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RESEARCH ARTICLE

Dual-Tier Cluster-Based Routing in Mobile Wireless Sensor Network for IoT Application

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ABSTRACT Mobile wireless sensor network (MWSN) technology is a fundamental element of the Internet of Things (IoT) in which hundreds to thousands of sensor nodes (SNs) are connected via wireless channels capable of providing a digital interface to real-life objects. Energy consumption, connectivity, scalability, and security are the main challenges in MWSN, and mobility increases the effort required to find an efficient routing protocol to improve the MWSN performance. In this paper, we propose a novel routing protocol based on the dual-tier clustering concept and virtual network zones to improve MWSN performance. The proposed protocol named ''Dual Tier Cluster-Based Routing'' (DTC-BR) divides the network area into virtual zones which a cluster-head mechanism selects the most appropriate SN to act as Cluster Head (CH). Furthermore, virtual zones are designed to cover the entire network area based on a dual-tier routing mechanism: the main connectivity zone (MCZ) and candidate cluster zone (CCZ). The DTC-BR protocol was deployed and assessed using MATLAB, assuming three levels: energy consumption, network lifetime, and scalability. The comparative results demonstrate the efficiency of DTC-BR, where the network lifetime increased by 6%, 21%, 25%, and 37% compared to state-of-the-art dynamic directional routing (DDR), mobility-aware centralized clustering algorithm (MCCA), low-energy adaptive clustering hierarchy-mobile energy efficient and connected (LEACH-MEEC), and low-energy adaptive clustering hierarchy mobile (LEACH-M) protocols, respectively. In addition, the simulation results show that DTC-BR is more efficient for large network sizes and a high number of SNs.

INDEX TERMS Mobile wireless sensor network (MWSN), cluster-based routing, cluster head (CH), virtual zone, energy-efficient.

I. INTRODUCTION

The Internet of Things (IoT) is one of the most significant applications of 5G and generates a large amount of traffic [1], [2], [3], [4]. IoT can be expressed as the process of automated data collection performed by sensor nodes (SNs), which can be static and/or mobile, provided, and accessed through the Internet [5], [6]. The revolution in wireless communication systems has widened the interaction of humans to include the interaction between machines in many applications and over various domains, such as military, environmental monitoring, agriculture, transportation, and education [7], [8], [9], [10]. In recent years, advancements in wireless networks have led to the proliferation of mobile wireless sensor networks (MWSNs) in healthcare [11], [12]. These applications are important in terms of the data flow, latency, processing, energy consumption, and security.

A crucial design aspect of wireless sensor networks (WSN) is their deployment. Deployment clearly affects most performance metrics, such as the network coverage area, connectivity, and consequently, network lifetime. In general,

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TABLE 1. Nomenclature table.

Acronym	Term
BS	Base Station
BR	Balance Ratio
CCZ	Candidate Cluster Zone
CH	Cluster Head
CM	Cluster Member
CSM	Cluster Selection Mechanism
CTEF	Clustering-Tree Topology Control Algorithm Based on the Energy Forecast
DDR	Dynamic Directional Routing
DTC-BR	Dual Tier Cluster-Based Routing
ECBR-MWSN	Enhanced Cluster Based Routing Protocol for Mobile Nodes in Wireless Sensor Network
EDADA-RPL	Energy and Delay Aware Data Aggregation in Routing Protocol
EEMCS	Energy-Efficient Mobility Based Cluster Head Selection
FND	First Node Dies
FOI-LEACH	Field Observation Instruments
GPS	Global Positioning System
HND	Half of the Nodes Dies
IoT	Internet of Things
LEACH	Low Energy Adaptive Clustering Hierarchy
LEACH-M	Low Energy Adaptive Clustering Hierarchy Mobile
LEACH-ME	LEACH-Mobile Enhanced
LEACH-MEEC	Low-Energy Adaptive Clustering Hierarchy-Mobile Energy Efficient and Connected
LND	Last Node Dies
MBC	Mobility-Based Clustering
MCCA	Mobility-Aware Centralized Clustering Algorithm
MCZ	Main Connectivity Zone
MHCA	Mobility-Aware Hybrid Clustering Algorithm
MSN	Mobile Sensor Node
MWSN	Mobile Wireless Sensor Network
PDR	Packet Delivery Ratio
SK	Sink Node
SN(s)	Sensor Node(s)
TDMA	Time Division Multiple Access
ULGAT	Unsupervised Learning and Genetic Algorithm Approach for Topology Control
WSN	Wireless Sensor Network

WSN deployment methods are classified into two categories: planned and random [13], [14], [15], [16].

SNs deployed closer to the sink node (SK) in multi-hop WSNs are required to transmit or forward more traffic than other distant SNs of the network. This topological drawback makes closer SNs consume their energy faster than others, which may create energy holes in the network [17].

The degree of restricted resources posed by WSN, such as limited memory, processing, and low battery capacity [16], [18], in addition to extra challenges added to MWSN owing to mobility, cause frequent changes in network topology [19]. To overcome the resource constraints faced by SNs, various energy-efficient routing protocols have been designed by researchers to utilize SN energy efficiently and maximize the network lifetime.

Based on the network structure, routing protocols are divided into two categories, the first being the flat routing protocols, and the second is the hierarchical or cluster-based routing [16], [20]. Because of these advantages, cluster-based routing protocols are effective for WSNs. In this paper, we propose a novel cluster-based routing protocol that uses a virtual zone technique to nominate and select a (CH). First, dual-tier cluster-based routing (DTC-BR) splits the entire network area into virtual zones called the main connectivity zone (MCZ). Furthermore, each MCZ involves a candidate cluster zone (CCZ), in which any SN located in this zone is a candidate CH for the associated MCZ. Second, a particular CH selection mechanism is applied to select the most appropriate SN to act as a CH. The proposed protocol is as follows:

- Virtual network layout;
- Dual tier cluster zones;
- Dynamic cluster head selection mechanism.

The remainder of this paper is organized as follows. Section II presents an overview of the MWSN concept and clustering routing-related studies. Section III describes the SN architecture and the energy and connectivity models adopted in this study. In Section IV, we elaborate the main concept of the proposed DTC-BR routing technique. Section V discusses the simulation results of the proposed DTC-BR compared with those of state-of-the-art protocols. Finally, Section VI presents conclusions and future works.

II. RELATED WORKS

In this section, we review related studies on clustering protocols adopted in several WSNs, where SNs are organized into groups termed clusters. The normal nodes in a cluster are called cluster members, and one of them is selected as the CH [21]. Many researchers have focused on clustering protocol techniques that would dissipate less energy, improve the connectivity between SNs, and consequently extend the lifetime of the network. The advantages of implementing a clustering protocol include reduced energy consumption, communication overhead during data transmission, increased connectivity, and decreased delay [22]. Dynamic clustering [23], weighted clustering [24] and hierarchical clustering [25] are some of the clustering protocols that have been successfully implemented. There are many approaches for nominating a CH in clustering based on several parameters, such as the remaining energy of the SN, SN location, or SNs density.

Many routing protocols have been proposed to optimize the energy depletion of WSN, some of which are discussed in this study.

The low energy adaptive clustering hierarchy (LEACH) is the first solid cluster-based routing protocol proposed by Heinzelman et al. in 2000, which inspired many other routing protocols. LEACH comprises static SNs with fixed base station (BS). The main idea is to nominate CHs with equal chances of all SNs becoming CH, ignoring the energy balance of the entire network. The LEACH procedure involves two phases: setup and steady-state phases per round [26].

However, LEACH was exposed to premature death and reduced the entire lifetime of the network because of the randomness of CH selection, without considering the remaining energy of the SN or the distance to the BS. Researchers have investigated and developed numerous protocols for static wireless WSNs. MSNs have been used in several Internet of Things applications. However, their mobility poses several challenges to WSN.

The first mobility-based routing protocol, introduced by Kim et al. in 2006, was a low-energy adaptive clustering hierarchy mobile (LEACH-Mobile or LEACH-M as short-term). LEACH-M supports the mobility feature of SNs in WSNs, where clusters are formed such that each cluster comprises a CH and regular SN. Regular SNs sense the data and forward them to the CH, whereas the CH establishes a router from the SNs to SK. Furthermore, the CH assembles and fuses the data from the SNs, and then transmits the emerging information to SK. The selection of CH was based on a random number and predefined threshold. The main idea of LEACH-M is to add membership declaration while the SN is moving and to confirm whether an MSN can communicate with a certain CH within an allocated time slot in the time division multiple access (TDMA) schedule [27]. Although the LEACH-M protocol outperforms the LEACH protocol in terms of data transmission and packet loss in MWSN compared to the stationary-centric LEACH protocol, the position and number of CHs are chosen randomly which has a negative impact on the packet delivery ratio (PDR), energy consumption, and eventually network lifetime.

