Routing Hole Mitigation by Edge based Multi-Hop Cluster-based Routing Protocol in Wireless Sensor Network

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Summary
In Wireless sensor network (WSNs) due to the harsh environments the degradation of energy is major issue. For addressing this issue, clustering techniques equalize energy utilization by distributing the workload among different clusters but energy-unaware path selection in multi-hop clustering technique leads to routing hole problem. To reduce the routing hole problem in WSNs, an energy-efficient least-edge computation (ELEC) cluster-based algorithm is proposed, which consider the value of edge count, link cost and energy level in selecting the next hope neighbor in data transmission. Results of our simulation reveal that ELEC achieves nearly double network lifetime by equal energy consumption in various parts of the network in addition just 5% energy left unused, as compared to existing routing strategies such as LEACH, GRACE, and AODV-EHA. Furthermore the percentage of node failure is half of the other existing routing strategies and 60% of packet drop noticeable decrease is noticed in ELEC as compared to GRACE, LEACH, and AODV-EHA.

Key words:
Wireless sensor network; Multi-hop clustering; routing hole problem; Energy-efficient clustering protocol

1. Introduction

Energy efficiency is a core issue in sensor networks because of dangerous environments that prevent recharging or changing of sensor node batteries in the networks. Thus, the development of processing techniques that can enhance energy efficiency and reduce power requirements across networks is an urgent concern. Balancing the energy consumption of transmission is crucial because transmission costs more than processing. With the routing protocols tasked to direct data from source to sink, significant efforts are being directed toward the design of novel [1-6] routing techniques and protocols to balance the energy consumption of the communication process.
The routing hole problem [7] is a primary concern in current routing protocols because of several shortcomings, including lack of coverage, random deployment, and ineffective routing techniques. Clustering methods equalize energy consumption by removing redundancy via aggregation and distributing the workload among different clusters. Cluster networks generally use single-hop routing in individual clusters [8]. However, the efficiency of single-hop communication lessens when the communication distance increases. By comparison, multi-hop communication is a more energy-efficient approach in large networks where inter-node distance is crucial[9]. Therefore, the present study proposes the use of a multi-hop communication technique based on combined low-energy adaptive clustering hierarchy (LEACH) and MTE protocols in clustered routing architecture to save transmission energy [10]. By equalizing energy expenditures, the proposed method increases energy performance for wireless sensor networks (WSNs). However, this method only accounts for the multi-hop communication of member nodes; the inter-cluster communications continue to be directed to the sink.
A routing hole problem emerges from the use of an energy-unaware path selection strategy in multi-hop clustering routing protocol as shown in Fig 1. A Routing Hole's consist of a region in the sensor network where a group of sensor nodes stops working and the area occupied by these nodes do not participate in the routing of the data [11]. A Routing Hole is a state where all the neighbor nodes are farther away from the destination than the node holding the current packet. The sensor node where the packet may get stuck or when the sending node failed to find the next valid node to reach the destination nodes is called as a routing hole or void node [12, 13].

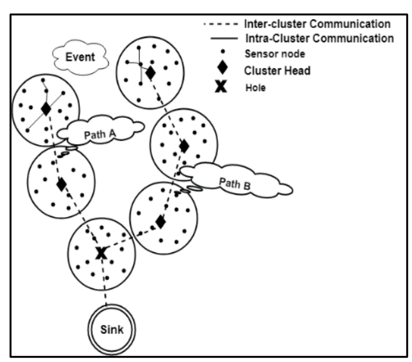

Fig. 1 Routing hole problem in the multi-hop clustering routing protocol.

Manuscript received January 5, 2019
Manuscript revised January 20, 2019

An energy efficient least edge Computation cluster based multi-hop algorithm is proposed in which the cluster head will forward the aggregated data to the base station via multi-hop. The source cluster head will select the next hop cluster head with minimum values of energy level, link weight, and edge count. It has been observed from simulation analysis that the proposed ELEC routing algorithm is more useful and beneficial as compared to other existing routing techniques such as GRACE, LEACH, and AODV-EHA in terms of network lifetime, residual energy, node failure percentage, and packet drop.

