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# An Efficient Load Balancing Scheme of Energy Gauge Nodes to Maximize the Lifespan of Constraint Oriented Networks

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**ABSTRACT** Resource limited networks have various applications in our daily life. However, a challenging issue associated with these networks is a uniform load balancing strategy to prolong their lifespan. In literature, various schemes try to improve the scalability and reliability of the networks, but majority of these approaches assume homogeneous networks. Moreover, most of the technique uses distance, residual energy and hop count values to balance the energy consumption of participating nodes and prolong the network lifetime. Therefore, an energy efficient load balancing scheme for heterogeneous wireless sensor networks (WSNs) need to be developed. In this article, an energy gauge node (EGN) based communication infrastructure is presented to develop a uniform load balancing strategy for resource-limited networks. EGN measures the residual energy of the participating nodes i.e.,  $C_i \in Network$ . Moreover, EGN nodes advertise hop selection information in the network which is used by ordinary nodes to update their routing tables. Likewise, ordinary nodes use this information to uni-cast its collected data to the destination. EGN nodes work on built-in configuration to categorize their neighboring nodes such as powerful, normal and critical energy categories. EGN uses the strength of packet reply (SPR) and round trip time (RTT) values to measure the neighboring node's residual energy ( $E_r$ ) and those node(s) which have a maximum  $E_r$  values are advertised as reliable paths for communication. Furthermore, EGN transmits a route request (RREQ) in the network and receives route reply (RREP) from every node reside in its closed proximity which is used to compute the  $E_r$  energy values of the neighboring node(s). If  $E_r$  value of a neighboring node is less than the defined category threshold value then this node is advertised as non-available for communication as a relaying node. The simulation results show that our proposed scheme surpasses the existing schemes in terms of lifespan of individual nodes, throughput, packet loss ratio (PLR), latency, communication costs and computation costs, etc.. Moreover, our proposed scheme prolongs the lifespan of WSNs and as well as an individual node against exiting schemes in the operational environment.

**INDEX TERMS** Wireless sensor network, routing protocol, heterogeneous WSNs, low power devices, load balancing, EGN nodes, connectivity of wireless nodes.

## I. INTRODUCTION

Wireless sensor networks (WSNs) are the collection of sensor nodes with built-in capacity of self-organization to form

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an operational network. These nodes are used to probe the environment and share their collected data with a common base station according to the application requirements. Generally, existing communication mechanisms designed for traditional networks are not suitable in these networks as sensor nodes are restricted in terms of power, processing and

communication capacities [1]. Therefore, communication mechanisms specifically designed for these networks have focused on efficient utilization of on-board battery, minimum communication or transmission overheads, lifetime optimization both nodes and networks, end-to-end (E2E) delay and packet delivery ratio, etc., [2], [3]. However, in terms of resource-limited networks, energy-efficient communication infrastructures with minimum possible overheads, uniform load balancing and prolong lifetime (both nodes  $C_i$  and networks) are an open research problem for the research community. Moreover, WSNs are more susceptible to scalability, data correctness, nodes consistency, delay tolerance, security and privacy issues [4], [5].

Hierarchical deployment and communication infrastructures were presented in the literature to resolve various issues that are tightly coupled with resource-limited networks such as lifetime, coverage area, scalability, end-to-end delay and packet loss ratio (PLR) [6], [7]. However, these approaches were either application specific, that is these are ideal solutions for limited coverage areas, or overlay complex (such as selection process of the cluster head (CH) for short time intervals in operational networks). Additionally, mobility of sensor node  $C_i$  or base station  $S_j$  in the underlined phenomena affects the performance of the resource-limited networks particularly in terms of lifespan, PLR, E2E delay and connectivity of nodes with the base station. For example, if sensor nodes are used on the high ways to form intelligent monitoring systems or infrastructures to control various activities such as over speeding, overloading and other transportation related activities. Although, these networks or devices perform exceptionally well for controlling each and every transportation activity but become very complex or even useless with the passage of time due to their heterogeneity, locations, scalability, movements etc [8], [9]. These problems occur due to the mutual cooperation mechanism among sensor nodes that are used to transmit the collected data of nodes deployed in locations where direct communication with the concerned base station is not possible. Hence, the transmission activity of these nodes is subjected to willingness (if it is free) or cooperation of the relaying node(s) in an operational network [10].

Bonola *et al.* [11] use cabs as data mules to ensure the successful delivery of the collected data to its intended destination. These cabs are embedded with necessary sensing and actuation devices to perform the operation (data collection and transmission) successfully. An intelligent sensor based job scheduling technique is utilized to develop a uniform load balancing strategy in cloud computing [12]. Job scheduling (data collection from static sensors) of these cabs are adjusted dynamically that is based on their priority and optimal energy or resources consumption. When a moving cab enters in the vicinity of an embedded sensing devices, it uses the shortest path to shares the status of assessing location technology such as 802.15.4 and Bluetooth. This mechanism is effective in environments when scalability of the underlined network ranges from hundred to thousand. Moreover, the existing

route discovery technique is not beneficial to optimize the cost and energy consumption simultaneously and it occurs due to adoptive nature of both devices and communication links [13]. Preethiya *et al.* [14] presented mobile double cluster head-particle swarm optimization (MDCH-PSO) Scheme to resolve the load balancing issue in heterogeneous WSNs. It consists of four phases such as CH selection, cluster scheduling, mobility and handover predication of CH. However, this model is very complex and hard to implement in real environment.

Zarin and Agarwal [15] proposed central controller node (CCN) based scheme to uniformly distribute traffic among active nodes in an operational heterogeneous network. In this model, CCN nodes use radio signal to balance energy consumption of the active nodes. However, reliable communication between a mobile node and a centralized controller is not always guaranteed. Likewise, Yu *et al.* [16] presented a centralized optimal task allocation scheme to address the uniform load balancing issue with resource limited networks. For this purpose, linear programming and distributed optimal task allocation algorithm was used to minimize energy consumption of sensor nodes. Ang *et al.* [21] proposed an energy aware cluster based multi-hop routing protocol to balance the traffic among active nodes in heterogeneous wireless networks. In scenarios where a node is unable to transmit its data to a concerned CH, then it uses hop count information to transmit this data to the destination. However, due to unnecessary RREQ packet broadcasting mechanism of active nodes, which is used to update neighboring nodes routing table, and extra burden on individual nodes make this model unrealistic and energy harvesting model. Therefore, an energy efficient load balancing scheme with minimum possible communication overhead is needed to be developed for heterogeneous WSNs.

In this article an EGN based communication infrastructure is presented to resolve the load balancing problem associated with resource limited networks. EGNs use the strength of packet reply (SPR) and round trip time delay (RTT) data to calculate the residual energy  $E_r$  of nodes reside in their coverage area in an operational network. The  $E_r$  values are assembled by EGNs in an advertisement packet, that is broadcasted in the network. This information is used by neighboring nodes to adjust their routing tables. Moreover, EGNs ignore neighboring nodes with residual energy  $E_r$  less than a specified threshold value which ensures a prolong lifetime of both individual node(s) and network. Initially, an EGN broadcasts a route request (RREQ) packet continuously after a specified interval of time. Each and every node reside in closed proximity of the concerned EGN respond with a route reply (RREP) message. EGN uses SPR value to calculate the residual energy ( $E_r$ ) of every responding nodes deployed in its coverage area. Similarly, RTT of each RREQ and RREP is used to improve the reliability of an operational network and to ensure uniform energy  $E_r$  consumption mechanism. Additionally, a three level -(which are powerful, normal and critical)- residual energy based categorization mechanism is

proposed to ensure a uniform traffic or load balancing among active nodes i.e., the selection process of next hop neighbor(s) is subjected to these levels. A neighboring node belongs to powerful level is preferred over nodes belong to normal whereas nodes in critical level are ignored.

The development of WSNs is encouraged by their applications in the real world. Therefore, designing a new protocol, modifying the existing protocols, or creating a communication infrastructure for WSNs, the limitation of wireless nodes is kept in mind to design an optimal scheme with accurate results. Similarly, while designing our proposed model, we have kept the applicability application of our scheme in terms of real-world deployment. The proposed model is applicable in Robotics, Body area networks, Industries, Machine monitoring, Agriculture, Military Installations, Threat detection systems, Irrigation, and Transportation, etc.

The remaining paper is organized as follows. The literature review and the limitations of the existing schemes is presented in section II. In section III, the proposed mechanism explained with pictorial diagrams, text description and algorithms is describe in detail. The experimental environment, simulation parameters, the results and discussion is presented in section section IV. Finally, the concluding remarks and future directions are provided in section V.

## II. RELATED WORK

In constraint oriented networks, efficient energy consumption and load balancing infrastructure play a vital role to improve their operational capabilities particularly lifetime, packet delivery ratio and E2E delay, etc.. Therefore, a uniform load balancing and energy efficient communication infrastructure is needed to be developed particularly for resource-limited networks. To resolve this issue, various mechanisms have been presented in the literature. A brief overview of existing techniques, particularly those which are closely related to the proposed model, is presented below.

He *et al.* [18] proposed an energy consumption model for WSN, which considers the physical limitation of active devices during the operational environment of deployed networks. Moreover, this model promotes the resource management framework for energy consumption in active devices of deployed WSN. The light-path provision technique was proposed by Liu *et al.* [19]. They used the knowledge theory information model to achieve load balancing in terms of scheduling modulation level and traffic management in the network. Sun *et al.* [20] proposed the hierarchical data job scheduling strategy (HDJS) based technique for Fog computing. The proposed model of HDJS dynamically manages the priority of tasks scheduling in the network to avoid task starvation and maximizes system output with optimal resources utilization.

