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Improved Fault Tolerance Energy Efficient Cluster Based Routing through Second-Cluster Head

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Abstract: Technology advancements in wireless sensor network (WSN)have attracted much attention and offera wide range of industrial and domestic applications to acquire data from sensors deployed in homogeneous or heterogeneous networks. Sensor nodes are tiny, powered by batteries with limited bandwidth, energy and resources. WSNs are designed to operate in hostile environments without human intervention. Recharge and replacement of node batteries are difficult due to the harsh environment. Node energy is exhausted faster due to continuous sensing, which results in node death. Early node death leads to decrease network lifetime, which affects overall network performance. To tackle energy problem, authors designed hierarchical cluster based routing protocol that balances nodes energy consumption and improves network lifetime. Low energy adaptive clustering hierarchy (LEACH), awell-known clustering technique and variants of LEACH offers energy efficiency by utilizing threshold function to select cluster head (CH).However, LEACH has drawback wherein CH is randomly selected irrespective of energy levels. In this paper, we propose improved fault tolerance and energy efficient cluster based routing through second-cluster head selection (i-FTEECR) by identifying the shortcoming of existing LEACH. In i-FTEECR, second-CH selection is employed to provide fault tolerance for current CH in case of break down between successive rounds. Nodes with high residual energy and distance closer to BS gets chance of being selected as CH and node with next highest residual energy is chosen as second-CH.

Keywords: *Aggregation, clustering, energy efficient, network lifetime and WSN*

1. Introduction

Wireless sensor network (WSN), comprises of tiny low-cost, low-power and smart computing multipurpose wireless sensor nodes that can perform data sensing and wireless communication. Nodes are scattered randomly in a sensing area, nodes configure themselves into wireless network to perform specific task without human intervention [1]. WSN offers wide range of application fields including smart city, industrial automation, smart homes, military and IoT (Internet of things). Nodes collect data from physical environment and forwards collected data to base station (BS) for further process and access over the internet [2-3]. Nodes are restricted to limited memory, bandwidth and energy. Battery is the primary source of energy for sensor nodes and considered as crucial component, it is infeasible to replaced or recharged at regular intervals due to their deployment in harsh environments. Nodes energy consumption is directly proportional to the WSN network lifetime. Therefore, energy dissipation of sensor nodes is important factor to extend network lifetime. To overcome energy issues, designing of optimal routing protocol can play an important role in achieving energy efficiency [4-10]. Several routing approaches have been designed for reliable data communication considering routing metrics. Hierarchical cluster based routing techniques provides optimal solution for energy constrained WSN and solution to optimize improving energy consumption. In cluster based routing scheme, whole network is segmented into smaller clusters, each cluster has cluster head (CH) gathers data from cluster members (CM) aggregate and forward aggregated data to sink or base station (BS) [11-15].Low energy adaptive clustering hierarchy (LEACH) and its variants offers load balancing cluster based routing protocols have proven energy efficient for WSN. However, LEACH still suffers from sharing of workload, random selection of CH without considering energy parameters and direct communication from CH to BS which results in rapid energy depletion. In this paper we propose improved energy efficient cluster based routing through dual cluster head (i-FTEECR). During route discovery i-FTEECR considers position and distance between each node with respect to BS. CH selection is based on energy parameters such as initial energy, residual energy and average network energy. Main contributions are as follows:

- Modification of existing LEACH by defining improved threshold calculation function for optimal CH selection, average energy and distance to BS for network stability improvement.
- Second-CH is picked in case of failure of current CH between two successive rounds in an effort to minimize re-election of CH process during CH failure.
- To reduce routing overhead, i-FTEECR adopts multihop communication.

Structure of this research article is as follows: Introduction is discussed in section I, section II present existing problem and motivation, related literature work is discussed in section III, process of proposed i-FTEECR scheme is presented in section IV, section V presents simulation results and analysis. Finally section VI states conclusion.

