INTRA-CLUSTER ROUTING WITH BACK-UP PATH IN SENSOR NETWORKS

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ABSTRACT

The novel applications of sensor networks impose some requirements in wireless sensor network design. With the energy efficiency and lifetime awareness, the throughput and network delay also required to support emerging applications of sensor networks. In this paper, we propose throughput and network delay aware intra-cluster routing protocol. We introduce the back-up links in the intra-cluster communication path. The link throughput, communication delay, packet loss ratio, interference, residual energy and node distance are the considered factors in finding efficient path of data communication among the sensor nodes within the cluster. The simulation result shows the higher throughput and lower average packet delay rate for the proposed routing protocol than the existing benchmarks. The proposed routing protocol also shows energy efficiency and lifetime awareness with better connectivity rate.

KEYWORDS

Intra-cluster routing; payoff function; wireless sensor network; throughput and energy- aware; back-up path.

1. INTRODUCTION

Wireless sensor network (WSN) is the connection among the tiny mobile or stationary sensor nodes so that they can share data wirelessly [6][18-19]. The use of sensor networks growing rapidly from healthcare to ocean bed monitoring, and from smart home to space shuttle. The innovative applications of sensor networks impose novel challenges on its protocol design. The energy efficiency, lifetime awareness, energy balancing, network throughput and delay minimization, antenna design and sensor miniaturization are the existing research challenges of sensor network design [9].

Clustering is a proven technique to ensure energy efficient communication. Most of the cluster based sensor network research handles the issue of inter-cluster routing and very few of them consider network throughput and network delay of their proposal. Currently, huge network traffic is generated by the sensors and devices of internet of things (IoT) [7][20], smart home and smart grid networks [10-13]. The throughput and delay must be considered for efficient management and control of this type of sensor enabled network.

In this paper, the intra-cluster routing protocol is proposed to ensure reliable data transmission through introducing back-up link in the communication path. Intra-cluster routing is the process

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to find out the efficient path to forward network traffic (or data) towards the cluster head within the cluster. We consider the link throughput, delay, packet loss ratio, interference, residual energy [14-17] and node distance to select the links and corresponding sensor node to establish path of the intra-cluster communication. We also use the penalty functions, which helps the sensor nodes not to select the path with lower than the required or expected throughput and delay. And thus in contrast of conventional cost model, we use the payoff function in determining intra-cluster communication path as Midha Surabhi et al. [8] used the payoff function in their game theoretic model.

2. LITERATURE REVIEW AND RELATED WORKS

Routing is the process of selecting best paths in a network. Routing strategy may design without constructing or considering any clusters. Most of the routing algorithms in wired network like Dijkstra's single source shortest path algorithm were developed without considering any clusters. Some of the routing policy like [21] developed a routing algorithm following no-clustering strategy. Intra-cluster routing is the process to find out the efficient path to forward data towards the cluster head within the cluster. Reference [5] proposed a method of intra-cluster routing.

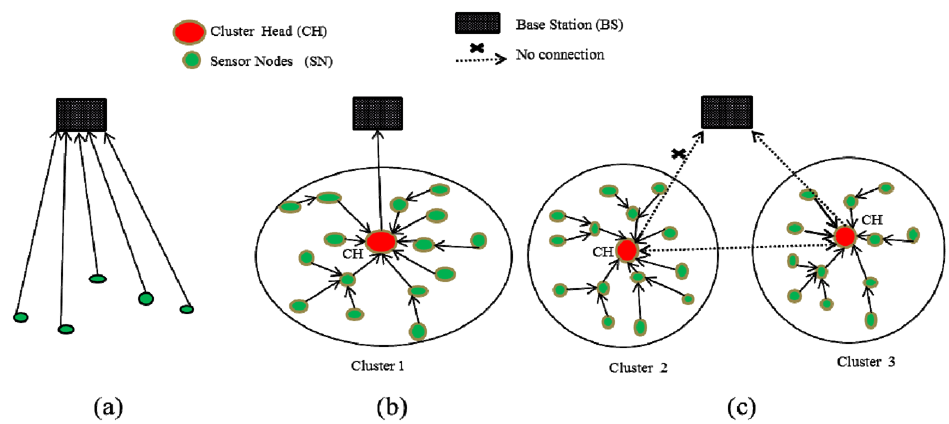


Figure 1: Different routing strategies (a) No Clustering (b) Intra-cluster routing (c) Inter-cluster routing

Inter-cluster routing is the process to find out the efficient path to forward data towards the base station (BS) following cluster to cluster communication. So, inter-cluster routing protocol deals with efficient communication among the clusters. Reference [22] proposed a method of inter-cluster routing. Different routing strategies are shown in Figure 1.