Singh Toor and Jain [17] suggested the analytical model approach for load balancing in wireless sensor networks. They used the ordinary nodes energy consumption information to choose the optimal path from source to destination

node and minimize energy consumption of deployed WSN. The task distribution technique for load balancing in WSN was proposed by Wang *et al.* [22]. In this scheme, they promoted a heuristic algorithm to schedule tasks in parallel in the deployed WSN environment, which can minimize energy consumption utilizing the decision-making process of wireless nodes. However, the time limitation of the proposed model affects the whole task schedule and performance in real-time deployment. Shao *et al.* [23] proposed an energy optimization protocol, whose main concerns were the network cost, running property, reliability, and energy consumption. However, the proposed scheme was very complex during implementation, which minimizes its uses in the real deployment environment.

Aissa *et al.* [24] proposed an energy efficient load balancing scheme for WSNs. The proposed model uses path distance information of participating nodes to achieve low energy transmissions and with optimal latency. Moreover, the proposed scheme increases the lifespan of WSNs in an ordinary condition, but with the limitation of specific area deployment such as inside closed buildings, etc.. However, the open area deployment of the proposed model affects its performance by means of distance path information, because transmission media is always susceptible to different external attacks. Miao *et al.* [25] was proposed the multi-hop relay communication and multipath weighted revenue algorithm scheme for load balancing in WSNs. However, both of the aforementioned functions were used in combination to update route information with collected data from participating nodes. Ma *et al.* [26] was proposed the single hop communication scheme, which uses the data collector algorithm to visit each in-range wireless node in deployed WSNs and measure its residual energy to schedule network traffic.

Cheng and Yu [27] had suggested the combined-TSP-Reduce algorithm (CRT) in their research article. They used the TSP algorithm to find each overlapping point as a visiting point (shortest path) in the network. However, the total path of source and destination nodes was too long in the network compared to each visiting point. Therefore, the communication among source and destination nodes in the real deployment of WSNs increases latency in the heterogeneous network environment. A software define method for load balancing in WSN was proposed by Fang *et al.* [28] in their research article. They used software configuration to upgrade normal sensor devices into smart devices, which will be capable to manage their task according to residual energy. The proposed technique was efficient in term of energy consumption, but the deployment phase was very complex in a heterogeneous environment, which minimizes its use in real deployment.

Data collection in WSN is a major concern utilizing communication metrics such as delay, energy consumption per bit, reliability parameters, and network performance. Due to limited onboard battery power, memory, processing, and limited transmission capabilities of these devices make them

more sensitive as discussed in the article [29]. However, in most of the deployment circumstances, wireless nodes transmit their collected information through multipath hop count communication in networks, which can cause delay issues in the real deployment infrastructure. Besides the latency issue reliability is another important issue associated with WSNs, in comparison to wired networks, because wireless nodes transmit their collected data through a wireless medium, which increases the chances of packet lost ratio in the network. The fairness of client works is guaranteed by promoting their work schedule methods on the basis of priority. Moreover, in constrain oriented networks, where the situation of high priority schedule exists, and high priority schedules are given preference over normal packets dynamically. Then this will consume more energy by means of readjusting the normal work schedule as discussed in the article [30]. Subsequently, this will save time for priority messages and after completion of the said task, the normal task starts again from its initiation state, which will consume energy for the second time in the network. Li *et al.* [32] proposed the Energy-Efficient Load Balancing Ant-based Routing Algorithm (EBAR) to resolve the load balancing of WSNs. They used improved pheromone trail and pseudo-random route discovery algorithms in composition to devise their EBAR scheme. Moreover, their scheme follows the greedy expected energy metrics to minimize energy consumption by route establishment. Sharma *et al.* [33] proposed the data dissemination scheme to address the load balancing issue in UAV coordinated WSNs. They used the properties of the firefly optimization algorithm in their scheme to achieve energy efficiency in deployed UAV coordinated WSNs. Wang *et al.* [34] was proposed a hybrid scheme of Game Algorithm and Distributed Cache Price Bargaining Algorithm to resolve the load balancing issue in satellite wireless networks.

Han *et al.* [35] was proposed the district partition-based data collection algorithm for underwater wireless networks to improves their lifetime. However, the priority-based traffic was managed in this scheme, which increases the packet lost ratio in an operational network. Therefore, this scheme was not effective for critical systems. Wang *et al.* [36] proposed a novel algorithm, which was designed from the combined merits of the clustering strategy and the compressive sensing-based (CS-based) scheme to address the load balancing issue in WSNs. The Game theory-based Energy Efficient Clustering routing protocol (GEEC) was proposed by Lin and Wang [37] to resolve the load balancing issue in WSNs. The proposed scheme uses the basic phenomena of game theory to address the load balancing issue in WSNs and prolong the network lifespan. The dual-cluster-head scheme for load balancing of WSNs was proposed by Lin and Wang [37] to minimize the energy consumption of deployed wireless nodes and prolong their lifetime. El Alami and Najid [38] proposed the enhanced clustering hierarchy (ECH) scheme to resolve the load balancing issue in WSNs. The used sleep and wake-up mechanism for adjacent nodes for WSN to minimize the energy consumption of participating nodes and

prolong the network lifetime. Lee and Teng [39] designed the low-energy adaptive clustering hierarchy protocol to address the load balancing issue in WSNs in terms of minimizing the energy consumption of wireless sensor and maximize their lifespan. To address the load balancing issue in WSNs, a low-energy adaptive clustering hierarchy protocol was proposed by El Alami and Najid [40], which uses the fuzzy interference system to overcome the packet lost ratio in an operational network. The cluster hierarchical routing protocol was proposed by El Alami and Najid [41], to resolve the load balancing problem in WSN. To resolve the load balancing issue in WSNs El Alami and Najid [42], proposed the Fuzzy Logic based Clustering Algorithm (CAFL). Moreover, the proposed model uses the residual energy information of ordinary nodes for cluster head selection. El Alami and Najid [43], suggested the three FUZZY (SEFP) method for heterogeneous WSN environment, in order to extend the life cycle of the sensor nodes in deployed WSN. They used the parameters such as distance from BS, distance between sensor nodes and residual energy information of ordinary nodes, while deciding the cluster head node in the network. Alami and Najid [44], proposed the Routing-Gi scheme to resolve the load balancing issue in WSN. Moreover, they divide the network area into two grids such as cluster grid and inner grid to communicate the collected data of wireless nodes in the network with minimum energy consumption.

#### A. LIMITATION OF EXISTING SCHEMES

Although, load balancing is a mature research area but the majority of the existing schemes are either application specific or overlay complex. Therefore, efficient load balancing in WSNs is still an open area for researchers to devise new techniques and resolve the aforementioned issue in WSNs. Moreover, it has been observed in the literature that most of the suggested techniques are not capable to address energy consumption issues associated with wireless nodes, such as dynamic nature and limited resources, etc. However, the latest routing techniques use hop count information for load balancing, but they degrade the network performance employing optimal decisions toward next hop. Likewise, in the mentioned schemes routing and data relaying are restricted, which can generate communications issues, such as latency, transmission and computation, etc. Some of the main issues associated with the existing scheme are:

- 1) Some of the existing schemes are specific to the system.
- 2) Overlay complex implementation in the real environment.
- 3) Transmission problems such as latency, packet lost ratio and network overhead, etc.
- 4) High network deployment cost.

#### B. CONTRIBUTION OF PROPOSED SCHEME

The literature suggests various schemes to prolong the lifetime of WSNs, but most of them have their pros and cons in terms of network performance, complex implementation,

specific system installation, etc. Therefore, an Energy Gauge Nodes (EGN) load balancing scheme is proposed in this article to resolve the load balancing issue in WSN. The proposed scheme not only improves the network lifetime, but also improve the communication reliability such as latency, throughput, communication costs, computation costs, individual nodes lifespan, and packets lost ratio. The steps adopted for the implementation of Energy Gauge Nodes (EGN) scheme are as shown below:

- 1) To interconnect deployed wireless nodes in network topological order.
- 2) Random deployment of Energy Gauge Nodes (EGN) in designated network infrastructure.
- 3) To establish a communication infrastructure among ordinary nodes, EGN nodes, and base stations in the deployed network.
- 4) EGN nodes to calculate accurate residual energy  $E_r$  of ordinary nodes and advertise their routing information in the network.
- 5) Efficient energy level categorization of ordinary nodes to balance its energy consumption with other ordinary nodes in the network.
- 6) To verify the performance reliability of the proposed ENG node scheme in the presence of its competitor's schemes in terms of network lifespan and communication metrics such as latency, packet lost ratio, and throughput.

However, the drawback of the proposed scheme is that each EGN node comprises only 15 ordinary nodes at a time. We therefore need to install a large number of EGN nodes during the construction of the topological architecture of the WSN network. However, if the number of EGN nodes is small in the area being deployed, there is a risk of overhead or congestion, although this is unusual situation, since we know the total number of ordinary nodes to be deployed in the region being defined and we can manage the number of EGN nodes accordingly.

