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Energy Efficient Cluster based Routing Scheme for WSN based IoT to Extend Network Lifetime

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Abstract

With the development and advancement of wireless sensor networks (WSN), the emergence of the Internet of Things (IoT) has achieved prominence in the modern era. With the increasing number of connected devices, WSN has become a key factor in the communication component of the IoT. In IoT-based WSN infrastructure, devices are equipped with intelligent sensors that sense the environment to collect data, process data, and deliver information to the sink or base station (BS). WSN-assisted IoT has become a key technology for various data-centric applications such as health care, smart cities, and the military. Sensor nodes in IoT devices are equipped with bound and irreplaceable batteries. An increased number of connected devices face serious issues of energy depletion, maintenance, and load balancing, which might result in device failure. Energy efficiency is considered a vital parameter in the design of an IoT based WSN, and this can be accomplished through clustering and multihop routing techniques. In this paper, we propose an energy-aware multihop routing scheme (EAMRS) for hierarchical cluster-based WSN-assisted IoT. EAMRS considers the improved low-energy adaptive clustering algorithm (I-LEACH) to select optimal cluster heads (CH). During data transmission, multihop routing is involved by considering routing metrics such as residual energy, distance to BS and optimal route choice to balance the energy load. However, conventional routing schemes fail to achieve the flexibility and adaptability prerequisites of load balancing mechanisms. EAMRS decreases computation overhead and restricts energy usage, resulting in a prolonged network lifetime.

Keywords: *Clustering, energy efficient, IoT, multihop and WSN.*

1. Introduction

Recent advancement in wireless communication and transition of wireless technology has made it possible to connect anything to everything in network. Wireless sensor networks (WSN) offer a wide range of applications, including agriculture, seismic control, target tracking, smart vehicles and environment monitoring [1-4]. In recent years, rapid growth being witnessed in WSN because of its unique characteristics and miniaturized low-power sensor embedded with electronic interface, which has now catapulted to several application platforms to manifest in the form of Internet of Things (IoT). The key concept of IoT is to enable communication between human and digital information from various objects around us such as tablet computer, smart phone and RFID enabled electronics gadgets through machine integrated end user service [5-8]. IoT provides an opportunity to transform human life as an emerging new technology and connects people with real physical world providing context aware information. IoT application comprises a network of WSN and IoT devices networked together with internet and with multiple sensing abilities to communicate across the networks. WSN assisted IoT have gained much attention in recent time for information transfer and minimizing the computational load on the network. Data gathered by sensors are processed and routed towards base station through multihop transmissions governed by routing protocol. Nodes consume more energy during data communication and are bounded to restricted power sources. The nodes energy consumption and network lifetime are highly depended on these routing protocols. Cluster based routing approach have proven an effective solution to increase network lifetime and improve energy efficiency [9]. Earlier authors presented various clustering algorithms such as low energy adaptive clustering hierarchy (LEACH), Centralized-LEACH, Threshold-LEACH, later on more advancement has been made to these approaches [10-13]. However, the cluster head (CH) selection in traditional approach was based on probabilistic method which led to increased energy consumption and computation overhead [14][15]. Moreover, nodes near to base station receive more data from other nodes consumes rapid energy resulting in faster battery drain and death of a node. In this paper, we propose an energy-aware multihop routing scheme (EAMRS) for hierarchical cluster WSN-assisted IoT. Optimal path towards BS is determined through energy and distance from the CHs. EAMRS adapts multihop routing through energy efficient nodes to provide reliable packet transmission and balance nodes energy. The main contributions are as follows:

- Optimal cluster head is selected through improved threshold function and distance to BS through modifying existing LEACH.
- Load among the sensor nodes are balanced through multihop routing by discovering optimal energy efficient routes with minimum hop count through estimating routing metrics such as queue length, available bandwidth and link quality.

