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Research Article

Optimized Cluster-Based Dynamic Energy-Aware Routing Protocol for Wireless Sensor Networks in Agriculture Precision

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Wireless sensor networks (WSNs) are becoming one of the demanding platforms, where sensor nodes are sensing and monitoring the physical or environmental conditions and transmit the data to the base station via multihop routing. Agriculture sector also adopted these networks to promote innovations for environmental friendly farming methods, lower the management cost, and achieve scientific cultivation. Due to limited capabilities, the sensor nodes have suffered with energy issues and complex routing processes and lead to data transmission failure and delay in the sensor-based agriculture fields. Due to these limitations, the sensor nodes near the base station are always relaying on it and cause extra burden on base station or going into useless state. To address these issues, this study proposes a Gateway Clustering Energy-Efficient Centroid- (GCEEC-) based routing protocol where cluster head is selected from the centroid position and gateway nodes are selected from each cluster. Gateway node reduces the data load from cluster head nodes and forwards the data towards the base station. Simulation has performed to evaluate the proposed protocol with state-of-the-art protocols. The experimental results indicated the better performance of proposed protocol and provide more feasible WSN-based monitoring for temperature, humidity, and illumination in agriculture sector.

1. Introduction

Precision agriculture refers to a science using advance technologies to provide cost management, crop growth, and production in agriculture fields. One of the major driver of agriculture precision is wireless sensor networks (WSNs) where the sensor nodes are monitoring the physical or environmental conditions including humidity, temperature, and illumination and send the sensed data to the base station (BS) via single-hop or multihop coordinator nodes [1–3]. This technology has various beneficial applications in other fields like healthcare, military, transportation, security, and agriculture. In healthcare, sensor nodes have deployed to collect the patient physiological or biometric information such as ECG, heart rate, and blood pressure [4]. In the military, sensor nodes are deployed to track the soldiers on the battlefield, for monitoring, find the location of platoons, and protect the forces. In security, sensor nodes can offer a careful watch to track and monitor the dangerous situation and remain alert against terrorist attacks [5]. In agriculture, sensor nodes are deployed to sense the temperature, pressure, humidity, and wind speed. In addition, the sensor nodes also sense environmental conditions for weather forecast and natural disaster happening probability. In these networks, the sensor nodes are categorized into coordinator and normal nodes to collect the data from the agricultural field [6]. The sensor nodes sense the required parameters and analyze the distance threshold (d_{Th}) and then forward the sensed data to the sink node by single-hop or multihop communication. The role of the sink node is to collect the data from sensor nodes and further transmit to gateway or BS and then further send to the central management system for decision making as shown in Figure 1.

Sensor nodes are small in size with low computational power and energy resources [7]. Sensor nodes are used for monitoring the environmental conditions like crop conditions

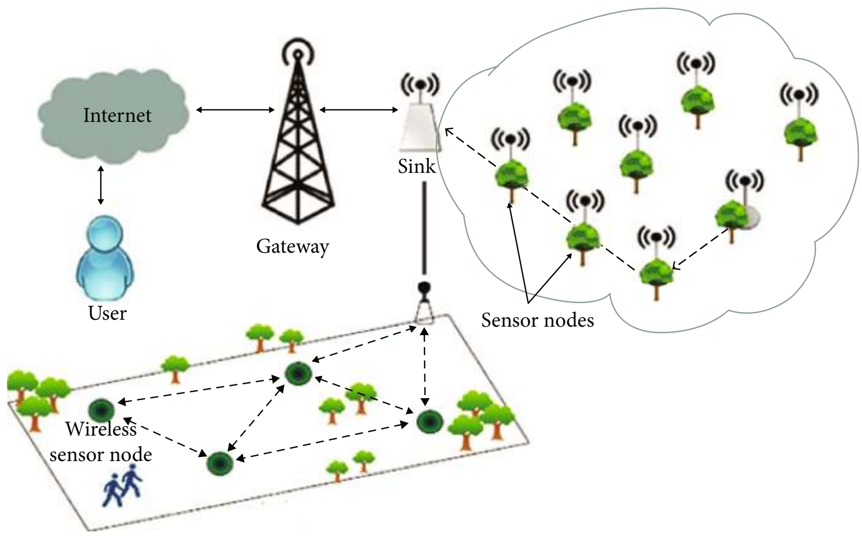

Figure 1: Architecture field with WSN deployment.

and other environmental parameters. The sensor nodes are deployed on the surface of soil or inside the soil. There are different technologies and standards which have been adopted based on applications and data rate, frequency band, power consumption, and distance. Some common technologies are Wibree, Wifi, GPRS, WiMAX, Bluetooth, and ZigBee [2, 8]. Monitored data was obtained from the deployed sensor nodes and then was wirelessly forwarded to the BS for data collection. The BS initiates the decision for further processes. Users received the crop growth information or other information related to the drip irrigation and take further initiatives to improve the microenvironment for their product [9]. In agriculture, for achieving the precision control, the sensor nodes monitored different parameters, analysis of monitored data for decision making and applying the control mechanism [10, 11]. There are various efforts to improve the cultivation in agriculture, precision farming, collecting, and sending the monitored data [12, 13]. The monitored data is about environmental conditions including weather, wind speed, temperature, soil humidity, chemical and physical properties of soil like the pH level, crop identification, leaf area index, leaf moisture content, and weed-disease detection. There is another way in which the sensor nodes captured the images of fruits, for automated harvesting, and predicted the soil moisture and organic contents [14, 15]. Mobility-based sensor nodes are used to measure the plant mass of crops and analyze the fertilization characteristics for best production. Soil strength measurement and prediction-based harvesting time are evaluated through special sensors [16, 17].

In addition, most of the agriculture precision WSN-based applications need in time and reliable data communication in the network. Due to limited battery resources, sensor nodes are not able to maintain their operations; recharging and replacement of batteries are not possible especially in dense forests and large areas [18, 19]. For data communication, the routing protocols are used to maintain the load balancing and maximize network lifetime. There are two main types of protocol flat and hierarchical. In flat routing protocols, all the nodes in the network play an identical role. The main issue in flat routing protocols is scalability, load balancing, route maintenance, and not feasible for the large networks [20, 21]. To address the scalability and load balancing issues in flat routing, hierarchical routing protocols are introduced. It is also called cluster-based routing, in which all sensor nodes in the network are separated into layers based on residual energy and assigned the different roles. In the entire network, the sensor nodes are divided into a group called clusters [22]. Each cluster has cluster members (CMs) and one cluster head (CH). The CH is responsible for coordination within the cluster and forwarding the data to other CHs or BS. Hierarchical routing protocols or clustering protocols are helpful especially for large-scale agriculture precision-based WSN. It utilized fewer resources, save more energy of sensor nodes, scalable, less packet overhead, and efficiently balances the load among the network as compared to flat routing protocol [23–25].

Complex routing processes and data transmission are the main causes of energy depletion among sensor nodes in agricultural precision WSN [26, 27]. Aiming at a higher energy efficiency for the entire network, a new protocol named Gateway Clustering Energy-Efficient Centroid (GCEEC) routing protocol is proposed to manage the energy resources. The main contributions of this paper is to minimize the energy consumption of sensor nodes and to reduce the load on CHs. The proposed protocol selects and rotates the CH on efficient location, i.e., near the energy centroid position in the cluster to reduce the energy consumption of sensor nodes in cluster and maximize the CH coverage. Furthermore, the protocol selects gateway node in cluster to facilitate the CH in agriculture environment and significantly reduces the load on CH.

The main objectives of this paper are as follow:

(i) To minimize the energy consumption and load balancing of the CH by the help of gateway node

(ii) Edge node becomes a gateway node to receive more than one joining message from adjacent CHs

The rest of the paper is organized as follows: Section 2 presents the related work in the area of agriculture-based WSN and its existing energy-based routing protocols. Section 3 presents the proposed work design and all steps including flow chart and algorithm. Section 4 presents the experimental results and analysis with state-of-the-art protocols. Last section concludes the paper with future direction.

2. Related Work

This section discussed the existing energy-efficient routing protocols for agriculture precession-based WSN and critically analyzed to find their limitations. Energy-efficient routing protocols are categorized into two categories, flat routing protocol and hierarchical routing protocols which are discussed in detail.

2.1. Flat Routing Protocol. In flat routing, all nodes in the network have the same role and perform the same tasks [24].

In [28], the authors proposed the dynamic distributed framework protocol known as Energy and Trust-Aware Mobile Agent Migration (ETMAM), in which a mobile agent is used to making route among sensor nodes for data aggregation based on energy and trust metric evaluation. A mobile agent is a self-determined software agent that can move autonomously among sensor nodes and carry the data for aggregation. To protect a mobile agent from malicious sensor nodes, ETMAM framework provides trust evaluation to the mobile agent and bypass the malicious sensor nodes. Furthermore, the framework also provides optimize migration route based on energy metrics as well as cloning method to aggregate the data from the sensor node. However, the proposed framework supports small route mobile agent and is where response time is low. Power-Aware Heterogeneous AODV (PHAODV) in [29] was proposed for the resource that should be utilized efficiently. In this protocol, the optimized routing path is created by considering the energy status of every sensor node to achieve the load balancing among heterogeneous networks. The path which consumes the least energy is selected as a routing path for data communication from the existing path in the routing table. Therefore, all the sensor nodes are keeping aware of the instantaneous change in energy level. Furthermore, link-aware dynamic threshold prevents from route exhausting and reduces the route error message. However, this protocol has more overhead which leads to energy depletion issues in the network.