Clustering can be formed using different levels of sensor nodes in perspective of cluster head. If the entire sensor node transmits data directly to the cluster head then this type of clustering is called 1-level clustering. If the sensor nodes of a cluster transmits data to the cluster head through relay of maximum two hop then this type of clustering is called 2-level clustering, Finally, If the sensor nodes of a cluster transmits data to the cluster head through relay of more than two hop then this type of clustering is called N-level clustering. Different levels of clustering in a cluster are shown in Figure 2. In this paper, we consider 2-level clustering for our proposal.

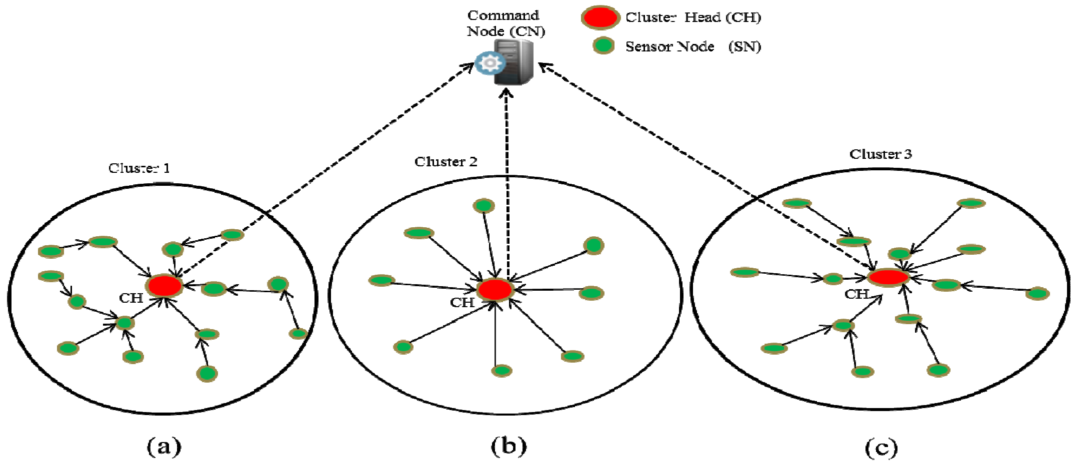


Figure 2: Different level of clustering (a) N- Level Clustering (b) 1-Level Clustering (c) 2-Level Clustering

Some of the protocols are based on hierarchical network structure and some are based on flat network structure, some are QoS based and some are negotiation based. However, the energy efficiency, lifetime awareness, security and network throughputs are the main design goals of WSN routing protocols. A multiple alternating path based on-demand routing protocol is proposed for ad hoc networks, which is an extension of AODV routing protocol [1]. The authors' explored multiple path of data transmission for higher throughput with energy efficiency. This proposal is not based on any clustering mechanism and thus hard to manage the sensor networks in densely deployed environment.

The energy efficient and dual-path routing protocol is proposed in [2], to handle the temporary failure of sensor node after cluster head died in cluster-based WSN. Here, the authors mainly focus on inter cluster routing and try to handle the exception of CH failing. Cluster-based multi-path routing for multi-hop wireless networks is proposed in [3]. The authors' also focused on inter-cluster routing with multiple paths to enhance network throughput. It allows only one path to go over a cluster to reduce interference among two parallel paths. Maintaining routing table for multiple paths causes' higher energy consumption in resource constrained sensor networks. Whereas in our proposed routing protocol we introduce backup links to enhance network throughput in an intra-cluster communication environment.

A proactive routing protocol i.e. Energy Adaptive Clustering Hierarchy (LEACH) is proposed in [4], where a cluster is formed according to the communication range and cluster head is selected by the base station (BS) in a uniform random distributed manner. It is the seminal paper, which shows the way to develop energy efficient WSN through clustering. It is proactive routing protocol, where the node in the network periodically sends data towards CH by following predefined schedule. Easiness of cluster formation and sensor network configuration is one of the best criteria of LEACH protocol. Multi-path or back-up path is not considered in LEACH protocol and thus lower network throughput, higher packet loss and retransmission rate diminish the gain of energy efficiency.

The energy-aware routing in cluster-based sensor networks (EARCBSN) is proposed in [5]. In the proposed method, the authors' assigns a centralized network manager or gateway node to manage intra-cluster communication efficiently. The gateway node sets the route mainly based on energy usage, distance, propagation delay, queuing cost and maximum connections per relay. The authors' show the higher throughput and energy efficiency of their proposed routing scheme through simulation. In contrast, we proposed a reactive intra-cluster routing protocol based on payoff function with the back-up links for energy efficiency, lifetime awareness and higher network throughput.