The whole paper is organised as follows: Section I describes Introduction, section II describes problem statement and motivation, section III describes related works done, section IV describes network model, Section V describe the proposed EAMRS scheme, section VI describes the results and performance evaluation and finally conclusion is drawn in section VII

Problem statement and Motivation

In WSN-assisted IoT, nodes are typically resource constrained with limited storage, low computational capability and limited energy. Nodes energy consumption is a significant drawback in wide range of applications making battery replacement impractical. Cluster based routing technique is an effective method to reduce energy consumption of node and to extend network lifetime. Network lifetime is directly proportional to nodes energy consumption and refers to time until the death of first node in the network due to energy depletion. Poor cluster formation and cluster head (CH) selection affects network procedures such as route discovery, data aggregation and rapid energy consumption which considerably affects in extending network lifetime. Therefore, it is required to find the solution for optimal cluster formation and effective cluster head selection considering energy parameters. Conventional clustering algorithm mainly focuses on energy efficiency and does not provide reliability guarantees. This motivates us to design energy aware cluster based routing algorithm in order to cope with limited battery power and adopt multihop manner to convey packets to the base station also balance energy load among nodes to prolong network lifetime.

Related Works

In [16], author proposed efficient cluster head selection to balance load using hybrid APRO approach for IoT applications. The optimal cluster head selection is determined through multi-attributes and coordination among these attributes. Multi-attribute decision making (MADM) function is considered for CH selection from the available coordination attributes. Clustering methods such as LEACH, LEACH-C and hybrid energy efficient distributed clustering (HEED) are compared and attributes including average distance to BS, residual energy, standard deviation power, average CH life, BS-CH connectivity and CH-load are evaluated using analytic hierarchy process (AHP) and preference ranking organization method (PROMETHEE) for rank based to choose best cluster heads. Parameters such as energy, network stability, and first and last node death are analysed. The proposed APRO scheme outperforms existing algorithms in terms of load balancing and extends network lifetime. However, this scheme has higher computational overhead due to evaluation of different attributes. In [17], author proposed novel scheme for cluster head selection through full connected energy efficient clustering (FCEEC) scheme. The optimal path from CH to BS is established using electrostatic discharge algorithm (ESDA) in multihop environment. ESD is an electrical discharge event which occurs in electronic circuits due to sudden power surge or capacitive coupling effects. Packets are quickly transferred across two nodes due to capacitive coupling effect between two conductors. ESDA scheme optimizes path selection from CH to BS and takes multihop across neighbouring CH to deliver packets to BS. Simulation results show proposed ESDA scheme achieves higher packet delivery rate, increases network lifetime compared to generic clustering methods. However, ESDA scheme limits to small network area and higher overhead. In [18], author proposed intelligent routing scheme for IoT-enabled WSN. Deep reinforcement learning (DRL) is adopted to execute intelligent routing for IoT-enabled WSN that reduces routing delay and extends network lifetime. Proposed scheme elevates energy hole problem within network through forming unequal clusters depending on load of the sensors and avoids immature death of network. The scheme operates in two phases: First, unequal cluster formation phase in which network is divided into unequal clusters to balance energy load among nodes. In second phase, multi-objective DRL routing is proposed for inter and intra cluster communication that significantly increases throughput and reduce delay. Simulation results show, the proposed scheme has enhanced throughput and packet delivery rate over existing scheme. However, this scheme fails to achieve reliability. In [19], author proposed dual tier cluster based routing (DTC-BR) for IoT applications. This scheme is based on dual-tier clustering technique and virtual network zone to enhance performance of mobile wireless sensor network. DTC-BR divides network into virtual zones and selects appropriate CH. Virtual zone consists of main connectivity zone (MCZ) and each MCZ involves candidate cluster zone (CCZ). DTC-BR considers energy, scalability and connectivity for efficient routing and eventually extends network lifetime. Each MCZ has fixed position and corresponding communication range for each sensor node. In each MCZ, CCZ is deployed at centre of MCZ with dynamic communication range depending on the network configurations. Cluster selection mechanism (CSM) is employed on CCZ to select reliable CH. Performance results show DTC-BR has significant enhanced network energy consumption and survival rate. However, this scheme has more complex computational function while splitting network into virtual zones. In [20], author proposed energy efficient hybrid routing protocol (PSOGA) by integration of particle swarm optimization and genetic algorithm (GA) for IoT to improve network lifetime. PSOGA proposes multi-objective optimization for selection of optimal route from source to BS for packet transmission. PSOGA involves two steps, first step involves in designing of trust model for secure data communication between CH and BS. Next step involves route determination through PSO and GA for data transmission. PSOGA determines score based on residual energy, hop count, buffer occupancy and reliable path. Next hop node is determined using score for successful data transmission. Performance evaluation shows increased network lifetime and higher packet delivery rate. However, this scheme requires complex function to evaluate trust model resulting in higher delay. In [21], author proposed routing scheme for WSN assisted IoT known as power efficient cluster based routing (PECR). The cluster formation and cluster head selection is done by employing K-means, the communication between CH to BS is according to relative location and residual energy. PECR decrease traffic burden and restricts energy usage at intermediate levels during data transmission phase. PECR operates at different levels, in first level the communication is between sensor node to CH and estimates energy usage considering the length of packets. In second level, communication between CH to main-CH (MCH) is established wherein MCH aggregates data. In third level, the aggregated data is transmitted to BS via MCH considering energy consumption evaluated in previous level and MCH takes multi-hop communication to reach BS. Simulation results show PECR extends network lifetime compared to other traditional routing schemes. However, PECR fails to balance nodes energy and does not achieve scalability. Summary of the above related works mainly focused on achieving energy efficient during routing. However, existing schemes fail to consider distance to BS, stability and adaptability to balance nodes energy.