### III. PROPOSED METHODOLOGY

The heuristic performance of WSN and IoT greatly depends on the energy consumption of wireless nodes. The appropriate utilization of wireless nodes in WSNs minimizes energy consumption and maximizes its lifetime. However, the literature investigates various techniques of routing protocols to minimize the energy consumption of WSNs. Moreover, most of the existing techniques are developed from the previous scheme with a slight modification, but these schemes have some limitations like specific to operation, homogeneous network infrastructure, region-based networks or complex implementation, etc.

The notation used in the paper are shown in table 1.

Therefore, in this article, we proposed an Energy Gauge Node (EGN) technique to resolve the aforesaid issue of load balancing in WSNs. The EGN node is used in the deployment phase with ordinary nodes to architect network

**TABLE 1. Abbreviation and notation used in the paper.**

Abbreviation/Notation	Description explanation
WSN	Wireless Sensor Network
EGN	Energy Gauge Node
SPR	Strength of Packet Reply
RTT	Round Trip Time
$E_r$	Residual Energy
RREQ	Route Request
RREP	Route Reply
PLR	Packet Loss Ratio
E2E	End to End delay
CH	Cluster Head
l	Packet Size
D	Distance
$C_i$	Ordinary node
$E_{tx}$	Energy Consumption during transmission
$E_{cons}$	Average Energy Consumption
$E_{am2}$ )	Amplifier Consumed energy
$T_i$	Working Time period of ordinary node
$E_i$	Initial Energy
$T_X$	Transmission of Packet
$T_r$	Reception of Packet
UDP	User Datagram Protocol
CBR	Constant Bitrate

topology. EGN nodes are special nodes, which have high onboard battery power with great processing, communication, and memory storage capabilities. EGN nodes calculate the residual energy ( $E_r$ ) of ordinary nodes and advertised their hop selection information in the network. The EGN node measures the residual energy ( $E_r$ ) of ordinary nodes in the network utilizing RREP information of responding nodes in their vicinity. Furthermore, the EGN nodes use their built-in configuration to advertises hop selection information of an ordinary node for neighboring nodes in the network, based on their  $E_r$  energy.

EGN node broadcasts a route request (RREQ) message in the network and the ordinary nodes in the closed vicinity respond with a route reply (RREP) message. EGN node uses the information of RREP packets such as node ID, Strength of Packet Reply (SPR) and Round Trip Time (RTT) to calculate the residual energy ( $E_r$ ) of responding node and advertise their hop selection information for neighboring nodes in the network. Likewise, the ordinary nodes in the proximity of an EGN node use this advertised information to transmit data from source to the destination node with minimal energy consumption.

Moreover, the ordinary nodes of the network are categorized into three categories, i.e. powerful, normal, and critical categories. Based on the mentioned categorization metrics, the sleep cycle of ordinary nodes is defined to balance the energy consumption of each participating node. At the initial stage of deployment, every node is full of energy, which is known as the powerful category. Similarly, the subsequent energy states are categorized as a normal and critical category.

To elaborate on the concept of energy categorization in our proposed model. The EGN node broadcasts RREQ in the network, the ordinary nodes in their proximity receives EGN RREQ and respond with RREP message. The ordinary nodes RREP message contains information such as node-ID, RTT, and SPR. EGN node use this information to calculate

the  $E_r$  energy of each RREP message based on RTT and SPR information, if all the RREPs messages have the same  $E_r$  energy. In this case, all of the nodes are eligible for hop selection in the communication process from source to destination, and EGN node advertises their candidate-ship of hop selection in the network. Similarly, if the  $E_r$  energy of an ordinary node is less than that of a powerful category, then the responding node is categorized as a normal node and its hop selection information is managed by an EGN node. Additionally, this node has not been further advertised by an EGN node for hop selection.

Furthermore, to explain the RREP processing of an EGN node in the proposed model is that each EGN node can accommodate 15 ordinary nodes in their vicinity. The nodes, they have low  $E_r$  energy level are not advertised by an EGN for hop selection, once the total number of nodes for an EGN reaches 10, they have the same  $E_r$  energy level. Then the configuration of an EGN node reverts and all nodes in the defined energy category is allowed for the communication and hop selection process according to EGN node configuration. Similarly, after the powerful category, the communicating ordinary nodes are categorized as normal nodes, and now they are allowed to participate in the communication process. Subsequently, the residual energy ( $E_r$ ) comparison and verification process is continuous in the network. When the  $E_r$  energy level of any ordinary node reaches a critical category, as discussed for the previous phase, its sleep cycle is managed by an EGN node. The advertisement of this node is ignored by an EGN node for hop selection in the network to maintain a balanced energy level among all participating nodes. Similarly, when the number of nodes in the normal category reaches 10 for an EGN, they have low  $E_r$  energy level, then the EGN node exhausts the defined configuration. Similarly, after this, the ordinary nodes in the vicinity of an EGN node is allowed to participate in the network.

Now the participating nodes in the vicinity of an EGN node are eligible for next-hop selection as per EGN advertisement in the communication process like the powerful category, but this time the ordinary nodes are categorized with critical energy category. Keeping in view, the operational mechanism of our proposed EGN nodes scheme, EGN nodes utilizes all participating nodes in the communication and next-hop selection process, which allows the participating nodes to consume balance energy in the network.

Therefore, our proposed model of EGN not only maximizes network lifespan with balance energy utilization, but it also minimizes network overhead by advertising route selection information with least E2E delay and high throughput. The route selection information of EGN allows ordinary nodes of the network to share information in (*unicast*) fashion. The unicast communication of ordinary nodes minimizes network overhead, latency, and maximizes throughput. Furthermore, our scheme maximizes network lifespan with balance energy consumption, which verify network performance reliability, in sense of communication cost and also allow all participating nodes to be alive until the critical category.

In case, an ordinary node receives packets from two or more EGN nodes it will respond with a RREP message. However, the concern EGN nodes will calculate their  $E_r$  energy and advertise their hop selection information in their vicinity. Once, the  $E_r$  energy of that specified ordinary node fall below the defined category, its hop count selection should be ignored by the concern EGN nodes, because the  $E_r$  calculation, energy categorization and hop count selection advertisement configuration of all EGN nodes are same. Therefore, the proposed model is very effective to allow each participating ordinary node work as hop selection node in the network, which balance the energy consumption of all ordinary nodes. The important thing to mention about our scheme is that the  $E_r$  energy calculation continues until a single RREP reply from an ordinary node, because route advertisement is the responsibility of the EGN node.

Figure 1 of the paper shows the basic diagram of the Energy Gauge Node (EGN) scheme. The diagram furthermore, shows the connectivity links among ordinary nodes, base station (BS), and EGN nodes with different color lines. However, the intra-connectivity among the ordinary nodes in the diagram are shown with orange lines, while the connectivity with BS is shown with red lines. EGN nodes are shown in pink color and their communication with ordinary nodes are shown with black lines. Moreover, as stated earlier in the paper, EGN nodes generate RREQ messages in the network, all the neighboring nodes (as shown in figure 1) respond with RREP messages. EGN node uses RREP information of responding nodes to calculate the residual energy ( $E_r$ ). Similarly, the ordinary nodes of the network transmit information from source to destination by following the advertised hop selection information of an EGN node. In this way, the information is transmitted from source to destination node, and likewise to remote location through concern base station and network cloud in a heterogeneous environment.

#### A. ENERGY MODEL FOR OUR SCHEME: ENERGY GAUGE NODE (EGN)

The energy model for EGN is presented in this subsection with consideration of heterogeneous wireless network infrastructure. Wireless nodes  $C_i \in$  network are dynamically distributed in the infrastructure-free environment, which is denoted by (n). The deployed nodes use hop count selection information to transmit data from source to destination. Furthermore, base station and network clouds are used to transmit the collected data to a remote location/destination.

However, the energy consumption model [31] is taken for data transmission in the network with packet size ( $l$ ) and distance ( $D$ ).

$$E_{tx} = \begin{cases} (E_{cons} \times (T_x \& T_r) + D^2 \times E_{am1}) \times l \\ \text{Where, } d \leq d_t \\ \\ (E_{cons} \times (T_x \& T_r) + D^4 \times E_{am2}) \times l \\ \text{Where, } d > d_t \end{cases} \quad (1)$$