3. Proposed Methods

The system model of intra-cluster routing protocol is presented in Figure 3, where we consider non-hierarchical or flat routing topology. The command node (CN) is the control unit of wireless sensor network management. As the CN is a high powered node with permanent electricity supply and having the back-haul communication link with the core network, the CN is responsible for routing table construction and distribution to each of cluster, and also propagate the collected sensor information towards the high end control center. The sensor nodes are deployed in random pattern to collect environmental data. The clusters of sensors nodes are dynamic in nature having a cluster head (CH), which is responsible for gathering environmental data from sensor nodes (SN) within its territory and then transfer the collected data towards the CN directly. The cluster heads are also dynamically changed in each and every round of data transmission. The cluster formation, route determination and data accumulation phases of our proposed intra-cluster routing protocol are discussed in following subsections.

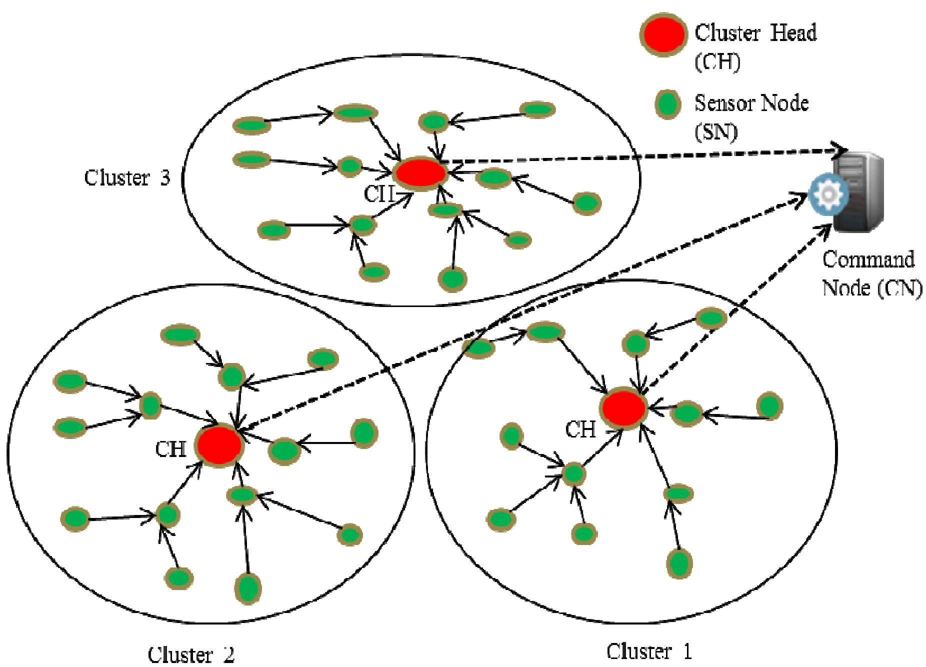


Figure 3. System model of intra-cluster routing protocol.

3.1 Cluster Formation

The cluster of sensor nodes is formed on the basis of nodes within the radio range. Some of the sensor nodes of a cluster can directly send data to the cluster head and some other node uses the relay node to send data to cluster head through multi-hop communication. For efficient communication purpose, the command node (CN) selects the cluster heads (CH) for each and every round of data transmission. The CN selects CH following uniform distribution so that each and every node becomes cluster head by turn. After receiving commands from CN, the CH broadcast his headship status to the sensor network and expecting membership request from normal sensor nodes (SNs). The SNs send the membership request with their positional and energy level information to the nearest CH. After receiving membership request with necessary information the CH determines the throughput, delay, SINR, packet loss ratio of the communication link between each SN and CH. The CH then sends that information to the CN for efficient routing table construction as we discussed in section 3.2.

The CN node then sends the routing table to CH. Finally, CH sends the routing information i.e. next hop node; back-up next-hop node and acting node status to each member SNs. CH also sends the soft and hard threshold to each of its member SNs for energy efficient data transmission. The cluster formation procedure is presented in algorithm 1 as intra-cluster routing procedure.

Algorithm 1: Intra-Cluster_Routing ()

1. Command node (CN) selects the cluster heads (CH) randomly to form clusters.
2. CH broadcast advertisement to the sensor network.
3. Sensor nodes (SN) transmit membership request to CH node with their position in cluster and energy level.
4. CH sends all sensor nodes position, energy level, throughput, delay, SINR, packet loss ratio to CN.
5. CN construct the routing table according to Algorithm 2 and sends the routing table to CH.
6. CH sends following information to all member nodes: the next-hop node, back-up next-hop node and state of the node with soft and hard threshold values.
7. Member sensor nodes act according to the defined state and sends data to CH based on the routing table.
8. CH compress the data and sends to the command

3.2 Routing Table Construction

The CN is responsible for efficient routing table construction based on the metrics supplied by the CH regarding the member SNs of its cluster. To construct the route of intra-cluster data dissemination, the CN uses the Greedy method to find out the best hop-by-hop data dissemination path by determining the best next-hop node of each of the member SNs. However, CN also finds the alternative next-hop node for reliable data transmission with higher throughput and lower packet loss. Among the adjacent nodes of any SN the best next-hop node and next-hop alternative nodes are determined according to the link suitability value of equation (1). We presented the procedure of routing table construction in algorithm 2.