Proposed EAMRS

Network Model and Assumptions

EAMR considers n sensor nodes randomly deployed in the sensing field, entire network area is partitioned into group of clusters. BS is placed far from the sensing area and all nodes are static after deployment.

Assumptions

- Nodes are assigned with unique ID’s
- Nodes are capable to handle any type of traffic
- Nodes are assigned with same initial energy, identical resource and network is homogeneous
- Distance between nodes are computed using Euclidean distance $D = \sqrt{(y_i - y_j)^2 + (x_i - x_j)^2}$ by using received signal strength indicator (RSSI)
- Nodes are aware of their energy levels and positions through global position system (GPS)

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:

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

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 EAMRS, we modify the threshold function of LEACH in setup phase and calculate distance to BS such that nodes with high residual energy and nearer to BS get priority to be selected as CH. 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:

$$TH(n) = \frac{P_{CH}}{1 - P \times (i \bmod \frac{1}{P})} \times \left(t \times \frac{D_{avg}}{D_i}\right) if\ n \in G$$

where, P_{CH} is the percentage of node being selected as CH. The 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. The distance between nodes and BS is represented by D_{to-BS} and distance between nodes (cluster members) to CH is denoted asD_{to-CH}. EAMRS 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

$$D_{optimum} = \min (D_{to-BS}, D_{to-CH})$$

(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 $T(n)$

Cluster Formation

After CH selection in setup stage, 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.

Energy Consumption Model

EAMRS adopts free space model (D^2) and multipath channel model (D^4) considering distance between communicating entities. The radio electronics and power amplifier are run by transmitter and receiver. Thus, to transmit k bit message over distance D, the eergy consumption is given as:

$$E_{T_x} = \begin{cases} E_{elec} * k + \varepsilon_{fs} * k * D^2, & D \leq D_0 \\ E_{elec} * k + \varepsilon_{amp} k * D^4, & D > D_0 \end{cases}$$

where D_0 is computed as $D_0 = \sqrt{\varepsilon_{fs}/\varepsilon_{amp}}$. The radio electronic energy E_{elec} is used depending on modulation, digital coding and encoding. Radio amplification for free space and multipath model is given as ε_{fs} and ε_{amp} when $D \leq D_0$ and $D > D_0$, where D_0 is threshold. Radio energy required to receiver k bit is given as:

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

Energy consumed by sensor node n_i to transmit and receive data to particular CH, within one hop communication range is expressed as:

$$E_{T_x}(n_i) = \gamma * E_{elec} * k + \varepsilon_{fs} * k * D^2$$

$$E_{R_x}(n_i) = \gamma * k * E_{elec}$$

where, γ is sum of sensor nodes within one cluster excluding CH.

Energy consumed by CH includes the energy consumption for receiving packets from CM aggregating data and transmitting aggregated data towards BS. Thus, consumption of CHs energy is computed as:

$$E_{T_x}(CH) = E_{R_x}(n_i) + (n_i + 1)kE_{agg} + E_{T_x}(n_i)$$

where E_{agg} is the energy consumed for 1 bit data aggregation

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 considering routing metrics.