LEACH-Mobile enhanced (LEACH-ME) is an improvement of LEACH-M protocol developed by Kumar in 2008, LEACH-ME is appropriate for MWSN where the CH selection is based on mobility factor that is calculated by the product of the MSN speeds' and the desired time for each SN as it moves from the existing position to another. SNs with minimum movement or group motion with non-cluster head members are referred to as CH [28]. Despite the experimental results showing a confident enhancement in the successful communication rate in comparison with LEACH-M, the LEACH-ME protocol consumes extra energy and requires more time slots for mobility factor calculation.

In 2012, Deng proposed a new protocol called mobility-based clustering (MBC) that is suitable for WSNs with MSNs. The random selection of CH is performed by the SNs themselves and based on the residual energy and the speed of mobility to avoid electing low-energy SNs as CHs, which balances the energy utilization among all SNs. The MBC protocol is similar to LEACH-M, in which the procedure is divided into two phases: setup phase and steady-state phase. The aim of this protocol is to establish a more appropriate link between MSNs and nominated CHs based on route constancy, considering the connection time for cluster formation [29]. Experiments show that this protocol can perform better in a dynamic environment, that is, high SNs mobility; however, it suffers from problems such as packet loss and link failure, in addition to incompetent network utilization.

In 2013, an enhanced cluster-based routing protocol was developed for mobile nodes in wireless sensor networks (ECBR-MWSNs). The ECBR-MWSN includes five stages: initialization, cluster formation, CHs election, data transmission, re-routing, and clustering. The ECBR-MWSN depends on three parameters for selecting CHs: the highest remaining energy, the lowest movement, and the least distance to SK. SK repeats the process of periodically electing new CHs units after a specified period. ECBR-MWSN aims to extend the network lifetime by balancing the energy conservation of the MSN [30]. This protocol outperforms LEACH-M and LEACH-ME; nevertheless, it has an additional overhead and limited scalability.

In 2016, Hong proposed a clustering tree topology control algorithm based on energy forecasting (CTEF) to save energy and preserve the load balancing of heterogeneous WSN by observing the energy forecasts of nodes. This protocol selects CHs using an objective function that includes SN energy, link quality, and packet loss rate. Non-CHs join the cluster based on distance and link quality. However, several non-CHs were selected to act as relay nodes to transmit data via multi-hop communication. The energy consumed by CHs in the CTEF is relatively high because it involves numerous tasks [31].

In 2018, a low-energy adaptive clustering hierarchy-mobile energy-efficient and connected (LEACH-MEEC) routing protocol was proposed, in which the selection of CHs was based on two parameters: the residual energy of MSNs and connectivity among the rest of the SNs. This protocol aims to improve packet delivery and prolong network lifetime [32].

In 2018, the unsupervised learning and genetic algorithm approach for topology control (ULGAT) [33] optimized the network topology. This approach is suitable for ultra-dense WSNs with deterministic deployment of sensed objects. However, this is a single objective.

Mobility-aware hierarchical clustering in mobile wireless sensor networks proposed 2019 two algorithms to overcome the disassociation problem between the sensor nodes and their cluster heads owing to the mobility of sensor nodes: mobility-aware centralized clustering algorithm (MCCA) and mobility-aware hybrid clustering algorithm (MHCA), both of which improve the data transmission rate [34].

Energy and delay-aware data aggregation in routing protocol (EDADA-RPL) for IoT is a traffic-based clustering protocol proposed in 2019 to construct a network topology containing (the hierarchical level value and cluster size) in addition to SNs density and traffic trends. This approach reduced the traffic and led to a longer network lifetime owing to efficient load balance. However, SNs far from the BS lose power faster than SNs near the BS [35].

The energy-efficient mobility-based cluster head selection (EEMCS) protocol was introduced in 2020 to maximize the lifetime of MWSN and overcome some of the problems in the existing cluster routing protocols, such as insufficient CH selection criteria. The EEMCS protocol operates in several stages, starting with the CH selection for cluster creation, followed by data collection and transmission. The selection of the CH is based on four parameters: remaining energy, mobility level, distance to the BS, and density of neighbors. These parameters affect the energy consumption of the entire network [36].

FOI-LEACH is an improved routing protocol developed by Umbreen et al. in 2020 that is based on LEACH for field observation instruments. This protocol depends on the residual energy, in addition to the rechargeability of the node, to select an optimal CH to reduce the premature death of CHs and prolong network lifetime. Additionally, this protocol focuses on the distance from the CH to the BS to alleviate the hotspot problem. However, scalability, which is inappropriate for small sensing fields, has not been considered [37].

In 2021, Reham et al. proposed dynamic directional routing (DDR), which adapts to the mobility of SNs to accomplish reliable and efficient routing in MWSN. DDR is implemented in two phases: the discovery phase and the data forwarding phase, which use geographic information to bind the direction and distance of communication when an SN chooses its parent node to control the flow of data in the MWSN, which optimizes the routes toward the sink [38]. This approach requires little energy to detect neighboring SNs and define the parent nodes. However, this solution might be locally optimal. Therefore, it is difficult to prevent a hotspot problem, resulting in a premature network.

A comparative table of different clustering routing approaches in MWSNs based on performance metrics, in addition to some features is presented in TABLE 2.

The above-mentioned protocols encounter some design issues, which can be classified into two categories: protocols that are implemented with static WSN, and which are not applicable in many environments that require mobility WSN. The second is the protocol implemented for the MWSN. This protocol dynamically constructs clusters while electing CHs randomly, based on the density of SNs, location of the SNs, or remaining energy. This technique overloads the network and eventually causes premature network death.

The mobility of SNs presents a significant challenge for designing an appropriate routing protocol for MWSNs. Therefore, the contributions of our study are to limit the impact of SN mobility and minimize the energy hole problem using a dual-tier concept, which proposes the following for better utilization of energy and extending network lifetime by improving the CH selection scheme:

- A virtual zone-based system was applied to the entire network, which divided the cluster area into two zones: MCZ and CCZ.
- Each MCZ had a fixed position and radius corresponding to the SN communication radius. The formation and distribution of these MCZs were performed only once.
- For each MCZ, we deploy a CCZ, which is a circular area at the center of the MCZ with a variable radius, depending on the configuration of the network user.
- A cluster selection mechanism (CSM) is used for all SNs located in the CCZ to nominate an SN as a CH based on an efficient selection.

In addition, the proposed protocol constructs clusters to avoid long-link problem. Therefore, whenever a distance threshold is reached, or the energy falls below a threshold value dynamically, it will nominate a CH from the CCZ to forward data that aggregates from its associated SNs within the MCZ, shrinking the long-distance communication.

Furthermore, our proposed algorithm guarantees high scalability and low computational complexity, with lower latency when the CH uses one hop and SNs use two hops.

III. NETWORK DEVELOPMENT MODELING

The revolution in the MWSN technology has improved its reputation for real-world IoT applications. This ubiquitous method requires an efficient approach to handle and process data appropriately in terms of point-to-point connections in a line synchronized with a consistent and reliable network [39]. Existing routing protocols have certain design issues, as previously mentioned.

The problem addressed in this study is the development of a cluster-based routing protocol that can address design gaps in existing protocols and overcome their disadvantages. Most protocols are designed to operate efficiently by using static SNs, but at the same time, this causes an energy hole at some point owing to their static nature deployment [40]. However, most of the current IoT applications require only partial or complete MSNs. Mobility in a WSN necessitates an efficient routing protocol that uses available power and extends the network lifetime.

A. NETWORK MODEL

To simplify the network model in the DTC-BR protocol, we adopted the following assumptions for the network model and SNs.

- SNs were considered homogeneous. Despite, all SNs have identical resources.
- All SNs have an equal data transmission range; i.e. 100 m.
- SNs with fully depleted energy are considered dead nodes and excluded from all operations.
- Each SN has a unique identity called SN ID.
- All SNs are aware of their energy and current positions; therefore, they are embedded in a global positioning system (GPS) or other position-determination devices.
- All SNs are mobile prior to the beginning of each round; however, all of them are stationary during each round, that is, the movement of SNs will be either before starting the round or after ending the round, with a predefined range and speed.

TABLE 2. Summary of the state-of-the-art clustering routing protocols.