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2. Problem Identification and Motivation

Continuous sensing of physical environment causes nodes to deplete energy faster, it is often infeasible to recharge or replace the node battery in most of the WSN applications. Energy efficiency of such network is critical. To improve network lifetime, cluster based routing approaches have proven prominent solution for WSN energy issues. To meet energy efficient requirements, Low energy adaptive clustering hierarchy (LEACH) is considered to be pioneer method, which focuses on grouping of sensor nodes into clusters to prolong network lifetime. Every node in LEACH, have fair probability of being selected as CH randomly and CHs are assigned time slots using time division multiplexing (TDMA) to transfer data towards BS. However, in LEACH there is a chance of low energy nodes being selected as CH which is a drawback. Several LEACH and its extensions were proposed which considers residual energy for CH selection, distance to BS, threshold function for energy calculation and multihop communication model. Proposed schemes had drawbacks of not maintaining network stability, energy load imbalance, unstable CH selection and higher computation overhead. Moreover, nodes positioned in harsh areas are vulnerable to environmental changes and conditions or hardware failure. Faulty CH nodes can disturb the data fusion process resulting network degradation. Therefore, it is necessary to select backup CH whenever the current CH goes down through fault tolerance. This motivates us to propose an improved cluster head selection by modifying existing LEACH for energy efficient routing and backup CH selection if current CH fails.

3. Related Works

In [16], author proposed LEACH protocol that segment whole network into group of clusters and chooses CH from each cluster. Rotation of CH in each cluster is randomized and energy load is evenly distributed among sensors in the network. To achieve robust and scalability, LEACH uses local coordination and incorporates data aggregation techniques to avoid redundant data transmission to BS. LEACH operates in two phase set-up and steady phase, performance results shows LEACH consumes less energy compared to other conventional routing schemes. However, drawback of LEACH is that, it does not considers energy parameters during CH selection, node having low energy is also being chosen as CH which results in early node death. In [17], author proposed optimized dynamic selection of cluster head to improve network lifetime. In this scheme, selection of CH includes three phases: setup, transmission and measurement phase. Nodes energy and mobility is initialized first, the process of CH selection in setup phase is chosen by utilizing rider cat swarm optimization method through determining the optimal threshold value. During CH selection, multi-objective criteria such as distance, energy and delay are considered. After selection of CH, data transmission begins from CH to BS. In measurement phase, the nodes residual energies are update. This scheme has advantages over low network delays and achieves higher throughput however fails to consider cost metrics during routing process. In [18], author proposed optimized routing scheme for cluster based WSN to extend network lifetime. In this routing scheme, optimal CH is chosen by utilizing butterfly optimization algorithm (BOA). During CH selection this scheme considers parameters such as node centrality, distance, residual energy, neighbour distance and node degree. The energy efficient path between CH to BS is identified using ant colony optimization (ACO) through fitness evaluation and node degree. Experimental results show, proposed routing scheme had extended network lifetime compared to existing LEACH and exiting optimization techniques. However, disadvantage of this scheme was higher computation overhead and scalability issues. In [19], author proposed fault tolerance method for cluster based WSN. Main objective of this method is to provide alternate CH during current CH failure in the network. Fault in CH results in more energy consumption wherein sensor nodes or cluster members (CM) continues to transmit data to failed CH. In this method failed CH is determined by reducing the usage of CSMA/CA through fault tolerance. This method has three models such as CH selection, fault detection and recovery model. Initially, three nodes with higher energy are chosen, two nodes are chosen as CH and third node as spare. Two CHs broadcast CH advertisement messages, according to highest and lowest energy levels sensor nodes determine to join cluster .Later lowest CH replays joint response to CH and acts as normal cluster member. Spare node advertises its ID and stays inactive .Functioning CH receives spare node information message and informs to join according to fault detection. Spare node gathers TDMA table from two CHs to detect failure CH and informs to BS about the fault. However, this method does not consider CH selection based on distance to BS, has higher overhead and network delay. In [20],author proposed fault tolerance routing for cluster based WSN, that aims to identify faulty node before their failure. This routing scheme chooses energy efficient paths towards BS addressing Bernoulli's law to select efficient nodes.BS sends the routing information packet to CH that contains hop information and ID. CH on receiving routing packets, it adds source ID with hop counts and rebroadcasts route discovery packet. CH chooses next hop CH with minimum hops for forwarding data. The probability of node failure is detected using energy level condition. After certain time period nodes energy level condition is evaluated, if energy value is higher than predefined value of its initial energy than node is said to be in good condition else declared as fault if its energy value is less than predefined number. Simulation results show significant improvements in achieving network lifetime, higher packet delivery and delay. However, this scheme fails to provide optimal CH selection and has higher computation overhead. In [21], author proposed cluster based fault tolerance routing scheme. Aiming to demonstrate fault tolerant of CH and treats CH as normal node which is prone to faults. K-means technique is utilized for network partition and selection of CH and cluster formation is determined using centroids of respective clusters. Secondary CH is introduced which is in standby mode in every cluster and becomes active whenever the current CH goes down between two successive rounds such that energy consumed for re-selection of CH is minimized and data loss is prevented. Performance analysis shows extended network lifetime and higher packet delivery rate. But, does not consider multihop transmission and has issue with scalability. Summary of discussed related review works focus on the energy aware routing to extend network lifetime and failed to concentrate on fault tolerance and multihop transmission. On the opposite end of the spectrum, in network cluster heads located inside each chromosome are provided to the K-Means method as beginning points to aid a quick clustering process.[22],[23].