The remainder of this paper is arranged as follows. Section 2 presents the current CH routing protocol methods. Section 3 discusses the proposed ELEC algorithm. Section 4 presents and discusses the results. Finally, Section 5 concludes.

2. Cluster head routing protocol strategies

Numerous studies on cluster-based routing protocols have been conducted[14-16]. For instance, the fuzzy-logic-based energy-efficient clustering hierarchy (FLECH) is proposed for non-uniform WSNs in [17]. FLECH combines key parameters, such as node centrality, distance to base station (BS) and residual energy in order to select the most suitable CH. Simulation results reveal the lifetime increase by FLECH over other cluster-based routing protocols, including ECPF, LEACH, CHEF, EAUCF, and MOFCA. In [18], the neuro-fuzzy energy-aware clustering scheme (NFEACS) is proposed to form energy-aware clusters. NFEACS realizes energy efficiency in two phases, namely, neural network system and fuzzy subsystem. The former supplies an efficient energy-related training set for tentative CHs, while the latter is applied in fuzzy logic to form clusters. Although results indicate the effectiveness of NFEACS for mobile sensor nodes, it is limited to such parameters and cannot be applied when static sensor nodes are needed.

Unequal clustering, which modifies the cluster size to be proportional to the distance to BS, is proposed to overcome the hot spot problem. In [19], an extensive survey of unequal clustering techniques, along with their specific characteristics, objectives, clustering processes and CH properties, is provided. An energy-efficient unequal chain length clustering (EEUCLC) protocol is proposed in [20]. EEUCLC utilizes suboptimal multi-hop routing and probability-based CH selection algorithms to decrease the workload on the CH. Simulation results demonstrate the success of EEUCLC in enhancing network lifetime and balancing energy consumption but probability based CH selection increases the routing overhead.

Energy-balanced cluster formation algorithms with efficient methods of molecular structure encoding and potential energy functions and an energy-efficient CH selection are proposed in [21]. The authors derive the methods and selection from a novel chemical reaction optimization technique. They consider several parameters, such as intra-cluster distance, the residual energy of sensor nodes and sink distance, for the CH selection phase and energy and distance for the cluster formation phase. While the results establish the superiority of the algorithm, the additional overhead required to design the molecular structure scheme results in maximum energy utilization. In [22], the authors propose LEACH, a clustering-based protocol that utilizes randomized rotation of the CH to distribute the energy load uniformly among sensors in the network. To achieve the robustness and scalability of dynamic networks, LEACH employs localized coordination and data fusion to decrease the number of data transmissions to the BS. However, if the CH is far away, then the direct transmission to BS from CH will exhaust additional energy, resulting in routing hole problems. In [23], the authors propose gradient cost establishment (GRACE), which minimizes communication bandwidth requirements and energy consumption, to improve reliable data delivery and network lifetime for energy-aware routing in WSNs. Simulations show that GRACE achieves better dynamic routing than one of the preferred routing algorithms (i.e. GRAB). An energy harvesting aware ad-hoc on-demand distance vector routing protocol (AODV-EHA), which features the advantage of the existing AODV in dealing with the temporary nature of WSNs and utilizes the energy-harvesting function of sensor nodes in the network, is presented in [24]. GRACE and AODV-EHA routing protocols are only applicable on flat routing, which has lower energy efficiency than hierarchical routing. Therefore, a routing protocol design with minimum resource expenditures (i.e. energy) is crucial for multi-hop clustering WSNs. The proposed work presents a novel energy-efficient algorithm for multi-hop clustering WSN, and the performance of the algorithm is tested through comparisons with other clustering protocols, such as LEACH, GRACE, and AODV-EHA.

3. Energy-efficient least-edge computation (ELEC) cluster based multi-hop algorithm

Numerous sensor nodes are randomly deployed in a network area. Depending on the distance of sensor nodes from CH, the nodes transmit the sensed data to the CH either through single- or multi-hop communication. The CHs send their collected data to sink through multi-hop to minimize the routing hole problem. The proposed routing protocol technique in this study streamlines the energy analysis by assuming that the data’s transmission time is similar to the receiving time. It takes into account the number of edges in the path from source CH to sink, the energy level and the link cost. All the sensor nodes are

assumed to be homogenous and thus have the same energy consumption for sensing. Every CH requires a distinct identification number to check the level of battery power.
The proposed ELEC for multi-hop clustering algorithm is deemed a reactive algorithm because it creates the local route table according to the needs of an event that occurs. The local route table is recognized by sensor nodes close to an event detect and transmit it to the CH by single or multi-hop clustering depending on the distance. If the data are far away from the CH, then the sensor node will send the data through multi-hop clustering; otherwise, the data are sent directly to the CH. After data collection, the CH forwards the data to the BS via multi-hop. Then, the source CH selects the next hop CH with minimum values of edge count, energy level and link weight.