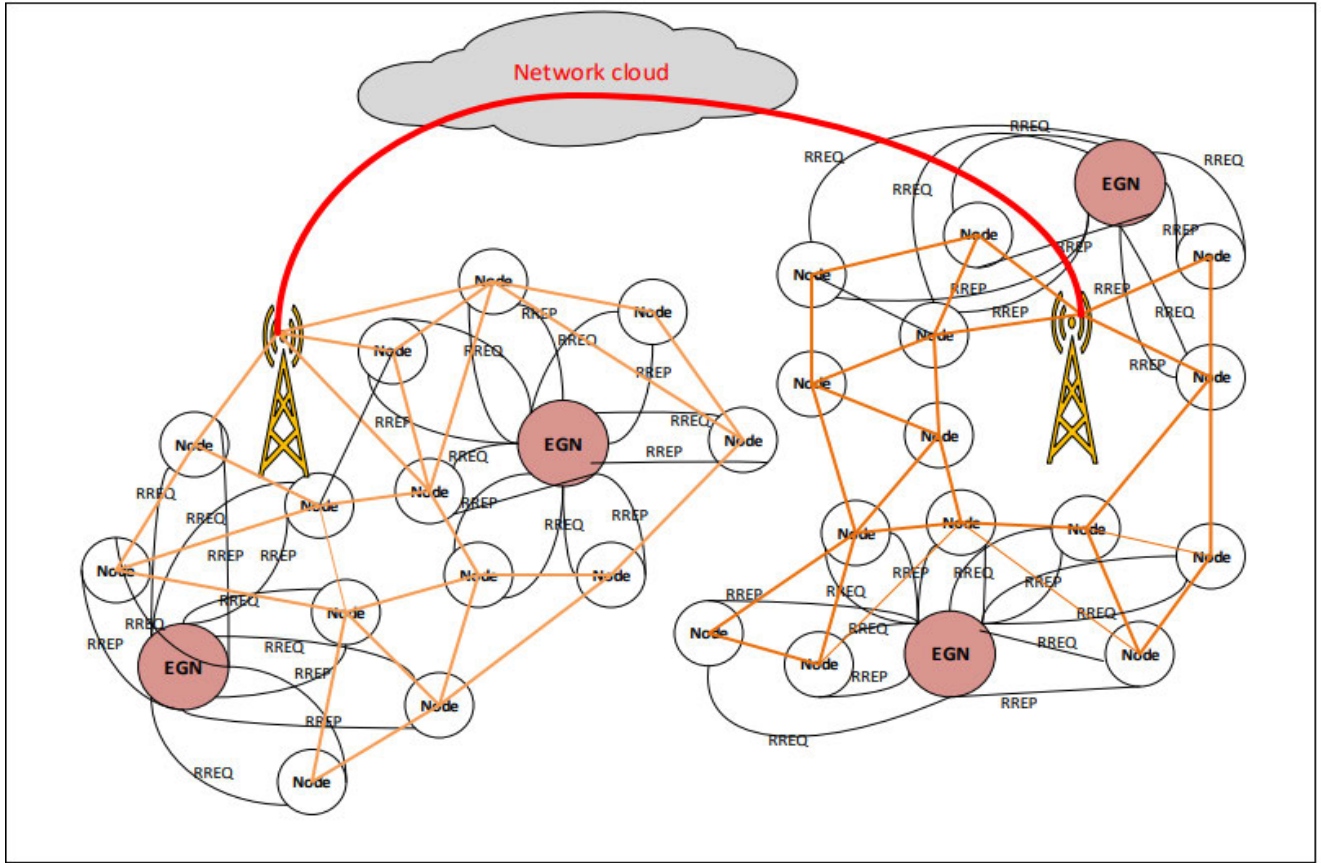


FIGURE 1. EGN scheme brief overview diagram.

where  $E_{cons}$  is the average energy consumption of the both sending and receiving of message packet.

$$Reception\ Energy\ (E_{Rx}) = E_{cons} \times l \quad (2)$$

To elaborate, the concepts of parameters used in equations 1 & 2. We used  $E_{cons}$  to shows the consumed energy for the transmission and reception of a particular data packet (in bits). However,  $T_x$  and  $T_r$  denotes the transmission and reception of a packet in the network. Moreover,  $E_{Rx}$  denotes the energy consumption of a sensor node, while receiving a message packet. The parameter  $D$  is used to represent the distance threshold between source to destination node, while the amplifier consumed energy is shown with the symbols  $E_{am2} \times D^4$  or  $E_{am1} \times D^2$  in equations 1 & 2, during the transmission process. Subsequently, the utilization of mentioned equations is adopted for energy categorization of the aforementioned matrices, such as powerful category, normal and critical. These categorizations are based on sensor nodes working life cycle with respect to residual energy  $E_r$ . The working life cycle of sensor nodes defines the time period, where the sensor node has enough energy to collect and process data in the network.

The operational mechanism of an EGN node can be elaborate by considering a network topology that has a dynamic

number of wireless nodes. The initial energy of each sensor node is  $E_i$ , which allows the sensor node to works for a time period ( $T$ ) in the network. So, the life cycle of a sensor node can be calculated by the following formula.

$$Time\ period(T_l) = (T \times E_i) \div Energy_{Tx}(E_{Tx}),\ (d, l) \quad (3)$$

$$(E_r) = (E_i) - (E_{cons}) \quad (4)$$

In equation 3  $T_l$  denotes the time period, where an ordinary node can work in the operational network. Similarly, energy consumption during transmission and reception is symbolized with  $Energy_{Tx}$  and  $Energy_{Rx}$ . The categorization of energy levels are made for defined metrics in the implementation phase as given in the following example.

The energy consumption of each participating wireless node is associated with the assigned task because the sensor node consumes energy during data collection, processing, transmission, and reception. Let assume that  $C_i \in C_{n-1}$  denotes the set of sensor nodes. EGN nodes calculate the residual energy and advertise hop selection information of participating nodes in the network by in the considering the same scenario. The energy consumption of an ordinary node

$C_i$  node at  $r$ -th round. Where  $i = (1, 2, 3, 4, \dots, n)$ .

$$E_{cons}^r(C_i) = \left\{ \begin{array}{l} E_{cons, C_i}^r \text{ (task consumption energy)} \\ + \sum_{c_j} c_i (E_{cons, c_j}^r) \end{array} \right\} \quad (5)$$

In equation 5  $E_{cons, ci}^r$  denote the energy consumption of an ordinary node  $C_i$ , while processing their assign task. Similarly,  $E_{cons, C_j}^r$  represents the energy consumption of an ordinary node  $C_j$ , when it transmits or receives a message packet in the network.

Therefore, the total energy consumption of an ordinary node in ( $r$ ) round should be assumed as  $E_{cons}^r$  for  $C_i$  node according to equation 5. Subject to equation 5, EGN nodes used RREP messages of the ordinary nodes to calculate their residual energy.

Moreover, in the proposed model, EGN node uses the RTT and SPR of responding nodes RREP(s) to accurately calculate their residual energy. The RTT time is adjusted with distance parameters of responding nodes RREP(s) based on SPR to verify their residual energy ( $E_r$ ). Once, an EGN node receives RREP message from an ordinary node in their vicinity, EGN checks the RTT and SPR metrics to calculate the  $E_r$  energy of the responding node. However, EGN used the generic formula of equation 4 to calculate the value of  $E_r$  energy of responding node by putting equation 5 as energy consumption of an ordinary node.

According to the given scenario, the formula became as:

$$\text{Residual Energy } (E_r) = \text{initial energy } (E_i) - E_{C_i}^r \quad (6)$$

EGN nodes follows equation 6 to calculate the residual energy of an ordinary node for ( $r$ ) rounds and categorizes its energy phase.

Let's assume that the initial energy ( $E_i$ ) of an ordinary node is 50,000 *mAH*, which is also known as a powerful category in our proposed model. Once, the communication process start and the network became operational, the energy of ordinary nodes are decreasing through  $E_{tx}$  and  $E_{Rx}$  as shown in equation 1 & 2, where  $E_{tx}$  represent the amount of consumed energy during the transmission of a packet and  $E_{Rx}$  represents the amount of consumed energy during the reception of a packet. Similarly, the residual energy ( $E_r$ ) of an ordinary node is also decreasing by means of  $E_{tx}$  and  $E_{rx}$ . Once, the  $E_r$  energy of an ordinary node reaches 30,000 *mAH*, it's non-availability of hop selection for transmission is advertised by an EGN node in the network.

Moreover, it is also pertinent to mention that this node is only not available for hop count or path selection, but it works as normal ordinary node in the network to collect and process information according to their assigned task. Once, the energy level ratio for an EGN node reach 10 nodes (in defined level of category), then EGN node reverts the operational paradigm for deployed location of the network. The revert configuration of EGN allows all the ordinary nodes to start participation in the network. However, when the residual energy  $E_r$  for a node reaches 15,000 *mAH*. In this case, it's sleep cycle

and non-availability for communication is adjusted again by EGN node in the normal category until nodes ratio of ordinary nodes reaches 10 for an EGN node. In this phase, once the ratio of ordinary nodes reaches 10 nodes, which have  $< E_r$  energy level (Normal category), then the EGN reverts the operational configuration and all ordinary nodes start participation in the network communication process.

## B. POWERFUL ENERGY CATEGORIZATION: PHASE 1

Wireless nodes and Energy Gauge Nodes (EGN) are dynamically deployed in the Unstructured region. The assumption will be made in the first phase to calculate the residual energy ( $E_r$ ) of ordinary nodes. In this phase, the EGN nodes generate RREQ messages in the network, and all in range nodes respond with RREP messages. However, the limit set for an EGN node is 15 ordinary nodes RREP(s) in their vicinity to measure their  $E_r$  energy and advertised their hop selection information in the network. EGN checks the SPR and RTT of incoming RREP packets to calculate the residual energy ( $E_r$ ) of the responding node. If the  $E_r$  energy of every responding node does not fall below the range of normal energy level/category  $\geq 30,000$  *mAH*, then the EGN node broadcasts the routing information of all responding nodes in the network (for hop selection). Likewise, all the ordinary nodes in the proximity of an EGN update their routing table. Similarly, they follow the advertised hop selection information of the EGN node for forwarding messages from source to destination node.

EGN nodes continuously broadcast RREQ messages in the network to measure the  $E_r$  energy of the participating ordinary nodes and advertise their hop selection information in the network. Wherever, the  $E_r$  energy of an ordinary falls below the defined category, then the EGN node does not advertise their hop selection information in the network. Consequently, the process of  $E_r$  energy measurement and route advertisement of an EGN node are continuous until the ratio of ordinary nodes for an EGN reaches ( $\geq$ ) 10 nodes, which is a limit set for an EGN node to revert its configuration. After, this the EGN nodes reverted their configuration and start advertisement of route selection information of all ordinary, but this phase in our scheme normal energy category. The detailed overview diagram of phase 1 is shown in figure 2.