Protocol Name	Energy Efficiency	Scalability	Complexity	Strength	Weakness
LEACH-M	Low	Poor	Low	Not require information of the global network	Assume that CHs are stationary Consume high energy Inefficient data delivery rate
LEACH-ME	Low	Poor	Low	Selects CHs with less mobility factor	Consume extra energy for calculating mobility factor of each SN
MBC	Moderate	Moderate	Low	Using residual energy and mobility to select CHs	Ignore the critical node occurrence problem that cause link break, and packet dropping
ECBR-MWSN	Moderate	Poor	high	Extend the network lifetime Balance the energy consumption among SNs	High overhead Limited scalability
CTEF	Low	Poor	Moderate	Provides an opportunity to find a suitable path based on the range or the distance between the SNs	CHs drain their energy faster which results in decreasing the network lifetime.
LEACH-MEEC	Moderate	Low	Low	Considered the connectivity among neighboring nodes and the remaining energy of MSNs	Low scalability in terms of number of SNs and networking area Not stable
ULGAT	Moderate	High	Moderate	Suitable for large-scale WSNs	Over-textitasing single-objective optimization
MCCA MHCA	Low	Low	High	Stabilize cluster formation, enhanced energy conservation and data rates	
EDADA-RPL	Moderate	Low	High	Reduces the data latency as well as cuts down packet loss	Technique becomes complicated while discovering alternate nodes
EEMCS	Moderate	Low	Moderate	Reducing duplicate data amongst networks improves energy utilization and increases network lifetime	do not consider the security aspect
FOI-LEACH	Moderate	Low	Moderate	Balance network energy consumption and alleviate the "hot spot" problem	Scalability issue is not considered, and this is not so suitable for small sensing field
DDR	Moderate	Moderate	High	Low energy consumption	Difficult to prevent the hotspot problem
The proposed protocol	Moderate	High	Low	Sufficient with large-scale of MWS Very low complexity	Not suitable to small-scale MSNs

- SNs can communicate directly with their CH or indirectly with SK through their CH, according to the TDMA time slot.
- The energy threshold is defined to avoid premature death of the SN owing to unbalanced energy reduction and is calculated based on the average energy of all SNs.
- There is one static SK equipped with sufficient resources i.e. limitless battery, memory and computing ability. In addition, the location of SK is fixed and known to all the associated SNs.

Table 3 summarizes the important notations used in the system model.

B. DEPLOYMENT STRUCTURE

MSNs were randomly distributed over a square field of 100×100 m^2. As observed in the literature, increasing the number of clusters results in increased energy consumption, and thus causes extra overhead. In the DTC-BR protocol, we utilized a couple of ranges and checked for suitable ranges to improve the network lifetime based on different combinations of parameter performances. Therefore, a predefined number of MCZ were implemented based on the testbed and executed only once to avoid the overhead of cluster formation.

The distribution of SNs was unequal in each MCZ. However, we considered a ratio for SNs density to avoid a high number of SNs in some MCZs and preserve the balance in energy consumption between all MCZs which we call the balance ratio (BR). The BR provides a slight difference in the number of MSNs in the different MCZs, and it is calculated as in (1).

$$\text{No.MSN}_{\text{MCZ}}^{i} = \left(-1^{i} \times BR\% + 1\right) \times \frac{\text{TotalNo.of MSNs}}{\text{TotalNo.of MCZ}} \tag{1}$$

where i is the MSN number.

The distance between two MSNs S_i, S_j located in the same MCZ is calculated using the Euclidean distance [41], as shown in (2):

$$d_{ij}\left(t\right) = \sqrt{\left(x_j - x_i\right)^2 + \left(y_j - y_i\right)^2} \tag{2}$$

In addition, we assume that at least one SN in the CCZ for each MCZ ensures higher connectivity between the SNs and CH. When all SNs are deployed, SK broadcasts a "Hello" message and waits for each SN to receive the start message to respond and send their energy level, in addition to their position.

TABLE 3. Summary of system variables.

Symbol	Description
BR	Balance ratio
S	Set of mobile sensor node
d_{ij}	Euclidean distance
d_{toCH}	Distance from SN to associated CH
d_{toSK}	Distance from CH to SK
β	Data packet size
E_t	Energy consumption
$D_{(S_i \leftrightarrow S_j)}$	Distance between the transmitter S_i and the receiver S_j
mp	multipath
θ_{mp}	Amplification energy
fs	Free space fs
θ_{fs}	Free space energy
δ_t	Energy dissipated in transmission
δ_r	Energy dissipated in reception
E_r	Energy consumption
E_s	Energy sensing
E_a	Energy aggregation
Er	Remaining energy
E_{current}	Current energy
E_0	Initial energy
R_c	Transmission radio range
ML_{SN_i}	Mobility level
C	Set of MCZs
R	MCZ radius
r	CCZ radius
CH	Set of CHs
d	Density
w	Weight percentage

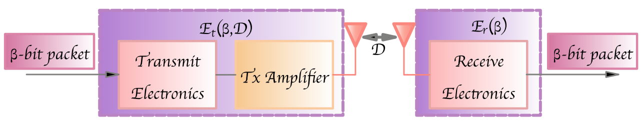

FIGURE 1. Radio energy dissipation model.

As a pre-requirement, we can change the network area, number of SNs, and consequently, the number of predefined MCZ and CCZ sizes.

C. DISTANCE

One of the main players in the energy dissipation process of an SN is the distance. SNs that are distant from their CH or SK consume more energy compared to closer. In the DTC-BR protocol, we used (2) to calculate the distance between SNs and their associated CH which is denoted as d_{toCH}, and the distance between the CHs and SK which is denoted as d_{toSK}.

D. ENERGY MODEL

As discussed earlier, all SNs have limited resources, and we aim to maximize the network lifetime through efficient energy utilization methods. Most SNs consume energy during data communication in WSN. Therefore, it is important to evaluate the energy costs of data transmission and reception during the interaction between the SNs and SK.

In the DTC-BR protocol, we used the energy model adopted in [26], as shown in FIGURE 1. To send a β-bit data packet from SN S_i to SN S_j the energy consumption E_t is calculated, as shown in (3).

$$E_t\left(S_i, S_j\right) = \begin{cases} \left(\delta_t + \theta_{fs} D^2_{(S_i \leftrightarrow S_j)}\right)\beta, & D_{(S_i \leftrightarrow S_j)} < d_0 \\ \left(\delta_t + \theta_{mp} D^4_{(S_i \leftrightarrow S_j)}\right)\beta, & otherwise \end{cases} \quad (3)$$

where $d_0 = \sqrt{\theta_{\text{fs}}/\theta_{\text{mp}}}$

According to the distance between the transmitter SN S_i and the receiver SN S_j which is defined as $D_{(S_i \leftrightarrow S_j)}$, a multipath mp model is used when the distance exceeds the threshold value with amplification energy θ_{mp}, otherwise free space fs is used with θ_{fs}, whereas δ_t and δ_r are the energy dissipated in transmitting and receiving one bit, respectively.

The energy E_r consumed to receive β-bit data packet by SN S_j is given by (4).

$$E_r\left(S_j\right) = \delta_r \beta \quad (4)$$

Moreover, we assumed that the energy consumed for sensing data is E_s, and the energy for aggregating data is E_a.

E. RESIDUAL ENERGY

In each round, the energy of the SN starts reducing during data communication because the energy depletion differs from one SN to another owing to its role in the network and the number of packets sent.

The remaining energy [42] is determined using (5):

$$\text{Er} = \frac{E_{\text{current}}}{E_0} \quad (5)$$

F. CONNECTIVITY

In DTC-BR, after forming the cluster MCZ, because all SNs reply SK with their ID and current position, the CH establishes a connection with its associated MSNs if they are within the MCZ radius (R) and not exceed the transmission radio range (R_c), $\left(S_i \longmapsto C_k | d_{(S_i, C_k)} \le R\right)$. All SNs can sense an area at any point within their radio-sensing range.

G. MOBILITY

Mobility plays a vital role in wireless sensor networks (WSN). SNs can move in any direction or round. Quick mobility negatively affects network communications. If the CH rapidly alters its location, the SNs will lose their connection, which may cause resource wastage, and frequent re-clustering will exert more energy. Additionally, an SN with a high mobility level has fewer opportunities to be selected as a CH.

In DTC-BR, the mobility factor is considered as an SNs that changes its positions randomly. In addition, we consider that all SNs have a static speed that is fixed at the beginning of the simulation. To calculate the mobility level [43], we used (6), which measures the difference between the latest and previous SN positions.

$$\text{ML}_{\text{SN}_i}(t) = \sqrt{(x_{\text{new}} - x_{\text{curr}})^2 + (y_{\text{new}} - y_{\text{curr}})^2} \quad (6)$$

IV. DUAL-TIER CLUSTER-BASED ROUTING

Many algorithms have been proposed to select the optimal CHs. Some of them work with stationary WSN and are based on probability, whereas others depend on defined threshold values for selecting the CH. However, some protocols have adopted revolutionary algorithms to select optimal CHs with a high time complexity. The best practice for selecting the optimal CH based on parameters that affect energy utilization as the main objective of CH selection is to neighbors energy consumption and utilize resources efficiently.