An Optimal Base Transmission Strategy (OTDS) [30] is proposed in which transmission distance is calculated to balance the energy consumption of the entire network. Data mule concept is proposed in which data is collected from sensor nodes and transmits to the BS. Data mule is a mobile node having sufficient storage and energy and collects the data from sensor nodes while roaming across the sensor field and sends it to the BS. PEGASIS-DSR Optimized Routing Protocol (PDORP) is proposed in [31] based on a hybrid approach having both characteristics of proactive (PEGASIS) and reactive (DSR) approach. Utilization of directional transmission scheme helps reduce the communication distance which ensures energy efficiency. Furthermore, a trust list is generated by each node to avoid acknowledgment of receiving packets; this will be updated at each round and randomly checked at any time. Besides this, PDROP also adopts a Genetic Algorithm (GA) and Bacterial Foraging Optimization (BFO) to discover the optimized path. However, complex routing processes consume more energy and have a serious impact on the network.

2.2. Hierarchical Routing Protocol. It is also called clustering routing protocols. In these protocols, the whole network nodes are divided into a group of nodes called clusters. Each cluster selects CH node which is responsible for transmitting the data to the BS.

In [32], the authors proposed a Mobile Sink-based Adaptive Immune Energy-Efficient clustering Protocol (MSIEEP) and addressed the energy hole problem. The protocol uses Adaptive Immune Algorithm (AIA) to find the sojourn path for the mobile sink. Moreover, the algorithm also finds the optimize number of CHs based on their dissipated energy and favorable location. AIA acts as a guide of the mobile sink. The significance of mobile sink is to collect the data from the isolated region of the CH which improved the connectivity of the network. The protocol does not fully address the hole problem due to load balancing issue. In [33], the authors proposed a distributed clustering algorithm, namely, Delay-Constrained Energy Multihop (DCEM) in which CH is selected in a distributed manner. BS initiates the protocol by broadcasting ADV message among network sensor nodes; therefore, each node calculates the distance between itself and BS using receive signal strength technique. After that, every sensor node broadcasts the advertisement message that contains its ID and energy level to its neighbor sensor nodes so that every neighbor node on receiving advertisement message compares its energy level with energy level information in receiving advertisement message. If the energy level is greater, then the sensor node becomes candidate CH; otherwise, it remains a cluster member. Similarly, the candidate CH elects by broadcasting an advertisement message procedure and becomes CH. The candidate CH with the same energy level is further proceeded by computing the trade-off energy and delay (TED) value. After computing, the candidate CH waits for the TED value to receive an advertisement message otherwise becomes the CH. Furthermore, the DCEM protocol uses intercluster multihop routing cost function to achieve a minimum cost route from CH to BS. DCEM does not consider the optimal location of the CH in cluster intercluster multihop routing among CH which consumes more energy.

In [23], the authors proposed the PSO-ECHS (Particle Swarm Optimization-Energy Efficient-based Cluster Head Selection) protocol that enhanced the network lifetime. In the PSO-ECHS algorithm, the CH is selected by fitness functions that consider the distance between sensor node and BS, as well as sensor node and neighbor nodes, and the residual energy of sensor nodes. By a minimum value of fitness function, the CH selected and start cluster formation by broadcasting the joining message. Each sensor node after receiving and joining messages calculates the joining weight value. The sensor node joins the CH which has the highest joining weight value. In [34], the authors proposed the Energy-Efficient Centroid-based Routing Protocol (EECRP) for data routing using wireless sensor devices. The term "centroid" is the mechanical engineering term which means the imaginary central point of mass concentration. Initially in protocol, the BS computes the energy centroid position among the network and divides the network into a cluster based on energy centroid position. The node near the energy centroid position is selected as the CH. At the time of CH rotation, the CH recomputed the energy centroid position and the node which is near to the energy centroid position elected as the next CH. Furthermore, the protocol also fixed the threshold distance called MAX distance between the CH and the BS where the CH transmits the data to the CM. If CH and BS distance are less than MAX distance, then the CH stores the information in the cache and deliver to the next elected CH at the time of CH rotation.

In [35], the authors proposed the Distributed Unequal Size Optimize Cluster (DUSOC) base technique to resolve the load balancing issue in the CH. According to the protocol, the BS elects the CH node based on an energy level as well as the distance from BS. The CH near the BS chooses the least number of sensor nodes as compared to the CH which is far away from the BS during the cluster formation stage. Furthermore, intercluster multihop routing among the CH approach is adopted for data transmission towards the BS. In [36], the authors proposed the Mobile Energy-Aware Cluster-Based Multihop (MEACBM) routing protocol in which heterogeneous WSN is divided into clusters, selecting the CH with the highest residual energy. Furthermore, the protocol maintains the coverage and connectivity in the network by constructing a subcluster for nodes that deployed far away in the network and compute the multihop route for interclustering combination among clusters and subclusters. After selecting CH, the algorithm divides the network into sectors and each sector is assigned with Mobile Data Cluster (MDC) node that collects the data from the CH. MDC node computes an efficient route that is found by Expectational Maximization (EM) algorithm. According to the EM algorithm, MDC computes the route by considering the CH residual energy and location. MDC moves to collect the data from the CH first, whose residual energy is minimum. Similarly, the MDC node collects data from other CH on an efficient route and delivered to the BS.

The authors in [37] proposed a Cluster Aided Multipath Routing (CAMP) protocol which divided the region of interest into virtual zones and assign one CH for each cluster. The noncluster member's condes have adopted the trade-off method for residual energy evaluation between itself and neighbor nodes and take decision. During this process, if the cluster member node is selected as the next forwarder, then it cancels the trade-off method and forwards the data to the CH via multihop communication. The authors claimed that the proposed CAMP protocol improves the energy consumption due to randomly selection of CH or based on residual energies of the nodes. In addition, CAMP also adjusts the tuning factors including remaining energy, node degree, and distance towards the sink node. However, with many benefits, this protocol has significant delay due to its energy calculation and randomly selection of CH in the network.

All the discussed studies mainly focused on energy-efficient routing for WSN that reveal the strength and limitations that lead to the development of the research problem. Based on the literature review, it is revealed that the CH has a heavy responsibility for data transmission of the cluster data towards the BS directly or relaying through other CH. The CH which directly sends data towards the BS consumes more energy. The CH far from the BS required more energy in transmitting cluster data towards the BS in a single hop. Consequently, these issues lead to the early energy depletion of CH's which are far from the BS. Moreover, in many schemes such as DUSOC [35], and DCEM [33], CAMP [37] CH sends the data towards the BS via intercluster multihoping. The CH near the sink continuously forwards the CH data towards the BS. Therefore, uneven load distribution among CHs tend to deplete their energy resources rapidly which leads to disrupt the data dissemination process and generate routing holes. The CH node selection and CH responsibility rotation are one of the most important features. Therefore, network coverage of CH among cluster nodes reduces and consumes more energy for data transmission to their CH. The optimal location of CH is an important factor which enhances the network coverage among clusters. The optimal location of CH must consider the position where energy density nodes found so that the CH responsibility rotation is must among the nodes that are rich in energy. It is discussed above that most of the existing clustering schemes such as DCEM [33] must improve their intercluster multihoping process to overcome load on the CH. Table 1 presents the protocol comparison in terms of their strategies and limitations.

3. Gateway Clustering Energy-Efficient Centroid (GCEEC) Protocol

The Gateway Energy-Efficient Centroid (GCEEC) routing protocol is proposed for agriculture precision WSN to improve the load balancing among CHs and energy consumption of the whole network. The GCEEC protocol selects the efficient location of CH near the energy centroid position and for gateway node selection for transmitting the data towards the BS via multihop communication which maximizes the CH coverage and reduces the transmission power of CH. This section is divided into two subsection network setup modules and process module. The network setup module presents the energy consumption model, energy centroid position, gateway node weight, and CH joining weight used in GCEEC protocol. The processing module explains the setup phase, transmission phase, and rotation phase of GCEEC.

3.1. Network Setup Module. The network model consists of 100 sensor nodes and one BS. Figure 2 shows the sensor

Table 1: Protocol strategies and limitations.

S#	Authors	Cluster	Strategies	Limitations
Flat routing protocols				
1	ETMAM [28] 2014	✗	Mobile agent route among the sensor for data aggregation considering energy and trust metrics	Framework support small route mobile agent and response time is low
2	PHADOV [29] 2014	✗	Link condition for optimize path, prevent route exhausting, and reduce route error message	Routing overhead increase
3	OTDS [30] 2015	✗	Data mule (mobile node) that has the ability to collect and store data from sensor node and transmit towards BS	In sufficient for different constraint and energy hole problem
4	PDORP [31] 2016	✗	Generate trust list to avoid acknowledgement	Cause significant delay
Hierarchical routing protocol				
5	MISSEEP [32] 2015	✓	Mobile sink for collecting data to alleviate hole	Protocol not fully addressed hole problem due to load balancing issue
6	DCEM [33] 2016	✓	Minimum inter cluster multihop routing cost function	DCEM not consider the optimal location of CH in cluster Intercluster multihop routing among CH consume more energy of CH
7	PSO-ECHS [23] 2017	✓	CH is selected by fitness functions that consider the distance between sensor node and BS, as well as sensor node and neighbor nodes, and the residual energy of sensor nodes	Robustness of the algorithm, however, needs to be verified with the heterogeneous nature of nodes
8	EECRP [34] 2017	✓	CH selected in energy density node region	MAX-dist consume more energy of CH in caching and transferring data
9	Awan et al. [35] 2018	✓	Cluster size reduction	Not focus on energy-efficient optimize route among cluster head
10	MEACBM [36] 2019	✓	Mobile data cluster node utilizes as CH data collection and transfer to BS	Subcluster nodes are taking more processes and lead to network overhead
5	CAMP [37] 2019	✓	Adjusts the tuning factors including remaining energy, node degree, distance towards the sink node.	Has significant delay due to its energy calculation and randomly selection of CH in the network.

nodes which are randomly distributed in the sensor field. Each sensor node after sensing sends the data to the regional CH, then transfer the data towards the BS via single-hop direct transmission or multihop gateway nodes; it depends on the distance between CH and BS.