Assuming CH transmits data towards BS through $(n_i - 1)$ hops and the distance is D. Energy consumed through single hop E_{SH} transmission to transmit k bit is expressed as :

$$E_{SH} = E_{T_x}(k, n_i \times D)$$

$$E_{SH} = k \times E_{elec} + k \times \varepsilon_{fs} \times (n_i D)^2$$

$$E_{SH} = k \times (E_{elec} + \varepsilon_{fs} \times {n_i}^2 \times D^2)$$

For multihop transmission E_{MH}, energy consumed is expressed as:

$$E_{MH} = n_i \times E_{tx}(k, D) + (n_i - 1) \times E_{R_x}(k)$$

$$E_{MH} = n_i \times k \times \left(E_{elec} + \varepsilon_{fs} D^2\right) + (n_i - 1) \times E_{elec} \times k$$

$$E_{MH} = k \times \{(2n_i - 1)E_{elec} + \varepsilon_{fs} \times n_i \times D^2\}$$

Queue Length

To avoid packet, drop due to congestion and packet retransmission delay, queue load is considered as QoS metric during forwarding packets to next hop node. Queue length of every node in next round is determined by forwarding action in the current round and expressed as:

$$Q_i^{t+1} = \min\{ [Q_i^t + n_{i,in-flow}^t - n_{i,out-flow}^t], QS_i\}$$

where, queue length of ith node at time instant t is represented as Q_i^t, the packet inflow and outflow of ith node is given as $n_{i,in-flow}^t$ and $n_{i,out-flow}^t$, buffer size of node i is given as QS_i. The packet outflow $n_{i,out-flow}^t$ of node depends on the available bandwidth strength and number of packet sent, which can be expressed as:

$$n_{i,out-flow}^t = \min\left\{Q_i^t, \frac{E_{n_i}}{p}, \frac{AWB_i}{bp}\right\}$$

where, $\frac{E_{n_i}}{p}$ represents energy required by node n_i to send maximum packets and the available bandwidth AWB_i required to send number of bits of packets bp

Bandwidth Availability

The available bandwidth link between two nodes $n_{(i,J)}$is computed including signal to interference noise ratio, interference and successful packet transmission which is expressed as:

$$ABW_{(i,j)} = \left(1 - \left(SINR_{(i,j)} + N_{(i,j)}\right)\right) * PT_{(i,j)} * bw_{(i,j)}$$

where, $SNR_{(i,j)}, N_{(i,j)}, PT_{(i,j)}, bw_{(i,j)}$ represents signal to interference, noise, probability of successful packet transmission and normal bandwidth link between node (i, j) respectively. $ABW_{(i,j)}$ can be used as routing metric for multihop transmission for increased packet delivery rate. Nodes estimate bandwidth according to channel utilization considering link capacity and link quality. Link capacity is the maximum throughput or physical transmission data rate. Channel fading due to interference and contention is measured in MAC layer. Available bandwidth is estimated by successful MAC layer transmissions. Therefore, $PT_{(i,j)} * bw_{(i,j)}$ is the bandwidth for successful transmission probability.

Link Quality

In multihop communication link quality is considered important factor for routing metric, interference and noise affects channel capacity and results in packet loss. Wireless link between two nodes may interfere with external noise and decreases data rate. EAMRS detects potential interference experiences by wireless links to determine reliable paths that suffers from less interference and noise to improve network performance and helps to balance load between nodes. Therefore, $\left(1 - \left(SINR_{(i,j)} + N_{(i,j)}\right)\right)$ is the link quality considering interference and noise.

EAMRS Algorithm

Start network Initialization
random node deployment (X, Y) axis
for each sensor node generate random number $r(0 \leq r < 1)$
compute probability of each node being selected as CH using $TH(n)$
compute distance between nodes to BS, CM to CH and CH to BS using D_{to-BS}, D_{to-CH} and $D_{optimum}$
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 data transmission between CM to CH and CH to BS
compute single hop E_{SH} and multihop transmission E_{MH} paths
during multihop transmission evaluate routing metrics, queue length, available bandwidth and link quality.
route data towards BS through energy efficient route.
end

Simulation and Performance Analysis

Simulation experiment of proposed EAMRS is carried on network simulation tool (NS2), running on Ubuntu 14.04. The network comprises of 300 nodes deployed in sensing area of 200x200 mts and nodes are assigned with identical initial energy. Relevant experiments are conducted and performance results of EAMRS are compared with PSOGA [20] and PECR [21]. Performance metrics such as throughput, packet delivery rate, number of alive nodes, network lifetime and energy consumption are analysed. The simulation parameters used is shown in Table No1.