The scope of this study is to develop a cluster-based routing protocol for MWSN that considers energy, scalability, and connectivity and eventually prolongs the lifetime of the entire network.

In this study, a set of CHs is defined, where each CH serves one MCZ and each SN is associated with one CH at a time. The SN can perform as either a cluster member (CM) or a CH. A CM is an ordinary node that is non-CH responsible for sensing data and sending it to the CH, whereas the CH is responsible for aggregating the received sensing data and eventually forwarding them to the BS/SK directly or indirectly by accessing the neighboring CH. SNs are mobile with specific mobility levels, which may lead to frequent changes in the network topology within rounds.

The main objective of our solution is to dynamically form a new optimal set of CHs after each network topology change in the two cases. First, the CH is unable to cover 90% of the area of its MCZ owing to the dynamic movement of SNs. The second case occurs when the energy depletion of the CH exceeds a predefined threshold.

Dual-tier cluster-based routing (DTC-BR) involves two phases.

- First, the virtual zone system, where DTC-BR splits the entire network area into several virtual zones to cover the area of interest that predefines the MCZ with an even size, in which each of them performs individually. Subsequently, for each MCZ, a CCZ was applied in which all SNs placed in this zone were potential CH candidates. Furthermore, the MCZ has a fixed position, with a radius that represents the communication radius of the SN. However, the CCZ is located at the center of the corresponding MCZ and its radius is variable, which is defined according to the nature of the application.
- Second, CSM is applied to each CCZ to select the best candidate from the CCZ node population to act as a CH. Indeed, all SNs located in the CCZ are potential CH candidates, based on certain metrics and priorities. The weights of SNs are measured as follows: the first is the minimal distance between the candidate node and the center of the CCZ, the second is the residual average energy threshold, which changes according to the nature of the application, and the third is the mobility.

SNs are deployed randomly within a fixed geographical region network to monitor the region continuously.

Initially, all SNs are homogenous MSNs; therefore, they have the same resources in terms of the initial energy, processer capacity, sensing range, and transmission range. They also have the same probability of being selected as a CH when the performance matrix is satisfied. After each round, the residual energy of each SN was computed to check against the predefined energy threshold, in addition to the distance from the MCZ center, which may change owing to the mobility of SNs, in addition to the mobility level. These metrics are used to select a new CH for each MCZ. SNs with the highest reaming energy, shorter distance to the center, and lower mobility were selected.

If the CCZ contains a single SN with a fair residual energy greater than the determined threshold, it is denoted as CH for the MCZ. However, if the residual energy of the SN is insufficient, the nearest SN to the center of the MCZ with residual energy that exceeds the average residual energy and is more stable is selected as CH.

For further clarification, we assume M represents a set of MSNs $\{S_1, S_2, \ldots, S_i | 1 \leq i \leq M\}$ deployed over the network area $x \times y$, so the coordinates of SN S_i are (x_i, y_i) and we use (7), which indicates the distance from SN S_i to SN S_j at time t.

$$d_{ij}(t) = \sqrt{\left(x_j - x_i\right)^2 + \left(y_j - y_i\right)^2} \tag{7}$$

There are N MCZ $\{C_1, C_2, \ldots, C_j | 1 \leq j \leq N\}$. Each MCZ had a set of SNs that were randomly deployed with an R_C of radius R. One SN per MCZ will be selected as CH $\{\mathrm{CH}_k \mid k \in \{1, 2, \ldots, N\}\}$. Each MCZ follows the principle that there is no overlap between the MCZ $\{C_j = \{S_1, S_2, \ldots, S_m, \mathrm{CH}_a\} | 1 \leq m \leq$ number of SNs within C_j and $\mathrm{CH}_a \subseteq C_j\}$. Therefore, each SN belongs to one and only one MCZ $\{S_i \in C_k \ \& \ S_i \notin \{C_1, C_2, \ldots, C_j | 1 \leq j \leq N | k \neq j\}\}$, and is connected to one CH at a time. Each CH should serve the maximum number of ordinary SNs located in the same MCZ. The proposed algorithm assigned a CH to each MCZ.

The DTC-BR operation begins with the MCZ formation phase, in which the networking area is divided into different zones, followed by two phases, based on the round technique. Each round began with a setup phase, when SK determined the CH for each MCZ. This is followed by a steady-state phase when the sensed data are transferred to the associated CH after the CH collects the data in the packets and transmits them to the SK. Moreover, a re-clustering process is invoked when required. Details of the proposed DTC-BR protocol are discussed in the following section. FIGURE 2 illustrates the comprehensive process of the two main phases of the proposed DTC-BR.

A. MAIN CONNECTIVITY ZONE FORMATION PHASE

In the initial stage, the network area was split into symmetric predefined numbers of regions called the MCZ, where each region was fragmented into two areas, and the area near the center was named the CCZ. Subsequently, the MSNs were randomly deployed over the MCZ, as shown in FIGURE 3.

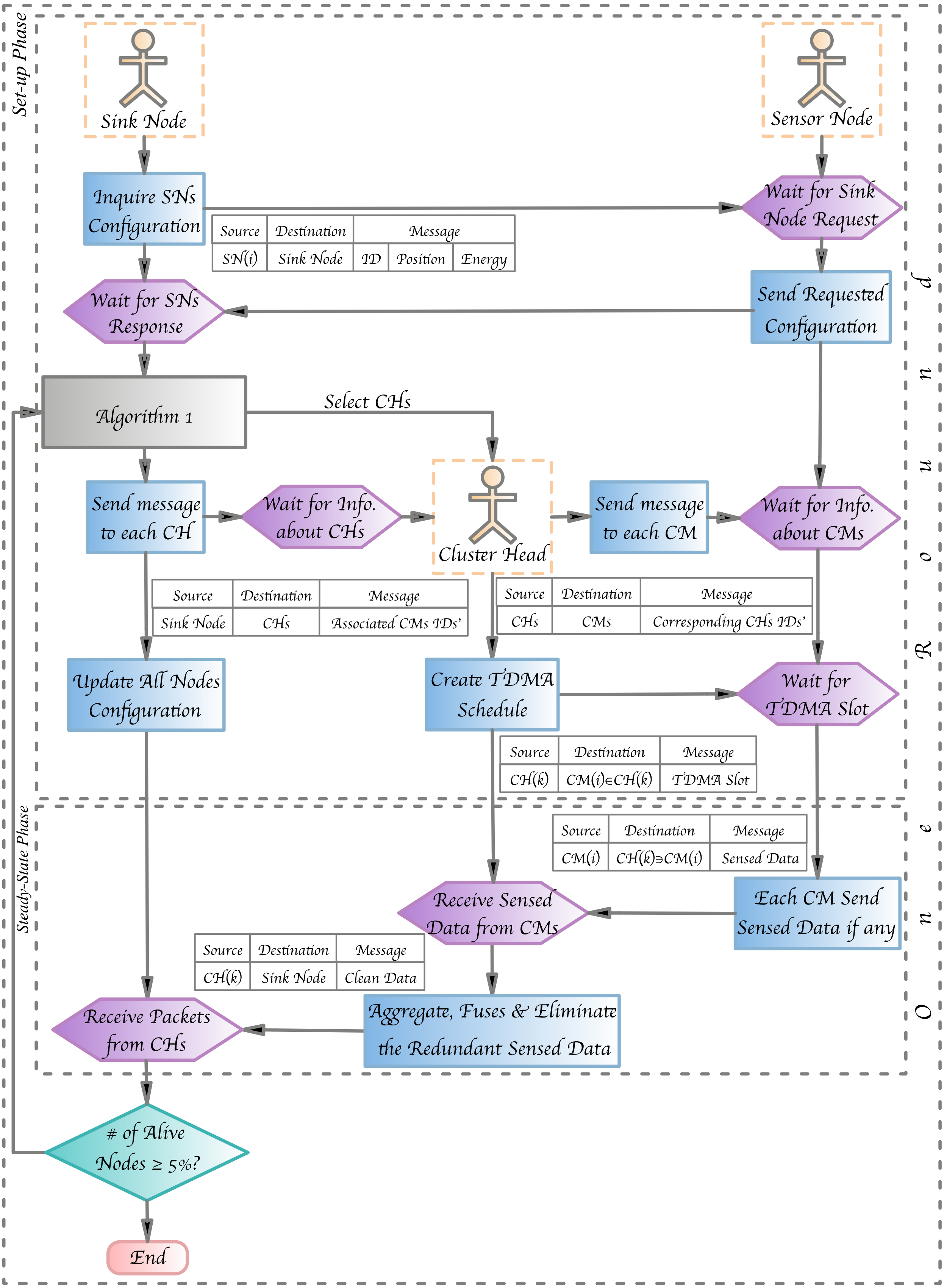

FIGURE 2. The proposed DTC-BR algorithm process.