3.1.1. Energy Consumption Model. Most of the energy is consumed by the sensor node during data transmission and receiving. The most popular and common energy model is proposed in [34] as shown in the following:

$$E = \begin{cases} l\left(e_r + e_t + \epsilon_{fs} d^2\right), & \text{if } d \le d_{Th}, \\ l\left(e_r + e_t + \epsilon_{mp} d^4\right), & \text{if } d \ge d_{Th}, \end{cases} \tag{1}$$

where l is the packet size, e_r and e_t are the transmitting and receiving energy, ϵ_{fs}andϵ_{mp} are required energy to send in free space and multipath, respectively. The transmission energy consumption depends on distance d.

3.1.2. Energy Centroid. Centroid is the mechanical term, which means the imaginary central point of mass concentration. It is the central point where the entire mass of object is concentrated. Similarly, energy centroid in cluster is the point where sensor node is having massive energy concentration which is distributed. Energy centroid [34] can be mathematically represented as in Equations (2) and (3), respectively.

$$X_{ec} = \frac{\sum_{i=0}^{n} \left(E_{i_{rs}}/E_o\right) X}{N}, \tag{2}$$

$$Y_{ec} = \frac{\sum_{i=0}^{n} \left(E_{i_{rs}}/E_o\right) Y}{N}, \tag{3}$$

where $E_{i_{rs}}$ = residual energy of node i, E_o = initial energy, X and Y are the coordinate of node i, N = total number of nodes in cluster, X_{ec} and Y_{ec} are the energy centroid.

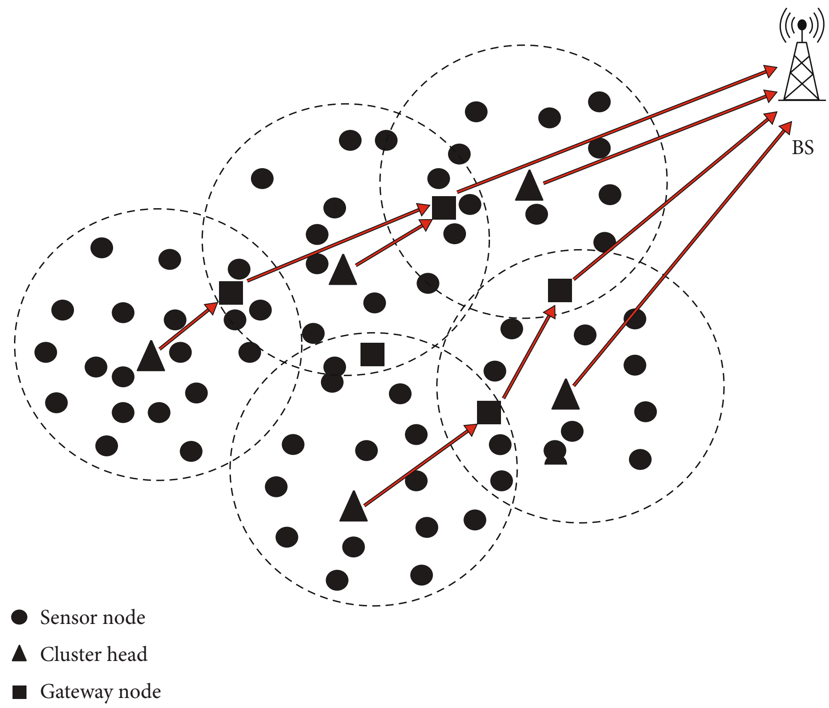

Figure 2: Network topology.

1-byte	1-byte	1-byte	1-byte	2-bytes
Message type	Sender's ID	*X* coordinate	*Y* coordinate	Energy level

Figure 3: LOCATION message.

Distance from the energy centroid position to the i^{th} sensor node for calculating candidate CH can be shown below.

$$d = \sqrt{(X_{\text{ec}} - X_i)^2 + (Y_{\text{ec}} - Y_i)^2}. \quad (4)$$

3.1.3. Gateway Node. Information gathering from sensor nodes and transmitting towards the BS is the main function of CH. Due to heavy responsibilities on CH due to the management of cluster data, the CH consumes more energy and sends the data directly to the BS or itself relaying on other CH and forwards the data towards the BS. Therefore, gateway node is formed in each cluster by CH which relay data towards the BS. The nodes in cluster which are adjacent to neighbor CH are called gateway nodes. Every CH computes the gateway node weight [38] by considering the CH residual energy, distance between the nodes in particular cluster and adjacent neighbor CH. The function is as follows:

$$G(i,j) = \left[\frac{S(i).E}{S(i).\text{Max}}\right] + \left[d(i,j)^2 + d(i,x)^2 + d(j,x)^2 + \frac{d(j,s)^2}{d(i,s)^2}\right], \quad (5)$$

where $S(i).E$ = residual energy of CH, $S(i).\text{Max}$ = initial energy, $d(i,j)$ = distance between CH i and CH j, $d(i,x)$ = distance between CH i to cluster member node x which are adjacent to neighbor CH j, $d(j,x)$ = distance between adjacent CH j to cluster member node x of CH i, $d(j,s)$ = distance between CH j to BS, and $d(i,s)$ = distance between CH j to BS.

Higher weightage of node becomes a cluster gateway node.

3.1.4. Cluster Head Joining Weight Function. When CH sends join request to neighbors, then in response, sensor nodes decide to be part of cluster or not base on CH joining weight function. The function consists the following parameter, CH residual energy $E_{\text{residual}}(\text{CH}_j)$, distance from CH to sensor node $\text{dist}(s_i, \text{CH}_j)$, distance from CH to BS $\text{dist}(\text{CH}_j, \text{BS})$ [23].

$$\text{CH joining weight}\left(s_i, \text{CH}_j\right) = \frac{E_{\text{residual}}\left(\text{CH}_j\right)}{\text{dist}\left(s_i, \text{CH}_j\right) * \text{dist}\left(\text{CH}_j, \text{BS}\right)}. \quad (6)$$

3.2. Process Module. In most of the agriculture precision WSNs, energy is the main concern due to limited resources of sensor nodes. The main objective of this study is design the protocol for energy-saving and efficiently utilize the resource during data processing. Clustering protocols

1-byte	1-byte	2-byte
Message type	CH ID	Avg energy

Figure 4: FEEDBACK message.

consist of three main phases: CH selection phase, gateway selection phase, data transmission, and CH rotation phase.

3.2.1. CH Selection Phase. Initially, the BS broadcasts the HELLO-MSG across the network. Hello message contains the BS ID and location. BS has more energy than ordinary sensor nodes, and if we use the BS to broadcast the Hello messages to other sensor nodes, it will decrease the load on other member nodes in the network. The sensor nodes send a reply with LOCATION message as shown in Figure 3. Message type contains the type of message. The "sender ID" contains the sensor node ID. The "X coordinate and Y coordinate" are the locations of the sensor node. The energy level contains the state of the sensor node. The LOCATION message size is 6 bytes as shown in Figure 3.

BS computes the average energy of the network and calculates the energy centroid positions in the network. After the calculation of energy centroid positions, BS divides the network into a cluster around the energy centroid position and chooses the CH. The BS chooses the CH node from the cluster which is nearest to the energy centroid position. After selecting the CH, the BS broadcasts the FEEDBACK message to the specific cluster as shown in Figure 4. The FEEDBACK message contains the message type and the information of feedback message, CH's ID, and average energy of the network.

After the first CH selection by the BS, the CH transmits joining message containing the CH ID, energy level, and location to the neighbor sensor nodes. The sensor node that receives the joining message calculates the joining weight value of CH. If the highest CH joining weight value is reached, then the sensor node joins the CH as a CM. Figure 5 shows the CH selection process.

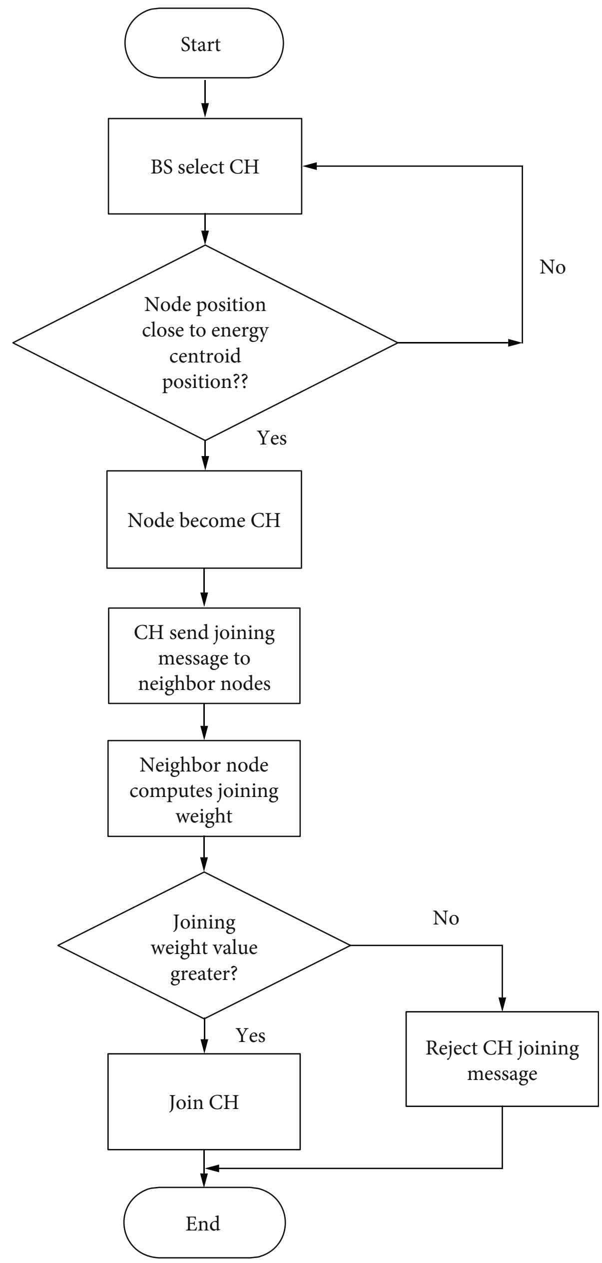

Figure 5: CH selection flow chart.