The energy level of CH:
In data routing, the energy critical node (CH) must be avoided as a next hop neighbor to balance the energy expenditures in WSN. Energy level defined as the ratio of initial energy and remaining energy of the CH, as shown in Eq. (1), where e_i is the initial energy and e_o is the remaining energy of CH. The proposed algorithm selects a CH with the minimum value of E_l.

$$E_l = \frac{e_i}{e_o} \tag{1}$$

Link weight (Lw):
In the proposed method, link weight indicates the communication energy consumption rates at the two ends CHs. It is defined as a function of the receiving and transmitting energy that uses a link to minimize the routing hole problem. High link weight requires additional transmission and has significant chances of developing a routing hole. Therefore, the algorithm avoids links with high weight values. The transmitted energy $\mathrm{E_t}$ and received energy $\mathrm{E_r}$ of l bit of data over a distance, m can be calculated using Eqs. (2) and (3), respectively. The link weight between two CH's (x and y) can be computed by Eq. (4).

$$\mathrm{E_{t_i(l,m)}} = \mathrm{E_{t_i-elect}}(\mathrm{l}) + \mathrm{E_{t_i-amp}}(\mathrm{l,m}), \tag{2}$$

$$\mathrm{E_{r_i(l,m)}} = \mathrm{E_{r_i-elect}}(\mathrm{l}), \tag{3}$$

$$\mathrm{L_{w(x,y)}} = \mathrm{E_{t(x)}} + \mathrm{E_{r(y)}} \tag{4}$$

Where,
E_{t_i} =required energy consumption for transmission
$\mathrm{E_{t_i-elect}}(l)$ = Transmitter electronic (the energy consumption for filtering, modulation the digital coding and spreading of the signal).
$\mathrm{E_{t_i-elect}}(l)$= Receiver electronic
$E_{t_i-amp}(l, m)$= Transmit amplifier
E_{r_i} = required energy consumption for receiving

Edge Count (Ed):
In WSNs, an edge or hop is a portion of the path between destination and source. A hop occurs, each time packets are passed to the next sensor node. The hop count or edge count refers to the number of intermediate sensor nodes through which data must pass between source and destination. Moreover, when the edge count increases, the stability of the WSN weakens and the energy consumption becomes unequal. Most of the energy is also consumed by computation and aggregation by a CH at every edge and the number of links and error probability increase. In addition, the increase in edge count leads to an increase in link number, which destabilizes the end-to-end connection and the eventual failure in routing discovery. Therefore, edge count is one of the most critical network features that has a considerable influence on network lifetime. It must be minimized to ensure network energy efficiency, link reliability, and connectivity. Edge count increases by 1 every time packets are passed on to the next CH. The edge count of CH Edi can be computed using the equation below:

$$\mathrm{Ed}_i = \mathrm{Ed}_{i-1} + 1 \tag{5}$$

Route processing in ELEC algorithm:
This section discusses the CH selection of the next hop neighbor in the route management for data transmission. Firstly, each CH sets the energy level that is advertised to its neighbor CH. The sensor nodes will detect whenever an event occurs and transmit the data to the CH. After data collection, the CH then generates an event message containing information, such as energy level, link weight, edge count, cost of parent CH (Pre-cost) and total cost until the current CH (cur_cost). Pre_cost of source CH and edge count Ed are zero because they do not have a parent CH. Eq (4) is used to calculate the link weight for neighbor CHs. Finally, the CH selects the lowest weight of neighbor CH, adds this to the pre_cost and then sets it as the cur_cost, as shown in the equation below:

$$cur\_cost = \mathrm{Pre\_cost} + Min\_cost(cost\ of\ neighbor\ CH's)$$

The source CH forwards the event message with updated cur_cost and edge count along with the data. When the event message is received, neighbor CH increases the edge count by 1, sets the cur_cost as the pre_cost and calculates the weight for its neighbor CHs. Next, the minimum cost of its neighbor CH weight is selected and added to the pre_cost and forwarded with data. This process continues until the data are received by the BS, which then returns an acknowledgment message to the data sender.

