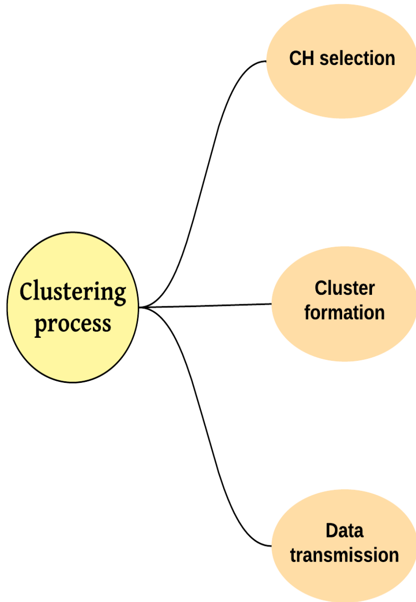


FIGURE 1. Clustering design process.

be minimized, and the clusters must be well-balanced. In addition, the algorithm complexity must increase linearly. In clustering techniques, one must also consider that the designed clustering algorithm must be able to meet the requirements of different applications. Furthermore, another crucial factor is ensuring that the designed algorithm is secure enough and can be used in very sensitive data applications and large-scale applications, such as agricultural or military applications. Table 2 summarizes some of the literature on the cluster formation method.

The cluster formation techniques minimize the problem of hot spots in WSN deployments. Table 2 addresses various cluster formation techniques proposed by researchers in recent years. As Table 2 illustrates, density-based clustering is another clustering algorithm widely applied in various WSN applications. Recently, the MDC and clustering techniques have attracted growing interest. The three most important challenges are the network division into clusters, CH election, and building an optimal MDC path. Therefore, many research studies on MDC and clustering approaches have been suggested to extend the network lifetime. The objective of Table 2 is to survey and synthesize the MDC approaches of recent studies in routing protocols.

Many researchers in the existing WSN literature have demonstrated that hierarchical routing, particularly clustering, is the most appropriate approach to increase the network lifetime and throughput and minimize energy consumption in WSNs. This approach involves a process of smart Voronoi clustering of SNs using localization algorithms as a basis for classification. We distinguished various categories of clustering techniques and localization algorithms. The most popular are Voronoi and the IR-DV-Hop algorithm. However, the difficulty lies in choosing the CH, supervising the clusters, and improving the QoS of WSNs.

TABLE 1. Summary of cluster head (CH) selection-based protocols.

Ref./year	Contributions	Completed validations	Limitations to address	Clustering method (distributed vs. centralized)	Data transmission parameter	Election of CH based on parameters	Rotation of CH	Algorithm complexity	Overhead	Mobility of CH
[11]/2023	HLBC focuses on the CH selection process optimization and the intra-group communication distance (IACD) reduction. In this contribution, multi-objective optimization based on ratio analysis (MOORA) has been used regarding 3 attributes as critical respectively, relay distance and remaining energy.	As a result, this framework has outperformed other leading-edge studies for homogeneous and heterogeneous scenarios.	This approach did not use the MDC in the transmission phase and was not tested in LS-WSNs. It did not improve the network QoS.	Centralized	Multi-hop	MOORA	Yes	TC: O (n^2) SC: (n)	M	static
[12]/2023	This article developed an energy-efficient cluster head selection utilizing an improved version of the GWO algorithm (EECHIGWO) to mitigate the imbalance between exploitation and exploration.	Improves network stability by 169.29%, 19.03 %, 253.73%, 307.89%, and 333.51% respectively, compared with SSMOECHS, FGWSTERP, LEACH-PRO, HMGWO and FIGWO.	This approach did not use the MDC in the transmission phase and was not tested in LS-WSNs. It did not improve the network QoS.	Centralized	Multi-hop	fuzzy logic system	raggedright Yes	TC: O (n^2) SC: (n)	M	static
[13]/2022	A fuzzy-based energy-efficient CH selection algorithm is presented in this paper to extend the network lifetime. In cluster formation, the K-means algorithm is employed to form a cluster efficiently.	The simulation results show that the proposed algorithm is more efficient than the existing ones.	This approach did not use the MDC in the transmission phase and was not tested in LS-WSNs. It did not improve the network QoS.	Centralized	Multi-hop	The selection of the CH is based on a fuzzy logic system.	Yes	TC: O (n^2) SC: (n)	M	static
[14]/2022	Dynamic selection of CHs in each subsector is realized using the whale optimization algorithm. A multilevel circular WSN where the nodes are randomly distributed with a higher node density toward the BS is considered. The large circular area is divided into a few sectors.	Performance was compared with implementations of the particle swarm optimization (PSO) and low-energy adaptive clustering hierarchy (LEACH) protocols. The approach reduces the residual energy ratio by 50% and 39% for the initial energy of 50 J compared to the PSO and LEACH protocols.	This approach did not use the MDC in the transmission phase and was not tested in LS-WSNs. It did not improve the network QoS.	Distributed	Multi-hop	The selection of CH is based on the whale optimization algorithm.	Yes	TC: O (n^2) SC: (1)	M	static

TABLE 1. *(Continued.)* **Summary of cluster head (CH) selection-based protocols.**

[15]/2022	A cluster-based routing scheme for a heterogeneous network (CRSH) was proposed to perform node clustering and data aggregation. This scheme uses the node energy level to select the most power-efficient node to be the CH and aggregates data to eliminate redundant data packets.	From the simulation results, this algorithm is more efficient than the existing algorithms.	This approach was not tested in LS-WSNs and did not improve the network QoS.	Centralized	Multi-hop	The selection of CH is based on residual energy.	Yes	TC: O (n) SC: (1)	M	static
[16]/2022	A new protocol for CH selection was proposed using the firefly algorithm (FA) and hesitant fuzzy method.	Simulation results demonstrate improved energy savings and increased network lifetime for the proposed protocol.	This approach was not tested in LS-WSNs.	Distributed	Multi-hop	The FA and hesitant fuzzy method.	Yes	TC: O (n^2) SC: (n)	M	static
[17]/2022	A cluster-based data aggregation framework for WSNs based on the blockchain technique was proposed.	The simulations found that this algorithm is more efficient than the existing ones.	This approach was not tested in HSND WSNs.	Distributed	Multihop	The selection of CH is based on energy.	A single turn of the CH	TC: O (n^2) SC: (n)	L	static
[18]/2022	A optimization algorithm based on teaching-learning was used to select the appropriate CHs from the existing SNs after distributing the SNs into the environment. The teaching-learning philosophy was modeled on a classroom and mimicked the effect of a teacher on the learner's performance. After collecting data from each cluster to send the information to the BS, CHs use the tabu search algorithm to determine the next step for transmitting information.	The proposed protocol in this research has a higher last node dead than 1) the LEACH algorithm by 75 %, 2) the ASLPR algorithm by 25%, and 3) the COARP algorithm by 10%.	This approach was not tested in LS-WSNs and did not improve the network QoS.	Distributed	Multihop	The selection of	No	TC: O (n^2) SC: (n)	M	static
[19]/2022	This approach employs the K-means machine learning algorithm to decrease energy consumption in the CH election step and an MDC as an intermediary between the CH and BS to enhance the QoS.	The MDC-K performance improves energy consumption and QoS metrics compared to the LEACH, LEACH-K, MDC maximum residual energy leach, and threshold-sensitive energy-efficient network (TEEN) protocols.	This approach was not tested in LS-WSNs and did not improve the network QoS.	Centralized	Multi-hop	The CH selection is based on the K-means algorithm.	Yes	TC: O (n^2) SC: (1)	L	static

TABLE 2. Summary of cluster formation method literature.

Cluster formation technique [ref.]/year	Methods	Advantages	Limitations
Unequal clustering [20] [21] /2019-2023	EADUC MHACO-UC, UCEH, Cognitive partition unequal clustering, EEUCLC, UC-GA, and UC-PSO	Helps solve the network hole problem (hotspot problem), balances the energy consumption of CHs, and improves the network lifetime.	Deploying unequal clusters can be tedious and may cause process overhead. It is not very scalable and might take a long time to form clusters.
K-means clustering [22], [23] /2022-2023	K-means, LCDGRA, Ununiform K-Means, KC-GA, KC-PSO, Mini Batch Mean, K-MCI (K-means modified cohort intelligence), ELM K-means (extreme learning machine K-means), K-means-based multiview clustering methods, and K-means subspace clustering model	K-means clustering is one of the simplest and most popular clustering algorithms. The k-means method represents each cluster by its center and iteratively updates the center and data point assignments to the centers until convergence criteria are met.	It can only be effectively used for small-scale networks. Network performance reduces dramatically if the selected k-value is not appropriate.
Grid clustering [24], [25] /2021-2023	GRIDCLUS, WaveCluster, optimal grid-clustering (OptiGrid), statistical information grid-based (STING), grid-based cluster head (GBCHS), grid-based clustering protocol (GCP), linear time grid-clustering method (m-Adic Clustering), fast density-grid-clustering algorithm, algorithm of the dislocated grid for wireless sensor network (GAF), power-efficient gathering in sensor information system protocol grid (PEGASIS), grid-based multipath with congestion avoidance routing protocol (GMCAR), grid-based predictive geographical routing (GPGR), grid-based reliable routing protocol (GBRR)	GRIDCLUS is an algorithm for the hierarchical clustering of very large datasets. Finding clusters is converted into an image segmentation problem using wavelets to leverage the multidimensional and low-noise properties. OptiGrid is an efficient algorithm for clustering high-dimensional databases with noise. STING divides the area into rectangular cells represented by a hierarchical structure. The root is at Level 1, its offspring at Level 2, etc. In PEGASIS, the network regions are divided into grids, and each grid selects a CH and data aggregator, lessening the burden of the CH. PEGASIS is valuable for real-time applications. GMCAR and GPGR are effective in QoS. GBRR divides a 2D WSN into equal grid sizes, using the node and grid position information to minimize energy consumption rather than calculate the network topology complexity.	The CH and data aggregator might die quickly if the network size increases. It is not very efficient in terms of enhancing network lifetime. It is difficult to adapt STING to larger spaces.
Density-based clustering approach [5], [26], [27] /2011, 2022, 2023	BRIDGE, CUBN, density-based spatial clustering of applications with noise (DBSCAN), distribution-based clustering of large spatial databases (DBCLASD), and density-based clustering (DENCLUE)	The DBSCAN does not require specifying the number of clusters beforehand and performs well with arbitrarily shaped clusters. It has a notion of noise and is robust to outliers. DENCLUE is designed to group large multimedia data and can successfully find arbitrarily shaped clusters while handling noise in the data. CUBN can find nonspherical shapes and large variations.	The DBSCAN cannot cluster datasets with large differences in densities well. Choosing a meaningful EPS value can be difficult if the data are not well-understood. The DBSCAN is not entirely deterministic because the algorithm starts with a random point. Therefore, border points reachable from more than one cluster can be part of either cluster.