3.2.2. Gateway Selection Phase. After selection of CHs, each CM who receive adjacent CH joining request computes the gateway node weight. The gateway node weight is then sent to CH. Higher gateway node weight value is selected for a gateway node. Gateway node then informs the adjacent CH by sending gateway message containing its location and its CH ID as shown in Figure 6 showing the gateway message for requesting the adjacent CH for its gateway node. When adjacent CH gateway node receives, it then computes the route towards the BS via adjacent gateway node multihopping.

The data transmission of CH via gateway node depends on distance between itself and BS. If distance is less than threshold distance (d_{Th}), then CH sends directly to BS; otherwise, CH uses gateway node for data transmission towards BS. Figure 7 shows the gateway selection process.

3.2.3. Data Transmission and CH Rotation Phase. After the selection of CH and gateway node, the data communication begins. CM senses the data and transmits to their particular CH. The CH then sends towards the BS via gateway nodes or directly transmits depending on threshold distance d_{Th}. Just before the end of the round, each CM sends their residual energy and location to CH. After that, the CH node calculates the average energy and energy centroid position. The CM that is near to the energy centroid position will be the next candidate CH. The following conditions for the CM can become the CH for the next round.

(i) Its energy level is greater than the average energy of cluster

(ii) Its distance from the energy centroid position of cluster is the smallest

Input: N=Total number of nodes
Output: BS divide entire network into Cluster
for i=1:N
  Node transmit their ID, Location and Energy level to BS
end for
$E = Average\,Energy$ of $entire\,network\,calculate\,by\,BS$
$c = centroid\,position$ of $cluster\,calculate\,by\,BS = (X_c, Y_c)$
for $i = 1 : C$
  $c_i = (X_{ci}, Y_{cj})$
  for $j = 1 : N$
    $d_i = dist(node(i), c_i)$
    if $(node(j)$ very close to $c_i)$
      Select as CH_j
    end if
  end for
end for
BS Broadcast Feedback Message contain Message Type, $CH\,ID$, Avg Energy E
for $i = 1 : N$
  $node(i)\,receive\,Feedback\,Message\,from\,BS$
    if $(node(i) = = CH\,ID)$
      $node(i)$ state $= CH_i$
      Broadcast joining message CH_i to neighbor nodes
    else
      Wait for CH joining message
    end if
end for
Neighbor nodes calculates joining weight
      $CH\,Joining\,Weight\,(s_{i,}CH_j) = E_{reidual}(CH_j)/dist(s_i, CH_j) * dist(CH_{j,}BS)$
if (neighbor node $CH\,Joining\,Weight\,greater$)
  Join CH
else
  Reject CH joining message
end if

Algorithm 1: CH Selection Phase.

1-byte	1-byte	1-byte
Message type	Gateway node ID	CH ID

Figure 6: Gateway message.

Figure 8 shows the data transmission and CH rotation flow chart.

The detail of GCEEC data transmission and CH rotation is discussed in Algorithm 2. Lines 1 to 8 show the data transmission directly or via gateway node towards the BS from the CH. From lines 8 to 11, wait till just a few moments before the end of round, each CM sends residual energy and location to respective CH. From line 12 to 16, it calculates the average energy of cluster, recalculate energy centroid position, and distance between each node among cluster from energy centroid position. Lines 18 to 23 select the CH for next round if the energy level of node is greater than the average energy and distance between CH when centroid position is smaller. Algorithm 3 shows the gateway node selection process.

4. Simulation Setup and Experimental Results

To evaluate the performance of GCEEC with other relevant algorithms, simulator selection is one of the challenge. A number of simulation environments have been developed for wireless networks such as Objective Modular Network Testbed in C++ (OMNET++) [39], Network Simulator2 (NS2) [40], and MATLAB [41]. NS2 is an event-driven, open-source simulator and is the best tool for analyzing communication networks. The NS2 provides executable ns script file name "Tool Command Language (TCL)." A simulation trace file is generated after running TCL file which is used for plotting graphs or result analysis. NS2 provides a tool called NAM (Network AniMator) to execute the animation files.nam. NS2 comprises of two main languages, i.e., C++ and Object-Oriented Tool command language (OTcl). C++ provides user facility to describe interior working mechanisms (executed at backend) of the stimulation objects, while OTcl provides the facility to setup the stimulation scripts and configuration of objects (executed at front) [40, 42]. In addition, NS2 has open-source modules and widely exploits in the

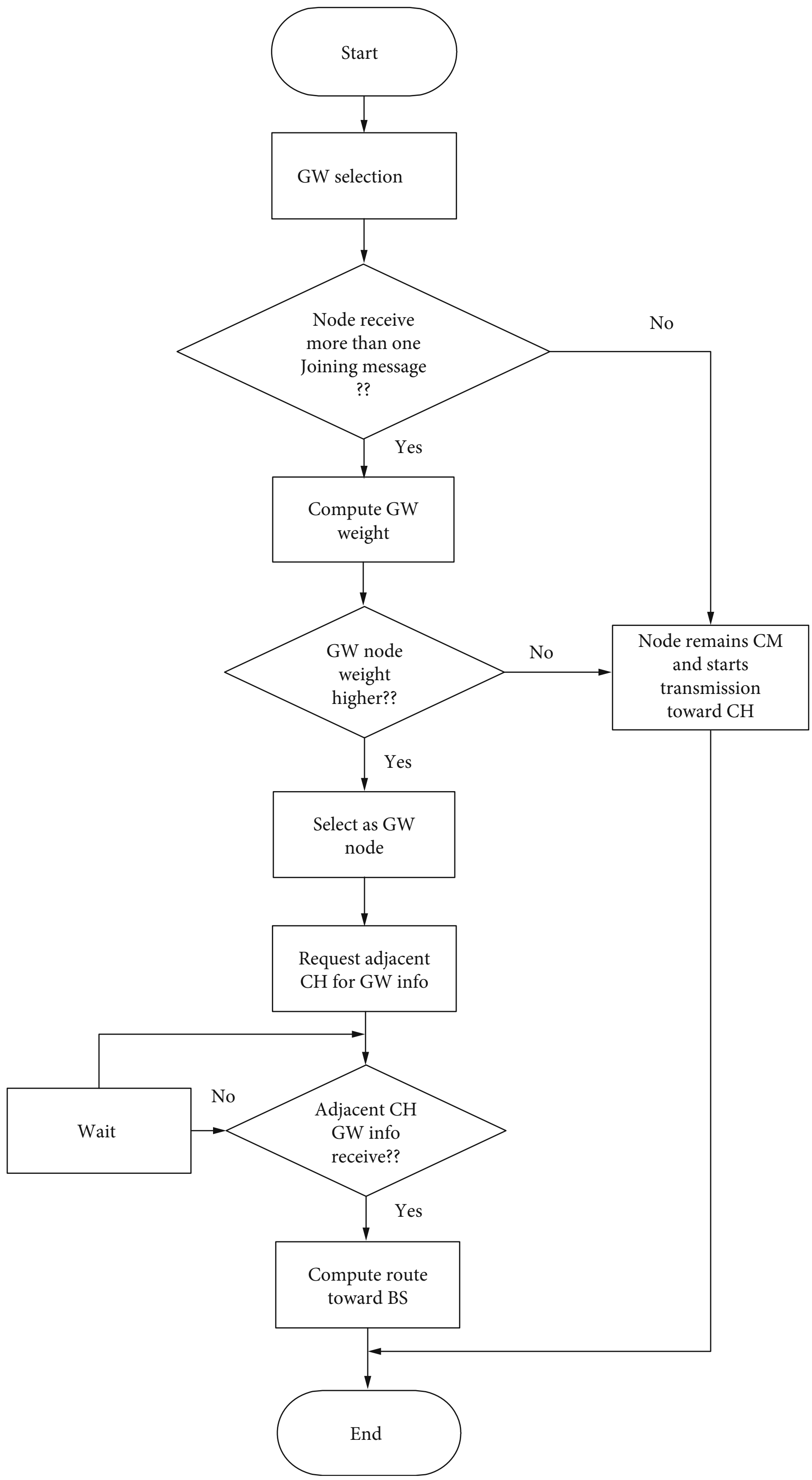

FIGURE 7: Gateway selection flow chart.

research community; new objects can be easily added using OTcl interpreter via corresponding objects in C++ class. In this research work, NS2 simulator is used to evaluate the performance of proposed GCEEC protocol with relevant scheme in terms of different performance parameters.