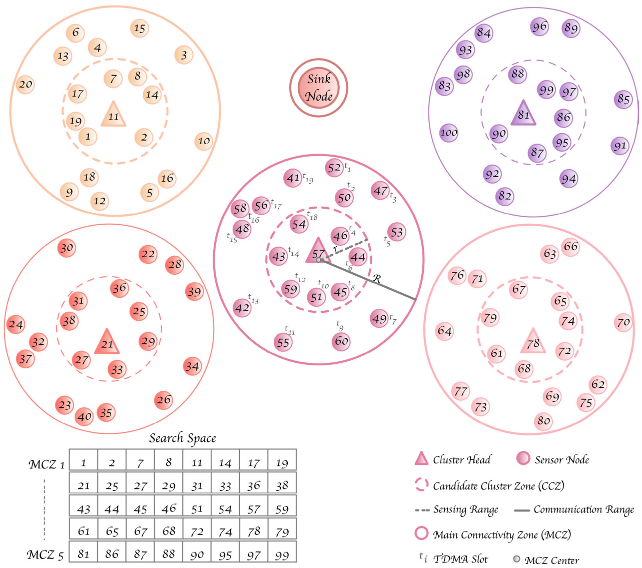

FIGURE 3. The set-up phase: MCZ formation.

Each zone was divided into two areas based on the distance between the MSNs and the origin of each MCZ. The first zone represents a set of neighboring MSNs with radius r and density $d \geq 40\%$ of the MCZ density. In contrast, the second zone, the MCZ, represents MSNs with radius $R - r$. The MCZ was fixed and this approach was executed only once. Therefore, the deterministic MCZ reduces the setup overhead for forming the MCZ at the beginning of each round, whereas CCZ splitting of each MCZ neighbors the computational process.

FIGURE 3, illustrate a target-based network area, for demonstration let us consider a 100×100 m^2 network area which is divided into five equal clusters called MCZ $\{MCZ_1, \ldots, MCZ_5\}$, and further each MCZ is segregated to areas near to MCZ origin named as CCZ $\{CCZ_1, \ldots, CCZ_5 | CCZ_n \in MCZ_n\}$, each MCZ contains a group of MSNs deployed randomly and distributed over the zones, the total number of MSNs are 100 as $\{S_1, \ldots, S_{100}\}$. Thus will consider $\{\{S_{41}, \ldots, S_{60}\} \subseteq MCZ_3\}$ and $\{\{S_{43}, S_{44}, S_{45}, S_{46}, S_{51}, S_{54}, S_{57}, S_{59}\} \subseteq CCZ_3\}$, all the MSNs that located in CCZ_3 are added as members of the search space where all MSNs are eligible to be selected as CH when the remaining energy of all nodes is greater than the energy threshold. Based on the characteristics of the search space, we calculate the weight of each MSN. We then select S_{57} as the CH for CCZ_3 among its neighbors, because it has the largest weightage and satisfies the energy threshold. The same process was repeated for all MCZ. CHs broadcast messages for their CMs and later coordinate communication with other MSNs in their R_C, then forward the sensed data to SK. In addition, CHs provided full coverage of all MSNs within their ranges.

TABLE 4 identifies the assigned weight of each parameter with the actual values. The appropriate weighting was inspired by [36]. According to several simulation tests, we selected the weightage that preserves the network energy and extends the lifetime. Furthermore, we evaluated several values with a defined rate of parameters that helped us to select the optimal CHs. Eq. (8) is used to compute the weight of each MSN.

TABLE 4. Weights parameters of CH selection.

Parameter	Weights	Used Values
Residual Energy w_1	0.4	50%, 70%, & 90%
Distance to the MCZ Origin w_2	0.3	5, 10, & 15 m
Mobility Level w_3	0.3	-

$$MSN_{weight} = Er \times w_1 + d_{toCH} \times w_2 + ML_{SN_i}(t) \times w_3 \quad (8)$$

The node with the largest weighting is the CH. The CH sets a TDMA timeslot for the associated SNs to send sensed data. Subsequently, the CH collects, aggregates, and fuses the data, and sends the data to SK.

B. SET-UP PHASE

SK instantiated during the first round. SK sends a message to all SNs to wake up and enquire about their configuration, such as SN IDs, locations, and energy. The CHs are selected from the MSNs of each MCZ based on the feedback from all SNs, which allows the algorithm to calculate the weightage of each SN. Our proposed protocol is distinguished from current clusters protocols mentioned in the literature, which elect the CHs among all alive MSNs while DTC-BR limits the candidate MSNs to be from a CCZ near the MCZ center to ensure wide coverage at the same time keep the number of clusters acquit, because an excessive number of clusters consumes additional energy and cause overhead [36]. SK builds an SNs search space from a set of MSNs located in the CCZ of each MCZ. SK checks the residual energies of all MSNs within that range, including the CHs in the list for the next round. When one criterion was insufficient, that is, 20% of CMs were uncovered by the CH or the residual energy of a CH was less than the threshold, the process was repeated to determine the most appropriate MSNs to act as a new CH for each MCZ. Algorithm 1 illustrates the pseudocode for CH selection.

The number of MCZ indicates the number of CHs in the network. Non-cluster nodes, that is, CMs, are assigned to the MCZ based on their positions. Each CH receives a short message from SK that contains the IDs of the associated CMs. Meanwhile, each CH will propagate an announcement message for all CMs within its R i.e. within its zone, to inform them that it is elected as a CH. All CMs communicate with their CH in TDMA mode controlled by the CH. This prevents intra-cluster collisions and neighbors the energy dissipation. Moreover, it enables MSNs to not be in the sleep mode.

C. STEADY STATE PHASE

In this phase, MSNs are awake and begin to sense the data from the environment. Each MSN sensed data within its sensing range according to the TDMA schedule managed by its associated CH and then transferred it to the CH-based. The CH maintains its receiver. Once the CH receives the data from

Algorithm 1 Pseudocode to Select Cluster Heads in MWSN Per Round

Input: MCZ_No, nodeID
Output: select a CH for each MCZ.
For $j \leftarrow 1$ **To** N //N is the total number of MCZ in the MWSN
  For $i \leftarrow 1$ **To** S //S is the total number of SNs within certain MCZ
    Calculate $d_i(t) = \sqrt{\left(x_i - x_{\text{MCZ}_j}\right)^2 + \left(y_i - y_{\text{MCZ}_j}\right)^2}$
    If $d_i(t) \le r$ **Then**
      $i \in \{\text{CCZ}(j)$
    Else
      $i \in \{\text{MCZ}(j)$
    End If
    Calculate $\text{Er}_i = \frac{E_{\text{current}}}{E_0}$ //Calculate the residual energy Er_i
    If $\text{Er}_i \ge E_{\text{threshold}}$ **Then**
      $\text{maxEr} = \text{Er}_i$
      Do while $k \in \{CCZ(j)$
        If $\text{Er}_k > \text{maxEr}$ **Then**
          $\text{maxEr} = \text{Er}_k$
        End If
        Calculate maxW_i
      End While
    End If
  End For
  $\text{CH}(j) \leftarrow \text{maxW}_i$
End For

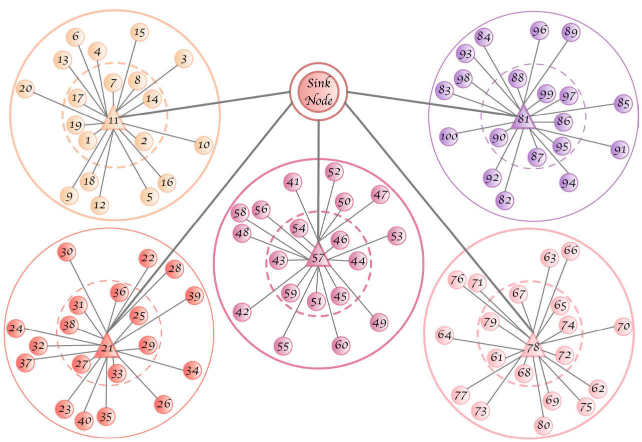

FIGURE 4. The steady-state phase nodes' formation.

the MSNs, it aggregates, fuses, and eliminates redundant data and sends it using single-hop communication directed to the SK or multi-hop communication through the nearest-neighbors CH. In multi-hop communication, the energy consumption of the CH also includes the energy required to forward the data to their neighboring CH in addition to the main energy of receiving, aggregating, fusing, and eliminating redundant data sent from their CM. Once all CHs send the data to SK, the initial round is completed. Subsequently, the next round begins and repeats the process, and new CHs are determined based on new parameter values. FIGURE 4 shows the communication directions in the steady-state phase.