Sample Scenario of the ELEC algorithm:
To understand route management in the ELEC algorithm, consider a sample network comprising a set of CHs {c1, c2, c3, c4, c5, c6} (see Fig 2). Table 1 below presents the energy levels and link weight, which is computed respectively using Eqs. (1) and (4).

Table 1: Energy level and link weight for the above scenario.

Sensor Nodes	Energy Level (El)	Neighbors CH	Link weight (Lw)
c1	4	c2,c3,c4	2,1,2
c2	6	c1,c3,c5	2,2,2
c3	5	c1,c2,c5,c6,c4	1,2,1,1,2
c4	7	c1,c3,c6	2,2,3
c5	5	c2,c3,c6,BS	2,1,2,1
c6	4	c4,c3,c5,BS	3,1,2,1

The cost of diverse paths from source CH to BS is calculated using Eq. (6). The BS then selects a path for low-cost transmission.

$$Cost_{x-y} = E_{l(x,y)} + L_{w(x,y)} + E_{d(x,y)} \tag{6}$$

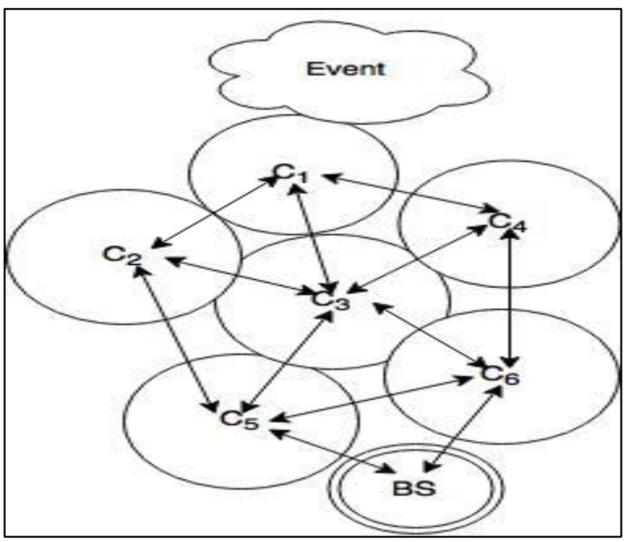

Fig. 2 ELEC example scenario

Fig 3 illustrates the CH selection of the next hop neighbor in the route processing for data transmission. Firstly, each CH sets the energy level that is advertised to its neighbor CH. In this sample scenario, the sensor nodes perceive the occurrence of an event and send information to CH C1. An event message containing the edge count, energy level, link weight, and cost of parent CH (pre-cost) and total cost until the current CH (cur_cost) is then generated by C1. Given that C1 does not have a parent CH, its event message with energy level (El=4) the edge count (Ed) and pre_cost are zero. The link costs for neighbor CHs C2, C3 and C4 are computed by Eq. (6). For instance, the link cost of C1 to C2 (i.e. Cost_{1-2}) can be computed as

$$Cost_{1-2} = E_{l(2)} + L_{w(1,2)} + E_{d(1,2)}$$

The costs for C3 and C4 are calculated using the same method. Fig 3 shows that C3 has the lowest cost. Therefore, C1 will add the cost of C3 with the pre_cost of zero and set it as cur_cost, as shown in the equation below:

$$cur\_cost = pre\_cost + cost(C_3)$$

C1 sends the event message to C3 along with the data. C3 then increases the edge count by 1, sets the cost in an event message as the pre_cost and computes the cost for its neighbor CHs C2, C4, C5, and C6. The minimum cost is selected from the cost of its neighbor CHs (i.e.7 for C6) and added with the pre_cost of 7. C3 transmits the event message to C6 along with the data. C6 verifies that BS is its next hop and thus sends the data directly to BS. The BS will then send an acknowledgment message to the source CH. Fig 4 illustrates the process flow in ELEC.