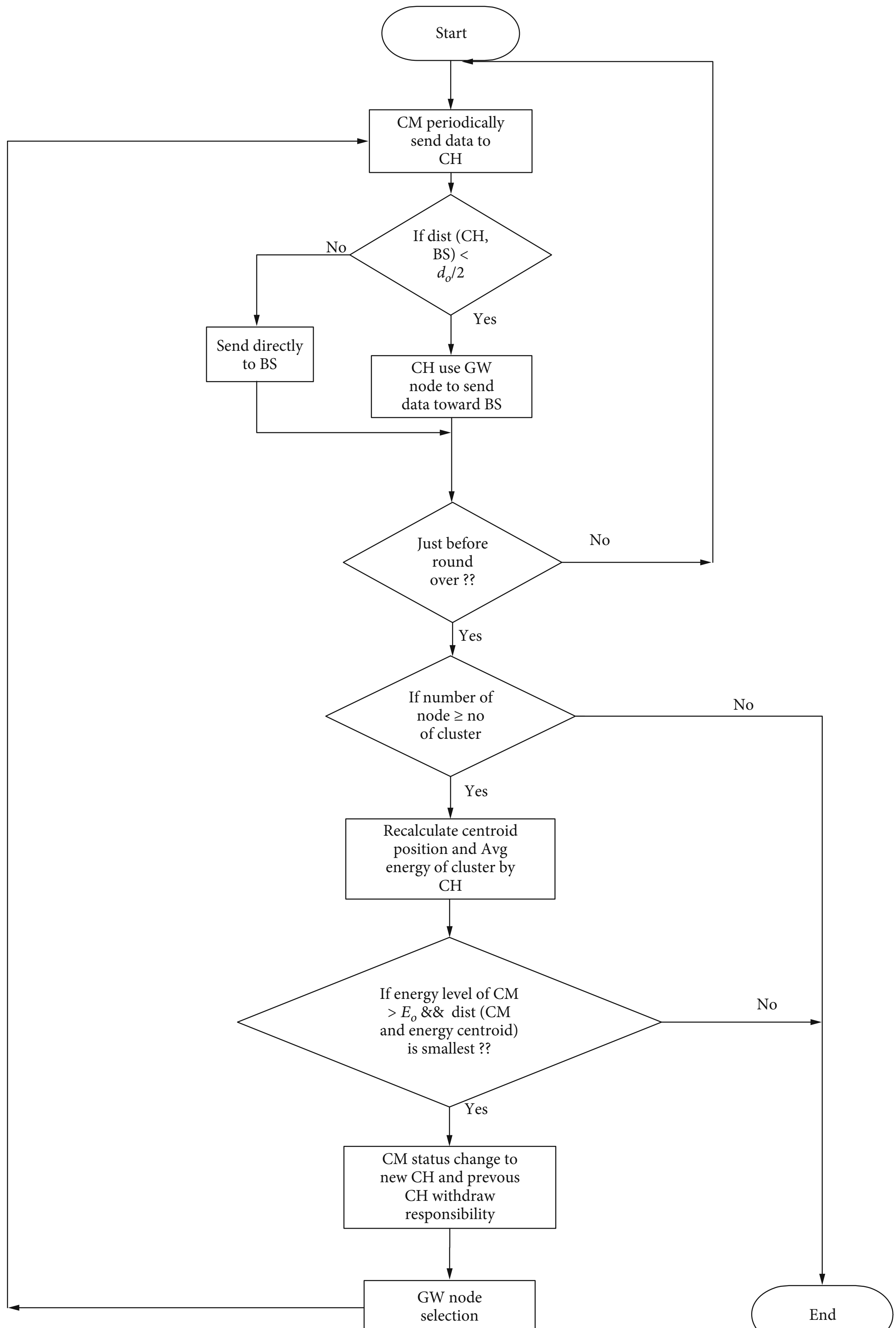

Figure 8: Data transmission and CH rotation flow chart.

do
CM sense and transmit sense data to CH
if $(dist(CH, BS) < d_o/2)$
CH directly transmit data to *BS* in single hope
else
CH use GW node to transmit data to *BS* in multi-hop
end if
while (just before round over)
for $j = 0 : CM$
each CM $node(k)$ send residual energy and location to their *CH*
end for
CH calculate avg energy of cluster
$E_o = \sum_{k=0}^{CM} E_k / CM$
CH calculate energy centroid of cluster
$X_{ec} = \sum_{i=0}^{CM} (E_{i\_rs}/E_o) X_i / CM$
$Y_{ec} = \sum_{i=0}^{CM} (E_{i\_rs}/E_o) Y_i / CM$
$d = \sqrt{(X_{ec} - X_i)^2 + (Y_{ec} - Y_i)^2}$
for $k = 0 : CM$
if $(energy\ level$ of $node(k) > E_o$ && d is $smallest)$
current *CH* change the status of node(k) = CH_k
current *CH* withdraw responsibility
end if
end for
CH_k transmit joining message as same as Algorithm 1

ALGORITHM 2: Data Transmission and Cluster Head Rotation.

4.1. Simulation Setup. This section presents the simulation setup to measure the performance of the proposed protocol design. The simulation is performed in the network, where we set 100 ∗ 100 m area with 100 sensor nodes. All the sensor nodes are static and know their location by means of GPS. The BS is located outside the network at position of (100,100). We have considered three network scenarios which are discussed as follow: 2%, 5%, and 10% of sensor nodes as CH. To analyze the performance of network by varying the number of CH in sensor nodes, we ran the simulation 5 times; the average of these instances of data is used for plotting the results. The simulation parameters used to evaluate the proposed protocol with existing protocols are in Table 2.

4.1.1. Performance Metrics. To determine the efficiency of the proposed schemes against specified objectives, the following performance metrics are used.

Network lifetime. The network lifetime is the expiration of the network life when the number of nodes depleted their energy when data transmission begins; the cluster nodes sense the data and send to their CH and then to BS via gateway node. In these experiments, the initial energy of node is 2 J which is reducing while transmitting and receiving control messages and data.

Network throughput. Network throughput refers to the receiving of packets by the BS. It is a successful transmission of sensing the data from CM of clusters to the BS via the CHs and gateway nodes.

Energy consumption. Energy consumption is the most valuable parameters for wireless sensor network in which sensor nodes utilize their battery resources in transmission and reception of data packets. In experiments, the energy consumes per round and consumes energy in clustering, assigning gateway node, sensing, and transmitting of data from CM of the cluster to the BS via the involvement of CH and gateway node. The confidence interval refers to possible range or values for the simulation parameters which are based on the simulation results. The 90% confidence level is the probability that the interval contains the value of the parameter. For this study, simulation confidence interval is at 90%.

4.1.2. Assumptions and Limitations

(1) Sensor nodes are static and are deployed randomly in field

(2) All nodes adjust their transmission power according to distance

(3) Communication channel is reliable and free of error

(4) The sensor nodes are aware of their locations through some localization techniques

(5) The BS is placed outside the network (100,100) location

(6) Every gateway node is in the range of its neighboring gateway node

4.2. Results and Discussion

4.2.1. Effect on Number of Alive Nodes. The number of alive nodes which indicates the network lifetime is as shown in Figures 9–11. This comparison is based on the alive nodes

```
for j = 0 : CM
  if (node(j) receive adjacent CH joining request)
    Compute GW node Weight for Adjacent Cluster Head
    G(i, j) = [S(i).E/S(i).Max]+[[d(i, j)^2 + d(i, x)^2 + d(j, x)^2 + (d(j, s)^2/d(i, s)^2)]
    Send GW weight value to CH
  else
    Round Start, CM periodically send data to their CH
  end if
end for
if (node(j) GW weight value higher)
  node(j) select as Gateway Node by CH
else
  node(j) Reject as Gateway node by CH
end if
Gateway node inform its status to adjacent CH and request for Adjacent CH Gateway node
while (Adjacent CH Gateway Node Information Receive)
  Compute Route
end while
if (dist(CH, BS) < d_Th)
  CH directly transmit data to BS in single-hop
else
  CH use GW node to transmit data to BS in multi-hop
end if
```

Algorithm 3: Gateway Node Selection.

Table 2: Simulation parameters.

Parameter	Values
Network area	100 m * 100 m
BS location	At the edge of the area
Number of sensor nodes	100
Initial energy (J)	2 J
Data aggregation energy	5 nJ/bit/signal
Transmission energy	50 nJ/bit
Reception energy	50 nJ/bit
Data transmission rate	5000 bps
ϵ_{fs}	10 pJ/bit/m^2
ϵ_{amp}	0.0013 pJ/bit/m^4
Round time	2 sec/round
Packet size	200 bits
MAC	802.11

vs. the number of rounds at 2%, 5%, and 10%, respectively. As it is shown that the proposed protocol GCEE performs better as compared to EECRP, CAMP, and MEACBM. The first node dies in the proposed scheme approximately in between 700 and 800 rounds. Similarly, the first node dies in EECRP very shortly because data transmitted by CH is on a single hop, while the proposed scheme utilizes multihop gateway nodes for data transmission from CH to BS. Moreover, as shown in the results that the CAMP protocol has almost the same results as MEACBM and the nodes die approximately at 550-800 rounds, these results are showing early depletion of sensor nodes. In addition, the results also indicated that at 2% and 10% of CH, the CH consumes more energy, so that node dies earlier. While in 5%, nodes die slowly. Therefore, 5% of nodes that are CHs have better conditions.

4.2.2. Average Data Transmission. Figure 12 shows the result of average data transmission by changing the number of CH nodes in the network. As compared to EECRP, CAMP, and MEACBM schemes, the proposed scheme of GCEEC performs better because CM data are transmitting towards the BS via the CH and multihop gateway node. Therefore, average data transmission enhances by increasing the number of CH. Furthermore, a lot of fluctuations in EECRP scheme is due to the concept of MAX-dist. MAX-dist is the threshold distance in which the CH sends the data to the BS successfully if the distance is less than the data forwarded; otherwise, CH stores the data in cache and wait for the next round due to which average data transmission reduces. In addition, Figure 12 also reveals when the number of CH is small, the average data transmission is less because the distance between the sensor nodes and the BS is large, and large amount of energy was consumed by all sensor nodes. As number of CH increases, the average data transmission increases. But as the number of CH increases by 5%, the average data transmission also reduces because amount of data to increase in network which creates energy dissipation is quicker among sensor nodes. The results indicate that the proposed protocol has stable data transmission as compared to EECRP, CAMP, and MEACBM.

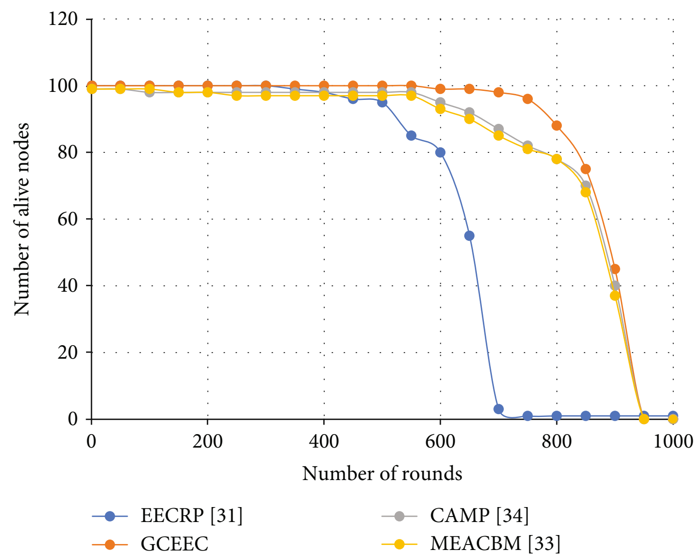

Figure 9: Number of alive nodes at 2% CH.