Table 1: Simulation parameters used

Parameters	Value
Nodes deployed	300
Memory size	50
MAC-Layer	802.11
Total run time	100 sec
Network size	200 x 200 mts
Data packet size	512-bytes
Comparing scheme	PSOGA and PECR
Traffic-Connections	CBR
Energy Assign	1J
Data Aggregation Energy	5nJ
E_{elec}	50nJ
E_{fs} and E_{amp}	10pJ and 0.013pJ
Base Station	1
No of Rounds	300

Performance Analysis

Packet Delivery Rate

Figure 1 shows the packet delivery rate of proposed EAMRS compared with PSOGA and PECR schemes. It is observed from the graph, EAMRS has higher packet delivery ratio of 96.47 % compared to PSOGA of 84.32% and PECR of 89.72%. The increased packet delivery rate is due to data communication through multihop transmission considering routing metrics. PSOGA discovers path towards BS through score based on residual energy and hop count. However, in PECR the route discovery is based on location and residual energy. PSOGA and PECR mainly focus on achieving energy efficiency, but fail to achieve path stability and reliability. The evaluation of queue length, bandwidth and link quality helps EAMRS to be aware of routing metrics during multihop communication for higher packet delivery.

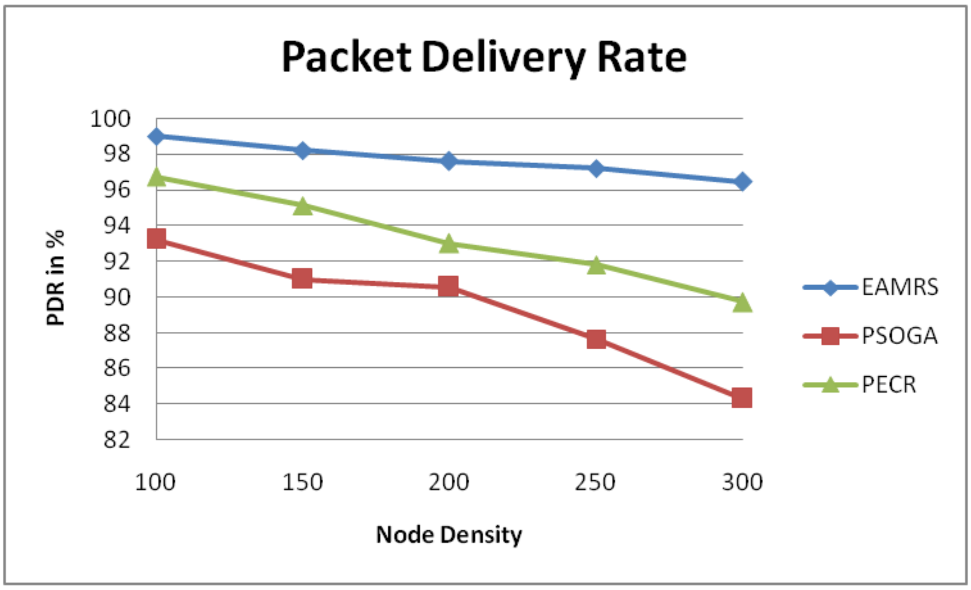

Figure 1: PDR vs Varying Node Density

Number of alive and dead nodes

Figure 2 shows the number of alive nodes under increasing number of rounds. It is seen from the graph, proposed EAMRS is efficient in exhibiting superior enhancement under extending network lifetime and energy optimization process for cluster based network. Sum of alive nodes demonstrate the evaluation criterion that nodes participate in efficient data transmission. The residual energy of PSOGA drops to zero at 500 rounds. But PECR exhibits superior performance than PSOGA at 500 rounds by keeping 52 alive nodes.