4. Proposed i-FTEECR scheme

4.1 System Model

i-FTEECR consists of sensor nodes randomly deployed in 2D plane of sensing area $M \times M$ and nodes are static after deployment. Nodes are assigned with identical energy and hardware circuit. Working of i-FTEECR is divided into rounds as in [16], where CH collects data from cluster members (CM). On receiving data, CH aggregates data and forwards aggregated data to BS. Nodes are aware of their locations and during data transmission i-FTEECR adopts multihop transmission to reach BS through shortest path.

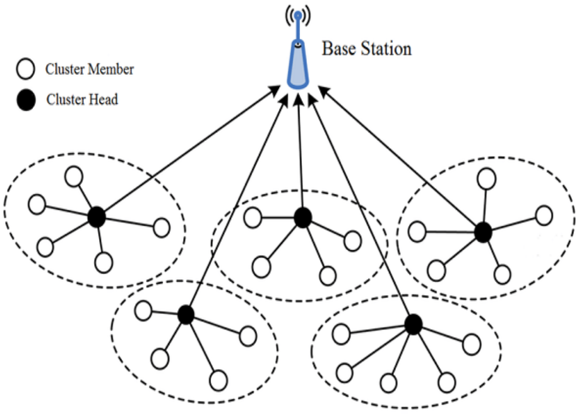

Fig 1. Cluster architecture

Below are the assumptions considered:

- Nodes and BS are stationary after deployment
- Data aggregation at CH is used to compress multiple data and avoids removes redundant data.
- Each node has unique ID and uses localization scheme.
- BS is placed at top of the network and has infinite resource.

4.2 Energy Model

Energy dissipation model of proposed i-FTEECR is according to [16], which adapts both free space (d^2) and multipath propagation model (d^4) considering distance between communicating entities. Free space model is utilised if the sender and receiver distance is less than threshold value d_0, otherwise multipath is utilised if threshold is greater than d_0. Radio energy dissipated by hardware circuit to transmit or receive per bit is given as E_{elec}, radio amplification for free space and multipath model is given as $E_{fs}$and E_{amp} respectively. Energy consumed to transfer l bit message across distance d is expressed as:

$$E_{T_x}(l,d) = \begin{cases} E_{elec} * l + E_{fs} * l * d^2, & d \leq d_0 \\ E_{elec} * l + E_{amp} * l * d^4, & d > d_0 \end{cases}$$

Radio energy expends at receiver to receive l bit is given as:

$$E_{R_x}(l) = l * E_{elec}$$

E_{elec}parameters depends on various factors such as modulation, digital coding and filtering

4.3 Cluster head selection

CH selection in LEACH is based on residual energy and operates in two phases: setup and steady phase, where each node generates random number $r(0 \leq r < 1)$ and node is selected as CH if $r \leq T(n)$ where $T(n)$ is the energy threshold value which is defined as:

$$T(n) = \begin{cases} \dfrac{P_{CH}}{1 - P_{CH} * (i * mod(1/P_{CH}))}, & n \in G \\ 0, & otherwise \end{cases}$$

$P_{CH}$is the ratio of total CH to sensor node which indicates the probability of sensor node becoming cluster head during round 0. G is the set of nodes not being selected as CH in recent $1/P_{CH}$ round, i represents the current round. However, LEACH does not consider distance to BS. In proposed i-FTEECR we modify the threshold function of LEACH in setup phase and calculate distance to BS such that nodes having high residual energy and nearer to BS get priority to be selected as CH. Second-CH is chosen when distance or residual energy is beyond predefined threshold value. For CH selection, improved threshold function considers distance to BS, initial energy and residual energy. CH is selected if the distance of the node is less than or equal to average distance of nodes from BS and is expressed as:

$$TH(n) = \frac{P_{CH1}}{1 - P \times (i \; mod \; \frac{1}{P})} \times \left(t \times \frac{d_{avg}}{d_i} \right) if \; n \in G$$

whereP_{CH1} represents percentage of node being chosen as CH1. Distance between nodes to BS is d_i and the average distance between nodes to BS is d_{avg} and t is the optimum constant value. On the other hand the second-CH is selected if the node distance is more than BS average distance then CH2 is chosen using the below equation.