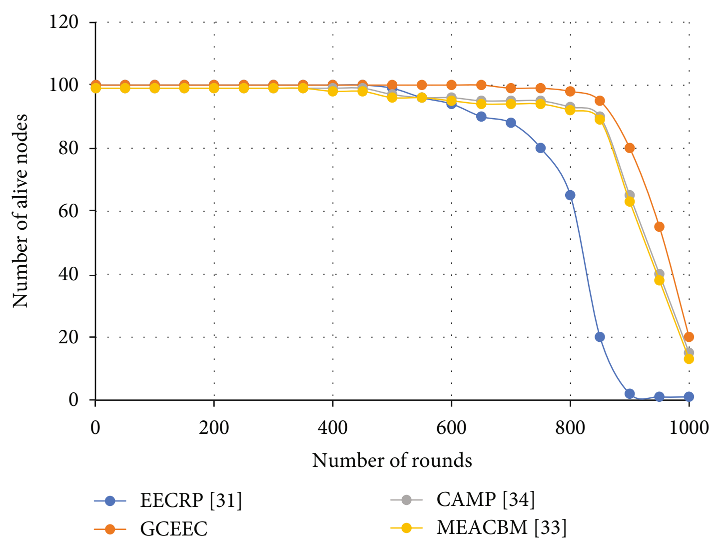

Figure 10: Number of alive nodes at 5% CH.

4.2.3. Round vs. Packet Received by Base Station. Number of data packet received by BS which is taken into consideration at different number of rounds. Figures 13–15 show the data packet received by BS at 2%, 5%, and 10% of CH, respectively. As it is shown, EECRP considerably receives fewer data packet to BS than GCEEC. Furthermore, packet received by BS in EECRP scheme is slower than GCEEC because of the adjustment of MAX-dist in EECRP where as in GCEEC, gateway nodes relay data from the CH to the BS. As compared to CAMP and MEACBM, the proposed protocol GCEEC has better data transmission. However, the MEACBM is better than EECRP due to the use of coverage and connectivity in the network by constructing a subcluster and computing the multihop route for interclustering combination among clusters and subclusters. In addition, the proposed scheme at 5% of CH performs better transmission of packet than 2% and 10% because in 5% of CH, nodes die slowly and have better coverage and have less burden on gateway nodes. While in 2% of CH, the distance between nodes and BS is greater so large amount of energy is consumed. Similarly, in 10% of CH, data transmission in network enhances; more data is relaying on gateway nodes which shorten network lifetime.

4.2.4. Rounds vs. Energy Consumption. As shown in Figures 16–18, the total energy consumption in EECRP is high as compared to the proposed schemes. It is due to the fact that EECRP scheme uses single-hop transmission by CH as well as threshold distance name MAX-dist. The single-hop transmission towards the BS causes load on the

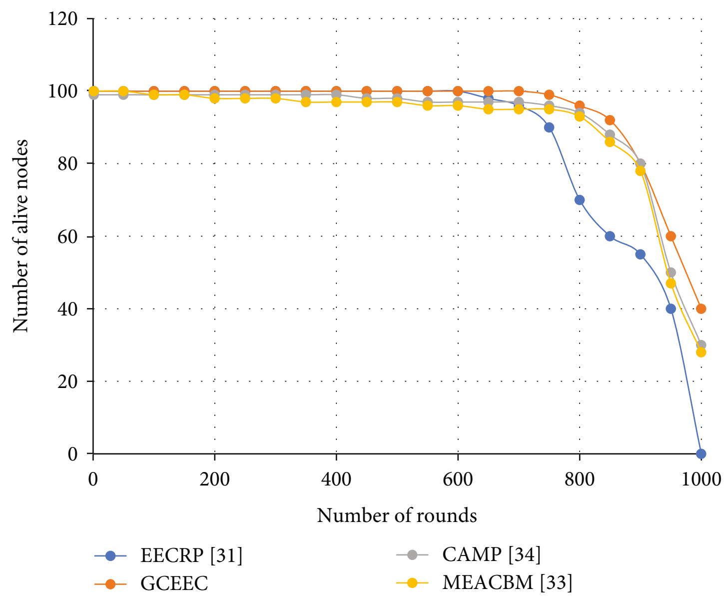

Figure 11: Number of alive nodes at 10% CH.

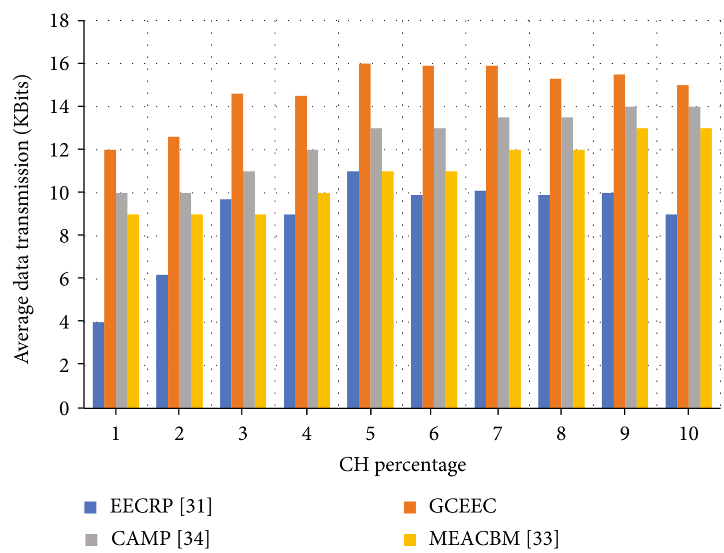

Figure 12: Average data transmission with different numbers of CHs.

CH, which consumes more energy. Furthermore, due to MAX-dist concept, i.e., CH stops transmission, stores data in cache when distance between CH and BS is greater than MAX-dist, and transmits all cache data to incoming CH during rotation phase. This MAX-dist cache process consumes more energy of CH during transmission and reception. In GCEEC, the load of CH is distributed due to selection of multihop gateway node which significantly reduces energy consumption. Therefore, overall energy consumption is reducing in the proposed protocol as compared to EECRP, CAMP, and MEACBM.

The objective of these experiments is to select the CH on efficient location in cluster and to reduce the load on CH. The proposed GCEEC protocol for agriculture precision selects the CH near the energy centroid position which maximizes the network coverage of cluster nodes and reduces the energy consumption. Furthermore, gateway nodes are selected among clusters which relays itself as well as other CHs and forward the data towards the BS which significantly reduces load on CH. The experimental results indicated that GCEEC performs better than EECRP, CAMP, and MEACBM protocols. All sensor nodes transmit limited amount of data to the CH, and the CH can bear all cluster node data in his memory. It can easily transfer to its gateway, and gateway can easily transfer the data to the next gateway and then further transmit towards the BS. Therefore, there will be more transmissions as compare to EECRP, CAMP, and MEACBM protocols, but it reduces the load on CH with the help of

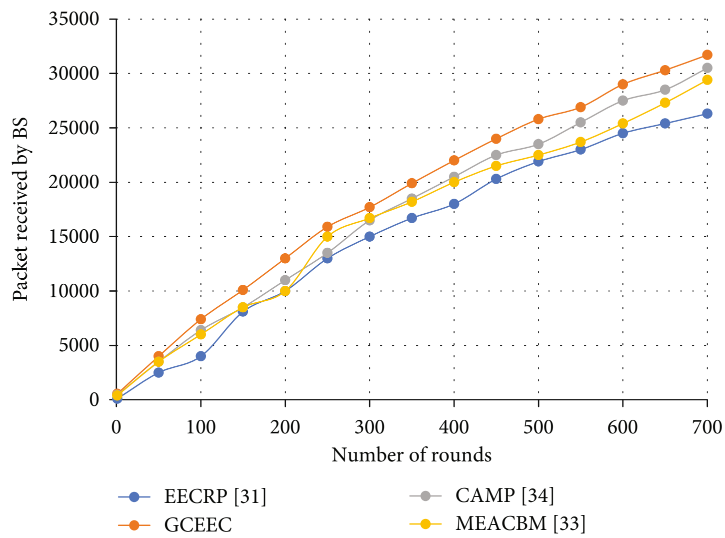

FIGURE 13: Packet received by BS 2% CH.

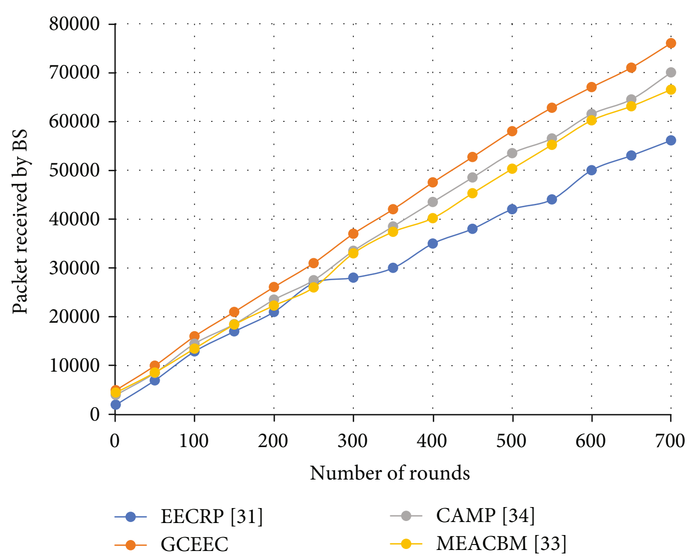

FIGURE 14: Packet received by BS 5% CH.

gateway node. Hence, we say that the proposed GCEEC protocol has much more energy and efficient as compared to state-of-the-art routing protocols.