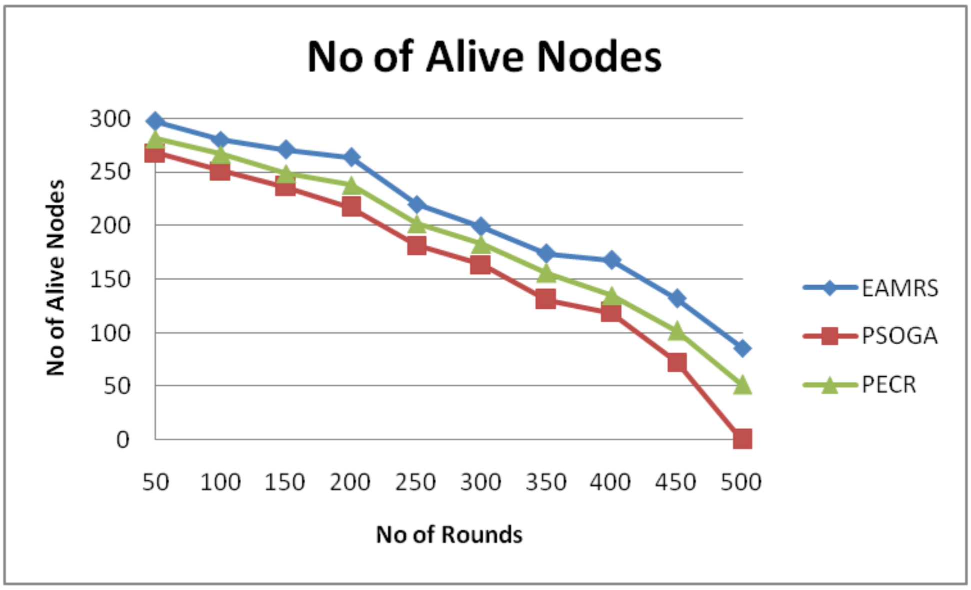

Figure 2: No of Alive nodes vs Varying No of rounds

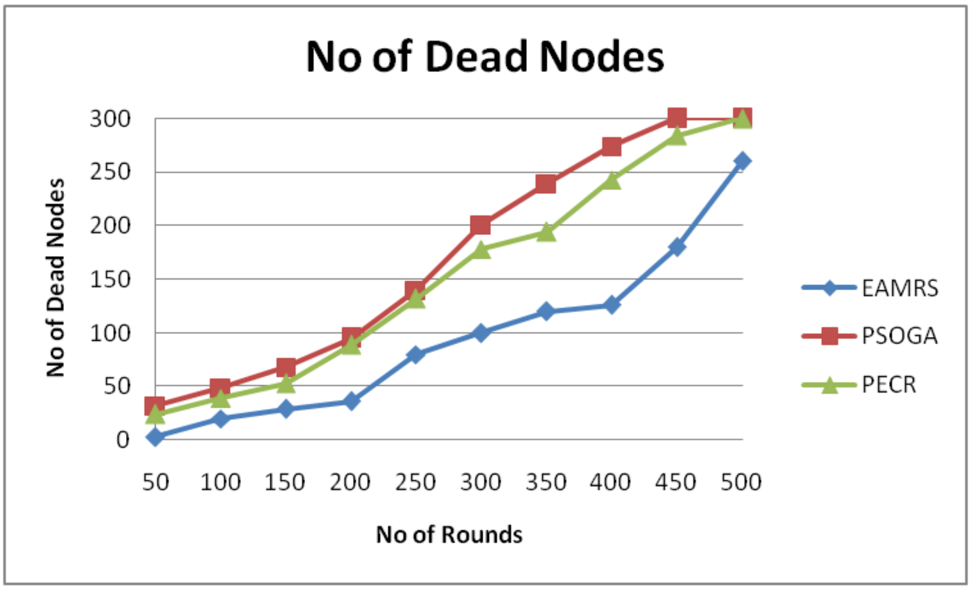

Figure 3: No of Dead nodes vs Varying No of rounds

However, proposed EAMRS was stable enough in extending network lifetime by keeping 86 alive nodes compared to PSOGA and PECR to maximum 500 rounds. Figure 3 shows the number of dead nodes under varying number of rounds. It is seen from the graph, death of first node for all three schemes occur at 50th round. As the number of round increases, the network stability of PSOGA and PECR is zero due to death of last node in round 450 and 485 respectively. However, EAMRS has higher network stability compared to other scheme due to more number of alive nodes.