TABLE 3. Summary of the MDC approaches in the data transmission phase.

MDC approaches [paper]/ year	Approach	Advantages	Challenges
[28]/2023	This paper proposes a delay-based data collection system using optimal mobile data collectors (DDC-OMDC) to collect data in a network disconnected with the optimal number of MDC within a specific delay for delay-intolerant applications.	The results of the simulation demonstrate that the suggested scheme is more efficient in collecting data in real-time as well as determining the optimal MDCs and optimal data collection trajec-tory to collect data within a specific deadline for delay-intolerant applications.	This approach was not tested for high-density and LSWSNs.
[29]/2023	In this approach, the overall number of SNs is also divided into clusters. One node acts as a BS, and the nearest BS node acts as a MDC for reliable data collection from CHs and common SNs.	This approach records the packet delivery rate, reliability, packet loss rate, and energy efficiency parameters of WSNs.	This approach was not tested for HSND-WSN and LSWSNs.
[19]/2022	This paper proposed the MDC-TSP-LEACH-K protocol that uses the grid function and K-means algorithms to minimize energy consumption during CH election.	The MDC-TSP-LEACH-K uses MDC to improve the QoS criteria for WSNs, minimize data collection latency, and extend the network lifetime in LS-WSNs.	This approach was not tested for HSND-WSN.
[30]/2022	This article assessed the MDC system's physical performance comprising uncrewed aerial vehicles (UAVs) and wake-up radio (WuR) technology to minimize energy consumption during data exchanges with SNs. This work performs data collection experiments using a quadrotor drone as the UAV and WuR technology-enabled motes as communication nodes.	The telemetry experiments indicate that if the MDC flies at an altitude of approximately 5 m, reliability diminishes monotonously over horizontal distance, averaging 75.4% of all successfully collected data packets, whereas the average latency is 27 ms. The reliability decreases significantly at a 10 m altitude to a mean of 14.33%, whereas latency increases with the horizontal distance to a mean of 71.16 ms.	This approach was not tested for HSND-WSN. This approach was not tested in LS-WSNs or all network QoS criteria.
[31]/2022	A new tree-clustering MDC algorithm (TCMDC) was proposed. This algorithm chooses the highest-weight SNs as CHs and implements the GA to calculate the path of the MDC.	The simulation results reveal that the MDC-K protocol significantly affects energy consumption and QoS metrics. The MDC-K realizes considerable enhancement in energy consumption, residual energy, throughput, latency, and stability, better than the maximum residual energy LEACH, TEEN, LEACH-K, and LEACH protocols.	This approach was not tested for HSND-WSN. This approach was not compared with other approaches using the MDC.
[9]/2021	The MDC-K protocol is a combination of the LEACH-K approach and MDC. In particular, the protocol uses the K-means algorithm to minimize energy consumption in the election phase of the CH and the MDC to minimize the delay during data collection.	The simulation results demonstrate that the MDC-K protocol significantly affects energy consumption and QoS metrics. The MDC-K realizes considerable enhancement in energy consumption, residual energy, throughput, latency, and stability, better than the maximum residual energy LEACH, TEEN, LEACH-K, and LEACH protocols.	This approach was not tested for HSND-WSN
[32]/2020	This approach investigated a mobile WSN data collection aided by several drones and UAVs. Considering the highly dynamic network, a balancing algorithm was proposed for collision-free communication between mobile nodes and multiple drones. The proposed algorithm has some applicability in real scenes.	The simulation results demonstrate that this algorithm has some applicability in real scenarios. This experiment confirmed the reliability of algorithms proposed in a difficult and realistic scenario through many experiences of a path on the Tongji campus in India.	These experiments used 15 mobile SNs on a path with 10 intersections and one island. This approach is not tested for HSND-WSN.
[10]/2021	This research suggests a novel hybrid protocol called MDC-LEACH-K, combining the low-energy adaptive clustering hierarchy K-means (LEACH-K) protocol and MDC to enhance the LEACH protocol.	This protocol performs an energy efficiency gain of 296% over the LEACH protocol, 237% over the threshold-sensitive energy-efficient network (TEEN) protocol, 257% over the LEACH-K protocol, and over 100% over the LEACH, TEEN, and MDC maximum residual energy protocols.	This approach was not tested for HSND-WSN.
[33]/2017	This paper proposed analytical methods to compute the energy consumption of nodes and determine the best number of clusters for two mobile data collection representative models: the single-hop sensor network with a mobile access point (SENMA) and multihop data mule (MULE) models.	These analytical models enable the network developer on an LS-WSN and experiment with various network scenarios in a small amount of time. In MULE, the approach demonstrated that when the number of clusters is increased, the energy consumption of the SN is not always reduced due to the "DREQ flooding problem." In SENMA, the approach demonstrated that, for the scenarios of LS-WSN, the SNs must spend significant energy to transmit to the mobile access point when the cluster number is lower.	This approach is not tested for HDWSNs. This approach is not tested forHSND-WSN. This approach did not test all the QoS criteria of the network.
[34]/2014	This paper proposes the MDC maximum residual energy leach protocol that utilizes a multi-hop routing strategy. This approach creates self-organizing, distributed clusters that select the CH randomly to balance the SN energy consumption and forward the data to the BS using MDCs.	The MDC maximum residual energy leach improves the lifetime of the network and the BS-level data collection.	This approach was only used for homogeneous networks and was not tested in LS-WSNs and all QoS criteria.

TABLE 3. *(Continued.)* Summary of the MDC approaches in the data transmission phase.

[35]/2015	This paper proposes a novel scheme for CH selection based on WSN density, a hybrid called node density-based clustering and mobile collection (NDCM).	This approach enhances the lifetime of the network and conserves the network energy. NDCM scheme provides a practical trade-off between network energy savings and packet latency.	This approach was not tested for high-density WSNs, LS-WSNs, or for all QoS criteria.
[36]/2016	This paper proposes four protocols: BEENISH, iBEENISH, MBEENISH, and iMBEENISH. BEENISH considers four SNs and CH energy levels based on the residual energy levels of the SNs and the average energy of the WSN, whereas iBEENISH varies the selection probability of CHs dynamically and efficiently, extending the WSN lifetime.	The simulation results demonstrate that BEENISH, MBEENISH, iBEENISH, and iMBEENISH are better than current protocols regarding network lifetime, stability time, and throughput.	This approach was not tested for high-density WSNs in LS-WSNs or all QoS criteria. This approach was not compared with other approaches using MDC.
[37]/2018	This paper provides a novel energy-efficient hybrid protocol for routing using MDCs (EEHP-MDC) that uses the clustering concept and employs multiple MDC nodes to collect data from different CHs and transmit it to the BS.	This distributed and centralized clustering approach improves the lifetime and conserves the SN energy consumption.	This approach was not tested for high-density WSNs in LS-WSNs or all QoS criteria.
[38]/2011	This paper provides the MDC minimum distance leach protocol. It uses a random CH selection and distributed clustering strategy to balance the SN energy consumption and transmit the data to the BS through the MDC.	This protocol significantly improved the SN energy consumption, network lifetime, and BS data collection compared to the LEACH protocol.	This approach was not tested for high-density WSNs in LS-WSNs or all QoS criteria.

III. IMPROVED RECURSIVE DV-HOP LOCALISATION ALGORITHM

The IR-DV-Hop algorithm enhances the DV-Hop algorithm [39] and implements a recursive solution of least squares. It uses a recursive approach for the location process based on a collection of anchor nodes chosen from a predefined population of anchors. The IR-DV-Hop algorithm concentrates on an algorithm for range-free localization in multihop homogeneous WSNs using a recursive calculation of the position of unknown SNs. It also concentrates on the second and third steps of the DV-Hop algorithm [8].

This approach employs a formulation optimized to compute anchor nodes' average hop size to reduce the localization error in the predicted distance between the anchor and the unknown SN, resulting in higher localization accuracy. Algorithm 1 presents the pseudocode of the IR-DV-Hop algorithm. In the IR-DV-Hop algorithm, anchors are randomly created in the WSN with a determined location. Using these anchors, this algorithm randomly selects anchor candidates to provide an estimation reference to the location process. The initial position of each unknown node is $P_0 = 0$. Subsequently, The unknown nodes calculate their position P_n using (Eq. 9) in [8].The major problem with WSNs in real applications is that certain anchor locations cannot be provided to continuously locate the unknown SNs for numerous reasons, such as lifetime, failure, and maintenance. Thus, the IR-DV-Hop algorithm considers a novel collection of anchor candidates chosen randomly and iteratively based on their availability within the anchor population for the position estimation process.