In figure 2, an EGN node is shown in the middle of the diagram with a pink color by generating RREQ messages in the network (as shown with green lines). The legitimate nodes of the network are responding with RREP messages (as shown with blues lines). The intra-connectivity among the ordinary nodes are shown with orange lines, which are used to transmit information from source node to destination node and likewise to BS. However, after the reception of RREP from ordinary nodes, EGN node calculates the  $E_r$  energy on the basis of SPR and RTT, if the  $E_r$  energy is greater than the defined level of normal category, then EGN node advertised the routing information of all responding nodes by a broadcast message in the network. Similarly, all the nodes in the closest proximity update their routing table for hop



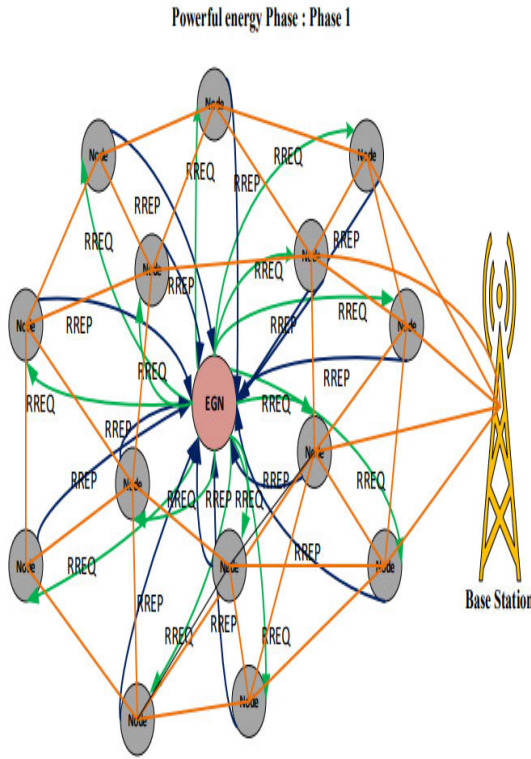


FIGURE 2. Detail connectivity diagram of EGN node with other ordinary nodes, while processing a RREQ for  $E_r$  calculation of responding nodes.

count selection in the network. The ordinary nodes use the advertised information of an EGN node to transmit their collected data from source to destination node in unicast fashion, which minimizes network overhead and energy consumption of ordinary nodes in the operational network. The proposed algorithm for phase 1 is shown below, where an ordinary node is represented by  $C_i$ , Energy Gauge Node by EGN and residual energy by  $E_r$ . The  $E_r$  energy categorization is considered for phase 1, where  $E_r$  energy level is  $\geq 30,000$  mAH. Moreover, the upper-bond of an EGN is 15 ordinary nodes, because each EGN can accommodate up to 15 ordinary nodes in their vicinity.

In algorithm 1, an EGN node initiates the RREQ message in the network. Initially, the EGN nodes have node RREP, but after advertisement of RREQ message, the ordinary nodes in their vicinity respond with RREP message. EGN node uses its built-in configuration to calculate the residual energy  $E_r$  of responding RREP nodes based on define metrics. However, each EGN node can accommodate 15 nodes in their vicinity to process their RREP(s) for calculation of  $E_r$  energy and advertised their hop selection information in the network. Therefore, we used for loop with upper bond 15 in the algorithm. After, calculation of  $E_r$  energy of incoming RREP message, if the  $E_r$  energy of incoming RREP message is  $\geq 30,000$  mAH, then EGN categorized it as a powerful energy level and advertised its hop selection information in the network. Likewise, if the  $E_r$  energy of incoming RREP is

**Algorithm 1** Nodes With Powerful Energy: Phase 1

**Require:** Advertise Route selection information of those nodes, they have high  $E_r$  energy level  $\geq 30,000$  mAH (Powerful category).

**Ensure:** Powerful energy category,  $E_r$  energy level of each responding node  $\geq 30,000$  mAH

- 1: EGN generates  $\rightarrow$  RREQ
- 2: Initially EGN have RREP  $\leftarrow 0$
- 3:  $C_i \in$  Ordinary nodes  $\leftarrow$  Responds with a RREP
- 4: EGN calculates  $E_r \leftarrow C_i$  (RREP)
- 5: **For** ( $i=0$ ;  $i \leq 15$ ;  $i++$ )
- 6: EGN Calculates  $\leftarrow E_r$  of  $C_i$  (RREP)
- 7: where RREP =  $i$
- 8: **If**
- 9:  $E_r$  of  $C_i \leftarrow \geq$  to 30,000 mAH
- 10: EGN  $\leftarrow$  Broadcast routing info of  $C_i \in C_{n-1}$
- 11:  $C_i \in C_{n-1} \leftarrow$  Update their routing table
- 12: **If-Else**
- 13:  $E_r$  of  $C_i$  RREP  $\leftarrow <$  30,000 mAH
- 14: EGN  $\leftarrow$  did not advertise  $C_i$  hop selection info
- 15: EGN  $\leftarrow C_i$  RREP = 10 =  $<$  30,000 mAH
- 16: **Then**
- 17: EGN  $\leftarrow$  Revert configuration to initial state
- 18: **end if**
- 19: EGN  $\leftarrow$  allow communication among  $C_i \in$  Ordinary nodes
- 20: **end for**
- 21: **return** Current state of legitimate nodes with  $E_r$

$< 30,000$  mAH, then EGN did not advertise its hop selection information in the network. The process of  $E_r$  energy calculation for incoming RREP(s) continues, once an EGN reaches 10 nodes, they have less  $E_r$  level as of the defined category. In this case, EGN node reverts its configuration to the next energy category.

*Theorem 1:* An Energy Gauge Node (EGN) advertised hop selection information of  $C_i \in$  Ordinary nodes **if**  $C_i$  node  $E_r$  energy  $\geq 30,000$  mAH.

*Proof of Theorem 1:* Let's assume that Energy Gauge Node (EGN) generates RREQ messages in the network. The  $C_i \in C_{n-1}$  or ordinary nodes receives EGN RREQ and respond with a RREP packet. EGN node process the received RREP of  $C_i$  node to calculate the  $E_r$  energy by following the defined calculation steps. After, calculation of  $E_r$  energy of responding node, EGN checks its value with a defined threshold value. In this case, the  $E_r$  energy of responding node is  $\geq 30,000$  mAH. So, the  $E_r$  energy of responding  $C_i$  node RREP  $\in$  powerful category.

**Hence,** the  $E_r$  of responding node ( $C_i$ ) RREP satisfy the said condition, because  $C_i$  RREP has  $\geq$  to 30,000 mAH  $E_r$  energy, which  $\in$  powerful category and its route selection information is advertised by an EGN node in the network.

**Conversely,** EGN node calculates the  $E_r$  energy of responding node ( $C_i$  node), which  $<$  30,000 mAH. So the  $E_r$

energy of responding ( $C_i$  node) did not  $\in$  powerful category. Therefore, EGN did not advertised its hop selection information in the network. The aforementioned theorem proves that only  $C_i$  nodes  $\in$  ordinary nodes are eligible for hop selection in powerful category, they have  $E_r \geq 30,000$  mAH.

**C. NORMAL ENERGY CATEGORIZATION: PHASE 2**

The normal energy category also follows the same steps of phase 1 (powerful category), but in this phase the  $E_r$  energy of  $C_i$  node  $\in$  ordinary nodes are  $\geq 15,000$  mAH. EGN node generates RREQ messages in the network and all in range or close proximity nodes respond with RREP messages. EGN node checks the *SPR* and *RTT* of responding node RREP to calculate the residual energy ( $E_r$ ) of responding nodes  $C_i$  node  $\in$  ordinary nodes. After, the calculation of  $E_r$  energy of responding node EGN node match it with define threshold values. If the value of responding node  $E_r$  energy is ( $\geq$ ) 15,000 mAH, then the EGN broadcast the routing information in the network for hop selection. The  $C_i$  node  $\in$  ordinary nodes update their routing table according to EGN node information and process their collected information via an advertised route of EGN in unicast fashion.

The comprehensive overview of ordinary nodes and EGN nodes connectivity are shown in figure 2 of the paper. However, the Steps followed in the normal energy category are shown in figure 3, where EGN node generates RREQ messages to and the participating  $C_i$  nodes  $\in$  ordinary nodes responds with RREP messages. EGN uses *SPR* and *RTT* information of responding RREP message to calculate  $E_r$  energy, as shown in the figure 3. Figure 3 of the paper shows the complete follow thorough of the normal energy category

(Phase 2). After the powerful energy, an ordinary node enters into this phase. In this phase the  $E_r$  energy of an ordinary node is  $\geq 15,000$  mAH. In figure 3, the ordinary nodes are shown with brown color and EGN node with pink color. EGN node initiates RREQ messages with ordinary nodes, which is shown with a green arrow in the figure. Similarly, the ordinary nodes respond with RREP messages to EGN RREQ, which is shown with black arrows in the figure. The dark yellow color links show the connectivity among ordinary nodes, which is advertised by EGN node to process their information in the network.

Algorithm 2 shows the step by step process of phase 2. The parameters of algorithm 1 is used in algorithm 2.

