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Ratings Based Energy-Efficient Clustering Protocol for Multi-hop Routing in Homogeneous Sensor Networks

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Abstract: Wireless Sensor Network (WSN) is a highly witnessed lively research domain due to sensors' energy constrain and communication overhead. Clustering is a reliable solution for better energy utilization and well-organized communication. Hence, a novel distributed non-overlapping clustering algorithm namely Ratings based Energy-Efficient Clustering (REEC) is proposed for the homogeneous network. In REEC, cluster heads (CHs) are selected by rating values of the sensor nodes computed through energy level, number of neighbours and distance to the base station (BS). Further, the route for the communication is established by the Energy Threshold and Minimum Distance Routing Protocol (ETMDRP). To avoid collisions during cluster communications, ETMDRP adopts a Medium Access Control (MAC) protocol namely Time Division Multiple Access (TDMA). The energy computation method for communication is mathematically analyzed. The experimental results proved that the developed network is energy efficient by unequal clustering technique thus its lifetime is extended. The delivery ratio is also enhanced with minimized delay by a proficient routing method.

Keywords: REEC, Cluster head, ETMDRP, Cluster communication, Multi-hop.

1. Introduction

Advances in the wireless domain, sensors have enabled a large-scale network for various applications such as Machine Malfunction, Military Intelligence, Disaster Management, Medicine, and Security Surveillance [1]. WSN can be either a homogeneous or a heterogeneous network that contains a collection of Sensor Nodes (SNs) and a Base Station (BS). In homogeneous, SNs have the same capabilities as energy, memory, and other resources. But, heterogeneous is expensive and those capabilities are contrast [2]. The sensors' battery neither is recharged nor replaced once if it is distributed in the un-attended sensing environment [3]. Due to energy limitation, nodes may not be able to communicate directly to the BS in a long distance. Therefore, to improve network scalability and reduce energy depletion, the multi-hop approach is introduced [4]. A multi-hop paradigm connects the neighbours called intermediate nodes for the data transmission. The multi-hop communication can be more efficient than single-hop because multiple short hops require less energy than a long hop. However, controlling the communication overhead, finding the optimal routes and minimizing the propagation delay are the key challenges in the multi-hop approach. Also, nodes closer to the BS are forced to handle the heavy traffic [5]. To achieve all those challenges and enhance the performance of the network, the clustering technique has been introduced.

Cluster-based WSN is an extremely vibrant research area for the researchers because the cluster has become a stable solution for the WSN objectives [6]. Cluster enables the efficient use of the sensor's resources and provides a structured way of communication. The cluster construction and CH election are the two fundamental functions in the clustering. SNs are grouped into clusters where each cluster contains a Cluster Head (CH) and a collection of Member Nodes (MNs) in the network layer [7]. The cluster communications namely Intra and Inter reduce the number of SNs involved in long-distance communications. Thus, it minimizes the energy consumption for the entire network. In the Intra-Cluster Communication, nodes forward the sensed data to the CH through multiple intermediate nodes where CH is considered as a target node and the data is accumulated. At last, CH transmits the aggregated data to the BS (destination) via multiple CHs which is called Inter-Cluster Communication. The efficiency of the cluster is based on the CH therefore, CH must be chosen vigilantly by the standard method. The CH rotation is mostly common in the clustering algorithms to balance the energy depletion uniformly [8, 9].

The route discovery for multi-hop cluster communication is a critical task in the network. Routing protocols are classified into three types, namely, proactive, reactive, and hybrid [10, 11]. In the clusters, the collision occurs when multiple SNs transmit the data concurrently to the CH. This issue can be proficiently solved through schedule based TDMA data transmission scheme. Finally, with the aim of better cluster formation method and multi-hop routing communication, the REEC Non-Overlap protocol is developed. The existing protocols consume massive energy when the cluster size is large and scalability is less due to bounded communication range. The major contributions and the features of the proposed work are:

- Non-Overlapping uneven size cluster model is constructed which avoids the hotspot problem.
- CHs are selected based on the Ratings of the SNs for effective cluster organization.
- CHs are re-elected that attain uniform energy depletion.
- Energy Threshold-based Minimum Distance Routing Protocol (ETMDRP) is proposed for the optimal route which enhances the performance of QoS (Quality of Service) metrics.
- MAC protocol (TDMA) is adopted that avoids the collision during the intra and inter-cluster communications.