Algorithm 1 IR-DV-Hop

Input: SNs distributed randomly in a *(100, 100)* m detection field, including anchoring SNs of coordinates (A_i, B_i) where $i = 1 \dots z$, and unknown SNs n to be located.

Output: The P_n estimation position of n unknown SNs.

Begin:

$P_n(0) = 0$; /* Initial position of unknown SN.

M = a×I; /* Convariance matrix M, where a is a very high positive number and I is the identity matrix.

Random selection of a set of candidate anchors for the localization process.

while The condition of arrest is not fulfilled **do**

1: Process of trilateration and calculation of the lowest number of hops between the selected anchors.

2: Improvement of the average distance of jumps between candidate anchors.

3: Minimum number of hops between selected anchors and unknown SNs.

4: Distance estimates between the unknown SNs and the closest selected anchors.

5: Estimation of the position P_n of an unknown SN utilizing Recursive Least Squares.

$P_{n+1}(0) = P_n + M_{n+1} An^T_{n+1}(B_{n+1} - An_{n+1} P_n)$ (Eq. 16) in

end while

$(x = P_n(1), x = P_n(2))$ /* Estimated coordinates of unknown SN n

end

IV. MOBILE DATA COLLECTORS-IMPROVED RECURSIVE DISTANCE VECTOR-HOP LOCALIZATION K-MEANS PROTOCOL

The intelligent MDC for smart LS-WSNs approach offers the MDC-IR-DV-Hop-K protocol, which is also based on rounds, where each round is divided into two phases: the initialization and transmission phases. Before moving to these phases, the SNs are distributed randomly. All SNs have the same initial energy and are homogeneous and fixed. Moreover, the BS is also fixed.

A. INITIALIZATION PHASE

In this approach, we take the BS outside the deployment area to test the difficult cases because most protocols test protocols where the BS is located in the center of the area [9], [10], [19], [24], [40], [41]. First, the BS applies the IR-DV-Hop algorithm in the WSN to determine the location of all SNs without error. Then, its fixed spiral is the MDC trajectory, beginning from the centroid of the area. The BS assigns each CH to the SN that belongs to $spiral_{MDC}$ with coordinates (x_i, y_i), with the minimum distance to the spiral MDC trajectory. The minimum distance is calculated as follows:

$$D(SN, spiral_{MDC}) = min\{\sqrt{(x_{spiral_{MDC}} - x_i)^2 + (y_{spiral_{MDC}} - y_i)^2}\}. \quad (1)$$

We use the K-means machine learning algorithm to find the position of the centroid area. Then, the BS selects the SNs located on the path of the spiral as CHs. The number of CHs is calculated as follows:

$$Number_{CH} = \sum_{i=0} (D(SN, spiral_{MDC}) = min\{\sqrt{(x_{spiral_{MDC}} - x_i)^2 + (y_{spiral_{MDC}} - y_i)^2}\}). \quad (2)$$

Finally, each CH chooses the member SNs closest to it. However, in most cluster protocols, the clusters are very large, and no load balancing occurs between the clusters, which leads to energy waste. Therefore, we propose a threshold to limit and balance the number of member SNs in each cluster. This threshold is calculated as follows (3):

$$Threshold = \frac{(Number_{livingSN} - Number_{CH})}{Number_{CH}}. \quad (3)$$

Each CH calculates the distance between itself and the other SNs to determine which SNs it accepts. If this distance is less than or equal to the minimal distance, the CH accepts this SN as a member SN whose number of members SNs is less than or equal to the threshold we calculated previously. Otherwise, this SN does not attach to this CH and attaches to another CH. Similarly, all clusters contain about the same number of SNs, and the CH assignment of a time division multiple access (TDMA) schedule for SN members is performed as illustrated in Fig. 3. After the cluster is created, each CH generates a TDMA schedule and sends these schedules to its member SNs in the cluster. The TDMA schedule prevents the data sent by the member SNs from colliding and allows the member SNs to enter sleep mode. The SN members transmit data to the CH during their time slot allocation. When an SN member sends data to the CH during its allocated time slot, another SN member in this cluster stays in the sleep state. This process is represented in Fig. 3 by a line connecting the red rectangle A. This feature of the MDC-IR-DV-Hop-K protocol reduces cluster collisions and energy consumption, which increases the lifetime of all SN members. In addition, CHs collect and aggregate data received from their cluster members, as presented in Fig.3.

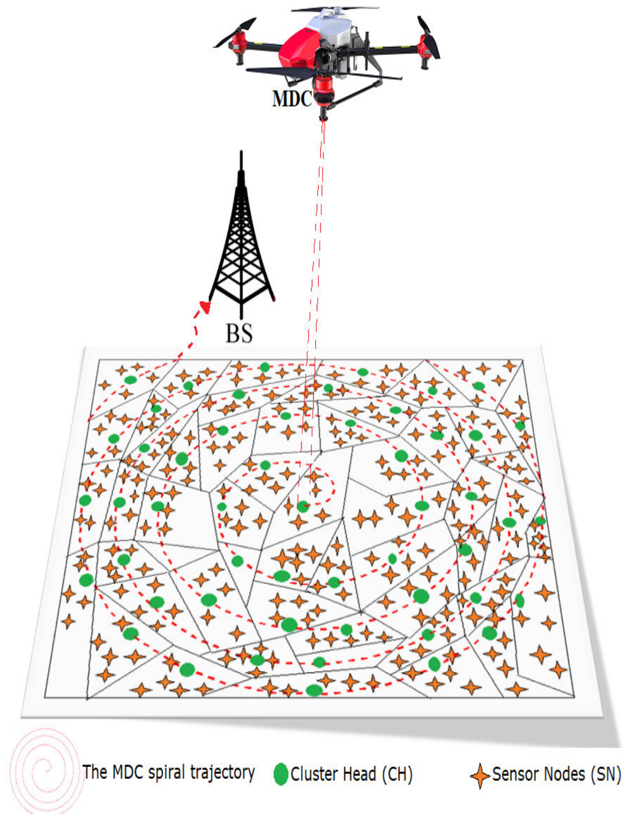


FIGURE 2. Process of the MDC-IR-DV-Hop-K.

B. TRANSMISSION PHASE

With the proposed approach in the initialization phase of the MDC-IR-DV-Hop-K protocol, the energy consumption is reduced, and the stability is increased compared to other clustering protocols. Nevertheless, improving the QoS criteria and reducing energy consumption is still a significant problem. Thus, we used the intelligent MDC based on the spiral trajectory starting from the centroid area as an interface between the CHs and BSs, as depicted in Fig.2.

The MDC intelligently performs by collecting data only from the CH that belongs to its path. The MDC collects the data, which are broadcasted by the CH to the MDC directly. Then, it completes the collection and provides data to the BS, as illustrated in Figs. 2 and 3. Fig. 3 illustrates the