Network Lifetime

Figure 4 shows the network lifetime under varying node density. It is observed from the graph, EAMRS has extended network lifetime compared to other schemes. The network connectivity is reduced when the first node dies in the network which interrupts data transmission towards BS. The unbalanced energy in PSOGA and PECR result is faster death of all nodes. However, EAMRS considers routing metric and energy metric for data transmission such that the energy among nodes is balanced. It is seen from the graph, first node death (FND) occurs at 50th round for all the schemes and half node death (HND) occurs at 260th round for PSOGA and PECR, whereas EAMRS has HND at 320th round. In PSOGA and PECR last node death (LND) occurs at 430th round compared to EAMRS of 500th round.

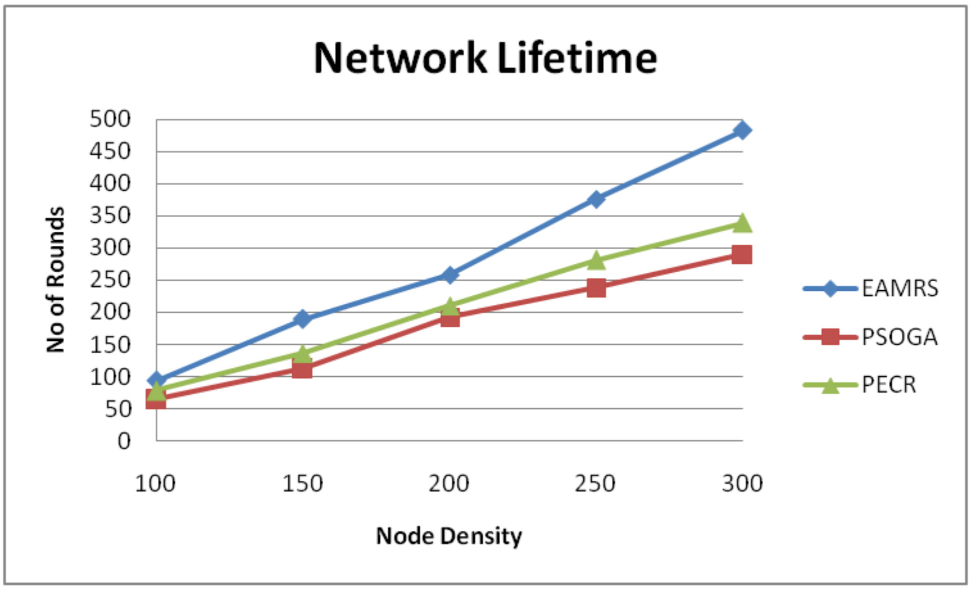

Figure 4: Network Lifetime vs Varying Node Density

Throughput

Figure 5 shows the throughput under varying node density. It is observed from the graph, throughput of EAMRS is higher compared to PSOGA and PECR. The path discover in EAMRS is based on routing metric which considers distance to BS, queue length, available bandwidth and link quality. However, PSOGA and PECR consider residual energy during path discovery. Due to external interference the channel gets faded and results in packet drop, retransmissions of dropped packet may lead to congestion in nodes queue due to more incoming packets. EAMRS takes multihop communication for reliable data transmission towards BS considering routing metrics. EAMRS has throughput of 119 kbps compared to PSOGA of 87 kbps and PECR of 104 kbps.