Algorithm 2: Routing_Table_Construction ()

1. Find the list of sensor nodes $\{d_1, d_2, \ldots d_m\}$, which are within 1-hop communication range from cluster head
2. For each sensor node N of the cluster C
3. Find the neighbouring sensor nodes $\{s_1, s_2, \ldots s_n\}$ of node N
4. Determine the feasible set of relay nodes by finding common nodes between the list of sensor nodes within 1-hop communication range from cluster head and the neighbouring sensor nodes of node N i.e. $\{a_1, a_2, \ldots a_k\} = \{d_1, d_2, \ldots d_m\} \cap \{s_1, s_2, \ldots s_n\}$
5. Determine the link suitability values $\{L_{N,a1}, L_{N,a2}, \ldots, L_{N,ak}\}$ from node N to each of the neighbouring sensor nodes $\{a_1, a_2, \ldots a_k\}$ using equation (1).
6. Find the sensor node a_i with maximum link suitability values $L_{max1} = max\{L_{N,a1}, L_{N,a2}, \ldots, L_{N,ak}\}$ and set the node a_i as the next hop node of N to construct the routing table for node N.

7. Find the sensor node a_j with maximum (i.e. second highest) link values $L_{max2}= max\{ \{L_{N,a1}, L_{N,a2}, \ldots , L_{N,ak}\} \setminus \{L_{N,ai}\} \}$ and set the node a_j as the back-up next hop node of N to construct the routing table for node N.
8. Define the state of the node N from the set of states' S={sensing, aggregating, active, relaying, inactive} sequentially following random distribution to construct the routing table for node N.

The link suitability value $L_{i,j}$ or payoff function is determined through equation (1), where i is any SN and j's are the adjacent sensor nodes of node i.

$$L_{i,j} = \alpha_1 * \frac{T_{obs}}{T_{req}} + \alpha_2 * \frac{R_{avg}}{R_{obs}} + \alpha_3 * \frac{PL_{tol}}{PL_{obs}} + \alpha_4 * \frac{SINR_{obs}}{SINR_{std}} + \alpha_5 * \frac{E_{res}}{E_{ini}} + \alpha_6 * \frac{D_{nr}}{D_{rg}} - T_{pnlt} - R_{pnlt} - PL_{pnlt} - SINR_{pnlt} - E_{pnlt} - D_{pnlt} - S_{pnlt} \quad (1)$$

Here, the link suitability value is determined through the payoff function, where not only the benefit factors but also the penalty or cost factors are considered. The considered factor are the distance between source and relay node, energy level of the node, throughput, delay, SINR and packet loss ratio of communication link. The penalty functions are formulated as in equation (2) through (7).

$$T_{pnlt} = \begin{cases} \frac{T_{req}}{T_{obs}} * \beta_1 \ ; \ if \ T_{obs} < T_{req} \\ 0 \qquad ; \ Otherwise \end{cases} \quad (2)$$

$$R_{pnlt} = \begin{cases} \frac{R_{obs}}{R_{avg}} * \beta_2 \ ; \ if \ R_{obs} > R_{avg} \\ 0 \qquad ; \ Otherwise \end{cases} \quad (3)$$

$$PL_{pnlt} = \begin{cases} \frac{PL_{obs}}{PL_{tol}} * \beta_3 \ ; \ if \ PL_{obs} > PL_{tol} \\ 0 \qquad ; \ Otherwise \end{cases} \quad (4)$$

$$SINR_{pnlt} = \begin{cases} \frac{SINR_{std}}{SINR_{obs}} * \beta_4 \ ; \ if \ SINR_{obs} < SINR_{std} \\ 0 \qquad ; \ Otherwise \end{cases} \quad (5)$$

$$E_{pnlt} = \begin{cases} \frac{E_{ini}}{E_{res}} * \beta_5 \ ; \ if \ \frac{E_{res}}{E_{ini}} < E_{thrs} \\ 0 \qquad ; \ Otherwise \end{cases} \quad (6)$$

$$D_{pnlt} = \begin{cases} \frac{D_{rg}}{D_{nr}} * \beta_6 \ ; \ if D_{nr} \gg Tr_{avg} \\ 0 \qquad ; \ Otherwise \end{cases} \quad (7)$$