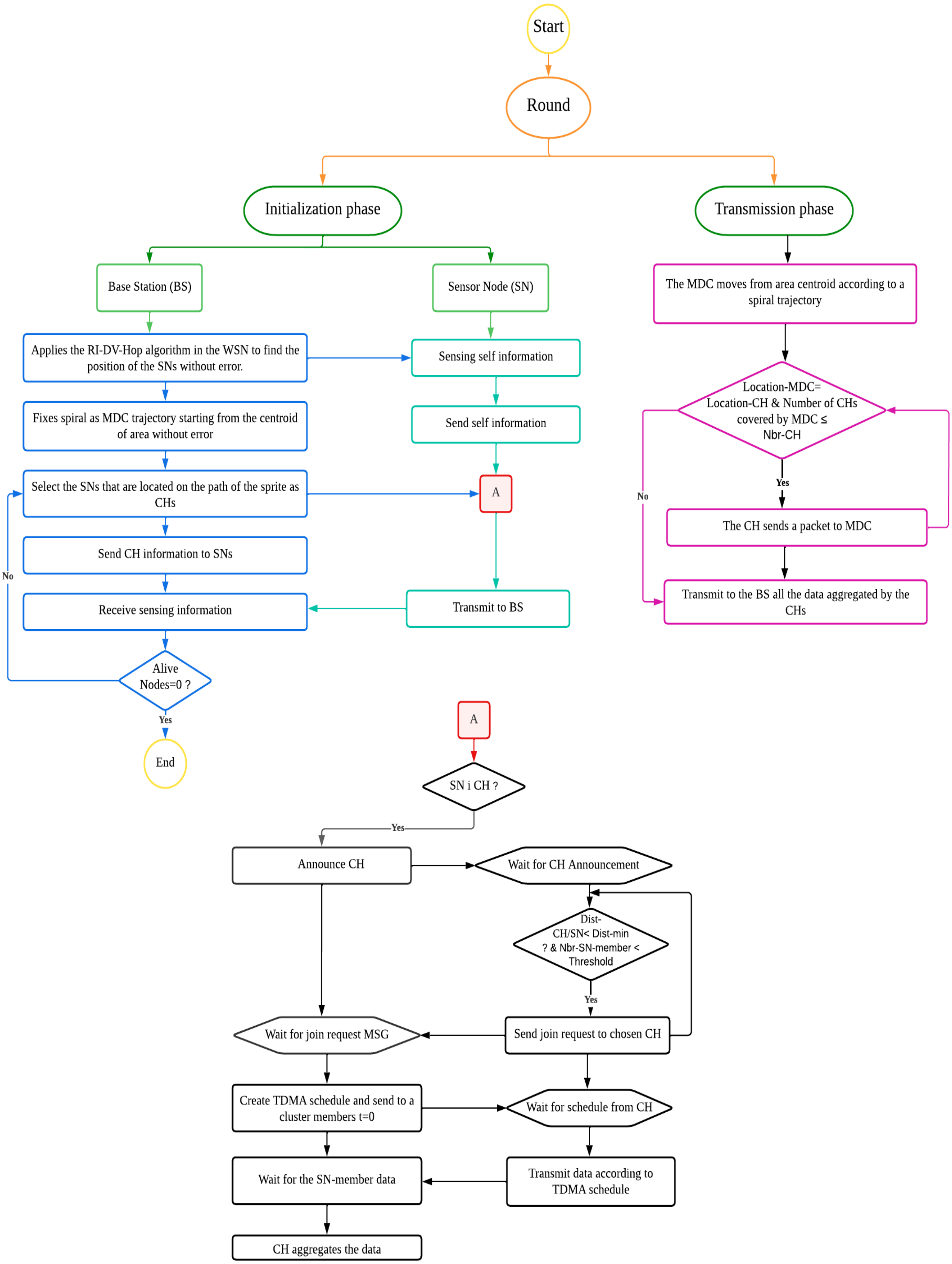


FIGURE 3. Algorithm of the MDC-IR-DV-Hop-K.

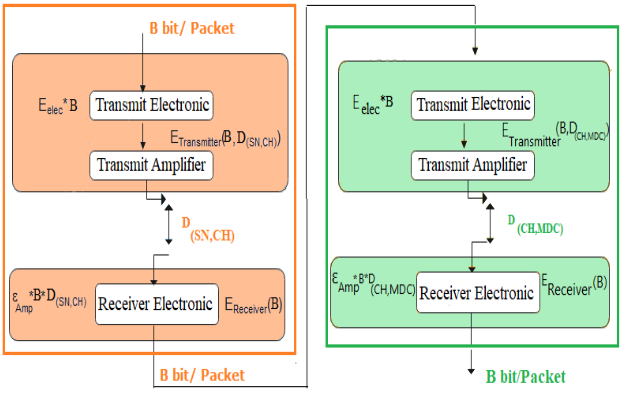


FIGURE 4. Energy model of the MDC-TSP-LEACH-K.

initialization and transmission phase of MDC-IR-DV-Hop-K data transmission between the BS and CH.

C. ENERGY MODEL OF THE MDC-IR-DV-HOP-K PROTOCOL

The MDC-IR-DV-Hop-K adapts the energy model of the LEACH-K [42], MDC-K [10], and MDC-TSP-LEACH-K [19] protocols, as presented in Fig 4. According to this model, the transmitter or receiver circuits operate with an electronic dissipation energy of E_{elec}= 50nJ/bit, and the transmitter amplifier uses ϵ_{Amp} = 0.0013 $pJ/bit/m^4$. However, when the distance is below a threshold of T, we use the free space model (energy loss D^2); otherwise, we use the multipath model (energy loss D^4). Alternatively, for a short-distance transmission, like an intra-group communication, a transmission amplifier's energy consumption is proportional to D^2, whereas, for a longer-distance transmission, like an inter-group communication, a transmission amplifier's energy consumption is proportional to D^4. In this case, a threshold transmission distance T is defined, in which:

$$T = \sqrt{\epsilon_{fs}}/\sqrt{\epsilon_{Amp}}. \tag{4}$$

Therefore, if the sender sends a B bit of data to the receiver up to a distance D, the energy necessary to send B bits of data is represented by:

$$E_{Transmitting} = (E_{ele}B) + \epsilon_{Amp}BD^4. \tag{5}$$

Thus, the necessary energy to obtain B bits of data is expressed by:

$$E_{Receiving}(B) = E_{ele}B. \tag{6}$$

Finally, the data collection energy consumed during a round is computed as follows:

$$E_{Round} = E_{Transmitting} + E_{Receiving}. \tag{7}$$

where:

- ϵ_{fs} denotes the free space energy loss.
- ϵ_{Amp} represents the power of multi-path models.
- E_{ele} indicates the energy dissipation per bit for transmission and reception.

TABLE 4. Simulation parameters.

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

V. SIMULATION STRATEGY, PERFORMANCE EVALUATION, AND RESULT DISCUSSION

This section evaluates the MDC-IR-DV-Hop-K protocol by comparing it to existing protocols that use MDC at the routing level. We compared the proposed protocol with others that have improved QoS metrics, such as latency, power consumption, and stability. We implemented it and tested its performance in MATLAB. We selected MATLAB due to the ease of its interface and because the required preprogrammed functions, such as the K-means and spiral trajectory functions, are available. In addition, it is easy to implement the mathematical model on MATLAB because MATLAB is a matrix language enabling the most natural expressions of mathematical computation. Different parameters and aspects were considered during a simulation to test the protocol performance in WSNs. Table 4 describes the simulation parameters.

Several parameters and factors are considered in the simulation to study the efficiency of the proposed approach. The simulation is divided into three scenarios. In the first scenario, we justify why we chose IR-DV-Hop as the localization algorithm. We tested the performance of IR-DV-Hop against other algorithms, such as the DV-Hop, UDV-Hop, and advanced DV-Hop algorithms. In the second scenario, we assessed the simulation results of the proposed MDC-IR-DV-Hop-K protocol with a variety of protocols, including the MDC maximum residual energy leach [34], NDCM [35], TCMDC [31], MBEENISH [36], EEHPMDC [37], MDC minimum distance leach [38], MDC-K [9], MDC-TSP-LEACH-K [19], MDC-LEACH-K [10] and a three-layer hierarchical architecture for optimized routing protocol based on clustering and the Khalimsky topology for mobile WSN (AMWSN) protocols [43]. In the third scenario, we studied the performance of the MDC-IR-DV-Hop-K protocol in the case of LS-WSNs.

A. FIRST SCENARIO

We justify choosing IR-DV-Hop as the localization algorithm and its advantages in this scenario. Therefore, we simulated and compared IR-DV-Hop with DV-Hop, UDV-Hop, and advanced DV-Hop. Within the simulation, the number of network SNs is 300 with a 15 m communication radius. The proportion of anchors randomly deployed in the detection field varies from 5% to 30% of the total SNs. Fig. 5 compares the localization error percentage obtained by the IR-DV-Hop algorithm and the DV-Hop, UDV-Hop, and advanced

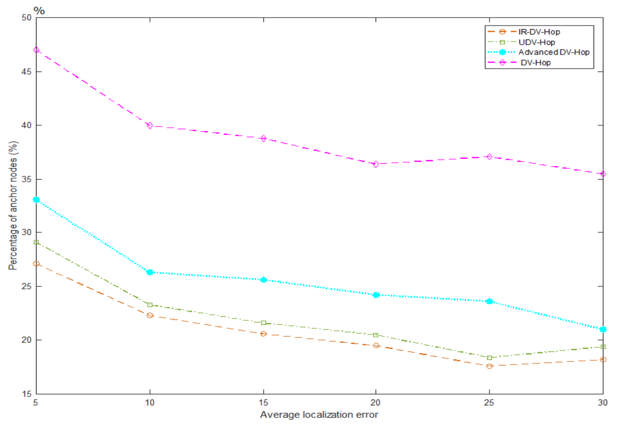


FIGURE 5. IR-DV-Hop, DV-Hop, UDV-Hop, and advanced DV-Hop algorithms' localization error percentage as a function of the percentage of anchor nodes.

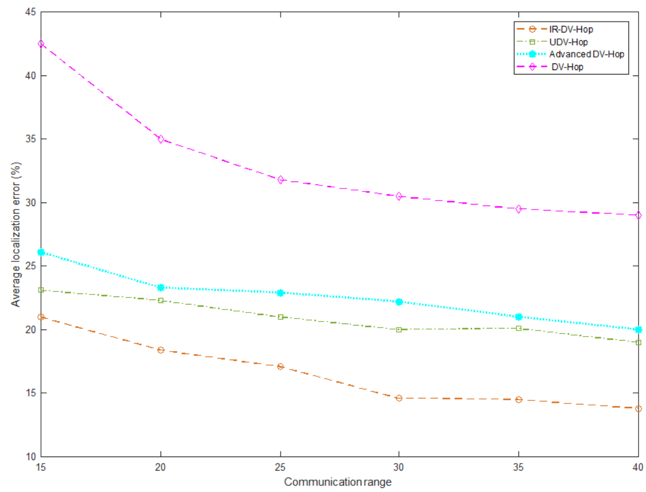


FIGURE 6. R-DV-Hop, DV-Hop, UDV-Hop, and advanced DV-Hop algorithms' localization error percentage as a function of the percentage of anchor nodes.

DV-Hop algorithms as a function of the percentage of anchor nodes.

As presented in Fig. 5, the IR-DV-Hop algorithm is more precise than the DV-Hop, UDV-Hop, and advanced DV-Hop algorithms. It reached a localization error below 17% at 30% anchoring, whereas the localization errors were around 19% for the UDV-Hop algorithm, around 21% for the advanced DV-Hop algorithm, and around 36% for the DV-Hop algorithm. Fig. 6 displays the localization error obtained by the IR-DV-Hop, DV-Hop, UDV-Hop, and advanced DV-Hop algorithms as a function of the variation of the communication radius of the nodes.