The paper is organized as follows: Section 2 presents the background study of the cluster-based WSN. The network and energy depletion models are given for the homogeneous sensor network in Section 3. Section 4 explores the proposed REEC Non-Overlap algorithm. The MSRP for cluster communication is discussed in Section 5. The energy computation, data transmission time and packet delivery ratio are analyzed in Section 6. Section 7 shows the simulation results. Finally, conclusions are given in Section 8.

2. Background study

This section gives the study of existing clustering protocols for multi-hop routing in WSNs. It also describes the drawbacks of each protocol.

Heinzelman et al. [12] proposed a proactive network algorithm called LEACH for increasing the network lifetime through energy efficiency. LEACH is completely a distributed and hierarchical protocol in which CHs are randomly selected in the setup phase. LEACH assumes that every node has adequate radio power to transmit the data directly to the BS in the steady-state phase. LEACH uses both TDMA and CDMA for data transmission. The demerits of this algorithm are the random selection of CHs without considering its energy, non-uniform energy distribution and single-hop communication.

Farooq et al. [13] presented a Multi-hop Routing with Low Energy Adaptive Clustering Hierarchy (MR-LEACH) protocol. Unlike LEACH, MR-LEACH follows multi-hop routing between CHs and BS for energy conservation. Sensor nodes join the CHs based on Received Signal Strength Indicator (RSSI). A new CH is selected in each round based on the available energy of the SNs. In MR-LEACH, CHs are acting as relay nodes to route the data to BS. MR-LEACH creates the equal clustering that is any node in the layer will reach the BS in an equal number of hops. The BS prepares the TDMA schedule and it is broadcasted to all CHs for the transmission. The problems in this algorithm are complexity in dividing the network into layers and recovery of data is impossible if CH dies.

ACT [14] is designed to reduce the size of clusters closer to BS because CHs need to relay more data. The network is divided into multiple levels to prolong life. In the ACT, BS calculates the number of clusters in each level according to the cluster radius. Moreover, clusters in the 1st level are the smallest in size. BS broadcasts a message to transmit the data directly when each sensor node in the 1st level can no longer serve as a CH. The CHs are rotated based on the threshold power (T). The results show that ACT can efficiently reduce the energy consumption of CHs and network lifetime is extended than MR-LEACH. The major disadvantages are cluster formation itself takes too many rounds thereby energy dissipation is more and data transmission delay is high due to different levels of data forwarding.

Ashfaq Ahmad et al. [15] proposed a protocol namely (ACH^2) based on away CHs formation and free association mechanisms to increase the stability period and throughput of WSNs. This protocol is implemented in homogeneous, heterogeneous, proactive and reactive environments. Each node generates a random number (rnd) and compares it with the threshold value (Th) for the CH election. The data transmissions from member nodes to CHs and CHs to BS are performed using the TDMA schedule. In ACH^2, the throughput is maximized by mixed-bias bandwidth allocation scheme. However, there is an uneven allocation of load on CHs and the cluster communication route is lengthy in this protocol.

3. Homogeneous sensor network

In homogeneous network, sensor nodes are alike and the topology is merely static. The network model and energy depletion model are given in this section.

3.1 Network model

The network consists of N nodes which are randomly and uniformly radiated in an $m \times m$ square region with the following assumptions:

- Sensor nodes appear with the Unique Identity.
- Nodes localities are oblivious.
- Sensor nodes and base station are stationery.
- BS is situated outside the sensing field.
- The radio channels are symmetric.
- Nodes are grouped into clusters.

3.2 Energy depletion model

In this paper, the first order radio model is used to compute the energy depletion. The energy consumption models such as free space (fs) and multi-path (mp) fading are discussed in [12]. The amount of energy required to transmit an L-bit packet over a distance d using the radio model is:

$$E_{Tx}(L,d) = E_{elec} \times L + \begin{cases} L \times E_{amp} \times d^2, if\ d \leq d_0\ (fs) \\ L \times E_{amp} \times d^4, if\ d > d_0\ (mp) \end{cases} \quad (1)$$

where d is the distance between two sensor nodes, E_{elec} is the energy depleted by the electronic circuit to send and receive L-bit packet, E_{amp} is the energy per bit required in the transmit amplifier over a distance d^2 and d^4 respectively.

The transmission range d_0 defines the maximum distance to propagate the packets between two points that means if d is larger than d_0 between transmitter and receiver then the mp model is considered otherwise fs is employed to compute the energy depletion.

To receive an L-bit packet $E_{Rx}(L)$, the energy expenditure is calculated as:

$$E_{Rx}(L) = E_{elec} \times L \quad (2)$$

The available energy AE of a node changes dynamically after every transmission and it is expressed as:

$$AE = IE - EU \quad (3)$$

where IE is the initial energy and EU is the energy utilized by the node.