D. RE-CLUSTERING PROCESS

The re-clustering process will be repeated in the following cases:

1) OUT OF SERVICE NODE

Which occurs when the residual energy of the node decreases to less than the energy-death threshold. Therefore, the type of node should check whether the node is a CM or CH. If it is a CM, then it simply broadcast an "out of service message" including its ID, but if it is a CH the process of reselecting another CH is instantiating to replace the existing one with the largest weightage among other SNs in the same MCZ after that the previous CH broadcast "out of service message" which contains the ID of the new CH and the dying CH. Consequently, the associated SNs in the MCZ will replace the dying CH with the new one, and lately, SK will update its list. The operations are illustrated in Algorithm 2 for case (1).

2) NODE MOVEMENT

As SNs within the networking area are mobile, they are free to move within the MCZ or move to another MCZ and can move beyond the network area boundaries. Therefore, when a node changes position, its type must be determined. So, if the node is CM it broadcast a "leave message" including its ID and position which cause the old CH to remove it from the list and the new CH based on its new position to establish a link with it or may totally remove from the SK list if the new position is out of the range. While if the type of node is CH, then select a node with maximum weightage to become the new CH for the MCZ, after that the moved CH broadcast a "leave message" containing its ID in addition to the ID of the new CH. All SNs within the MCZ remove the old CH and join the new CH. As demonstrated in Algorithm 2, case (2).

E. TIME COMPLEXITY ANALYSIS

Time complexity is a crucial indicator used to assess the efficiency of an algorithm. It estimates the total times needed to execute an algorithm. The time complexity of the proposed DTC-BR protocol is the total complexity of all phases that compromise the three phases: the first is the main connectivity zone formation phase, which requires $O(1)$, the second is the set-up phase where the selection of CH for each zone is performed and the approximated time complexity is required $O(R \times n)$ where R is the maximum round, n is the number of SNs per MCZ, while the time complexity of the third phase is $O(n)$, and in the last phase, the time complexity needed to operate the re-clustering $O(n)$. Therefore, the time complexity is required to run the proposed algorithm is $O(n)$ which is relatively low compared with other existing protocols.

V. SIMULATION RESULTS AND DISCUSSION

This section emphasizes the evaluation metrics and specifications of the simulation environment and discusses the results of the simulations.

A. PERFORMANCE METRICS

We used MATLAB Environment (2021a) to implement our proposed DTC-BR protocol and evaluated its performance by comparing the proposed algorithm with well-known existing

Algorithm 2 Pseudocode of Re-Clustering

Input: nodeID, Position, E_r, $E_{\text{threshold}}$
Output: re-structure network topology.
(A) **Case (1):** **If** $\mathrm{Er}_i < E_{\text{threshold}}$ **Then**
    If ID_i.type = CH_i **Then**
        Find $\mathrm{MCZ}_m \in \mathrm{CH}_i$
        For $j \leftarrow 1$ **To** n //n is the total number of SNs within MCZ_m
            Calculate Er_j, d_j //As in the Algorithm 1
        End Fo
        Find maxW_j
        $\mathrm{ID}_j \leftarrow \mathrm{CH}_j$
        Broadcast outofservice(ID_i, ID_j)
        $\mathrm{MCZ}_m \leftarrow \mathrm{MCZ}_m \setminus \mathrm{ID}_i$
        Do while $k \in \{\mathrm{MCZ}_m$
            my$\mathrm{CH}_k \leftarrow \mathrm{ID}_j$
        End While
    Else
        Broadcast outofservice(ID_i)
        $\mathrm{MCZ}_m \leftarrow \mathrm{MCZ}_m \setminus \mathrm{ID}_i$
    End If
    Update SK list
End If
(B) **Case (2):**
If ID_i.newPos $\geq$ netArea **Then**
    SK $\leftarrow$ SK\ID_i// remove SN_i from SK
End If
If ID_i.oldPos $\neq \mathrm{ID}_i$.newPos **Then**
    If ID_i.type $= \mathrm{CH}_i$ **Then**
        If ID_i.oldPos $\in \mathrm{MCZ}_m$&ID_i.newPos $\notin \mathrm{MCZ}_m$ **Then**
            For $j \leftarrow 1$ **To** n //n is the total number of SNs within MCZ_m
                Calculate Er_j, d_j //As in the Algorithm 1
            End Fo
            FindmaxW_j
            $\mathrm{ID}_j \leftarrow \mathrm{CH}_j$//$\mathrm{SN}_j$ become CH for MCZ_m
            Broadcast leave(ID_i, ID_j)
            $\mathrm{MCZ}_m \leftarrow \mathrm{MCZ}_m \setminus \mathrm{ID}_j$
            Do while $k \in \{\mathrm{MCZ}_m$
                my$\mathrm{CH}_k \leftarrow \mathrm{ID}_j$//$\mathrm{SN}_j$ join myCH_k
            End While
        End If
    Else
        Broadcast leave(ID_i, newPos)
        If ID_i.oldPos $\in \mathrm{MCZ}_m$&ID_i.newPos $\notin \mathrm{MCZ}_m$ **Then**
            $\mathrm{MCZ}_m \leftarrow \mathrm{MCZ}_m \setminus \mathrm{ID}_i$// remove SN_i from MCZ_m
    Else If ID_i.newPos $\in \mathrm{MCZ}_k$ **Then**
            $i \in \{\mathrm{MCZ}_k$// add SN_i to MCZ_k
            my$\mathrm{CH}_k \leftarrow \mathrm{ID}_i$//$\mathrm{SN}_i$ join myCH_k
        End If
        Update SK list
    End If
End If

protocols. The following key parameters were considered as the basis of the evaluation metrics.

1) Scalability is a feature that supports pervasive network scenarios and is related to the ability to support WSN expansion to include more SNs or extend the area of interest, continue to perform well, and achieve robustness objectives in large-scale WSN [44].
2) Network lifetime is a crucial metric for supporting QoS in a WSN and refers to the time interval of how long the network is qualified to maintain its maximum functionality and/or achieve particular objectives throughout its operation [45]; that is, the number of rounds a node survives in the network. Therefore, a longer network period implies longer lifetime.
3) Energy consumption is another crucial metric for evaluating the performance of any protocol because it estimates the amount of energy used in data communication to transfer packets between nodes (SNs and CH) and SK in one round [36], [42]. This can be examined in two ways: first, the rate of energy dissipated per round and second,) the number of dead SNs per round.
4) The average energy is a key factor in a WSN to check its performance and indicates the evaluation of the residual energy of all SNs at the end of the simulation.

B. SPECIFICATIONS OF SIMULATIONS

We performed several simulations using MATLAB to evaluate the performance of the DTC-BR protocol against the DDR, MCCA, LEACH-MEEC, and LEACH-M protocols using different numbers of SNs and varying network area sizes. We performed the simulation by testing various numbers of MSNs ranging between 300, 500, 600, and 1000 which were randomly distributed in a square area varying from $100 \times 100\text{m}^2$ to $400 \times 400\text{m}^2$ with a single static SK.

The simulation parameters are listed in TABLE 5. Where all deployed MSNs are homogenous and use the same initial energy, E_0, whereas the E_t, E_r, θ_{mp}, θ_{fs}, E_a are the energy consumption parameters of the first-order radio model, and the values used in the simulation are constant according to the radio model standard.

C. RESULTS AND DISCUSSION

We evaluated our proposed DTC-BR protocol by assuming that the network failed to operate when the number of live SNs was less than 5% of the total number of SNs in the WSN.

The main interest is network scalability which is examined by changing the number of SNs beside the networking area, in addition to network lifetime, which is assessed according to the number of operational SNs as a function of the simulation time (round number) and length of time the SNs can survive in a WSN. We observed the number of first node dies (FND), half of the node dies (HND), and last node dies (LND). Moreover, the performance was tested based on the total energy exhaustion of all SNs during the data communication in one round. Another evaluation metric is the average energy, which is the sum of the residual energy of all active SNs to preserve communication between SNs and SK.

1) NODE DENSITY EFFECT

The simulation was run with an initial energy of 0.5 Joule and 300 MSNs deployed randomly on a networking area of $100 \times 100\ m^2$ to test the network performance of the proposed DTC-BR protocol versus DDR, MCCA, LEACH-MEEC, and LEACH-M protocols. We increased the number of MSNs to 500 and 1000 with the same initial energy and network area, respectively, to study the effect of scalability on

TABLE 5. Simulation parameters.