According to Fig. 6, the IR-DV-Hop algorithm has about a 15% lower localization error than the DV-Hop algorithm, 5% lower than the advanced DV-Hop algorithm, and 3% lower than the UDV-Hop algorithm. In addition, in the case of a high communication radius value of around 40 m, the IR-DV-Hop algorithm has an approximately 14% error in localization, whereas the DV-Hop has about a 28% error in localization. Advanced DV-Hop has about a 19% error

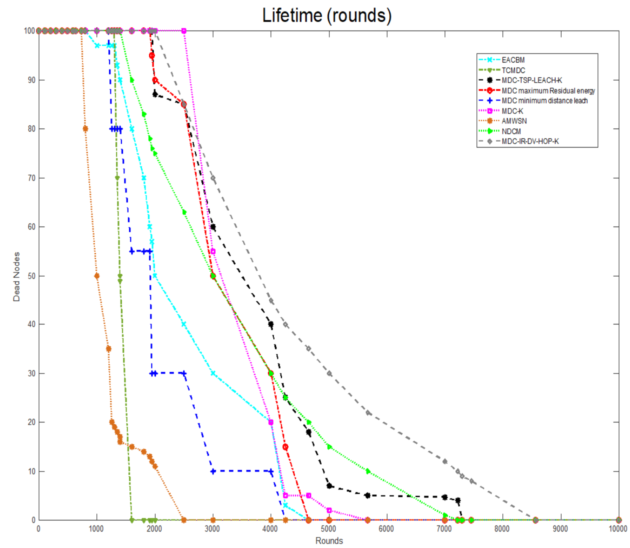


FIGURE 7. Comparison of the MDC-IR-DV-Hop-K approach with the EACBM, TCMDC, MDC maximum residual energy leach, MDC minimum distance leach, MDC-K, MDC-TSP-LEACH-K, AMWSN, and NDCM protocols in terms of lifetime.

in localization, and UDV-Hop has an error of about 17%. Based on the simulation results in Figs. 5 and 6, IR-DV-Hop provides higher localization precision than the DV-Hop, UDV-Hop, and advanced DV-Hop algorithms. Consequently, we chose IR-DV-Hop as the localization algorithm for the proposed approach.

B. SECOND SCENARIO

To evaluate the performance of the MDC-IR-DV-Hop-K protocol, we simulated both MDC-IR-DV-Hop-K protocols with various protocols, including the EACBM, TCMDC, MDC maximum residual energy LEACH, MDC minimum distance leach, MDC-K, MDC-TSP-LEACH-K, AMWSN, and NDCM protocols using MATLAB. In this scenario, we analyzed the simulation results and adopted performance measures. These findings were analyzed for a trade-off between lifetime, throughput, stability, and latency over 10 500 rounds. Fig. 7 compares the MDC-IR-DV-Hop-K approach with the EACBM, TCMDC, MDC-TSP-LEACH-K, MDC maximum residual energy leach, MDC minimum distance leach, MDC-K, MhSa-LEACH, AMWSN, and NDCM protocols in terms of lifetime.

As observed in Fig. 7, the proposed MDC-IR-DV-Hop-K protocol enhances the network lifetime with better performance than the EACBM, TCMDC, MDC maximum residual energy leach, MDC minimum distance leach, MDC-K, MDC-TSP-LEACH-K, AMWSN, and NDCM protocols, but it is not as stable as the MDC-K protocol. According to the simulation results, MDC-IR-DV-Hop-K also improves the residual energy of SNs. The numerical results demonstrate that the proposed approach can reduce the energy consumption of the SNs. Fig. 8 demonstrates the stability of the proposed approach compared to the EACBM, TCMDC, MDC maximum residual energy leach, MDC

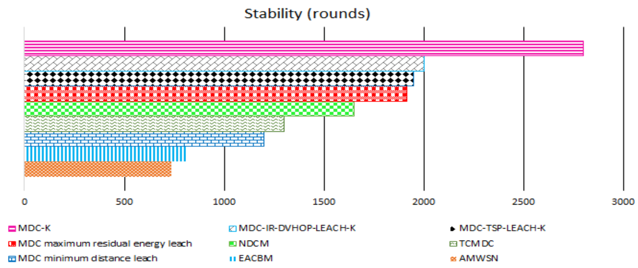


FIGURE 8. Comparison of the MDC-IR-DV-Hop-K approach with the EACBM, TCMDC, MDC-TSP-LEACH-K, MDC maximum residual energy leach, MDC minimum distance leach, MDC-K, MhSa-LEACH, AMWSN, and NDCM protocols in terms of stability.

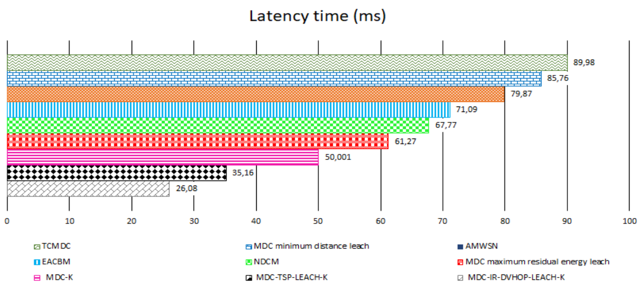


FIGURE 9. Comparison of the MDC-IR-DV-Hop-K approach with EACBM, TCMDC, MDC-TSP-LEACH-K, MDC maximum residual energy leach, MDC minimum distance leach, MDC-K, MhSa-LEACH, AMWSN, and NDCM protocols in terms of latency time.

minimum distance leach, MDC-TSP-LEACH-K, AMWSN, and NDCM protocols.

As depicted in Fig. 8, the stability improves a little bit from 733 (rounds) in AMWSN to 807 (rounds) in EACBM, 1200 (rounds) in MDC minimum distance leach, 1302 (rounds) in TCMDC, 1650 (rounds) in NDCM, 1913 (rounds) in MDC maximum residual energyleach, 1950 (rounds) in MDC-TSP-LEACH-K, 2001 (rounds) in MDC-IR-DV-Hop-LEACH-K, 2800 (rounds) in MDC-K, and 2000 (rounds). The proposed protocol is less stable than the MDC-K protocol but is more stable than MDC-TSP-LEACH-K, which is a routing protocol that uses the MDC for the LS-WSN with a very short period. Fig. 9 depicts the latency time of the proposed approach MDC-IR-DV-Hop-LEACH-K compared to the EACBM, TCMDC, MDC maximum residual energy leach, MDC minimum distance leach, MDC-TSP-LEACH-K, AMWSN, and NDCM protocols.

As observed in Fig.9, using the MDC spiral movement based on the locations proposed by the IR-DV-Hop algorithm in this approach, the latency decreases to 26.08 ms from the MDC-IR-DV-Hop-K protocol compared to 35.16 ms from the MDC-TSP-LEACH-K protocol, 50.001 ms in the MDC-K protocol, 61.27 ms in the MDC maximum residual energy leach protocol, 67,77 ms in the NDCM protocol, 71.09 ms in the EACBM protocol, 79.87 ms in the AMWSN protocol, 85.76 ms in the MDC minimum distance leach protocol, and 89.98 ms in the TCMDC protocol. However, we conclude from the experimental results that the MDC-IR-DV-Hop-K protocol is the best solution to reduce the latency time compared to the MDC-TSP-LEACH-K and other routing protocols. Fig. 10 presents the throughput of the proposed approach (MDC-IR-DV-Hop-LEACH-K) compared to the EACBM, TCMDC, MDC maximum residual energy leach, MDC minimum distance leach, MDC-TSP-LEACH-K, AMWSN, and NDCM protocols.

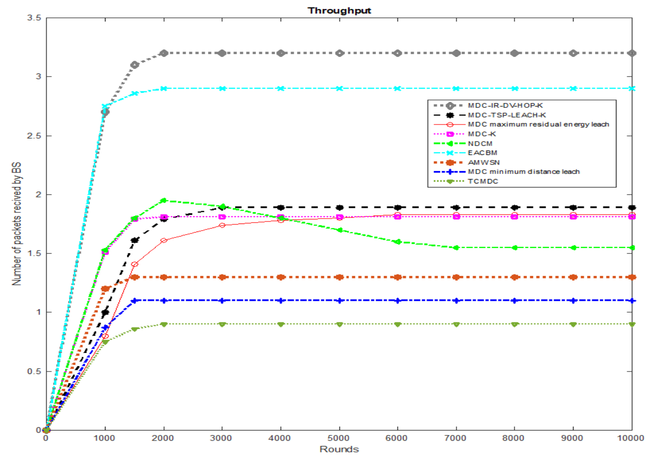


FIGURE 10. Comparison of the MDC-IR-DV-Hop-K approach with the EACBM, TCMDC, MDC-TSP-LEACH-K, MDC maximum residual energy leach, MDC minimum distance leach, MDC-K, MhSa-LEACH, AMWSN, and NDCM protocols in terms of throughput.