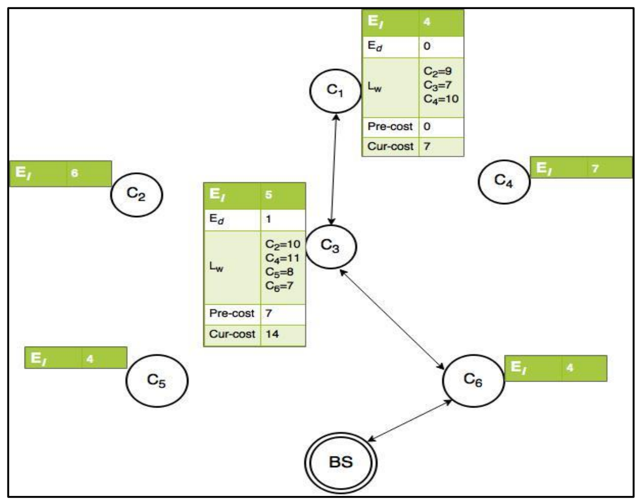

Fig. 3 Route processing in ELEC algorithm

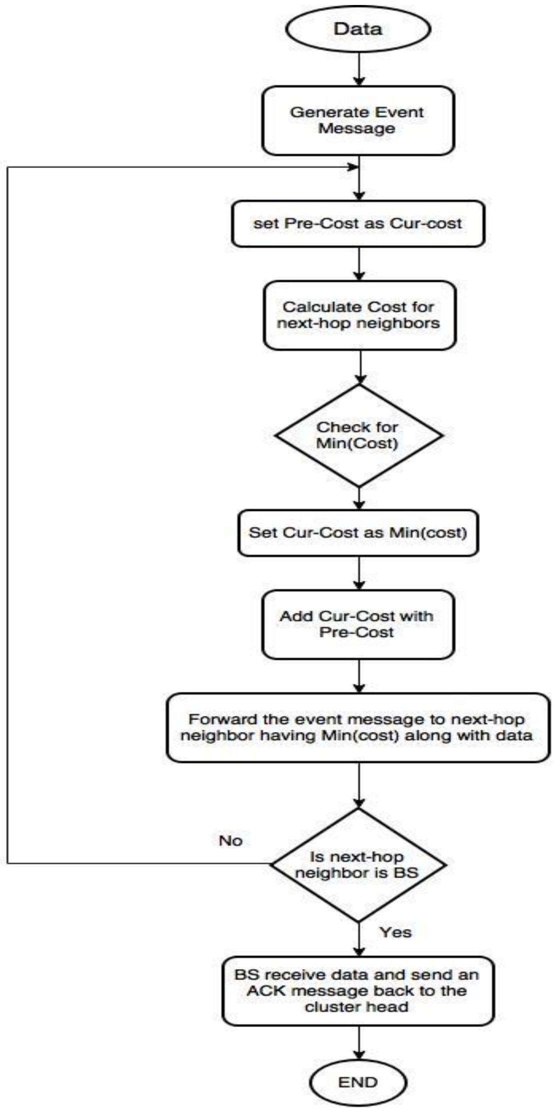

Fig. 4 Flowchart of ELEC algorithm

4. Results and Discussion

In this section, the performance in WSNs of the ELEC multi-hop clustering algorithm is evaluated by answering the following questions:

- How does the ELEC algorithm reduce the routing hole problem in WSNs?
- How does the network routing protocol improve the network performance?

Simulation Setup: We format the WSN to examine the performance of the proposed routing protocol. An extensive simulation is carried out in Matlab R2014b to assess the proposed routing protocol. Random data traffic is produced from the sensor nodes, which have a transmission range of 150 m. The BS is maintained at the side of the topology, as listed in Table 2.

Table 2: Simulation parametric values

Parameters	Value
Number of nodes	500
Initial energy	1 J
Nodes distribution	Random
Communication Range	150m
Simulation Time	4000 units
Simulation Tool	Matlab R2014b

Performance Metrics:
A set of performance metrics, such as network lifetime, packet drop percentage, residual energy and node failure percentage, is used for performance assessment of the proposed routing protocol. A technique that uses the sensor node energy in a balanced mode is necessary to improve the performance of WSN. On the basis of these performance metrics, the simulation results are compared with current routing strategies, such as GRACE [25, 26], AODV-EHA and LEACH.