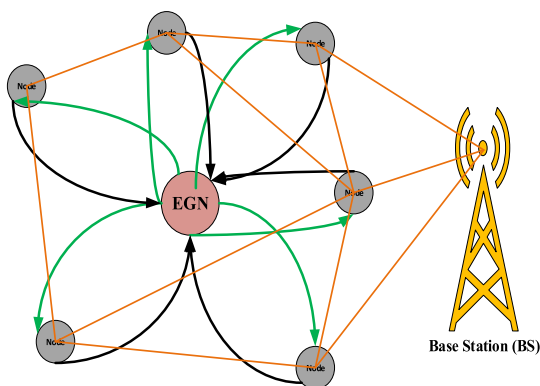
**Algorithm 2** Nodes With Normal Energy Category: Phase 2

**Require:** Allow only those ordinary nodes, they have  $E_r$  energy  $\geq 15,000$  mAH.

**Ensure:** Normal energy category,  $E_r$  energy of each responding node  $\geq 15,000$  mAH

- 1: EGN generates  $\mapsto$  RREQ
- 2: Initially EGN have RREP  $\leftarrow 0$
- 3:  $C_i \in C_{n-1}$  responds  $\leftarrow$  RREP message
- 4: EGN calculates  $E_r$  energy  $\leftarrow$  responding  $C_i \in C_{n-1}$
- 5: EGN node receives RREP for i, where i is the number of ordinary nodes
- 6: **For** (i=0; i  $\leq$  15; i++)
- 7: EGN calculates  $E_r \leftarrow C_i$  RREP
- 8: **If**
- 9:  $E_r$  energy of  $C_i \leftarrow \geq 15,000$  mAH
- 10: **Then**
- 11: EGN  $\leftarrow$  advertise  $C_i \in C_{n-1}$  route selection info
- 12:  $C_i \in C_{n-1} \leftarrow$  Updates their routing table
- 13:  $C_i \in C_{n-1} \leftarrow$  follows EGN advertised route
- 14: **If-else**
- 15:  $C_i$  RREP  $E_r$  energy  $\leftarrow < 15,000$  mAH
- 16: EGN  $\leftarrow$  Did not advertise  $C_i$  hop selection info
- 17: EGN  $\leftarrow C_i \leftarrow RREP = 10 = < 15,000$  mAH
- 18: EGN  $\leftarrow$  Revert configuration to initial state
- 19: **end if**
- 20: EGN  $\leftarrow$  allow communication among all  $C_i$  nodes  $\in$  ordinary nodes
- 21: **end for**
- 22: **return** Current state of legitimate nodes with  $E_r$  energy.

An EGN node initiates RREQ message with ordinary nodes (As shown with green lines). The ordinary nodes in close proximity shown with brown color respond with a RREP packet (As shown with black arrows).



EGN uses Equation (4) to calculate the  $E_r$  energy of responding node, If the  $E_r$  energy is  $< 30,000$  mAH and  $> 15,000$  mAH. Then EGN apply Phase two configuration or normal energy category



**FIGURE 3.** Graphical overview of normal energy category.

responding nodes  $\in$  ordinary nodes. Likewise, the ordinary node  $C_i$  uses EGN route selection information to transmit data from source to the destination node via EGN advertised hop selection information. Moreover, if the  $E_r$  energy of  $C_i \in$  ordinary nodes is  $< 15,000$  mAH, then the EGN node did not advertise hop selection of  $C_i$  node until this ratio reaches 10 nodes for a specific EGN node. After, that the configuration of an EGN node is reverted to its original state and the energy calculation process is continues. Likewise, all the  $C_i \in$  ordinary nodes are eligible for route selection (hop count) to transmit a packet from source to destination node in the network.

**Theorem 2:** An Energy Gauge Node (EGN) advertise hop selection information of  $C_i \in$  ordinary nodes in the network, if a node  $C_i$  has  $E_r$  energy  $\geq 15,000$  mAH.

*Proof of Theorem 2:* Let's assume that EGN generates a route request RREQ message in the network. Once the  $C_i$  node  $\in$  ordinary nodes in the close proximity receive EGN RREQ message, they respond with a route reply RREP packet. EGN node uses the RREP information such as RTT and SPR to calculate the  $E_r$  energy of responding  $C_i$  node. After, the calculation  $E_r$  energy of  $C_i$  node, EGN matches the value of  $E_r$  energy of  $C_i$  node to define its category. The  $C_i$  node  $E_r$  energy is  $> 15,000$  mAH. Thus EGN advertised the hop selection information of  $C_i \in$  ordinary nodes in the network.

**Conversely**, if an ordinary node ( $C_i$ ) responds with an RREP message to EGN RREQ message in their vicinity. EGN calculate the  $E_r$  energy of responding  $C_i$  node. The  $E_r$  energy of responding  $C_i$  node is  $< 15,000$  mAH. The EGN did not advertise it hop selection information in the network, because  $C_i$  node did not fall the normal energy category.

**Hence**, theorem-2 proves that EGN node only advertise the route selection information of  $C_i$  node  $\in$  ordinary nodes, they have  $E_r$  energy  $\geq 15,000$  mAH.

### D. CRITICAL ENERGY CATEGORIZATION PHASE: PHASE 3

The subsequent step of the normal category is a critical category, which is also known as phase 3. The  $E_r$  energy verification process of EGN nodes are continuing in the network. Once, the residual energy level of ordinary nodes  $< 15,000$  mAH, then they are categorized as a critical category in the proposed model. In this category, EGN nodes advertised the hop selection information of all participating nodes in the network. Moreover, EGN nodes initiate RREQ messages and  $C_i$  node  $\in$  ordinary nodes in their vicinity respond with RREP messages. However, in this phase, the EGN node did not categorize ordinary nodes and advertised hop selection information in the network. The EGN node hop advertisement process is continued until the  $E_r$  energy level of  $C_i$  node  $\in$  ordinary nodes reaches (0) because hop selection advertisement is the responsibility of EGN node in the proposed model.

**Theorem 3:** An EGN node advertised hop selection information of  $C_i$  node  $\in$  ordinary nodes in the network, if  $C_i$  node has  $E_r$  energy  $\geq 0$  mAH.

*Proof of Theorem 3:* Let's suppose that an EGN node generates RREQ message in the network. The  $C_i$  node  $\in$  ordinary nodes in their vicinity respond with RREP message. The EGN node calculates the  $E_r$  energy of responding RREP messages and advertised their hop selection information in the network. The EGN node continuously initiates RREQ messages and their vicinity ordinary nodes respond with RREP messages. Likewise, EGN nodes use the RREP information of responding nodes to advertise their hop selection in the network. However, in this phase, EGN nodes did not categorize the ordinary nodes of the network and advertise their hop selection candidate-ship until their last RREP message, where the  $E_r$  of an ordinary node became 0 mAH.

**Conversely**, if an ordinary  $C_i$  of the network having  $E_r$  energy  $< 0$  mAH, they will be unable to respond EGN node RREQ.

**Therefore**, theorem 3 proves that EGN node advertise hop selection information of those  $C_i$  node, they have  $E_r$  energy  $> 0$  mAH.

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### Algorithm 3 Nodes With Critical Energy: Phase 3

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**Require:** Allow  $C_i$  node  $\in$  ordinary nodes, they have high  $E_r$  energy  $\geq 0$  mAH.

**Ensure:** participation of  $C_i$  node  $\in$  ordinary nodes, they have  $E_r$  energy  $\geq 0$  mAH.

- 1: EGN node generates  $\mapsto$  RREQ
  - 2:  $C_i$  node  $\in$  ordinary nodes  $\leftarrow$  responds with RREP
  - 3: EGN node calculates  $E_r$  energy & advertised hop selection information  $\leftarrow C_i \in$  ordinary nodes
  - 4: **For** ( $i=0$ ;  $i \leq 15$ ;  $i++$ )
  - 5: where  $i =$  is the number of nodes
  - 6: EGN advertise hop selection information of  $C_i \in C_{n-1} \leftarrow$  until  $C_i E_r$  energy = 0 mAH
  - 7:  $C_i$  node  $E_r$  energy = 0 mAH  $\leftarrow$  EGN did not receives  $C_i$  RREP in their vicinity
  - 8:  $C_i$  node  $\leftarrow$  considered as dead node
  - 9: **end for**
  - 10: **return** Current state of legitimate nodes with  $E_r$  energy.
- 

Algorithm 3 of the paper overviews phase 3 of the proposed model in detail. The EGN node initiates RREQ messages and the  $C_i$  nodes  $\in C_{n-1}$  respond with RREP messages. EGN node uses RREP information such as RTT and SPR to calculate the  $E_r$  energy and advertised their hop selection information in the network. However, in this phase, the EGN node did not categorize ordinary nodes as shown in the algorithm 3. EGN nodes advertise hop selection information of ordinary nodes until their  $E_r$  energy becomes 0 mAH. At 0 mAH an ordinary node is considered as a dead node in the deployed network.