Parameter	Value
Network area size	100×100 m² 400×400 m²
Radius of MCZ R	25 m
Radius CCZ r	5, 10, 15 m
MSN number	300, 500, 600, 1000
SN initial energy E_0	0.5 J
Transmit energy E_t	50 nJ/bit
Receive energy E_r	50 nJ/bit
Amplification energy of multi-path θ_{mp}	0.0013 pJ/bit/m²
Amplification energy of free space θ_{fs}	10 pJ/bit/m²
Aggregation energy E_a	5 nJ/bit
Sink Node location	Static / inside
MCZs number	5
Balance ratio BR	10%
Cluster heads' percentage	1 per cluster division
Deployment architecture	Random deployment
Sensing range	30 m
Transmit range R_c	100 m
Data packet size	4600 bit
Control packet	200 bit
Speed of MSN	2 m/s
Max pause period of MSN	5 s
Period of each round	5 s
Maximum number of rounds	2000

TABLE 6. Network lifetime comparison statistics using 300, 500, and 1000 MSNs.

Network Area is $100 \times 100\ m^2$						
# of SNs	# of Round	Protocol Name				
		DTC-BR	DDR	MCCA	LEACH-MEEC	LEACH-M
300	FND	266	217	229	198	143
	HND	480	445	500	482	483
	LND	> 1000	778	860	> 1000	> 1000
500	FND	272	230	239	212	157
	HND	475	477	440	482	438
	LND	> 1000	720	680	> 1000	976
1000	FND	275	234	239	183	127
	HND	482	405	370	408	395
	LND	> 1000	683	728	> 1000	798

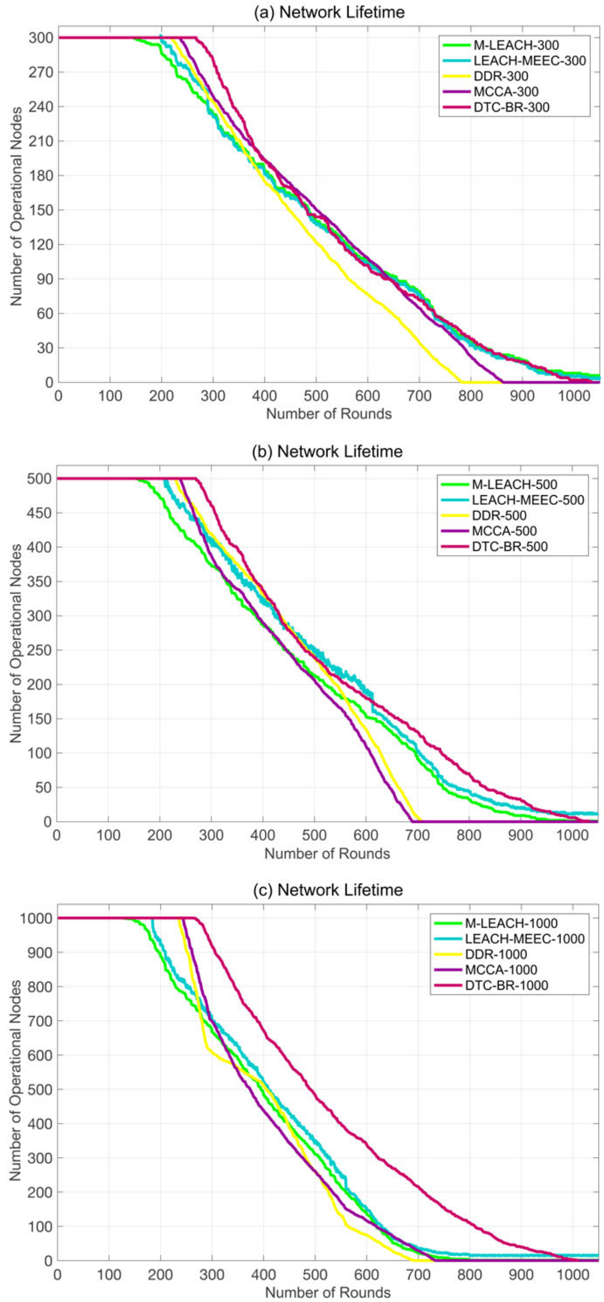

FIGURE 5. Node density effect in DTC-BR, DDR, MCCA, LEACH-MEEC, and LEACH-M protocols with SNs: 300, 500, and 1000.

MWSN. FIGURE 5 (a), (b), and (c) show the network lifetime comparison using 300, 500, and 1000 MSN, respectively. A comparison of the statistical results is presented in TABLE 6.

The results in FIGURE 5 (a) show that the number of operational SNs of the proposed DTC-BR protocol was stable until 266 rounds which was approximately double that of LEACH-M and could function fully. The first die node was approximately 143.

In FIGURE 5 (b), the number of live nodes remains the same until 272 rounds which is the best time compared to the DDR, MCCA, LEACH-MEEC, and LEACH-M protocols. Moreover, DDR and MCCA protocols cannot cope with dense SNs in the same region.

As shown in FIGURE 5 (c), the number of live nodes decreases in the early stages of LEACH-MEEC and LEACH-M in rounds 183 and 127, respectively. However, the DTC-BR protocol increases the number of SNs, resulting in an adequate performance, and approximately half of the SNs operate well.

The entire network in the DTC-BR, LEACH-MEEC, and LEACH-M cases survived for longer. In the case of DTC-BR, increasing the number of SNs in the same area network results in high performance; therefore, the entire DTC-BR network

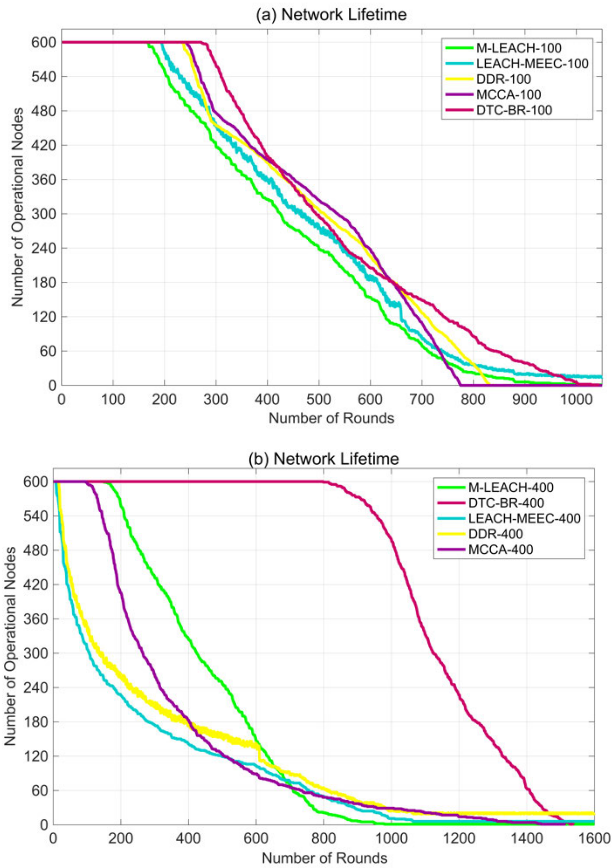

FIGURE 6. Network area effect DTC-BR, DDR, MCCA, LEACH-MEEC, and LEACH-M protocols with: $100 \times 100\mathbf{m}^2$ and $400 \times 400\mathbf{m}^2$.

TABLE 7. Statistical results of using $100 \times 100m^2$ and $400 \times 400m^2$.

# of SNs is 600						
Network Area	# of Round	Protocol Name				
		DTC-BR	DDR	MCCA	LEACH-MEEC	LEACH-M
$100 \times 100m^2$	FND	283	235	247	192	170
	HND	490	503	533	454	425
	LND	> 1000	828	770	> 1000	950
$400 \times 400m^2$	FND	617	16	100	8	163
	HND	1137	150	270	110	430
	LND	> 1500	> 1500	1310	1090	945

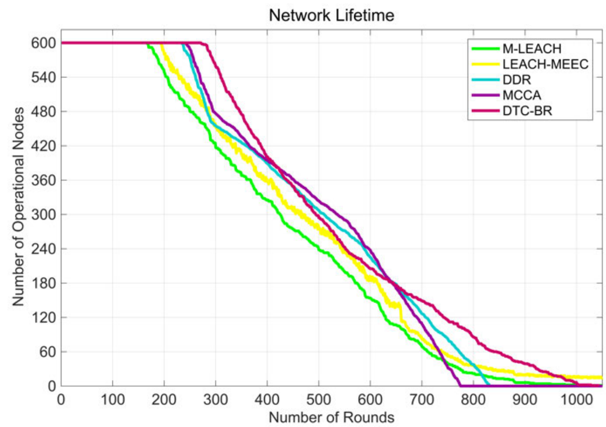

FIGURE 7. Comparison of DTC-BR, DDR, MCCA, LEACH-MEEC, and LEACH-M protocols.

outperforms the existing methods mentioned in this section for the three cases of 300, 500, and 1000 SNs.