Network Lifetime:
Network lifetime is a primary concern in WSNs and requires an energy-aware routing protocol strategy for improvement. Network lifetime can be defined in various ways depending on the application of the concerned area. The current work considered three definitions of network lifetime, namely, CH node failure, 10% node failure and last packet received.
Fig 5 shows the network lifetime according to the three above mentioned definitions. The lifetime of the ELEC routing protocol is compared with GRACE, LEACH, and AODV-EHA. At first node failure, the lifetime of a GRACE, LEACH, and AODV-EHA deployed network is about 400, 390 and 100 simulation seconds respectively, and for the proposed ELEC routing protocol, it is about 1000 simulation seconds. There is a considerable increase of about 600 simulation seconds as compared to other routing strategies. The same increase can be observed for the other's network lifetime definition, i.e., at 10% of the node failure the increase is about 1500 simulation seconds and for the time until the last packet is received at the sink, the network lifetime of the proposed ELEC routing strategy increases about 2000 simulation seconds.

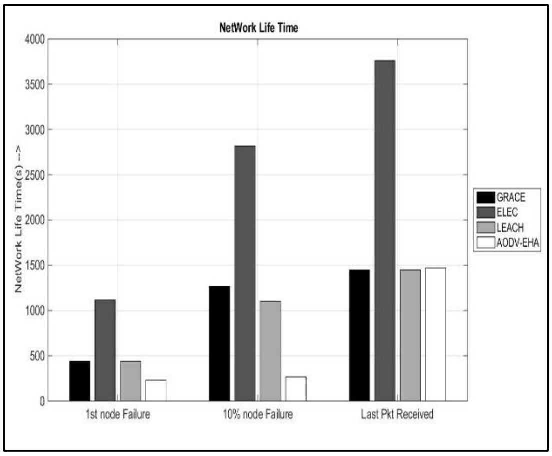

Fig. 5 Network lifetime

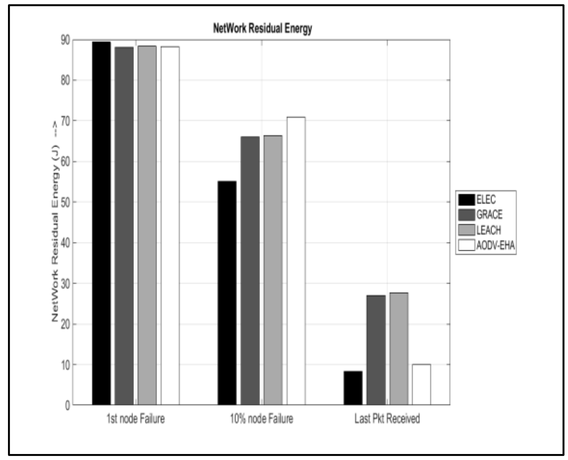

Fig. 6 Residual energy

Residual energy

The total energy depletes throughout the network during network lifetime is defined as energy consumption. In this section, the residual energy of the proposed routing protocol is compared with other routing techniques such as GRACE [25, 26], LEACH and AODV-EHA. The residual energy of ELEC is compared with other existing routing protocol strategies like GRACE and LEACH. The results show that ELEC has balanced residual energy till the lifetime of the network, because of balanced energy consumption. Instead, GRACE and LEACH have rapid energy consumption and much of the energy is unused when the lifetime of the finish due to the unbalanced energy consumption.

It is confirmed from Fig 6 that up to 90% of the total energy of the network is left unused during network lifetime at first node failure in all routing protocols ELEC, GRACE, LEACH, and AODV-EHA. When both the 10% of the nodes failures is considered the end of network lifetime, the residual energy of GRACE, LEACH, and AODV-EHA is about 65% to 70%, while ELEC is 55%. When the GRACE, LEACH and AODV-EHA routing strategies are used in the network, the residual energy of a network where the last packet received at the sink is considered as the end of network lifetime, up to 30% of the total energy of the network is left unused.

The residual energy of the proposed ELEC routing protocol during network lifetime at 10% of the node failure, and till the last packets received at the sink are 55% and 5% are left unused of the total energy respectively.