Table 1. Used symbols and their description

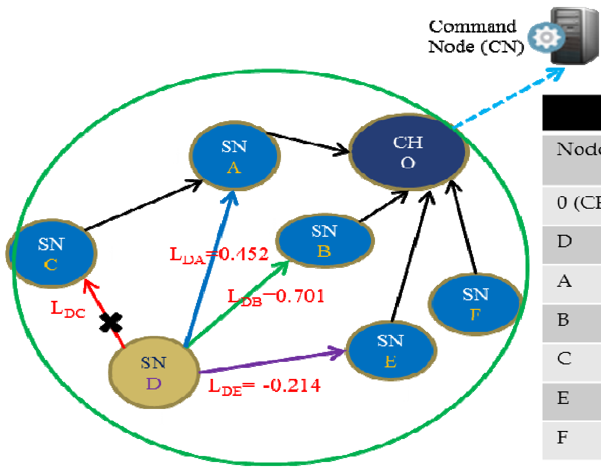
Symbol	*Description*
$L_{i,j}$	Link's suitability value of link between node *i* and *j*
T_{obs}	Observed Throughput
T_{req}	Required Throughput
T_{pnlt}	Penalty for not fulfilling the Throughput requirement
R_{obs}	Observed Response time
R_{avg}	Average response time (standard)
R_{pnlt}	Penalty for not fulfilling the Response time requirement
PL_{obs}	Observed Packet Loss ratio
PL_{avg}	Tolerable Packet Loss ratio
PL_{pnlt}	Penalty for higher packet loss than the tolerable range
$SINR_{obs}$	Observed Signal_to_Interference Noise Ratio
$SINR_{std}$	Standard Signal_to_Interference Noise Ratio
$SINR_{pnlt}$	Penalty for higher Noise in signals
E_{ini}	Initial Energy of a sensor node j
E_{res}	Residual energy of the sensor node j
E_{pnlt}	Penalty of selection of a node which has lower residual energy than a threshold energy (E_{thrs})
D_{nr}	Distance from node to relay
D_{rg}	Distance from relay to gateway
D_{pnlt}	Penalty for selecting a node which is very far from the node i ; that is, distance is more than the average transmission range (Tr_{avg})
S_{pnlt}	State switching (changing) cost
$\alpha_1, \alpha_2, ..., \alpha_6$	Weighting factors of link's gain
$\beta_1, \beta_2, ..., \beta_6$	Weighting factors of link's penalty

The symbol used in equation (1) through (9) is explained in table 1. The summations of weighting factors are considered as 1, which formulated as in (8) and (9).

$$\alpha_1 + \alpha_2 + \cdots + \alpha_6 = 1 \tag{8}$$

$$\beta_1 + \beta_2 + \cdots + \beta_6 = 1 \tag{9}$$

For example, to construct the routing table for node D, the CN node calculate the link suitability values {$L_{D,C}$; $L_{D,A}$; $L_{D,B}$; $L_{D,E}$} from node D to its 1 hop neighbouring node {C, A,B,E}. According to equation (1) through (9) and the measured values of table 1, we found the link suitability values of links as {$L_{D,C}$=0.374; $L_{D,A}$=0.452; $L_{D,B}$=0.701; $L_{D,E}$=-0.214}. Among the link suitability values the highest and second highest values are $L_{D,B}$=0.701 and $L_{D,A}$=0.452. So, we set node B as the next hop node for D and we set node A as the next hop alternative node of node D, as shown in figure 4. Using algorithm 2, we can construct the full routing table as shown in figure 4. Link L_{DC} cannot determine as a back-up path because the SN_C have already 2-level path.



Routing Table			
Node	Next Hop	Next Hop Alternative	Node State
0 (CH)	0	0	active
D	B	A	active
A	0	…	aggregate
B	0	…	relay
C	A	D	sensing
E	B	A	inactive
F	B	E	sensing

Figure 4. Routing table construction of an example cluster.

Defining states of different node is a practice in sensor networks for energy efficient communication. We consider five different states of sensor nodes for ensuring energy efficiency and the states are sensing, aggregating, active, relaying, and inactive state. Firstly, we define the states of sensor nodes following uniform distribution. Secondly, we maintain the sequential pattern of changing states as sensing → aggregating→ active → relaying→ inactive state. The CH remains active throughout the data communication in a single round. In sensing state, the sensing circuitry of a node remains on and it temporarily stream the sensed data to its buffer. In aggregating state, the sensing and relaying circuits of the node are off and it compares its streamed data with hard and soft threshold, compresses the data and then sends those data towards the gateway in next round when it becomes active. In relaying state, only the communication circuitry remains on to relay the data from other active nodes. In active state, the sensor node can transmit data; it also can sense, aggregate and relay data. Thus the cluster head must be an active node. In inactive state, the node turns off its sensing and communication circuitry and it again becomes alive after predefined waiting time.

4. Simulation

4.1 Experimental Configuration

The performance of the proposed intra-cluster routing approach studied through simulation using a calculation tool. We studied the energy dissipation, lifetime awareness, throughput, average packet delay and connectivity rate to validate our proposed routing algorithm. We also compare our results with the benchmark routing protocol LEACH. However, we studied the performance of EARCBSN and compare the achieved results with our proposed method for the justification of improved performance. The LEACH is just 1-level routing and the EARCBSN is 2-level routing without back-up path.