$$TH(n) = \frac{P_{CH2}}{1 - P \times (i \; mod \; \frac{1}{P})} \times \frac{E_{init}}{E_{resi}} \; if \; n \in G$$

The distance between nodes and BS is represented byd_{to-BS} and distance between nodes (cluster members) to CH is denoted as d_{to-CH}. We determine minimum distance between d_{to-CH} to d_{to-BS} where (x_i, y_i) and (x_{BS}, y_{BS}) are coordinates of i th node and BS, distance is computed as :

$$d_{to-BS} = \sqrt{(x_j - x_{BS})^2 + (y_j - y_{BS})^2}$$

$$d_{to-CH} = \sqrt{(x_j - x_{CH})^2 + (y_j - y_{CH})^2}$$

and

$$d_{optimum} = \min\left(d_{to-BS}, d_{to-CH}\right)$$

$(x_j, y_j)$and(x_{CH}, y_{CH}) are the coordinates of cluster members and CH, $d_{optimum}$ selects the lowest value between d_{to-BS} and d_{to-CH} for cluster members and further updates the threshold value by computing $T(n)$

4.4 Cluster Formation

After CH selection, CH broadcast advertisement (CH-ADV) message which include CH-ID and coordinates to sensor nodes using CSMA. When sensor nodes receives CH-ADV message they generate distance table to CH and sends JOIN reply message to CH with lowest distance based on the received signal strength intensity to form the cluster. CH allocates TDMA schedule to cluster members (CM) based on the size of the CMs

After cluster formation, proposed i-FTEECR continues to search for second-CH among cluster members in each cluster. Next higher energy level node will be selected as second-CH based on the energy threshold value E_{Thresh} and distance threshold D_{Thresh}. If residual energy of CH is less than E_{Thresh} or distance of CH from BS is greater than D_{Thresh} node having highest residual energy will be chosen as second-CH which can perform data aggregation and forwards data to BS through CH. Threshold function to select second-CH is given as :

$$d_{avg} = \frac{1}{n}\sum_{i=1}^{n} d_{to-BS}$$

$$E_{Thresh} = \varphi \times E_{init}$$

$$D_{Thresh} = \Delta \times d_{avg}$$

φandΔ represents energy and distance threshold factors, E_{init} is the initial energy.

4.5 Data transmission

In steady phase, CH gathers data from each cluster members (CM) at different timeslot to avoid data collision. After data gathering, CH performs data aggregation to remove redundant data and compress data using data compressive methods for efficient bandwidth utilization. Aggregated data is transmitted towards BS through optimal path using multihop CH transmissions.

Assuming CH transmits data towards BS through $(n_i - 1)$ hops and the distance is d. Energy consumed through single hop transmission to transmit l bit is expressed as :

$$E_{hop} = E_{T_x}(l, n_i \times \mathrm{d})$$

$$E_{hop} = l \times E_{elec} + l \times E_{fs} \times (n_i d)^2$$

$$E_{hop} = l \times (E_{elec} + E_{fs} \times {n_i}^2 \times d^2$$

For multihop transmission, energy consumed is expressed as:

$$E_{multi-hop} = n_i \times E_{tx}(l, d) + (n_i - 1) \times E_{R_x}(l)$$

$$E_{multi-hop} = n_i \times l \times \left(E_{elec} + E_{fs} d^2\right) + (n_i - 1) \times E_{elec} \times l$$

$$E_{multi-hop} = l \times \{(2n_i - 1)E_{elec} + E_{fs} \times n_i \times d^2\}$$

4.6 Proposed i-FTEECR Algorithm

Start network Initialization
random node deployment (x, y) axis
for each sensor node generate random number $r(0 \le r < 1)$
calculate probability of each node being selected as CH using $TH(n)$
compute distance of nodes to BS using d_{to-BS}
if$d_i \le d_{avg}$
calculate threshold value using node distance and average distance
else
calculate threshold value using nodes residual energy and initial energy
if $r < TH(n)$
select node as CH
broadcast CH-ADV and wait for CM to join
end if
end
initiate second-CH selection among CM
if $E_{CH} < E_{Thresh}$or $D_{CH} > D_{Thresh}$
select node as second-CH and assign data aggregation task
else
data aggregation is done by CH
end if
end