### E. COMPARATIVE FORMAL ANALYSIS OF THE PROPOSED SCHEME

In this section, the formal analysis of the proposed model is made with its rival schemes to clarify its effectiveness

**TABLE 2.** Detailed comparative formal analysis of our scheme with rival schemes.

Scheme name	Complex implementation	Operational Complexities	Homogeneous environment or System Specific	Heterogeneous environment
Kenneth et al. [21]	Yes	Yes	No	No
Aissa, et al, [20]	No	Yes	Yes	No
Sun et al. [16]	No	No	Yes	Yes
Tan et al. [25]	Yes	No	Yes	Yes
Our scheme	No	No	No	Yes

in the deployed area. The competitor's schemes of our proposed model have some limitations which include complex implementation, specific to the system or homogeneous environment, high implementation cost, network overhead, and complex operational requirement, etc. Our proposed scheme surpasses the aforementioned limitation of existing schemes by a simple implementation, reliable network traffic, heterogeneous environment deployment, simple operational framework, and least implementation costs. Table 2 contains the detailed formal analysis of our proposed scheme with its rival schemes in terms of the aforementioned metrics.

#### F. COMPLEXITY OF THE PROPOSED SCHEME

The analysis of complexity is an important factor in evaluating the applicability, reliability, performance, and robustness of the algorithms. The best complexity case for our proposed algorithm is  $O(m + t)$ , where  $m$  denotes the length of message packets and  $t$  represents the time interval. The complexity of our proposed algorithm is idealistic in the current network infrastructure because the next-hop count is selected in one iteration, where the traditional algorithm first generates initiation packet in the network, after, that they compute the next hop count. Similarly, the worse case complexity for the proposed algorithm is  $O(Mn) + O(t)$ , where  $n$  is a constant value and  $m$  is the length of the half message packets in time  $t$  series. However, in the worst-case scenario, the performance of our proposed algorithm is better than the traditional algorithm, because of its limited comparing computation size.

#### IV. EXPERIMENT RESULTS ANALYSIS

In this section of the paper, a comprehensive statistical analysis are over-viewed. The proposed scheme of EGN nodes were implemented in the simulation environment, where OMNeT++ was used as simulation tool. Moreover, OMNeT++ simulation tool has the capability to check the feasibility of WSNs, IoT and Ad hoc networks projects, because act as real time simulation tool to check the statistical analysis. The experiment of proposed scheme was conducted by specifying a network area, distributed wireless nodes, BS and EGN node to develop network topology. After distributing wireless nodes in the designated environment of network framework, EGN nodes and base stations were also managed in the network infrastructure. Moreover, the EGN nodes were configured for their assigned task, such as to measures  $E_r$  energy of each incoming RREP, and also to advertise their hop selection information in the network.

Furthermore, the connectivity of ordinary nodes were extended to base stations for the heterogeneous network environment. The parameters taken to develop the network infrastructure and implement the proposed scheme are shown in table 3. Moreover, these parameters are mandatory to develop network infrastructure of our proposed scheme.

**TABLE 3.** Parameters set of data used in proposed scheme implementation.

Name of Parameter	Values of parameters
Simulation Environment	1000 x 1000 $m^2$
Simulation Tool	OMNeT++
Channel bandwidth	8 Mbps
Consumed energy ( $E_{TX}$ )	65.6 mW
Wireless nodes $C_i \in C_{n-1}$	50, 100, 300, 500, 800
Number of Base Stations (BS)	2,6,10,15
Consumption of energy during Idle state	1.02 mW
Consumed energy during transmission of a packet ( $T_x$ )	65.6 mW
Consumed energy during reception of a packet ( $T_r$ )	48.6 mW
Consumption of energy during Sleep mode	0.7 $\mu$ W
Transmission interval of EGN	25 $\mu$ sec
Residual Energy $E_r$ of a node	$E_i - E_{cons}$ equation (4)
Energy Gauge nodes (EGN)	4, 10, 25, 60, 95
Initial Energy of nodes $E_i$	50,000 mAh
Initial Energy of EGN	250,000 mAh
Transmission range	100 meters
Network Traffic type	UDP and CBR
Packet Size	128 Kbps

The simulation environment for the proposed scheme was taken 1000  $\times$  1000 square meters, where a dynamic number of ordinary nodes were distributed in an unstructured manner. EGN nodes and BS(s) were also deployed in the offline phase. However, to verify the reliability factor of the proposed scheme, we have changed the simulation environment in terms of a grid selection, where the environment was taken as 1000  $\times$  1200 meters and 1000  $\times$  1500 meters consequently. The communication parameters were kept constant during the change of the simulation grid to overview the results of the proposed model for comparative analysis. Moreover, ENG nodes are special nodes, which have the capabilities to calculate the residual energy  $E_r$  of ordinary nodes and advertised their hop selection information in the vicinity. EGN node can accommodate 15 ordinary nodes at a time to calculate  $E_r$  energy and advertise hop selection of these in the close proximity. To verify the feasibility of proposed model for heterogeneous WSNs environment base station was used to transmit information to the remote location. The channel bandwidth and energy consumption for ordinary nodes were kept constant during simulation analysis. Moreover, the used parameters have been defined with its preferred values in 3.

**TABLE 4.** Detailed comparative computational analysis of our scheme with its competitor schemes.

Scheme name	Ordinary nodes at site	Next-Hope	Base Station	Total Cost
Kenneth et al. [21]	$3T_{XOR} + 4T_{msg} + 4T_{es}$	$6T_{XOR} + 6T_{msg} + 4T_{es}$	$6T_{XOR} + 6T_{msg} + 5T_{es}$	$15T_{XOR} + 17T_{msg} + 13T_{es}$
Aissa, et al. [20]	$4T_{XOR} + 4T_{msg} + 4T_{es}$	$8T_{XOR} + 6T_{msg} + 4T_{es}$	$7T_{XOR} + 6T_{msg} + 6T_{es}$	$19T_{XOR} + 16T_{msg} + 12T_{es}$
Sun et al. [16]	$3T_{XOR} + 5T_{msg} + 6T_{es}$	$5T_{XOR} + 5T_{msg} + 8T_{es}$	$6T_{XOR} + 6T_{msg} + 10T_{es}$	$14T_{XOR} + 16T_{msg} + 24T_{es}$
Tan et al. [25]	$3T_{XOR} + 3T_{msg} + 3T_{es}$	$4T_{XOR} + 3T_{msg} + 5T_{es}$	$6T_{XOR} + 6T_{msg} + 6T_{es}$	$13T_{XOR} + 12T_{msg} + 14T_{es}$
Our scheme	$3T_{XOR} + 3T_{msg} + 3T_{es}$	$3T_{XOR} + 3T_{msg} + 3T_{es}$	$3T_{XOR} + 2T_{msg} + 4T_{es}$	$9T_{XOR} + 8T_{msg} + 10T_{es}$

### A. PERFORMANCE EVALUATION OF THE PROPOSED SCHEME

This section of the paper evaluates the performance reliability of our scheme. The proposed scheme was implemented in the OMNet++ simulation tool. Moreover, the evaluation made during simulation experiment for our scheme against different metrics are over-viewed in this subsection. The performance of our scheme was evaluated in terms of energy consumption, network lifespan, communication cost, throughput, E2E delay and PLR ratio against its rival scheme. However, in the initial implementation phase the energy levels of ordinary node were set according to table 2 parameters.

### B. COMPUTATION COST ANALYSIS OF OUR SCHEME WITH IT'S RIVAL SCHEMES

The results of the proposed scheme were also seen for computation cost, because the schemes, they have the least computation cost are given preference over the competitor's schemes if they do not compromise network performance. Therefore, we have evaluated our proposed scheme with an existing scheme in terms of computational cost to comprehensively overview the network reliability metrics i.e., network lifetime, communication cost and network overhead, etc.. The detailed evaluations of computational cost for the proposed scheme in the presence of the rival schemes are illustrated in table 4. The exclusive OR operation is symbolized in the below table with  $T_{XOR}$ , where the processing time of a message is denoted by  $T_{msg}$  and  $T_{es}$  represent the session time, where two nodes establish a communication session. In WSNs, the computation cost starts from ordinary nodes communication with neighbor's nodes, which subsequently, moves to next-hop count up-to destination node.

### C. COMMUNICATION COST ANALYSIS OF OUR SCHEME

The communication cost of proposed scheme was compared to its rival scheme on the basis of packet transmission from source to destination nodes, where the related factor such as latency, PLR and optimal path was observed to accurately calculate the communication cost of our scheme. Although, the performance of proposed scheme was significant in terms of communication, due to unicast communication and minimum network overhead. Therefore, our proposed model has the least communication cost, which is shown in table 5. The

**TABLE 5.** Communication cost comparison table of our scheme and different existing schemes.

Scheme Name	The Number of messages sent	Total number of Bits
Kenneth, et al. [17]	7	7,168
Aissa, et al. [24]	8	8,192
Sun, et al. [20]	10	10,240
Tan, et al. [29]	10	20,240
Our Scheme	6	6,134

route advertisement of EGN node not only minimized the communication cost, but it also minimizes network overhead. Our scheme has the lowest communication cost among the competitors schemes except Ang *et al.* [21] scheme, but the implementation complexity of this scheme minimizes its use in the real deployment. Moreover, the EGN node route advertisement allows the ordinary nodes to transmit the messages in unicast direction through advertised route information, which is as a whole maintain the reliability factor of network communication.

### D. ENERGY CONSUMPTION OF OUR SCHEME

The results observed during experiment simulation for energy consumption was exceptional for our scheme. As stated earlier in the paper, the EGN node route advertisement for hop selection, enables the ordinary node of the network to update their routing table without additional communication with adjacent nodes. Practically, this was observed during the simulation that the ordinary nodes use the advertised route selection information of EGN node for their transmission of data from source to destination node. Similarly, the  $E_r$  energy calculation of EGN node was observed for specific ordinary node  $C_i$  over a different interval of time, which was found quite excellent. Overall the energy consumption of our proposed model for various ordinary nodes found consistence and according to equation 1 and 2 calculation as defined for EGN node. The results statistic captured during simulation for our scheme are compared with its rival schemes in figure 4.