The simulation scenario is presented in figure 5, where the blue cross mark represents the command nodes position, the black circles are represented as sensor nodes (SNs) and the red circles are represented as the cluster heads (CHs). There are total 200 nodes deployed in 100x100 square meters of area. Total 11% of the sensor nodes are selected as the CH for each round. The simulation parameters and their assumed values are presented in table 2.

Table 2. Simulation parameters and values for performance study

Simulation Parameters	Symbols	Values
Topology	---	2D and flat
Number of nodes	N	200
Simulation Area	W x H	100 x100 square meters
Packet size	b	512 bits
Total number of rounds	R	4500
Transmitter circuitry energy per bit	ETx_circuit	50 nJ/bit
Transmitter amplification energy per bit per square meter	ETx_amplifier	100 pJ/bit/m2
Receiver circuitry energy per bit	ERx_circuit	50 nJ/bit
Sensing energy per bit	ERx_sensing	50 nJ/bit
Initial energy of each node	E_o	1 joule
Aggregating energy per bit	Epx_aggregation	4.3x10^-3 nanojoules/bit
Channel bandwidth	B	5 Mbps
Round equivalent time in millisecond	T	20 ms

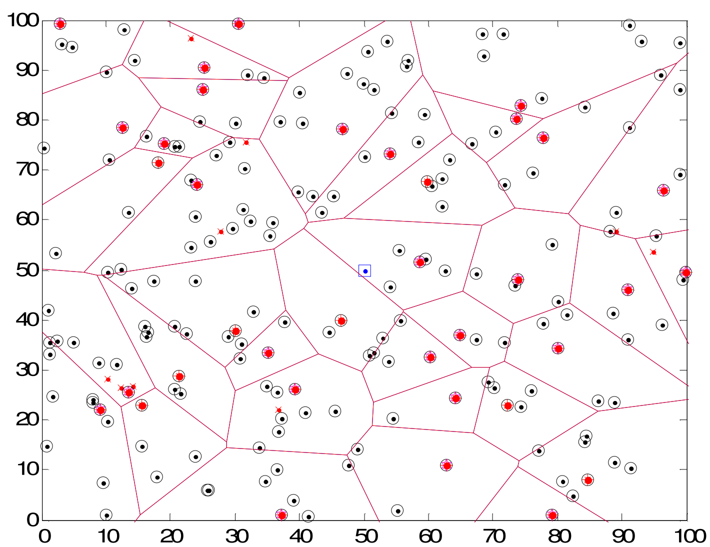


Figure 5: Simulation environment, considering 200 nodes in 100x100 meters

4.2 Experimental Results

Energy efficiency is the first consideration in wireless sensor networks protocol design. The cumulative energy consumption rate in different rounds of data transmission is determined through simulation study. Figure 6 shows that the energy consumption of LEACH protocol is highest because of the hierarchical and proactive nature of LEACH and also all nodes remain alive in all time. The energy consumption of EARCBSN is also higher than the proposed intra-cluster routing protocol because additional retransmission of packets in case of link failure. The deployment of back-up link and introduction of aggregating state turns the proposed routing method as energy efficient than the existing benchmarks.

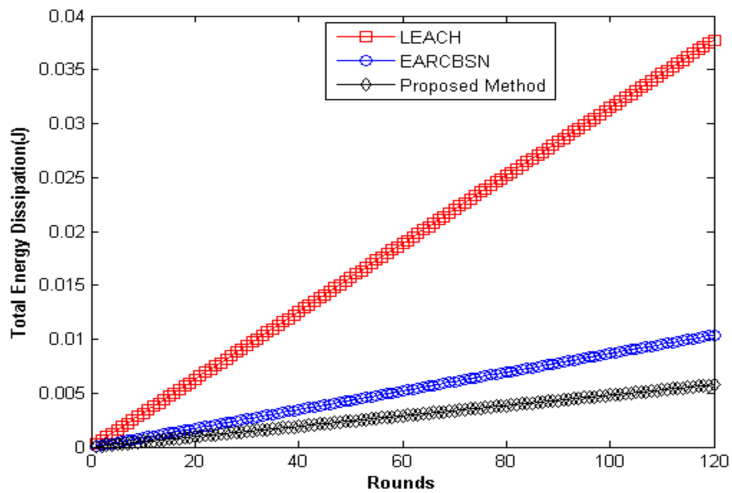


Figure 6: Cumulative Energy Consumptions of Different Routing Protocols

Lifetime awareness is another important metric to measure the performance of wireless sensor network protocol. The protocol with greater lifetime can transmit data in longer time. Figure 7 and 8 shows the lifetime awareness of the studied routing protocol. Figure 7 shows that, in case of LEACH and EARCBSN first node dies at 935th and 1141st round respectively, on the other hand, in case of our proposed approach the first node dies at 1283th round. Earlier collapsing of node makes the network paralyzed.