5. Simulation and Performance Analysis

In this section the performance results of proposed i-FTEECR compared with existing RSCO [17] and FEHCA [21] scheme is discussed. Proposed scheme is evaluated using performance metrics namely network lifetime, residual energy, packet delivered at BS and energy consumption. Network lifetime is the key performance metric measured which is defined as the time duration between start of the network operation and the last node death and network reliability. Stability period is number of completed rounds before the death of first node in the network.

5.1 Simulation environment setup

Simulation experiments are carried on network simulator tool (NS2) which is an event driven simulator. The network comprises of 100 nodes deployed in network of 300x300 mts and nodes are homogeneous. BS is placed at top of sensor node deployment and has infinite energy and resources. Table 1 shows the detailed simulation parameters used.

Table 1. Simulation parameters used

Parameters	Value
No of Nodes	100
Memory size	50
MAC Contention	802.11
Simulation run time	100 sec
Deployment Area	300 x 300 mts
Message length	512-bytes
Communication-range	250-mts
Protocols Compared	RSCO and FEHCA
Traffic-Connections	CBR
Initial-Energy	2J
Data Aggregation Energy	5nJ
E_{elec}	50nJ
$E_{fs}$and E_{amp}	10pJ and 0.013pJ
Optimal Probability t	1
BS	1
Rounds	50
E_{Thresh} and D_{Thresh}	0.25 and 0.5
φ and Δ	0 and 9999

5.2 Network Lifetime

Figure 2 shows the network lifetime of proposed i-FTEECR compared with RSCO and FEHCA. It is observed from the graph the first node of i-FTEECR dies at 38rounds compared to FEHCA at 25 rounds and RSCO at 22rounds respectively. i-FTEECR has prolonged network lifetime compared to FEHCA and RSCO this is due to proper energy balance among node and selection of CH based on distance to BS. However, other scheme does not consider distance to BS and mainly concentrates on cluster centroids. If $E_{CH} < E_{Thresh}$ second-CH which has high residual energy can also perform data aggregation.

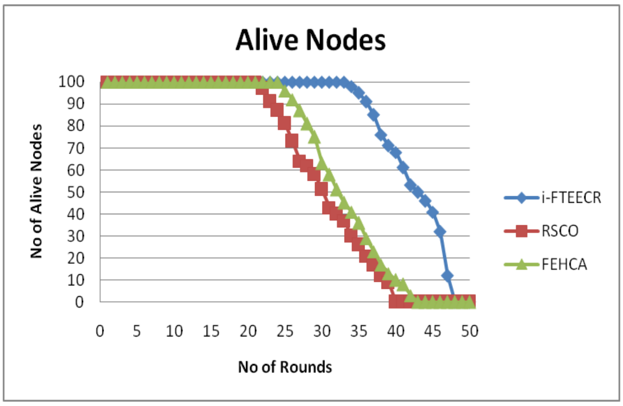

Fig 2. No of alive nodes vs No of Rounds

5.3 Residual Energy

The effect of residual energy is shown in the Figure 3, illustrates the decrease in residual energy as number of rounds increases. However, proposed i-FTEECR exhibits slower decrease of energy as number of rounds is increased. It is observed from the graph, all nodes are dead after 40rounds in RSCO, 45 round in FEHCA compared to 50 rounds in i-FTEECR. i-FTEECR considers improved threshold function to select CH, such that the distance is lesser than average distance of sensor node to BS. If CH energy is lower than E_{Thresh} or CH to BS distance is more than D_{Thresh} next node with high residual energy will be chosen as second-CH which can perform data aggregation and forwards data to BS. Therefore, this strategy can effectively reduces energy consumption and extends network lifetime.