4. Ratings based energy-efficient clustering algorithm

The energy conservation, network lifetime extension, collision avoidance [17], and end-to-end delay minimization are the major objectives of WSNs. To accomplish such objectives, clustering is considered as one of the promising solutions. Hence, a novel clustering algorithm has been proposed namely Rating based Energy Efficient Clustering (REEC). The main goal of this algorithm is to enhance the network lifetime through energy efficiency and improve the QoS metrics.

4.1 Cluster construction

The homogeneous network is logically divided into clusters where clusters are formed into Non-Overlapping clusters. In non-overlapping, clusters are disjoint where it consists of Member Nodes (MNs) and Cluster Heads (CHs).

4.1.1. Notations and definitions

- Network Size (N): the sum of SNs deployed in the square sensing area.
- Cluster Count (CC): counts the clusters constructed in the network where $CC=k$. It determines the number of CHs required.
- Cluster Size (CS): the number of SNs in each cluster. It varies from one to other clusters.
- Node Degree (ND): neighbours of a node identified by d_0 using Euclidean metric.
- Rating value (R_v): computed to all SNs based on the value of the parameters which determines the CHs in all k clusters.
- Hop Count (HC): defines the number of hops in a transmission.

4.1.2. Non-overlapping cluster

The cluster construction process is commenced once the SNs are disseminated in the sensing environment. Initially, the BS finds the Center of Mass $CM(\overline{x},\overline{y})$ of a sensing region ($m\times m$) that is, the average position of all nodes, weighted according to their masses and it is identified by:

$$\left.\begin{array}{l}\overline{x} = m_1x_1 + \cdots + m_nx_n \,/\, m_1 + \cdots + m_n \\ \overline{y} = m_1y_1 + \cdots + m_ny_n \,/\, m_1 + \cdots + m_n\end{array}\right\} \quad (4)$$

where m is the mass of the sensing region and $x=h/2, y=w/2$. Once the coordinates of CM are identified then, BS finds the average distance d between the CM and SNs by using the Euclidean distance metric.

$$d(CM,N) = \sum_{a=1}^{n} \frac{\sqrt{(\bar{x}-x_a)^2+(\bar{y}-y_a)^2}}{n} \quad (5)$$

where x and y are the coordinates of node a that is, $a(x,y)$. Next, BS calculates the number of clusters k required to partition the N nodes. The optimal value of k is determined by using the communication energy model [16].

$$k = \frac{\sqrt{N}}{\sqrt{2\pi}}\sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}}\,\frac{m}{d_{to}^{2}BS} \quad (6)$$

where m is the side of a given square region and $d_{to}BS$ represents the average distance between the CH nodes and BS.

Now, BS selects the initial mean points M for k clusters. The selection of an outlier node as a mean point may mess up the clustering. Therefore, to avoid such a situation, the polar coordinate system is used along with the values of CM, d, and k. The mean points describe their position in terms of distance and the angles are measured from the directions.

$$\left.\begin{array}{l}M_x = \bar{x} + d \times cos\theta \\ M_y = \bar{y} + d \times sin\theta\end{array}\right\} \quad \forall b \quad (7)$$

where $b=1,2,\ldots,k$ clusters and θ is represented as $2\pi/k\times(b-1)$. In C clusters, each M is one of the clusters and the purpose of finding M is to prevent unnecessary localized convergence. Subsequently, SNs find the nearest M by using the squared Euclidean metric distance as given below.

$$d.min. \sum_{b=1}^{k}\sum_{xy_a\in C_b} d\left(xy_a\,, xy_{M_b}\right)^2 \quad (8)$$

where, xy_a is the coordinates of node a, and xy_{Mb} is the coordinates of mean points of b cluster. The next step is to assign each SN to a cluster. It is mathematically expressed as:

$$\left.\begin{array}{l}C_b{}^{(t)} = \{xy_a\colon d(xy_a,\ xy_{Mb}{}^{(t)})^2 \le d(xy_a, xy_{Mb}{}'^{(t)})^2\} \\ \forall b', 1 \le b' \le k\end{array}\right\} \quad (9)$$

where $C_b{}^{(t)}$ is the cluster b in the t[th] time and b contains the nodes in which the distance from the node xy_a to the mean of xy_{Mb} is smaller than that of the distance from the node to the mean of all other $xy_{Mb}{}'$.