The applications for precision agriculture have deployed to analyze the environmental parameters such as humidity, crop conditions, and soil monitoring. All the data communication process among small sensor nodes is based on feasible and energy-efficient sensor systems to improve the monitoring systems for further decision making. Routing protocols are playing a very crucial role for data collection in field. Complex routing protocols lead to consuming more energy, overhead, and packet dropping. In this paper, after designing the proposed GCEEC routing protocol, we analyze the performance with state-of-the-art routing protocols and observed that proposed protocol consumes less energy which impacts on better data delivery in agriculture fields. After designing the protocol, now we compare the whole system performance with existing systems in agriculture precision field. Table 3 presents the comparison of some of the existing agriculture precision systems and proposed system in terms of overhead, coverage area, energy consumption, network lifetime, scalability, and other performance parameters. Table 3 indicates that most of the existing systems have more overhead and not scalable to adjust in other agriculture fields like [43, 44]. The proposed system is scalable especially for agriculture precision applications such as precision farming, horticulture, orchard, precision agriculture, precision fruticulture, precision horticulture, quality, tree fruits, and vegetables. The table below also indicates the different parameters to evaluate the existing agriculture precision system and their possible applications in terms of network overhead, coverage area, energy consumption

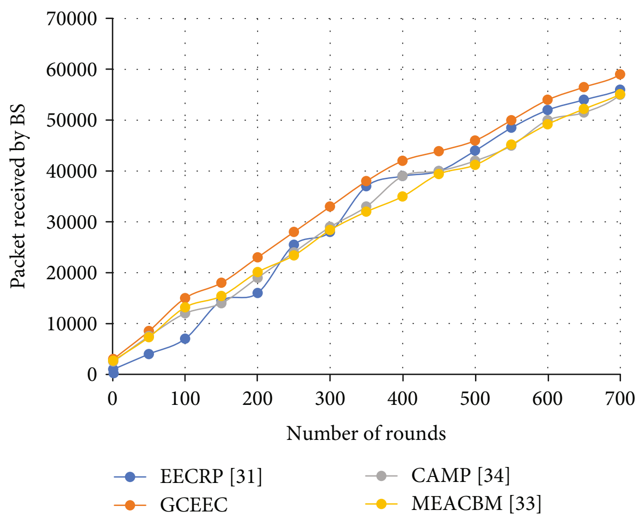

Figure 15: Packet received by BS 10% CH.

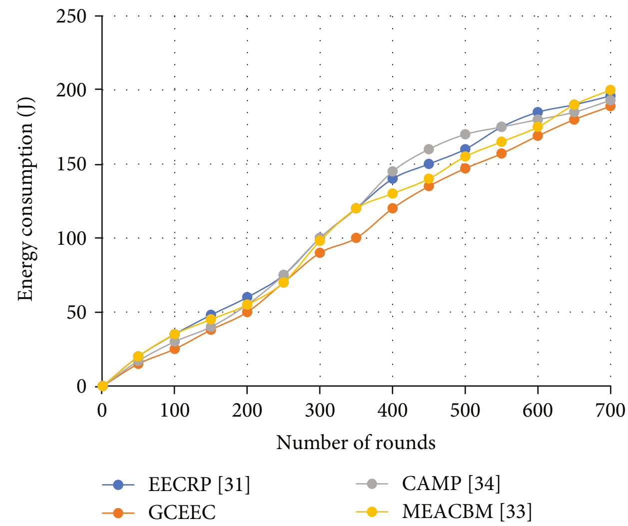

Figure 17: Energy consumption at 5% CH.

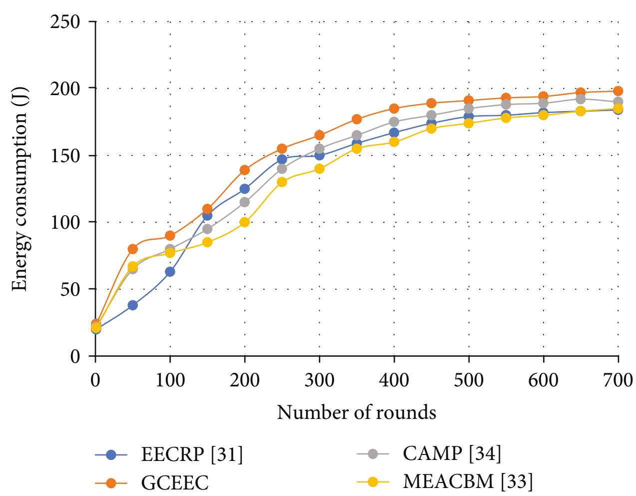

Figure 16: Energy consumption at 2% CH.

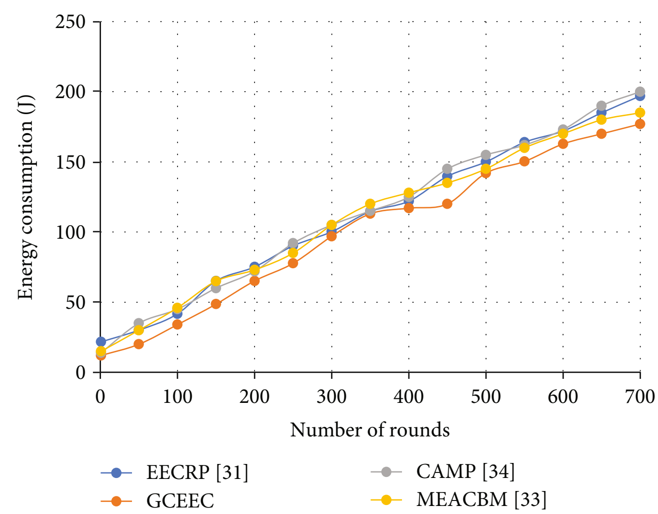

Figure 18: Energy consumption at 10% CH.

reduction, network lifetime, scalability, and system limitations. Some systems have moderate but still suffered with other parameters such as [41] which is moderate but still suffered in network lifetime. The system in [42] has high overhead and also not considered energy consumption and scalability. The systems [39, 40, 44] are not scalable and also suffered in overhead issues. The proposed system GCEEC is scalable and offers moderate network lifetime.

5. Conclusion

Wireless sensor network (WSN) is one of the emerging technique and technology especially for agriculture sector. In WSN, sensor nodes sense the physical and environmental conditions of soil and crop and send the data to the sink node by single-hop or multihop communication. Due to low computational power and limited battery resources, complex routing processes may cause energy depletion of the sensor nodes. Most of the routing protocols do not consider load balancing for a feasible routing path. This research improves load among the sensor nodes especially on the cluster head (CH). Furthermore, research also improves the optimized location and rotation of CH among energy density sensor nodes. In this research, Gateway Clustering Energy-Efficient Centroid-based Routing Protocol (GCEEC) is proposed for WSN. The proposed protocol selects and rotates the CH near the energy centroid position of the cluster. In addition, each CH chooses the gateway node for multihoping itself and other CH data towards the BS which reduce load among the CH. We performed the experiment on a well-known network simulator named NS-2.35 to analyze the performance of GCEEC for different criterion which includes network lifetime, network throughput, and energy consumption. The experimental result revealed that network lifetime, throughput, and energy consumption of our protocol is better than EECRP protocol. In the future, we will analyze the proposed

Table 3: Comparison table.

S#	Agriculture precision system references	Applications	Overhead	Coverage area	Energy consumption reduction	Network lifetime	Scalability	Limitation
1	[45]	Greenhouse	Moderate	50 m	Moderate	Limited	Moderate	Time consuming, synchronization accuracy
2	[46]	Agriculture	High	150 m	Not considered	Moderate	Not considered	Not feasible for other quality of services parameters
3	[47]	Crop farming	Moderate	180 m	20 times more compared to traditional systems without CH	Limited	Not considered	Not reliable communication beyond 80 m
4	[44]	Tree monitoring	High	180 m	High	Limited	Not considered	Its solar system has irregularity on different aspects
5	[48]	Precision agriculture	Moderate	40 m	High	Limited	Not considered	System is more complex and leads to predefined path issues
6	[43]	Forest monitoring	High	672 m	High	Moderate	Not considered	Packet loss, energy consumption
7	Proposed system (GCEEC)	Precision agriculture	Low	200 m	Low	Long	Considered	Fixed for agriculture precision only

protocol with other environments like drone-assisted WSN, wireless body area networks, and sensor-based transportation systems.

Data Availability

No data have to be included.

Conflicts of Interest

The authors declare that they have no conflict of interest.

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References

[1] K. Sneha, R. Kamath, M. Balachandra, and S. Prabhu, "New gossiping protocol for routing data in sensor networks for precision agriculture," in *Soft Computing and Signal Processing: Proceeding*, pp. 139–152, Springer, 2019.

[2] K. N. Qureshi and A. H. Abdullah, "Adaptation of wireless sensor network in industries and their architecture, standards and applications," *World Applied Sciences Journal*, vol. 30, no. 10, pp. 1218–1223, 2014.

[3] K. N. Qureshi, A. H. Abdullah, F. Bashir, S. Iqbal, and K. M. Awan, "Cluster-based data dissemination, cluster head formation under sparse, and dense traffic conditions for vehicular ad hoc networks," *International Journal of Communication Systems*, vol. 31, no. 8, article e3533, 2018.

[4] M. Salayma, A. Al-Dubai, I. Romdhani, and Y. Nasser, "New dynamic, reliable and energy efficient scheduling for wireless body area networks (WBAN)," in *2017 IEEE International Conference on Communications (ICC)*, pp. 1–6, Paris, France, May 2017.

[5] T. Rault, A. Bouabdallah, and Y. Challal, "Energy efficiency in wireless sensor networks: a top-down survey," *Computer Networks*, vol. 67, pp. 104–122, 2014.

[6] K. O. Flores, I. M. Butaslac, J. E. M. Gonzales, S. M. G. Dumlao, and R. S. J. Reyes, "Precision agriculture monitoring system using wireless sensor network and Raspberry Pi local server," in *2016 IEEE Region 10 Conference (TENCON)*, pp. 3018–3021, Singapore, Singapore, November 2016.