Fig. 10 illustrates the throughput simulation results of the MDC-IR-DV-Hop-K protocol versus EACBM, TCMDC, MDC-TSP-LEACH-K, MDC maximum residual energy leach, MDC minimum distance leach, MDC-K, AMWSN, and NDCM protocols. The plots in Fig. 10 demonstrate that the integration of the MDC using the spiral trajectory starts with the centroid of the area and increases the throughput by a significant amount. We observed that the throughput value of MDC-IR-DV-Hop-K at 10 000 rounds is equal to 32 060 packets/round compared to 29 110 packets/round for the EACBM protocol, 18 910 packets/round for the MDC-TSP-LEACH-K protocol, 18 300 packets/round for the MDC maximum residual energy leach protocol, 18 100 packets/round for the MDC-K protocol, 15 500 packets/round for the NDCM, 13 000 packets/round for the AMWSN protocol, 10 000 packets/round for the MDC minimum distance leach protocol, and 9001 packets/round for the TCMDC protocol. The proposed protocol increases the throughput value by minimizing the distance traveled by the MDC through the spiral movement starting from the simulation centroid area using the K-means algorithm and the precision of SN localization at the CH selection level using IR-DV-Hop algorithm. Fig. 10 demonstrates that the BS packet count for TCMDC is very low compared to other protocols. Comparing the MDC-IR-DV-Hop-K and NDCM reveals that MDC-IR-DV-Hop-K is better than NDCM from 1500 rounds. In 1500 rounds, the BS received packet count deviates significantly from the preceding round. The second scenario studies the proposed approach in LS-WSNs and HSND-WSNs to ensure the effectiveness of the approach.

TABLE 5. The comparison analysis of reliability for cluster head election and clustering of our protocol and some clustering protocols in the literature.

Ref./year	Contributions made	Completed validations
[44] / 2022	This paper proposed a route optimization technique to enhance the mobile BS of mobile WSNs based on the enhanced dragonfly optimization algorithm. This algorithm makes the most of the abundant storage space, sufficient energy, and high-performance computing energy of the mobile BS to provide network connectivity and improve WSN communication efficiency.	The proposed approach balances the energy consumption of SNs to achieve the network QoS and improve WSN reliability compared to the random motion method, artificial bee colony algorithm, and basic dragonfly optimization algorithm.
[45] / 2022	This paper suggests a reliable and energy-efficient data collection strategy for HWSNs using extreme online sequence machine learning and the gray wolf optimization algorithm.	Simulation results indicate that this algorithm significantly enhances data collection efficiency and decreases energy consumption, improving network reliability and extending network life.
[15] / 2022	This article offered a clustered routing scheme for a heterogeneous network (CRSH) to perform SN clustering and network data aggregation.	The proposed scheme was compared to the current protocols to evaluate its efficiency to provide more reliability and extend the lifetime of the low-energy protocols.
[16] / 2022	A new CH selection protocol was suggested in this article based on the firefly (FA) and hesitant fuzzy algorithms. This protocol uses three SN parameters to compute the score of each SN and select the optimal CHs.	The performance evaluation included various criteria based on energy efficiency and lifetime but not the system reliability.
[19] / 2022	This paper proposes the MDC-TSP-LEACH-K algorithm that provides new CH selection and clustering techniques using the grid function and K-means to improve the QoS and lifetime of the WSN.	The MDC-TSP-LEACH-K improves QoS, decreases power consumption, and provides higher reliability in delivering packets to BSs via smart MDCs.
[46] / 2018	This article suggested the EM-LEACH algorithm to enhance the WSN's reliability, lifetime, and energy efficiency. This algorithm adopts a new CH selection and residual energy-based round-robin time calculation rules. In addition, EM-LEACH optimizes the communication method from single-hop to multihop transmission between the CHs and BS using the generic multihop routing and leveling operational processes.	The assessment focused on QoS-related aspects, such as reliability, throughput, latency time, and stability.
Proposed protocol	This paper proposes a novel intelligent routing protocol based on the IR-DV-Hop localization algorithm to determine the accurate location of SNs without errors in LS-WSNs and determine the CHs and optimal route traversed by the MDC for energy efficiency, latency, and reliability. Specifically, the proposed MDC-IR-DV-Hop protocol uses the MDC as an intermediate between CH and BS to enhance the QoS of WSNs, reduce delays while collecting data, and improve the transmission phase of the routing protocol. The MDC-IR-DV-Hop protocol uses K-means to reduce the distance between SNs and the CH and employs the IR-DV-Hop localization algorithm to determine the accurate location of SNs without errors in LS-WSNs and determine the CHs and optimal route traversed by the MDC.	The performance evaluation focused on various aspects related to the network's lifetime, QoS, and stability.

C. SECOND SCENARIO

Improving the QoS criteria and prolonging the lifetime of WSNs is a difficult challenge, particularly for LS-WSNs, owing to the large geographic areas for data collection, high SN density, and high quantities of data to collect. This scenario is divided into two subscenarios. First, we study the efficiency of the proposed protocol in the LS-WSN compared to a protocol that uses an MDC in LS-WSNs. Second, we study the efficiency of the proposed protocol with density variation compared to a protocol that uses an MDC in HSND-WSNs.

1) EVALUATION OF THE MDC-IR-DV-HOP-K IN AN LS-WSN

In this subscenario, we also test the performance of the proposed MDC-IR-DV-Hop-K protocol in LS-WSNs. More precisely, we estimate the QoS criteria values for different network sizes compared to a protocol that uses the MDC in LS-WSNs. Fig. 11 compares the MDC-IR-DV-Hop-K approach, MDC-TSP-LEACH-K, MDC maximum residual energy leach, MDC minimum distance leach, and MDC-K protocols in terms of lifetime, throughput, stability, and latency time in different area sizes.

Fig. 11 demonstrates that as the area size is scaled up, the lifetime, throughput, and stability decrease a little, which is evidence that the advantages of the proposed protocol remain nearly stable with a sizable area. For instance, the latency also increases from 26.08 ms in a 100×100 area to 29.09 ms in a 1500×1500 area. Throughput changes from 32 060 packets/round in a 100×100 area to 31 890 packets/round in a 1500×1500 area. Lifetime alters from 8566 rounds in a 100×100 area to 8471 rounds in a 1500×1500 area. The stability changes from 2001 rounds in a 100×100 area to 1813 rounds in a 1500×1500 area. Based on these results, the MDC-IR-DV-Hop-K is the best solution for the LS-WSN regarding lifetime, throughput, latency, and reliability. However, in the case of stability, the MDC-K is still better than the MDC-IR-DV-Hop-K and MDC-TSP-LEACH-K protocols.

2) EVALUATION OF MDC-IR-DV-HOP-K IN AN HSND-WSN

We evaluated the effect of varying the SN density in the MDC-IR-DV-Hop-K protocol. The simulation consists of 100 to 2000 homogeneous SNs with an initial energy of 0.5 J, randomly dispersed in an SN field of 100×100 m. The BS is located at (0.5, 125), at least 125 m. We compared

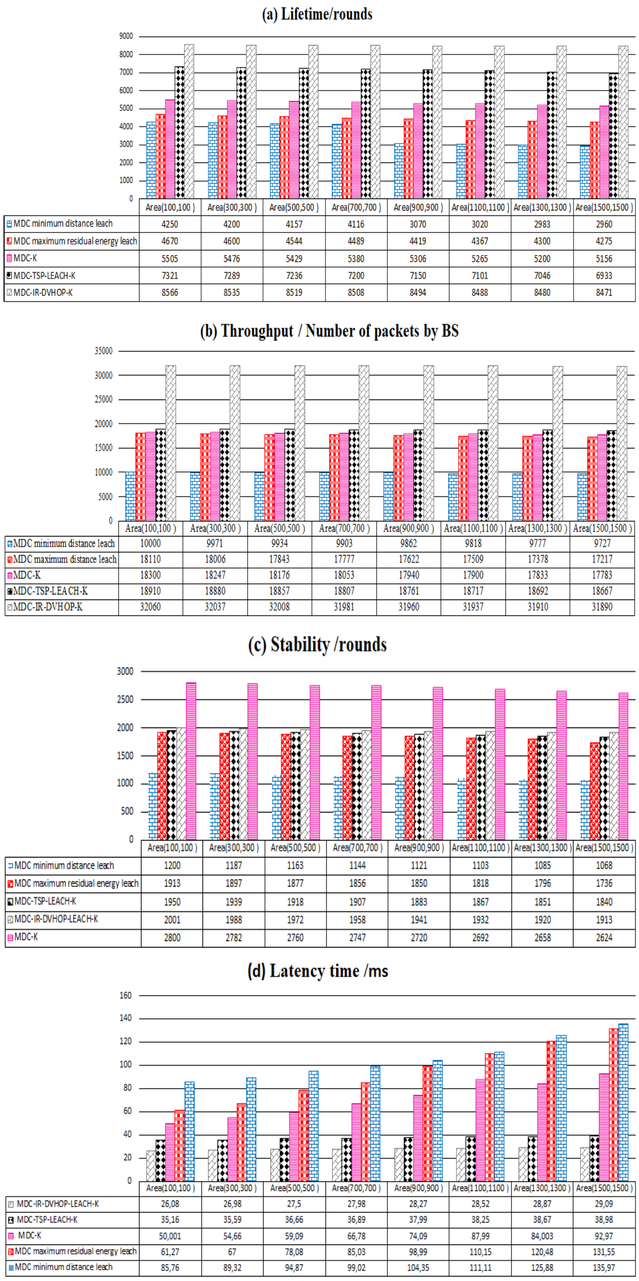


FIGURE 11. Comparison of the MDC-IR-DV-Hop-K approach, MDC-TSP-LEACH-K, MDC maximum residual energy leach, MDC minimum distance leach, and MDC-K protocols in terms of lifetime, throughput, stability, and latency time in different area sizes.