Again, new mean points are generated by taking the mean of all nodes assigned to the clusters.

$$xy_{Mb}{}^{(t+1)} = \frac{1}{|C_b{}^{(t)}|}\sum_{xy_b\epsilon C_b{}^{(t)}} xy_b \quad (10)$$

Now, reassign the nodes to the respective clusters. Such a process is iterative until it converges on a cluster partition that remains same.

$$\left.\begin{array}{l}C_b{}^{(t+1)} = \{\, xy_a : d(xy_a, xy_{Mb}{}^{(t+1)})^2 \\ \le d(xy_a, xy_{Mb}{}'^{(t+1)})^2\,\}\ \ \forall b', 1 \le b' \le k\end{array}\right\} \quad (11)$$

The clustering process ends when the constant mean points are met and nodes join the clusters with minimum distances.

4.2 Cluster head election

In general, CH is elected by following any one of the methods such as deterministic, probabilistic and pre-assigned. However, in the REEC, CH is elected by considering certain parameters that are more controllable and trustworthy.

The BS computes the Rating value (R_v) for all SNs and its computation method is given in Section 4.2.1. After the computation of R_v, the CH election is initiated. A node, which has higher R_v is elected as CH in the cluster and it is broadcasted to the MNs. The CH election in each cluster is expressed as:

$$CH_{elect} = Max\ [R_v(a)]_{a=1}^{n}\ , \forall C_b\ , 1 \le b' \le k \quad (12)$$

where C_b represents the Cluster b. The Node's R_v is dynamic because it changes after every transmission and CHs are rotated when R_v goes below the pre-defined level. Moreover, a node that had been acted as a CH in the previous rounds cannot become again

Table 1. Condition on parameters for CH election

Parameter	Value
Available Energy (X_1)	High
Node Degree (X_2)	High
Distance to BS (X_3)	Low

Table 2. Message header for node's information

C_ID	N_ID	Nei_IDs	ND	AE	d_BS
C_1	01	4, 6, 9, 11	4	0.7J	110m

Table 3. Values for X_3

Distance to BS (X_3)	Value
≤ 100 m	3
101 m - 125 m	2
> 125 m	1

as a CH within the same cluster. The classical conditions are given for each node in the cluster to be elected as CH in Table 1.

4.2.1. Rating value computation

The proposed clustering algorithm introduces a new method called Rating value (R_v) computation to elect an optimum CH which is performed by BS. To compute the rating, BS sends a message to all the SNs and collects the information such as Cluster ID (C_ID), Node ID (N_ID), Node Degree (ND) along with Neighbor IDs (Nei_IDs), Available Energy (AE) and Distance to BS (d_BS). The message header is given below with sample data.

BS takes three parameters as input values for R_v: (i) Available Energy, Node Degree and Distance to BS. The AE of a node is calculated by using Eq. (3), the ND is identified by the d_0 and the d_BS is calculated by the position (coordinates) using the Euclidean metric. The R_v is computed for each node in the cluster as:

$$R_v = \sum_{i=1}^{3} X_i \tag{13}$$

where X_i represents the parameters (X_1, X_2, and X_3). The R_v calculation of each parameter is given in the example.

Example: Let assume, the R_v lies between 1 and 9 (R_v1 to R_v9) in which each parameter acquires 3 values and it is 9 as a sum. The computation method is as follows:

$$X_1 = AE \times 3/\mathrm{IE}$$
$$X_2 = ND \times 3/\mathrm{CS}$$

The values are given for the parameter X_3 based on the distance in Table 3.

A node (N_1) takes the sample data from Table 2 and assumes IE is 1J and CS is 10. Now, the $R_v(N_1)$ is computed by applying these values using Eq. (17).

$$R_v(N_1) = 2.1+1.2+2 = 5.3 \text{ out of } 9.$$

Similarly, the ratings are calculated to all SNs and a higher R_v node is elected as a CH in each cluster.

4.3 Cluster head re-election

The CH re-election process occurs when R_v goes down the threshold value T_v ($R_v < T_v$). In such a case, all MNs participate in electing a new CH for the next round in a particular cluster. The R_v of all SNs including CHs is updated after every transmission by the BS. Mostly, when the residual energy of a CH falls below the threshold, it causes re-election. Because the neighbours and the distance will not change due to cluster static. However, after a certain number of rounds, the neighbour nodes may die due to insufficient energy. Therefore, the proposed model once again considers the current R_v of MNs for CH rotation. The CH re-election process is expressed as:

$$\left. \begin{array}{l} CH_{re-elect} = Max\,[R_v(a)]_{a=1,2,\dots,m-1,m+1,\dots,n}, \\ \quad \text{where } R_v(m) < T_v \end{array} \right\} \tag{14}$$

where m represents a node acted as a CH in the previous round. Once a new CH is elected, BS broadcasts it to all MNs in the particular cluster.