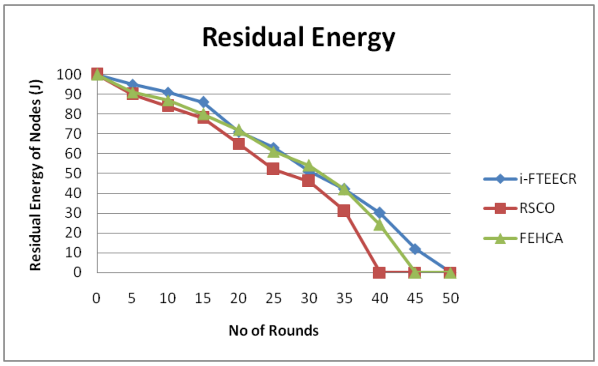

Fig 3. Residual Energy vs No of Rounds

5.4 Amount of Data Delivered

The amount of data delivered at BS is determined by number of alive nodes in the network. After data aggregation, the optimal and energy efficient path towards base station is selected by considering d_{avg} and $d_{optimum}$ such that CH is selected if the distance of the node is less than or equal to average distance of nodes from BS. Figure 4 shows the percentage of packets delivered at BS. It is observed from the graph, packets delivered at BS is higher in proposed i-FTEECR compared to RSCO and FEHCA. If current CH fails, second-CH completes the task of delivering packets to BS such that packet retransmission is avoided. However, existing scheme has higher retransmissions of lost packet which consumes more energy.

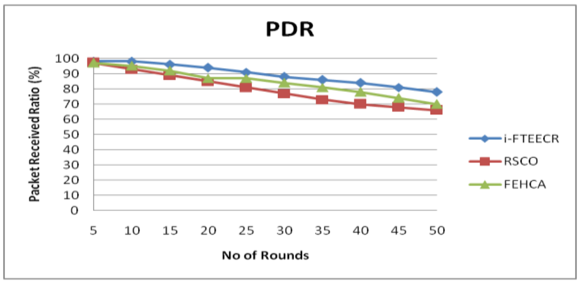

Fig 4. Packet delivery Ratio vs No of Rounds

5.5 Energy Consumption

Figure 5 shows the performance of energy consumption of proposed i-FTEECR compared with RSCO and FEHCA under same simulation conditions. The energy consumption increases as the number of rounds is increased. To optimize CH selection CH, i-FTEECR employs improved threshold function that considers function considers distance to BS, initial energy and residual energy. CH is selected if the distance of the node is less than or equal to average distance of nodes from BS. However, existing RSCO and FEHCA considers CH selection based on residual energy and centroids. Thus, energy consumption of proposed i-FTEECR is less than RSCO and FEHCA.

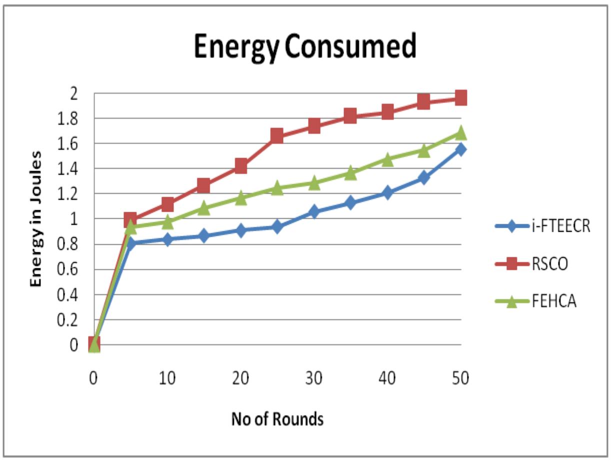

Fig 5. Energy Consumptionvs No of Rounds

6. Conclusion

For any WSN, energy consumption is the major issue since nodes are battery operated with limited energy. To acquire maximum network lifetime hierarchal cluster based routing have proven better energy efficiency. In cluster based routing energy is consumed whenever communication between CH and BS is established. Due to imbalance energy consumption CH may die after certain rounds resulting in packet loss and more energy consumption for reselection of CH. To overcome this issue we propose an improved energy efficient cluster based routing through dual cluster head (i-FTEECR). During route discovery i-FTEECR considers position and distance of each node with respect to BS. CH selection is based on energy parameters such as initial energy, residual energy and average network energy. Presence of second-CH provides backup, if current CH goes down and also performs data aggregation.i-FTEECR ensures balanced energy utilization and employs multihop communication for reliable data transmission. Simulation results shows i-FTEECR outperforms in terms of energy consumption, residual energy and packet delivery ratio compared with RSCO and FEHCA. In particular i-FTEECR extends network lifetime by 36% compared to RSCO and 23% to FEHCA. In future, machine learning methods can be utilized for better energy calculation for large scale WSN.

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