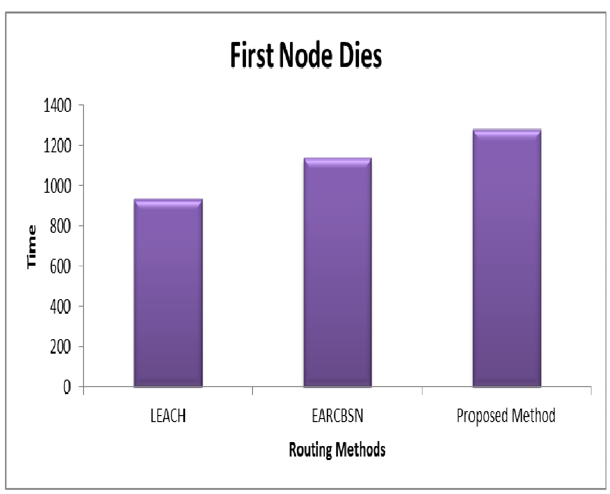


Figure 7: Network partitioning in different routing protocols

The quicker collapsing of nodes guides the sensor networks in an unstable state. Figure 8 shows that, in case of our proposed intra-cluster routing protocol, the network remains alive up to 3956th rounds whereas the LEACH and EARCBSN remains active up to 1308th and 2377nd rounds respectively. The controlled reactive nature of our proposed protocol helps the sensor networks to remain alive in longer time. The balancing of energy consumption of different nodes is controlled by assigning states of nodes in uniform manner. The use of hard and soft threshold also plays vital role in lifetime awareness of our proposed method.

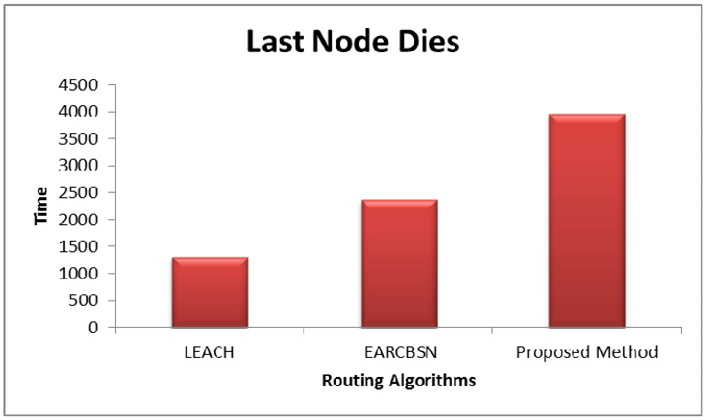


Figure 8. Lifetime of different benchmarked routing protocols

Figure 9 shows the throughput of different routing protocols in different rounds. We analysed the throughput considering the link capacity of 5 Mbps. The hierarchical structure of LEACH hinders the throughputs of LEACH protocol. The higher packet loss and retransmission issue hinders the throughput of EARCBSN. The flat routing topology and the backup links of the proposed routing method increase the network throughput.

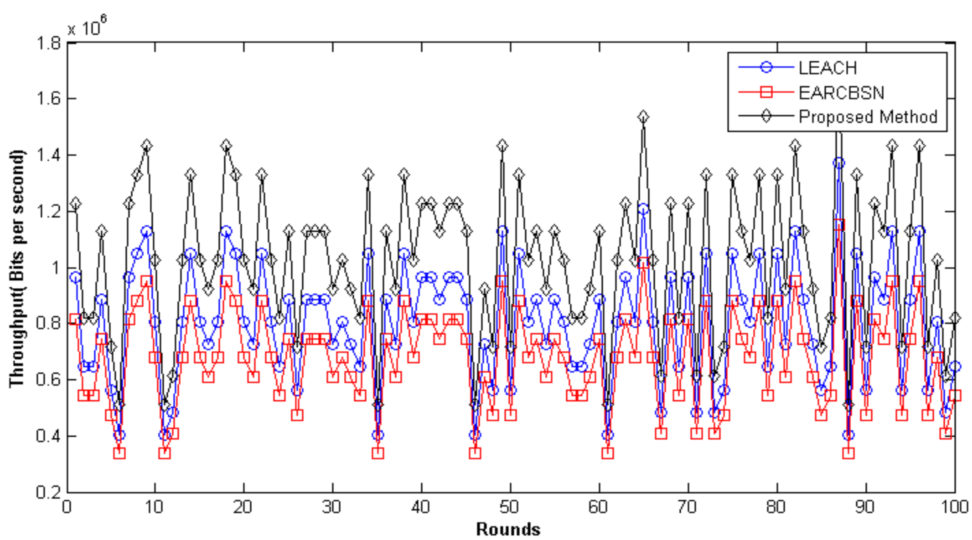


Figure 9. Communication throughput of different routing algorithms

The average delay of per packet data transmission is studied and presented in figure 10. The LEACH used hierarchical clustering architecture (i.e. cluster head level 1, cluster head level 2 etc.), whereas we use flat clustering architecture (i.e. each cluster head is directly connected to command node). For that reason the sensor node can send data directly to command node with lower delay. In the proposed method, we have back-up path to transmit data, so less packet drops are happening in this case, whereas there is no back-up path in LEACH and EARCBSN, so more packet drops are happening, as a result more retransmission is required in case of LEACH and EARCBSN and thus proposed method experiences lower average packet delay than the existing LEACH and EARCBSN.