5. Energy threshold based minimum distance routing protocol

In WSNs, every process consumes energy whereas route detection also entails the energy [18-19]. Therefore, the energy-efficient routing protocol ETMDRP is proposed which reduces the energy wastage by the proficient routing mechanism.

ETMDRP is a hierarchical and table-driven routing protocol where each sensor node maintains a routing table. In ETMDRP, the route is established by selecting the next forward node (NFN) between the source and destination. The selection of NFN is based on two important attributes that are energy threshold (E_r) and minimum distance. ETMDRP checks the node's energy level to receive and transmit the data before finding the shortest route. If the node's available energy is more than E_r, then the minimum distance node is identified and elected as NFN. Such a process of NFN selection guarantees successful data transmission and the minimization of energy consumption.

ETMDRP adopts multi-hop routing for cluster communication in which SNs and clusters are connected. The multi-hop paradigm occurs at two different situations in the entire transmission: (i) when a source node is not in transmission range (d_0) to CH (Intra-Cluster) and (ii) when a CH node is not in d_0 to *BS* (Inter-Cluster). The proposed ETMDRP consists of two important phases such as Data Transmission Phase and Cluster Communication Phase.

5.1 Data transmission phase

After the CH election process, transmission is initiated by the source node. The data forwarding from Source to CH (stage-1) and CH to BS (stage-2) are the two stages of a complete transmission. ETMDRP adopts a MAC protocol for data transmission such as TDMA to reduce the overhead.

TDMA is a well-suited transmission schedule for cluster communications (Intra and Inter) where a channel is divided into multiple non-overlapping time intervals based on the number of MNs and CHs in the network. The frame is broadcasted to MNs through CH neighbours. It consists of M slots in which each MN transmits the data to the selected NFN in the allotted slot. Similarly, CHs also transmits to BS in the given slots. Such unique slots for all nodes reduce the traffic load and data are sent in the order. TDMA tends to low duty cyclic operation that is, a node turns ON its radio interface only during the slot otherwise, turn OFF and recline in a sleep state. Thus, CH and MNs could conserve energy more.

5.2 Cluster communication phase

In the clusters, communication is a data sending and receiving medium between the source and destination. The cluster communication [20] is classified into two types: Intra-Cluster Communication and Inter-Cluster Communication. The proposed ETMDRP is applied in both types for seamless communication.

5.2.1. Intra-cluster communication

The data transmission between the MNs and CH within the same cluster is known as Intra-Cluster Communication (IRACC). The sensed data is transmitted to CH by the source node in different planes such as plane-1 (Direct transmission – single hop), plane-2 (transmission from source to CH through neighbours – 2 hops) and plane-N (multiple relay nodes). The hop count over a transmission determines the number of intermediate nodes involved between the source and CH.

Assume, a node (N_a) in a cluster j, sense the data which needs to be transmitted to CH. If N_a has adequate energy to transmit and exists within d_0 then the data is directly transmitted to CH in case of single-hop otherwise, a multi-hop scenario should be handled.

Algorithm 1. Intra–Cluster communication between source node and CH

N_a	- A member node (source)
CH	- C*luster* Head node (target)
$NN_a = \{N_b, N_c, N_d\}$	- Neighbours of N_a
AE	- Available Energy
E_r	- Energy required for receiving and forwarding the data
ENN_a	- A set of Eligible Neighbours, if energy is more than E_r
NFN	- Next Forward Node
d_0	- Transmission Range
HC	- Hop Count, initialized with Zero

Start

1. **if** ($AE_{Na} >= E_r$)
2. **if** ($d\,(Na,CH) <= d_0$) then
3. N_a directly transmits the data to CH.
4. CH acknowledges to N_a after receiving the data.
5. **endif**
6. **else**
7. **for** each NN_a do
8. **if** ($AE_{NNa} >= E_r$) then
9. $ENNa = NNa$;
10. **else**
11. Not eligible for NFN.
12. **endfor**
13. $NFN = N_a$ finds a nearest node from ENN_a;
14. $HC = HC+1$;
15. N_a forwards the data to NFN.
16. NFN acknowledges to N_a.
17. **endif**
18. **else**
19. Data transmission is suspended.
20. Repeat the steps from 2 to 17 until the data reaches CH.