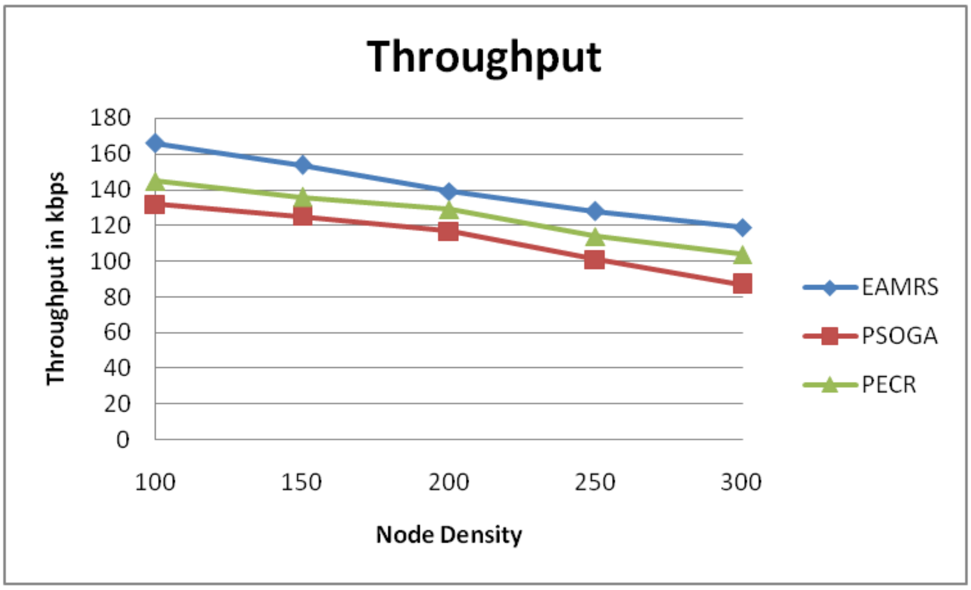

Figure 5: Throughput vs Varying Node Density

Energy Consumption

Figure 6 shows the energy consumption under varying node density. It is observed from the graph, EAMRS consumes less energy compared to PSOGA and PECR scheme under same simulation conditions. EAMRS adopts improved threshold function for optimal cluster head selection and multihop transmission reduces significant distance transmission and restricts the energy usage to minimal. In PSOGA the data transmission is initiated based on the score values which determine secure and energy efficient nodes. PSOGA consumes more energy during trust evaluation while determining score. Data transmission in PECR is carried out at different levels which have more energy drain in forwarding data towards BS.

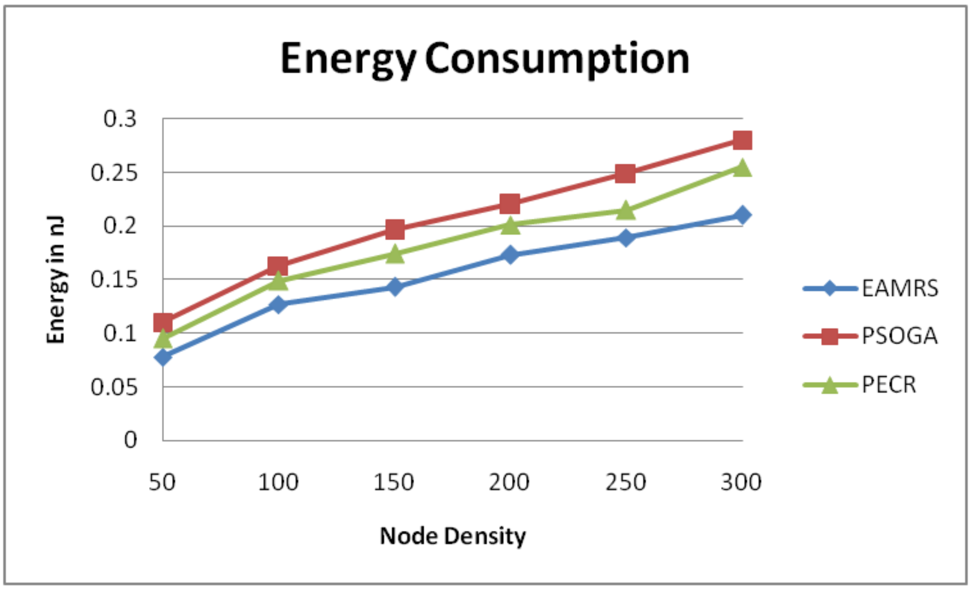

Figure 6: Energy Consumption vs Varying Node Density.

4. Conclusion

In WSN based IoT, 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 this paper, we propose an energy-aware multihop routing scheme (EAMRS) for hierarchical cluster WSN-assisted IoT. Optimal path towards BS is determined through energy and distance from the CHs. EAMRS adapts multihop routing through energy efficient nodes to provide reliable packet transmission and balance nodes energy. Optimal cluster head selection is done through modifying threshold value and routing data using multihop communication helps to balance energy load among nodes. Paths towards BS are determined through estimating routing metrics such as queue length, available bandwidth, link quality and residual energy. Simulation results show, proposed EAMRS outperforms existing PSOGA and PECR scheme in terms of energy efficient improvement of 34% compared with PSOGA and 27% compared with PECR. In future, BS or sink relocation scheme can be modelled for energy harvesting and to reduce the burden of discovering paths towards sink.

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