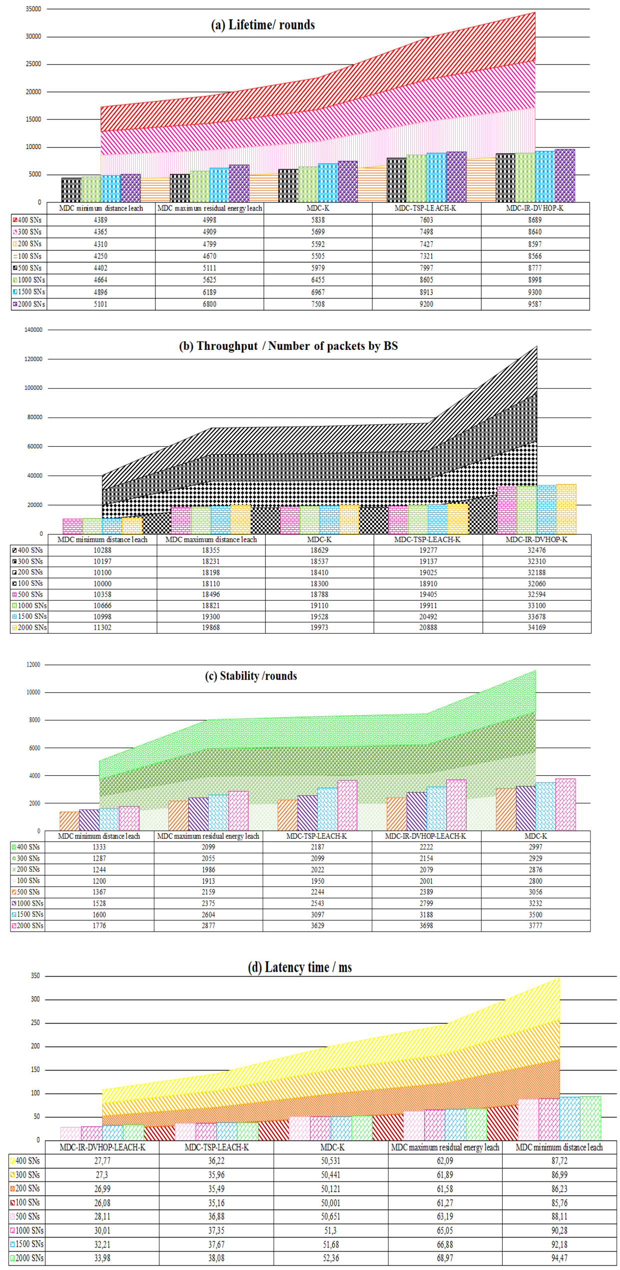


FIGURE 12. Comparison of the MDC-IR-DV-Hop-K approach, MDC-TSP-LEACH-K, MDC maximum residual energy EACH, MDC minimum distance leach, and MDC-K protocols in terms of lifetime, throughput, stability, and latency time in different area sizes.

the MDC-IR-DV-Hop-K protocol with MDC-TSP-LEACH-K, MDC maximum residual energy leach, MDC minimum distance leach, and MDC-K protocols. Fig. 12 compares the MDC-IR-DV-Hop-K approach, MDC-TSP-LEACH-K, MDC maximum residual energy leach, MDC minimum distance leach, and MDC-K protocols in terms of lifetime, throughput, stability, and latency time for different number of SNs.

The simulation results of this scenario revealed that varying the density of SNs maintains the same benefit and improvement in lifetime, throughput, stability, and latency. As illustrated in Fig.12, as the number of nodes increases, the latency slightly increases but is still lower than that of the MDC-TSP-LEACH-K, MDC maximum residual energy leach, MDC minimum distance leach, and MDC-K protocols. In addition, the throughput of the MDC-IR-DV-Hop-K increases from 32 060 packets/wave in a density of 100 SNs to 34 169 packets/wave in a density of 2000 SNs in comparison with 11 302 packets/wave for MDC minimum distance leach in 2000 SNs, 19 868 packets/round for MDC maximum residual energy leach in 2000 SNs, 19 973 packets/round for MDC-K in 2000 SNs and 20 888 packets/round for MDC-TSP-LEACH-K in 2000 SNs. In contrast, the proposed protocol maintains its same lifetime benefits with the variation of SN density and is still the best compared to the MDC-TSP-LEACH-K, MDC maximum residual energy leach, MDC minimum distance leach, and MDC-K protocols. Thus, the MDC-IR-DV-Hop-K is the best solution for high SN density WSNs in terms of lifetime, throughput, latency, and reliability. However, in the case of stability, the MDC-K is still better than the MDC-IR-DV-Hop-K and MDC-TSP-LEACH-K protocols in terms of stability. Table 5 compares the proposed protocol and selected related protocols in the literature to evaluate the efficiency of the MDC-IR-DV-Hop-K protocol in enhancing the reliability of the routing protocol.

VI. CONCLUSION

This paper proposes a new smart routing protocol called MDC-IR-DV-Hop, combining the IR-DV-Hop localization algorithm, K-means algorithm, and MDC. Specifically, this protocol uses the IR-DV-Hop localization algorithm to determine the accurate location of SNs without errors in LS-WSNs and determine the CHs. In addition, the MDC is used as an intermediate between the CH and BS to enhance the QoS criteria of WSNs, minimize time delays during data collection, and extend the WSN lifetime. The simulation results demonstrate that the MDC-IR-DV-Hop considerably influences energy consumption and QoS metrics. Particularly, this protocol significantly improves energy consumption, latency time, throughput, and stability gains compared to the EACBM, TCMDC, MDC maximum residual energy leach, MDC minimum distance leach, MDC-K, MDC-TSP-LEACH-K, AMWSN, and NDCM protocols. Moreover, the simulation results reveal that the MDC-IR-DV-Hop is more suited for LS-WSNs and HSND-WSNs. In future research, our interest is to investigate the MDC-IR-DV-Hop in large-scale mobile WSNs.

REFERENCES

[1] A. S. Sadeq, R. Hassan, H. Sallehudin, A. H. M. Aman, and A. H. Ibrahim, "Conceptual framework for future WSN-MAC protocol to achieve energy consumption enhancement," *Sensors*, vol. 22, no. 6, p. 2129, Mar. 2022.

[2] R. Dogra, S. Rani, H. Babbar, and D. Krah, "Energy-efficient routing protocol for next-generation application in the Internet of Things and wireless sensor networks," *Wireless Commun. Mobile Comput.*, vol. 2022, pp. 1–10, Mar. 2022.

[3] A. J. Wilson and A. S. Radhamani, "Real time flood disaster monitoring based on energy efficient ensemble clustering mechanism in wireless sensor network," *Softw., Pract. Exper.*, vol. 52, no. 1, pp. 254–276, Jan. 2022.

[4] N. M. Shagari, R. B. Salleh, I. Ahmedy, M. Y. I. Idris, G. Murtaza, U. Ali, and S. Modi, "A two-step clustering to minimize redundant transmission in wireless sensor network using sleep-awake mechanism," *Wireless Netw.*, vol. 28, no. 5, pp. 2077–2104, Jul. 2022.

[5] A. E. Ezugwu, A. M. Ikotun, O. O. Oyelade, L. Abualigah, J. O. Agushaka, C. I. Eke, and A. A. Akinyelu, "A comprehensive survey of clustering algorithms: State-of-the-art machine learning applications, taxonomy, challenges, and future research prospects," *Eng. Appl. Artif. Intell.*, vol. 110, Apr. 2022, Art. no. 104743.

[6] R. Gantassi, A. Ben Yagouta, and B. Ben 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.

[7] S. Messous and H. Liouane, "Online sequential DV-Hop localization algorithm for wireless sensor networks," *Mobile Inf. Syst.*, vol. 2020, pp. 1–14, Oct. 2020.

[8] S. Messous, H. Liouane, and N. Liouane, "Improvement of DV-Hop localization algorithm for randomly deployed wireless sensor networks," *Telecommun. Syst.*, vol. 73, no. 1, pp. 75–86, Jan. 2020.

[9] R. Gantassi, B. Ben 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.

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

[11] I. B. Prasad, S. Gangwar, Yogita, S. S. Yadav, and V. Pal, "HCM: A hierarchical clustering framework with MOORA based cluster head selection approach for energy efficient wireless sensor networks," *Microsyst. Technol.*, pp. 1–17, Jul. 2023.

[12] M. R. Reddy, M. L. R. Chandra, P. Venkatramana, and R. Dilli, "Energy-efficient cluster head selection in wireless sensor networks using an improved Grey Wolf optimization algorithm," *Computers*, vol. 12, no. 2, p. 35, Feb. 2023.

[13] G. Jayaraman and V. R. S. Dhulipala, "FEECS: Fuzzy-based energy-efficient cluster head selection algorithm for lifetime enhancement of wireless sensor networks," *Arabian J. Sci. Eng.*, vol. 47, no. 2, pp. 1631–1641, Feb. 2022.

[14] B. N. Priyanka, R. Jayaparvathy, and D. DivyaBharathi, "Efficient and dynamic cluster head selection for improving network lifetime in WSN using whale optimization algorithm," *Wireless Pers. Commun.*, vol. 123, no. 2, pp. 1467–1481, Mar. 2022.

[15] 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.

[16] 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.

[17] A. Kumar, S. Yadav, V. Kumar, and J. Srinivas, "A cluster-based data aggregation framework for WSN using blockchain," in *Evolutionary Computing and Mobile Sustainable Networks*, Springer, 2022, pp. 661–672.

[18] A. Sedighimanesh, H. Zandhessami, M. Alborzi, and M. Khayyatian, "Training and learning swarm intelligence algorithm (TLSIA) for selecting the optimal cluster head in wireless sensor networks," *J. Inf. Syst. Telecommun.*, vol. 10, no. 37, pp. 37–48, Feb. 2022.