Stop

5.2.2. Inter-cluster communication

The communication between CHs and BS defines Inter-Cluster Communication (IERCC). The energy consumption is having a high impact when the distance is more in IERCC. Therefore, multi-hop is much needed to facilitate the transmission that minimizes energy consumption at each CH. In Non-Overlapping Inter-Cluster Communication (NOIERCC), each CH aggregates the data after collecting it from the other CHs. If CH has required energy to transmit and falls within d_0 then the data is directly transmitted to BS in single-hop otherwise, the multi-hop scenario is considered.

Algorithm 2. Inter–Cluster communication between CH and BS (Non-Overlapping)

CH_{C1} - Cluster Head of Cluster 1
BS - Base Station (destination)
$NCH_{C1} = \{CH_{C2}, CH_{C3}, CH_{C4}\}$ - Nearest CHs of C_1
$ENCH_{C1}$ - Eligible Nearest CHs, if energy is more than E_r

Start

1. **if** ($AE_{CHC1} >= E_r$)
2. **if** ($d(CH_{C1}, BS) <= d_0$) then
3. CH_{C1} directly transmits the data to BS.
4. BS acknowledges to CH_{C1} after receiving the data.
5. **endif**
6. **else**
7. **for** each NCH_{C1} do
8. **if**($AENCH_{C1} >= E_r$) then
9. $ENCH_{C1} = NCH_{C1}$;
10. **else**
11. Not eligible for NFN.
12. **endfor**
13. NFN = CH_{C1} finds a nearest CH node from $ENCH_{C1}$;
14. $HC = HC+1$;
15. CH_{C1} forwards the data to NFN.
16. NFN acknowledges to CH_{C1}.
17. **endif**
18. **else**
19. Data transmission is suspended.
20. Repeat the steps from 1 to 17 until the data reaches BS.

Stop

6. Energy computation analysis

The energy calculation has been derived from the radio energy depletion model discussed in Section 3.2. Consider the following parameters to compute the energy depletion in all cluster communications.

- Transmitter: $T_p(fs) = L \times E_{elec} + L \times E_{fs} \times d^2$ and $T_p(mp) = L \times E_{elec} + L \times E_{mp} \times d^4$
- Receiver : $R_q = L \times E_{elec}$
- Aggregator : $A_r = L \times E_{DA}$

The following representations are used for counting the number of transmitters, receivers and aggregators.

- $T_p(fs)$ and $T_p(mp)$ = 1 if 'p' is a transmitter otherwise not a transmitter.
- R_q = 1 if 'q' is a receiver otherwise not a receiver.
- A_r = 1 if 'r' is an aggregator otherwise not an aggregator.

6.1 Energy calculation for IRACC

The IRACC uses multi-hop routing for the energy conservation between the source (MN) and CH.

Let assume, there are L-bit packets to be transmitted to CH through multiple intermediate nodes. The energy consumed for transmitting and receiving a packet from one MN to its neighbour MN is:

$$E_{MNtoMN} = T_p(fs) + R_q \tag{15}$$

The energy utilization between the source and CH where multiple intermediate nodes are involved in the transmission are calculated as:

$$E_{MNtoCH}(L) = \sum_p \sum_q (T_p(\mathrm{fs}) + R_q) \tag{16}$$

The energy expenditure to aggregate the packets at each CH is:

$$E_{CH\_Agg}(L) = \sum_r A_r \tag{17}$$

The total energy depletion for L-bit packets transmitted from the source to CH (IRACC) is estimated as:

$$E_{tot\_IRACC}(L) = E_{MNtoCH}(L) + E_{CH\_Agg}(L) \tag{18}$$

6.2 Energy computation for NOIERCC

The CH's energy is dissipated whenever it transmits, receives and aggregates the packets. Assume that the transmission distance between CHs is $d>d_0$. The energy consumption to transmit a packet from one CH to another CH is:

$$E_{CHtoCH} = T_p(mp) \tag{19}$$

When the CH receives and aggregates the packets then the energy expenditure at CH is calculated as:

$$E_{CH} = \sum_q \sum_r (R_q + A_r) \tag{20}$$

Finally, the total energy depletion for transmitting, receiving, aggregating and forwarding the packets to BS through multiple CHs in NOIERCC is estimated as:

$$E_{tot\_NOIERCC} = \sum_p \sum_q \sum_r (T_p(mp) + R_q + A_r) \tag{21}$$

7. Simulation

The performance of the proposed protocols is experimentally shown using MATLAB. The parameters used for the simulation are listed in Table 4.