2) NETWORK AREA EFFECT

Tests were also performed using 600 MSNs with different network areas to assess network scalability. We started with an initial energy of 0.5 Joule and $100 \times 100\ m^2$ network area, and then we enlarged it to $400 \times 400\ m^2$ we executed the simulation for both cases on the DDR, MCCA, LEACH-MEEC, and LEACH-M protocols, and compared the results with our proposed DTC-BR protocol. FIGURE 6 (a) and (b) show a network lifetime comparison using $100 \times 100\ m^2$ and $400 \times 400\ m^2$ respectively. TABLE 7 presents the statistical results obtained for the various network area sizes.

FIGURE 6 (a) the result here shows the number of dies SNs in all compared protocols: DTC-BR, DDR, MCCA, LEACH-MEEC, and LEACH-M are gradually increasing, and similar to FIGURE 5 (b).

FIGURE 6 (b) illustrate that the DTC-BR protocol network lifetime performance excel DDR, MCCA, LEACH-MEEC, and LEACH-M protocols, so in DTC-BR the first SN dies in the late stage at round 617 however the first SNs in the LEACH-MEEC, and DDR protocols die very fast in 8 and 16 rounds respectively also, its shown for DDR, MCCA, LEACH-MEEC, and LEACH-M protocols that 50% of the SNs dies in early stage as compare with DTC-BR protocol.

We can conclude that using 600 SNs with $400 \times 400\ m^2$ SNs has a significant impact on the network lifetime of DTC-BR. By contrast, if we use the same parameter values, the overall functionality approach is the worst. Therefore, the scalability of the DTC-BR has been proven to yield better results.

FIGURE 7 shows the number of surviving MSNs when the protocols were run for more than 1000 rounds. The figure shows that dead MSNs of MCCA expired at round 770, followed by DDR at round 828, whereas MSNs expired at round 950 in LEACH-M. However, the network failure of the DTC-BR and LEACH-MEEC protocols exceeded 1000 rounds. In the DTC-BR protocol, all MSNs were active for 282 rounds; the first MSN died, one-third of the MSNs died in round 400, and half of the MSNs died in round 490. According to the LEACH-M, LEACH-MEEC, DDR, and MCCA protocols, all MSNs operated for 169, 191, 234, and 246 rounds, respectively. In addition, the rate of MSNs death was accelerated through rounds in the MCCA, DDR, LEACH-MEEC, and LEACH-M protocols by 6%, 21%, 25%, and 37%, respectively, compared with the proposed DTC-BR protocol.

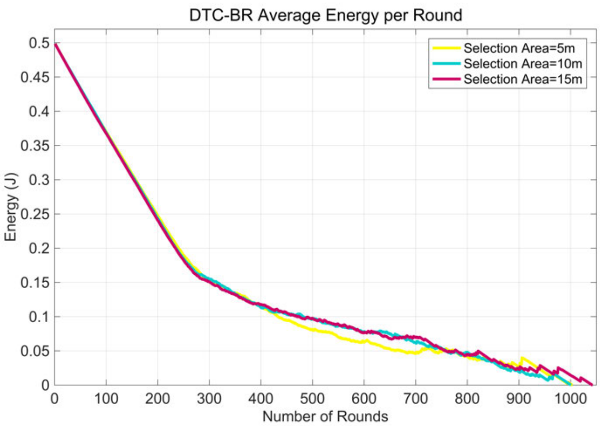

FIGURE 8. Average energy residuals for DTC-BR based on different CCZ radiuses.

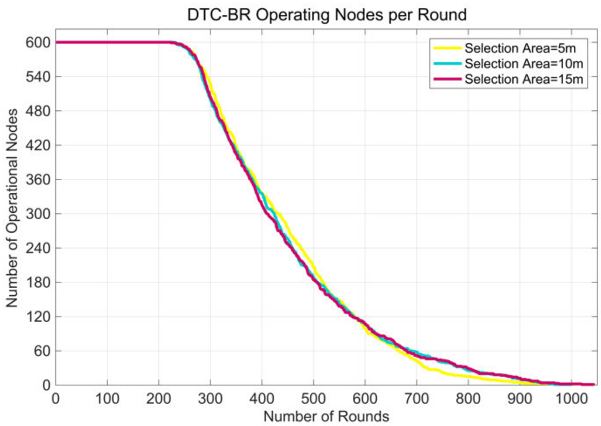

FIGURE 9. Operational nodes for DTC-BR based on different CCZ radiuses.

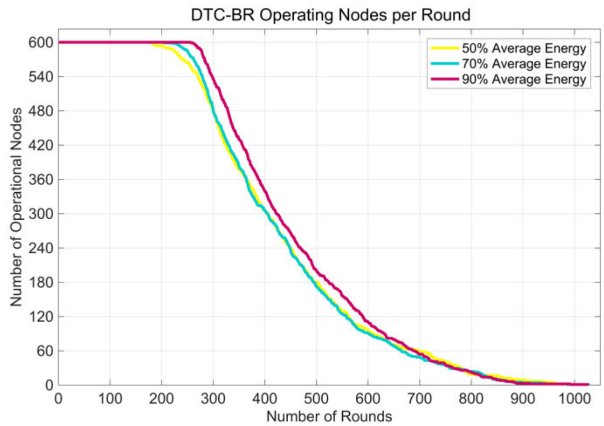

FIGURE 10. Operational nodes in DTC-BR based on different threshold values.

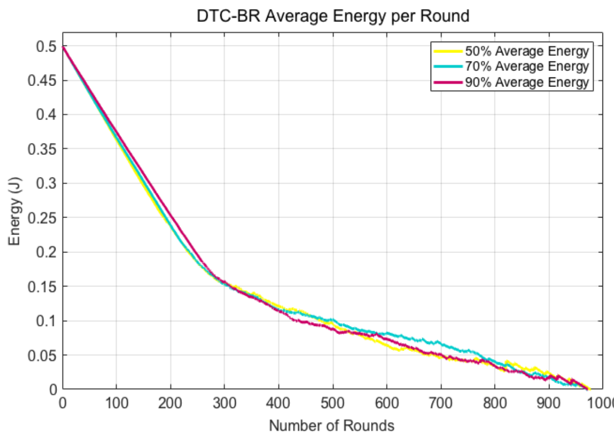

FIGURE 11. Average energy residuals for DTC-BR based on different threshold values.

3) CCZ RADIUS SIZE EFFECT

The CCZ radius length is another factor affecting the performance of the proposed protocol, and the accuracy of the estimated radius is important. In FIGURE 8, the DTC-BR is examined for three different CCZ radius values: 5, 10, and 15 m, which demonstrates the impact of the radius on the residual energy across rounds. The results indicate that all three-radius provided similar results. However, the 10 m CCZ radius outperformed both the 5 m and 15 m radius because the energy consumption was reduced when the distance from the CH to all other CMs was smaller, and within the average CCZ radius, the number of SNs with high residual energy was greater.

FIGURE 9 shows the number of operational MSNs along with the rounds at different CCZ radius values. The three values provided nearly the same results in terms of the operational MSNs. However, the simulation results prove that the 10 m CCZ radius indicates that approximately 95% of the SNs will be connected to the CH. In addition to maintaining the energy consumption.

4) AVERAGE ENERGY EFFECT

FIGURE 10 and FIGURE 11 show the assumed energy threshold values with the number of live MSNs and average residual energy, respectively. The simulation results indicate that an average energy threshold of 90% yields the best performance in terms of the operational MSNs and average energy consumption.

VI. CONCLUSION

The utilization of appropriate resources in WSN is essential to maintain the network alive for a maximum period, particularly in a dynamic environment where all SNs are mobile. A cluster-based routing protocol can be used to improve the performance of the MWSNs. In this study, a new cluster-based routing mechanism called DTC-BR was developed for MWSNs to reduce energy consumption, maximize scalability, and consequently extend the network lifetime. In addition, this technique adopts a virtual MCZ because it is performed once at the beginning of execution to avoid the overhead of cluster formation by restricting the selection of

SNs nominated as CH from CCZ with the least distance to the center point of the MCZ. This maximizes connectivity in line with the better success rate of data transmission.

MATLAB was used to implement the proposed method, and the simulation results of the DTC-BR protocol were observed using state-of-the-art DDR, MCCA, LEACH-MEEC, and LEACH-M protocols. The simulation results demonstrated a significant enhancement in terms of network energy consumption and survival rate of MSNs, which consequently increased the network life span by up to 6%, 21%, 25%, and 37% compared with the DDR, MCCA, LEACH-MEEC, and LEACH-M protocols, respectively.

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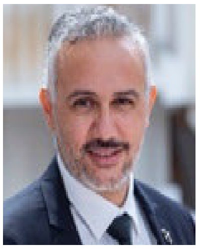

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