We also studied the connectivity rate of different routing protocols in figure 11. The connectivity rate is the ratio of number of connected nodes with CH and total number of living nodes on the network. Dis-connectivity may occur due to interference, hidden nodes, signal obstacles and inactive nodes and out of transmission range. As the proposed routing protocol allows some node to be in inactive state, the connectivity rate goes down up to 68.75%. The lowest connectivity rate of LEACH and EARCBSN is higher than the proposed method, but the networks of LEACH and EARCBSN goes down rapidly due to higher energy dissipation. With the cost of connectivity rate the proposed intra-cluster routing algorithm gain energy efficiency and longer lifetime.

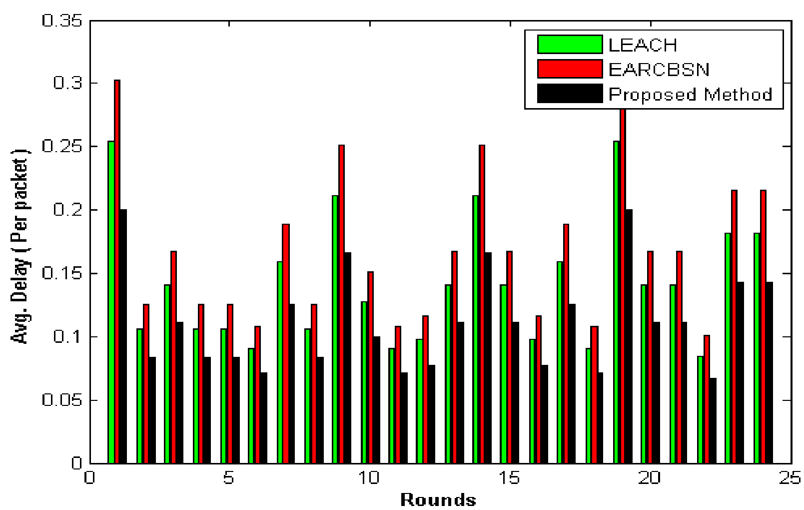


Figure 10. Average delay of different routing protocols

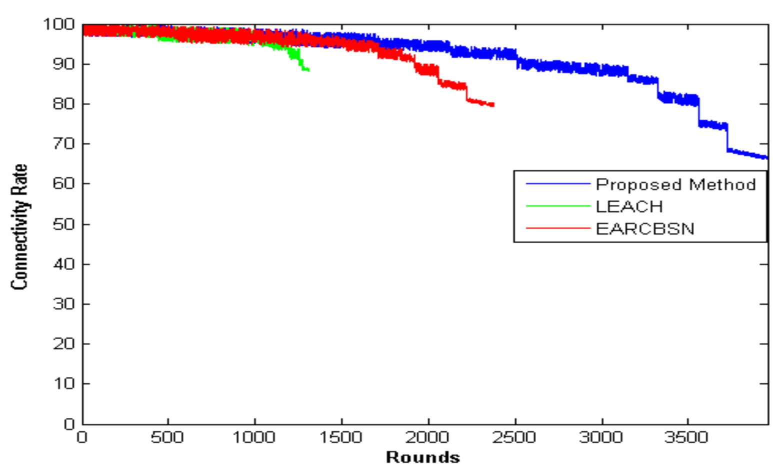


Figure 11. Connectivity rate different routing protocols in different rounds of data transmission

5. CONCLUSIONS

The intra-cluster routing protocol with back-up path is proposed in this research. The simulation results show the energy efficiency and longer lifetime of sensor networks. Although the proposed routing protocol shows lower average connectivity rate, but the back-up path, payoff function and different states of sensor node helps to deliver packets with higher throughput and lower rate of average packet transmission delay. In this proposal, we introduce a new method of link value determination, based on the maximum link value we select links for determining the next hop node of a source node and also determine the next hop alternative to enhance the reliability of sensor networks data communication. We studied energy dissipation, network lifetime, throughput and average delay and compare those with existing EARCBSN method. We found that the proposed method outperforms over the EARCBSN method. We will apply some machine learning and game theoretic approach to design the payoff function, which may enhance the performance of our proposed routing approach.

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