7.1 Results discussion

The results of various performance metrics such as energy efficiency, network lifetime, end-to-end delay and packet delivery ratio for non-overlapping cluster are discussed in this section. The proposed REEC Non-Overlap is compared against the existing algorithms such as MR-LEACH [13], ACT [14], and ACH^2 [15].

7.1.1. Energy depletion

Fig. 1 shows the amount of energy depleted by the nodes including CHs during the data packet transmission at different simulation rounds. REEC Non-Overlap achieves optimal energy consumption

Table 4. Simulation parameters

Parameter	Value
Sensing Area (mxm)	100 x 100
Network Size (N)	100 nodes
BS Position	(50, 150)
Data Size	400, 800, 1200, 1600 and 2000 bits
Transmission Range (d_0)	10 m
Node's Initial Energy (IE)	1J
E_{elec}	50 nJ/bit
E_{fs}	10 pJ/bit/m^2
E_{mp}	0.0013 pJ/bit/m^4
E_{DA}	5 nJ/bit

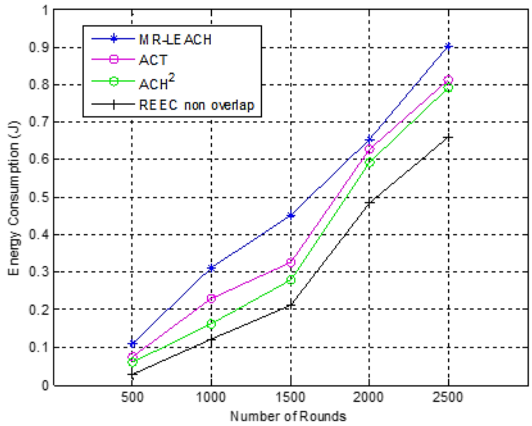

Figure. 1 Energy depletion for non-overlapping protocols

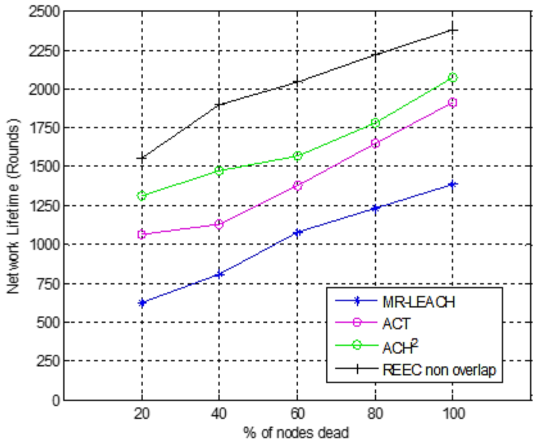

Figure. 2 % of nodes dead for non-overlapping

when compared with ACH^2, ACT and, MR-LEACH. The hop nodes are found in the smaller distance and the method of CH election is the reason in the proposed work.

The energy consumption of the proposed and existing algorithms is given in Table 5. It is observed that the energy depletion of REEC non-overlap is 17.33%, 22.04% 26.66% less than ACH^2, ACT, and MR-LEACH respectively.

7.1.2. Network lifetime

Fig. 2 shows the percentage of dead nodes over the different rounds. As per Fig. 2, the lifetime of the REEC Non-Overlap network is much better than other non-Overlapping protocols. This is due to the establishment of communication in both Intra and Inter-cluster through multiple intermediate nodes that reduce the distance and energy consumption.

The average calculated lifespan in different rounds is 2025, 1651, 1436, 1030 for REEC Non-Overlap, ACH^2, ACT and, MR-LEACH respectively.

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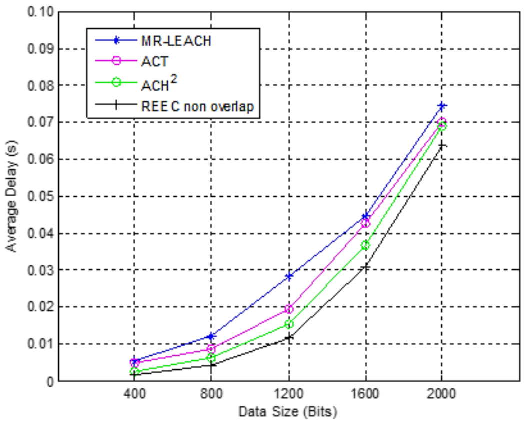