[19] R. Gantassi, Z. Masood, and Y. Choi, "Enhancing QoS and residual energy by using of grid-size clustering, K-means, and TSP algorithms with MDC in LEACH protocol," *IEEE Access*, vol. 10, pp. 58199–58211, 2022.

[20] S. Arjunan and S. Pothula, "A survey on unequal clustering protocols in wireless sensor networks," *J. King Saud Univ. Comput. Inf. Sci.*, vol. 31, no. 3, pp. 304–317, Jul. 2019.

[21] S. S. Vellela and R. Balamanigandan, "Optimized clustering routing framework to maintain the optimal energy status in the wsn mobile cloud environment," *Multimedia Tools Appl.*, vol. 83, no. 3, pp. 7919–7938, Jan. 2024.

[22] H. Kurita, M. Suganuma, Y. Wang, and F. Narita, "K-means clustering for prediction of tensile properties in carbon fiber-reinforced polymer composites," *Adv. Eng. Mater.*, vol. 24, no. 5, May 2022, Art. no. 2101072.

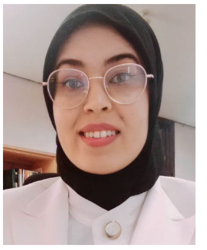
[23] R. Talib, "How we can use energy efficiency built upon the method of K-means clustering to extend the lifetime of WSN," *Al-Salam J. Eng. Technol.*, vol. 2, no. 1, pp. 40–45, 2023.

[24] R. Gantassi, B. B. Gouissem, and J. B. Othman, "The use of grid-sizes clustering and K-means algorithms to enhance the QoS in LEACH protocol," in *Proc. IEEE Int. Conf. Commun.*, Jun. 2021, pp. 1–6.

[25] A. Mazinani, S. M. Mazinani, and M. J. M. Alyasiri, "EFTVG: An energy efficient fuzzy-timer clustering approach in an adaptive virtual grid cluster based WSN," 2023.

[26] M. Maravarman, S. Babu, and R. Pitchai, "Analysis of density-based methods for selecting cluster heads," in *Proc. Int. Conf. Adv. Comput., Commun. Appl. Informat. (ACCAI)*, May 2023, pp. 1–7.

[27] F. Murtagh and P. Contreras, "Methods of hierarchical clustering," 2011, *arXiv:1105.0121*.
[28] T. Wala, R. Kumar, N. Chauhan, and A. K. Sharma, "DDC-OMDC: Deadline-based data collection using optimal mobile data collectors in Internet of Things," *Int. J. Commun. Syst.*, vol. 36, no. 10, p. e5486, Jul. 2023.
[29] M. Pulujkar, S. Kumar, V. Deshpande, and D. Waghole, "Design and implementation of the SIRC protocol for achieving QOS parameters in wireless sensor networks," *Int. J. Intell. Syst. Appl. Eng.*, vol. 11, no. 2, pp. 311–315, 2023.
[30] A. V. Sheshashayee, J. Buczek, C. Petrioli, and S. Basagni, "Experimental evaluation of wake-up radio ranges for UAV-assisted mobile data collection," in *Proc. IEEE Wireless Commun. Netw. Conf. (WCNC)*, Apr. 2022, pp. 716–721.
[31] M. Meddah, R. Haddad, and T. Ezzedine, "An efficient mobile data gathering method with tree clustering algorithm in wireless sensor networks balanced and unbalanced topologies," *Wireless Pers. Commun.*, vol. 123, no. 4, pp. 3699–3717, Apr. 2022.
[32] X. Ma, T. Liu, S. Liu, R. Kacimi, and R. Dhaou, "Priority-based data collection for UAV-aided mobile sensor network," *Sensors*, vol. 20, no. 11, p. 3034, May 2020.
[33] K. L. Ang, J. K. P. Seng, and A. M. Zungeru, "Optimizing energy consumption for big data collection in large-scale wireless sensor networks with mobile collectors," *IEEE Syst. J.*, vol. 12, no. 1, pp. 616–626, Mar. 2018.
[34] 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.
[35] R. Zhang, J. Pan, J. Liu, and D. Xie, "A hybrid approach using mobile element and hierarchical clustering for data collection in WSNs," in *Proc. IEEE Wireless Commun. Netw. Conf. (WCNC)*, Mar. 2015, pp. 1566–1571.
[36] M. Akbar, N. Javaid, M. Imran, N. Amjad, M. I. Khan, and M. Guizani, "Sink mobility aware energy-efficient network integrated super heterogeneous protocol for WSNs," *EURASIP J. Wireless Commun. Netw.*, vol. 2016, no. 1, pp. 1–19, Dec. 2016.
[37] B. A. Mohan and H. Sarojadevi, "Energy-efficient hybrid protocol for routing based on mobile data collectors in wireless sensor network," in *Smart Computing and Informatics*, Springer, 2018, pp. 523–531.
[38] A. Muhammad, A. Nasrullah, and K. Nidal, "Mobile data collector based routing protocol for wireless sensor networks," *Sci. Res. Essays*, vol. 6, no. 29, pp. 6162–6175, Nov. 2011.
[39] R.-B. Wang, W.-F. Wang, L. Xu, J.-S. Pan, and S.-C. Chu, "Improved DV-Hop based on parallel and compact whale optimization algorithm for localization in wireless sensor networks," *Wireless Netw.*, vol. 28, no. 8, pp. 3411–3428, Nov. 2022.
[40] B. Ben Gouissem, R. Gantassi, and S. Hasnaoui, "Energy efficient grid based K-means clustering algorithm for large scale wireless sensor networks," *Int. J. Commun. Syst.*, vol. 35, no. 14, p. e5255, Sep. 2022.
[41] A. Ben Yagouta, R. Gantassi, and B. Ben Gouissem, "Compromises between energy consumption and quality of service metrics in wireless sensor networks with mobile sink and cluster based routing protocols," in *Proc. Int. Conf. Internet Things, Embedded Syst. Commun. (IINTEC)*, Oct. 2017, pp. 60–66.
[42] 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.
[43] O. Mezghani and M. Mezghani, "A three-layer hierarchical architecture for optimized routing protocol based on clustering and khalimsky topology for mobile wireless sensor networks," in *Proc. Int. Wireless Commun. Mobile Comput. (IWCMC)*, May 2022, pp. 1400–1405.
[44] Y. Yue, D. Lu, Y. Zhang, M. Xu, Z. Hu, B. Li, S. Wang, and H. Ding, "A data collection method for mobile wireless sensor networks based on improved dragonfly algorithm," *Comput. Intell. Neurosci.*, vol. 2022, pp. 1–16, May 2022.
[45] Y. Bai, L. Cao, S. Wang, H. Ding, and Y. Yue, "Data collection strategy based on OSELM and gray wolf optimization algorithm for wireless sensor networks," *Comput. Intell. Neurosci.*, vol. 2022, pp. 1–18, Feb. 2022.
[46] S. Al-Sodairi and R. Ouni, "Reliable and energy-efficient multi-hop LEACH-based clustering protocol for wireless sensor networks," *Sustain. Comput., Informat. Syst.*, vol. 20, pp. 1–13, Dec. 2018.



RAHMA GANTASSI (Member, IEEE) received the Ph.D. degree in computer science from the University of Tunis El Manar (UTM), Tunisia, in 2021. She is currently a Postdoctoral Researcher Fellow with the Energy ICT Lab, Chonnam National University (CNU), South Korea. She has published several academic papers in international refereed journals and conferences. Her current research interests include the Internet of Things (IoT), optimization of wireless sensor networks (WSN), and optimizing quality of service (QoS) in WSN. She has also served as a local organizing and a program committee member for various international conferences and a reviewer for several refereed journals.

SANA MESSOUS received the Diploma degree in electronical engineering from the National School of Electronics and Telecommunication (ENET'Com) of Sfax, Tunisia, in 2016. She is currently pursuing the Ph.D. degree with the Electrical Engineering Department, National Engineering School of Monastir, Tunisia. Her current research interests include localization algorithms and optimization in wireless sensor networks.

ZAKI MASOOD (Member, IEEE) received the B.S. and M.S. degrees in electrical engineering from Bahria University, Pakistan, in 2010 and 2015, respectively, and the Ph.D. degree in electrical engineering from Chonnam National University (CNU), South Korea, in 2021. He was a Senior Lecturer with the Department of Electrical Engineering, Bahria University. He is currently a Postdoctoral Researcher with the Energy ICT Lab, CNU. His research interests include wireless energy harvesting, the Internet of Things (IoT) technology, and artificial intelligence (AI) energy for smart grids.

QUOTA ALIEF SIAS received the bachelor's degree in electrical engineering from Institut Teknologi Bandung, Indonesia, in 2013, and the master's degree in power system engineering from Institut Teknologi Sepuluh Nopember, Indonesia, in 2017. He is currently pursuing the Ph.D. degree in electrical engineering with Chonnam National University (CNU), South Korea. His research interests include artificial intelligence (AI) energy for smart grids and renewable energy systems.

YONGHOON CHOI (Senior Member, IEEE) received the B.S. degree in electronics engineering from Sungkyunkwan University, Seoul, South Korea, in 1999, and the M.S. and Ph.D. degrees in information and communications engineering from Korea Advanced Institute of Science and Technology, Daejeon, South Korea, in 2003 and 2010, respectively. He was a Postdoctoral Visiting Scholar with the Department of Electrical Engineering, Stanford University, Stanford, CA, USA, from 2010 to 2013. Since 2014, he has been with the Department of Electrical Engineering, Chonnam National University, South Korea, where he is currently a Professor. His research interests include design, analysis, optimization of wired/wireless communication systems, smart grid communications and networking, energy trading, network economics, and IT convergence networks.