[7] X. Feng, J. Zhang, C. Ren, and T. Guan, "An unequal clustering algorithm concerned with time-delay for internet of things," *IEEE Access*, vol. 6, pp. 33895–33909, 2018.

[8] D. M. Omar and A. M. Khedr, "ERPLBC-CS: energy efficient routing protocol for load balanced clustering in wireless sensor networks," *Adhoc & Sensor Wireless Networks*, vol. 42, 2018.

[9] C. Savaglio, P. Pace, G. Aloi, A. Liotta, and G. Fortino, "Lightweight reinforcement learning for energy efficient communications in wireless sensor networks," *IEEE Access*, vol. 7, pp. 29355–29364, 2019.

[10] M. Srbinovska, C. Gavrovski, V. Dimcev, A. Krkoleva, and V. Borozan, "Environmental parameters monitoring in precision agriculture using wireless sensor networks," *Journal of Cleaner Production*, vol. 88, pp. 297–307, 2015.

[11] J. Lloret, M. Garcia, D. Bri, and J. Diaz, "A cluster-based architecture to structure the topology of parallel wireless sensor networks," *Sensors*, vol. 9, no. 12, pp. 10513–10544, 2009.

[12] T. Kalaivani, A. Allirani, and P. Priya, "A survey on Zigbee based wireless sensor networks in agriculture," in *3rd International Conference on Trendz in Information Sciences & Computing (TISC2011)*, pp. 85–89, Chennai, India, December 2011.

[13] K. N. Qureshi, S. Din, G. Jeon, and F. Piccialli, "Link quality and energy utilization based preferable next hop selection routing for wireless body area networks," *Computer Communications*, vol. 149, pp. 382–392, 2020.

[14] S. A. Kumar and P. Ilango, "The impact of wireless sensor network in the field of precision agriculture: a review," *Wireless Personal Communications*, vol. 98, no. 1, pp. 685–698, 2018.

[15] M. H. Anisi, G. Abdul-Salaam, and A. H. Abdullah, "A survey of wireless sensor network approaches and their energy consumption for monitoring farm fields in precision agriculture," *Precision Agriculture*, vol. 16, no. 2, pp. 216–238, 2015.

[16] D. S. Long and J. D. McCallum, "On-combine, multi-sensor data collection for post-harvest assessment of environmental stress in wheat," *Precision Agriculture*, vol. 16, no. 5, pp. 492–504, 2015.

[17] X. Fu, G. Fortino, W. Li, P. Pace, and Y. Yang, "WSNs-assisted opportunistic network for low-latency message forwarding in sparse settings," *Future Generation Computer Systems*, vol. 91, pp. 223–237, 2019.

[18] S. Palaniappan and P. Periyasamy, "WISEN: mote as an innovative approach in precision agriculture monitoring using wireless sensor network," *International Journal of Printing, Packaging & Allied Sciences*, vol. 4, no. 5, pp. 3475–3487, 2016.

[19] A. Mehmood, S. Khan, B. Shams, and J. Lloret, "Energy-efficient multi-level and distance-aware clustering mechanism for WSNs," *International Journal of Communication Systems*, vol. 28, no. 5, pp. 972–989, 2015.

[20] N. A. Pantazis, S. A. Nikolidakis, and D. D. Vergados, "Energy-efficient routing protocols in wireless sensor networks: a survey," *IEEE Communications Surveys & Tutorials*, vol. 15, no. 2, pp. 551–591, 2013.

[21] A. Mehmood, J. L. Mauri, M. Noman, and H. Song, "Improvement of the wireless sensor network lifetime using LEACH with vice-cluster head," *Ad Hoc & Sensor Wireless Networks*, vol. 28, no. 1-2, pp. 1–17, 2015.

[22] C. M. de Farias, L. Pirmez, G. Fortino, and A. Guerrieri, "A multi-sensor data fusion technique using data correlations among multiple applications," *Future Generation Computer Systems*, vol. 92, pp. 109–118, 2019.

[23] P. C. S. Rao, P. K. Jana, and H. Banka, "A particle swarm optimization based energy efficient cluster head selection algorithm for wireless sensor networks," *Wireless Networks*, vol. 23, no. 7, pp. 2005–2020, 2017.

[24] K. Guravaiah and R. L. J. A. Velusamy, "BEACH: balanced energy and adaptive cluster head selection algorithm for wireless sensor networks," *Ad Hoc & Sensor Wireless Networks*, vol. 42, 2018.

[25] X. Fu, G. Fortino, P. Pace, G. Aloi, and W. Li, "Environment-fusion multipath routing protocol for wireless sensor networks," *Information Fusion*, vol. 53, pp. 4–19, 2020.

[26] X. Liu, "Atypical hierarchical routing protocols for wireless sensor networks: a review," *IEEE Sensors Journal*, vol. 15, no. 10, pp. 5372–5383, 2015.

[27] N. Jan, N. Javaid, Q. Javaid et al., "A balanced energy-consuming and hole-alleviating algorithm for wireless sensor networks," *IEEE Access*, vol. 5, pp. 6134–6150, 2017.

[28] G. P. Gupta, M. Misra, and K. Garg, "Energy and trust aware mobile agent migration protocol for data aggregation in wireless sensor networks," *Journal of Network and Computer Applications*, vol. 41, pp. 300–311, 2014.

[29] H. Safa, M. Karam, and B. Moussa, "PHAODV: power aware heterogeneous routing protocol for MANETs," *Journal of Network and Computer Applications*, vol. 46, pp. 60–71, 2014.

[30] X. Liu, "An optimal-distance-based transmission strategy for lifetime maximization of wireless sensor networks," *IEEE Sensors Journal*, vol. 15, no. 6, pp. 3484–3491, 2015.

[31] G. S. Brar, S. Rani, V. Chopra, R. Malhotra, H. Song, and S. H. Ahmed, "Energy efficient direction-based PDORP routing protocol for WSN," *IEEE Access*, vol. 4, pp. 3182–3194, 2016.

[32] M. Abo-Zahhad, S. M. Ahmed, N. Sabor, and S. Sasaki, "Mobile sink-based adaptive immune energy-efficient clustering protocol for improving the lifetime and stability period of wireless sensor networks," *IEEE Sensors Journal*, vol. 15, no. 8, pp. 4576–4586, 2015.

[33] T.-T. Huynh, A.-V. Dinh-Duc, and C.-H. Tran, "Delay-constrained energy-efficient cluster-based multi-hop routing in wireless sensor networks," *Journal of Communications and Networks*, vol. 18, no. 4, pp. 580–588, 2016.

[34] J. Shen, A. Wang, C. Wang, P. C. K. Hung, and C. F. Lai, "An efficient centroid-based routing protocol for energy management in WSN-assisted IoT," *IEEE Access*, vol. 5, pp. 18469–18479, 2017.

[35] K. M. Awan, A. Ali, F. Aadil, and K. N. Qureshi, "Energy efficient cluster based routing algorithm for wireless sensors networks," in *2018 International Conference on Advancements in Computational Sciences (ICACS)*, pp. 1–7, Lahore, Pakistan, February 2018.

[36] K. M. Awan, P. A. Shah, K. Iqbal, S. Gillani, W. Ahmad, and Y. Nam, "Underwater wireless sensor networks: a review of recent issues and challenges," *Wireless Communications and Mobile Computing*, vol. 2019, Article ID 6470359, 20 pages, 2019.

[37] M. Sajwan, D. Gosain, and A. K. Sharma, "CAMP: cluster aided multi-path routing protocol for wireless sensor networks," *Wireless Networks*, vol. 25, no. 5, pp. 2603–2620, 2019.

[38] F. Amin and M. Zubair, "Energy-efficient clustering scheme for multihop wireless sensor network (ECMS)," in *17th IEEE International Multi Topic Conference 2014*, pp. 131–136, Karachi, Pakistan, December 2014.

[39] A. Varga, "OMNeT++," in *Modeling and Tools for Network Simulation*, K. Wehrle, M. Güneş, and J. Gross, Eds., pp. 35–59, Springer Berlin Heidelberg, Berlin, Heidelberg, 2010.

[40] T. Issariyakul and E. Hossain, *Introduction to Network Simulator NS2*, Springer Publishing Company, Incorporated, 2010.

[41] O. Lartillot, P. Toiviainen, and T. Eerola, "A Matlab toolbox for music information retrieval," in *Data Analysis, Machine Learning and Applications*, pp. 261–268, Springer, Berlin Heidelberg, 2008.

[42] K. Fall and K. Varadhan, "The ns manual," 2011, https://www.isi.edu/nsnam/ns/ns-documentation.html.

[43] P. Mathur, R. H. Nielsen, N. R. Prasad, and R. Prasad, "Data collection using miniature aerial vehicles in wireless sensor networks," *IET Wireless Sensor Systems*, vol. 6, no. 1, pp. 17–25, 2016.

[44] T. Zou, S. Lin, Q. Feng, and Y. Chen, "Energy-efficient control with harvesting predictions for solar-powered wireless sensor networks," *Sensors*, vol. 16, no. 1, p. 53, 2016.

[45] Y. Song, J. Ma, X. Zhang, and Y. Feng, "Design of wireless sensor network-based greenhouse environment monitoring and automatic control system," *Journal of Networks*, vol. 7, no. 5, p. 838, 2012.

[46] S. Nikolidakis, D. Kandris, D. Vergados, and C. Douligeris, "Energy efficient routing in wireless sensor networks through balanced clustering," *Algorithms*, vol. 6, no. 1, pp. 29–42, 2013.

[47] D. L. Ndzi, A. Harun, F. M. Ramli et al., "Wireless sensor network coverage measurement and planning in mixed crop farming," *Computers and Electronics in Agriculture*, vol. 105, pp. 83–94, 2014.

[48] T. H. F. Khan and D. S. Kumar, "Mobile collector aided energy reduced (MCER) data collection in agricultural wireless sensor networks," in *2016 IEEE 6th International Conference on Advanced Computing (IACC)*, pp. 629–633, Bhimavaram, India, February 2016.