Figure. 3 End-to-End delay

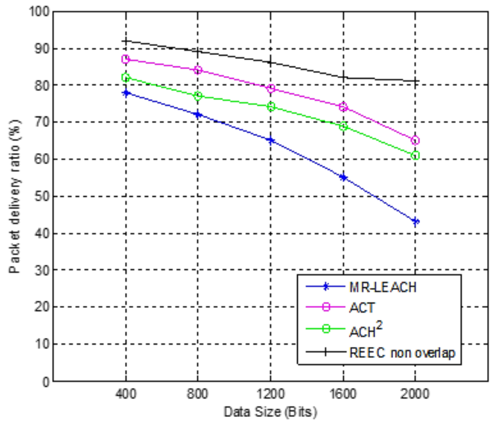

Figure. 4 Delivery ratio at different data size

7.1.3. End-to-End delay

Fig. 3 imparts the average delay for the proposed and existing algorithms. The delay is shown in seconds and it increases since the data size increase from 400 to 2000 bits in all the algorithms. REEC Non-Overlap displays less delivery delay because IERCC is prompt by the scheduling scheme. In Table 5, it is noted that the delay of REEC Non-Overlap is 8.66% less than ACH^2, 16.72% less than ACT and 27.66% less than MR-LEACH.

7.1.4. Packet delivery ratio

Fig. 4 presents the delivery ratio of data packets in the simulation. The proposed algorithm shows a better ratio (in %) than the existing clustering algorithms. Table 5 exemplifies a reduction in ratio

Table 5. Comparison among the Protocols for Non-Overlapping

Metrics	**MR-LEACH**	**ACT**	**ACH^2**	**REEC Non-Overlap**
Energy depletion(J) of Network in Rounds				
500	0.08443	0.06957	0.05864	0.03982
1000	0.20039	0.17924	0.16530	0.14783
1500	0.39421	0.37645	0.35921	0.22574
2000	0.63819	0.60427	0.58945	0.50865
2500	0.87966	0.83715	0.77629	0.68907
% of nodes dead in Rounds (Network Lifetime)				
20	628	1067	1316	1543
40	832	1158	1464	1904
60	1094	1375	1587	2055
80	1219	1656	1795	2228
100	1376	1923	2091	2396
Average delay (s) at different data size (bits)				
400	0.00562	0.00459	0.00341	0.00282
800	0.01302	0.00876	0.00687	0.00474
1200	0.02846	0.01903	0.01595	0.01836
1600	0.04569	0.04312	0.03762	0.03169
2000	0.07457	0.06988	0.06870	0.06345
Packet delivery ratio (%) at different data size (bits)				
400	77	87	82	92
800	73	84	77	89
1200	65	79	74	86
1600	56	74	69	83
2000	43	65	61	82

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when there is a rise in data size. The data packet drops are less in REEC Non-Overlap due to the optimum selection of the NFN method and less number of collisions. The average delivery ratio of REEC Non-Overlap is 86%, 73% in ACH^2, 78% in ACT and 63% in MR-LEACH.

8. Conclusion and Future work

Previous studies elevate to develop a novel method to minimize the clustering overhead and to seamless cluster communications. Hence, a clustering protocol with a multi-hop scenario namely REEC Non-Overlap has been proposed for homogeneous WSN. Clusters are constructed by the center of mass in which trustworthy CHs are selected based on the ratings of SNs and CHs are rotated to attain the even distribution of load in the network. Based on this approach, the clustered network is formed that acquires the least number of rounds. The route for cluster communication is established with a new advent of ETMDRP. In ETMDRP, a multi-hop route for both intra and inter-cluster communication minimizes the energy dissipation of clusters. In the analysis, the mathematical expressions show the computation method of energy utilization of IRACC and NOIERCC for the proposed work. The REEC Non-Overlap has been compared against MR-LEACH, ACT, and ACH^2. Simulation results show that the average energy depletion of the proposed protocol is less by 12%, 9%, and 7% respectively in overall rounds. Also, REEC Non-Overlap lifetime is enhanced through energy efficiency. The method of creating a multi-hop communication in this work eases the energy through intermediate nodes. More importantly, the end-to-end delay and packet delivery ratio of REEC Non-Overlap has improved by avoiding the collisions using the TDMA protocol with ETMDRP. The data arrival at BS in REEC Non-Overlap has also enhanced by 23%, 8%, and 13% respectively.

The further scope of this paper towards developing an overlapping clustering method for minimizing the energy depletion of CHs in IERCC and data delay between CHs.

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