Node Failure percentage:

A node failure is a situation when the sensor node cannot take part in the network functionality. Many reasons can cause the node failure, but the proposed work considers the node failure due to energy exhaustion. Sensor's failure will cause a sensing routing hole so that affect the routing protocols performance of WSN [27].

Fig 7 shows the node failure percentage of ELEC compared to GRACE, LEACH, and AODV-EHA. It can be seen that in GRACE, LEACH and AODV-EHA up to 79%, 80%, and 68% nodes fail at 1500 simulation seconds while its take 3800 simulation seconds in ELEC routing protocol when 70% of nodes fails.

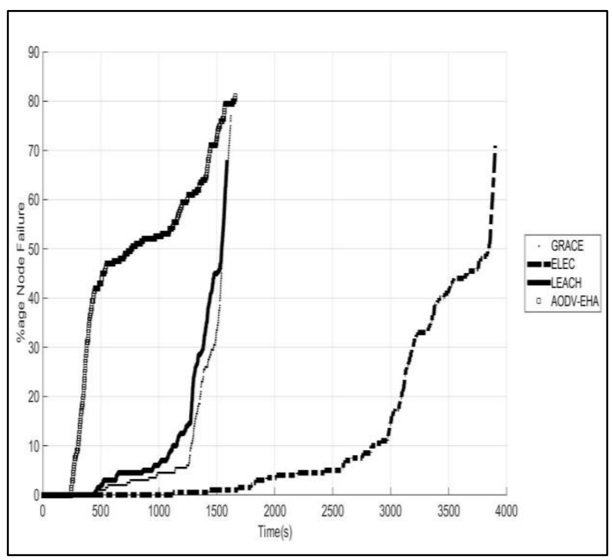

Fig. 7 Percentage of node failure

Percentage of packet drop:

Packet drop is the failure of one or more forwarded packets to arrive at the base station. The packet delivery ratio will be minimized due to packet drop [28]. Packet drop can be caused by a number of factors, including unbalanced energy consumption. The packet drop increases with time because of failure of nodes, but the results show that the packet drop percentage of ELEC algorithm is minimum due routing hole avoidance as compared to GRACE, LEACH, and AODV-EHA. Fig 8 shows that in GRACE, LEACH and AODV-EHA due to the rapid node failure up to 80% packet dropped in 1500 simulation seconds while in ELEC routing protocol the packet drop is just 20% in 3000 simulation seconds. Which is 60% of packet drop noticeable decrease in ELEC as compared to GRACE, LEACH, and AODV-EHA.

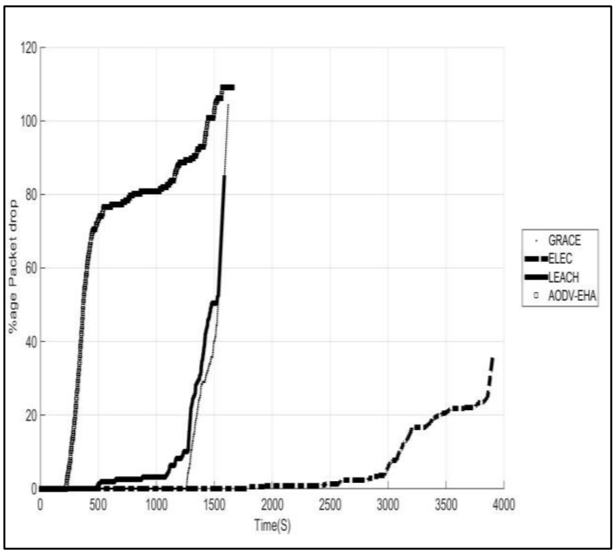

Fig. 8 Percentage of packet drop

5. Conclusion

ELEC multi-hop clustering algorithm, wherein the CH transmits collected data to the BS through multi-hop communication, is proposed in this work. The source CH selects the next hop CH with minimum values of edge count, energy level and link weight. It has been observed from simulation analysis that proposed ELEC routing algorithm is more useful and beneficial as compared to other existing routing techniques GRACE, LEACH, and AODV-EHA in terms of network lifetime, residual energy, node failure percentage, and packet drop.

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