### E. NETWORK LIFETIME RESULTS ANALYSIS

The network lifespan analysis was observed for varying number of nodes and time scenario. The results observed during simulation for our efficient routing scheme based on EGN

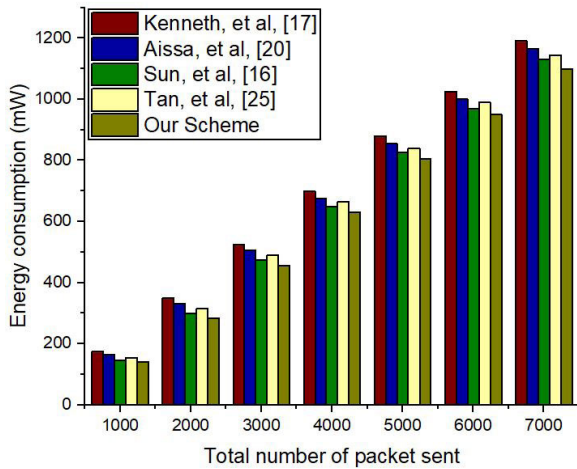


FIGURE 4. Analysis of energy consumption of the proposed and field proven schemes.

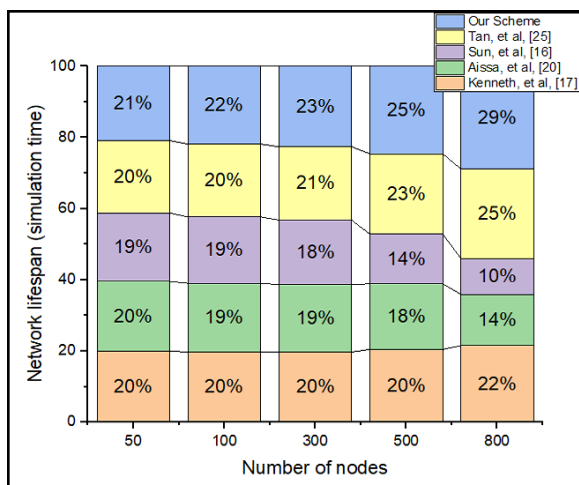


FIGURE 5. Statistical lifespan analysis of our scheme and its rival scheme.

node route advertisement was excellent in comparison with its rival schemes. Moreover, with this energy efficiency ratio our scheme has the least communication cost as shown in 2. Furthermore, the communication overhead observed on the network was minimized, due to ordinary nodes unicast communication. Similarly, the route selection information was advertised by an EGN node in the network, which allows the ordinary nodes to transmit messages as per routing table information. This not only minimize energy consumption of an individual node, but it also maximizes the network lifespan, which had been observed in our scheme during simulation analysis. Moreover, the network lifespan comparisons were made for dynamic number of nodes (participating in the network) based % network time. The statistical analysis of our scheme and its competitors are shown in figure 5.

**F. BALANCE ENERGY CONSUMPTION ANALYSIS OF PROPOSED SCHEME**

The energy consumption of the proposed scheme was evaluated during the simulation for defined categories until the

final stage of an ordinary node, where the  $C_i$  residual energy  $E_r$  was 0 mAH. The EGN nodes were used in the proposed model to calculate the  $E_r$  of participating nodes and advertised their hop selection information in the network. Moreover, EGN nodes use their built-in configuration to categorize the ordinary nodes of the network based on a  $E_r$  energy level in the defined energy category.

Three energy categories were defined for ordinary nodes, which includes powerful, normal, and critical energy category. During the simulation ordinary nodes have assigned initial energy of 50,000 mAH. Three energy categories were made for EGN nodes built-in configuration by dividing the initial energy of ordinary nodes into three parts. The first range was set about > 30,000 mAH as a powerful category,  $E_r$  energy > 15,000 mAH for the normal category, and  $E_r$  energy < 15,000 for the critical category. The simulation network becomes operational by exchanging information, the EGN nodes were found initiating RREQ messaging in the network. In response, EGN nodes receive RREP(s) messages from their vicinity ordinary nodes. The EGN nodes continuously calculate the residual energy of responding nodes and advertised their hop selection information in the network. The ordinary nodes update their routing table according to EGN node route selection information and transmit their messages in the unicast communication by following EGN nodes advertised route information. The unicast communication of ordinary nodes in the network minimizes energy consumption by following EGN advertised route selection information for their transmission of data to destination node/location. Moreover, one EGN node can accommodate 15 ordinary nodes in their vicinity to calculate  $E_r$  energy and advertised their hop selection information in the network. Moreover, the configuration of EGN nodes was set about 10 nodes to have to revert their configuration.

EGN nodes checks for their built-in revert configuration, when the ratio of responding ordinary nodes reaches 10 nodes, they have less energy level than the defined one. Then the EGN node was found to revert its configuration and allow its vicinity nodes to participate in the communication process. In this manner, EGN nodes allow maximum participating nodes to be selected for hop selection communication in the network. Moreover, the ordinary nodes, they consumed more energy in the defined category were not advertised for hop selection to process the neighbor's nodes messages to the destination node. This balances the energy consumption of all participating node in the network with a better E2E delay. Therefore, the energy categorization of the proposed model allows maximum nodes to participate in the network until the end-stage with equal energy consumption. The maximum nodes were found to participate in the operational network during the simulation. The participating nodes not only minimized the energy consumption but it also minimized the network overhead, communication cost, and prolong the network lifespan with maximum alive sensor nodes. The live node's participation in the proposed scheme until the end-stage proved a balance energy consumption

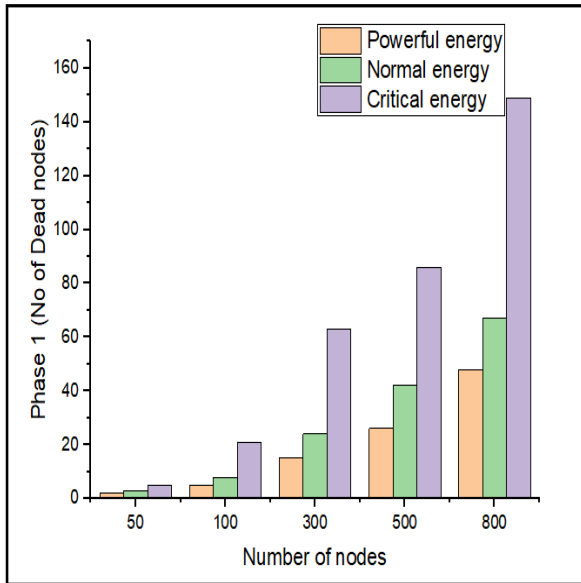


FIGURE 6. Graphical statistics of dead nodes during operational network in all three phases.

about 95 % in captured results, which verifies the importance of our scheme. Figure 6 shows the graphical analysis of the proposed scheme with the competitor’s schemes.

**G. ENERGY GAUGE NODE SCHEME THROUGHPUT STATISTICAL RESULTS ANALYSIS WITH COMPETITORS SCHEMES**

Figure 7 of the paper represents the throughput statistical analysis of our scheme in the presence of rival schemes. The performance reliability of communication was also checked for the proposed scheme in terms of throughput. The number of ordinary nodes and network traffic was increased gradually in the simulation environment to overview the result statistic for throughput. The results observed for throughput during simulation for our scheme reveal significant improvement

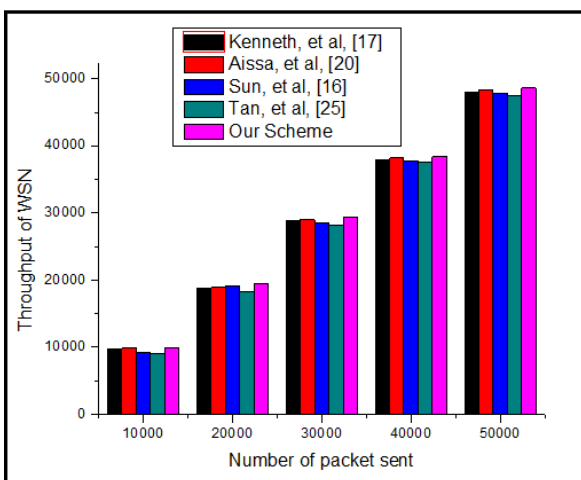


FIGURE 7. Throughput analysis statistics of our scheme with its rival schemes.

over the existing schemes. The route advertisement information of EGN node not only minimized the network overhead, but it also improves the network throughput, because every node had next-hop selection information to transmit messages. Moreover, the unicast communication of legitimate nodes in the network, maximizes throughput, with minimum congestion and contention chance.

**H. ENERGY GAUGE NODE SCHEME END-TO-END DELAY (E2E) RESULTS EVALUATION WITH RIVAL SCHEME**

The results statistics of the Energy Gauge Node (EGN) scheme was also seen for E2E delay during simulation. The network traffic was increased gradually to capture the results statistics for the E2E delay for our scheme. The results observed for E2E during simulation showed consistency in terms of time during the entire process of communication. Moreover, we evaluate the E2E delay of our scheme with the rival schemes to overview the performance reliability. Figure 8 of the paper shows the E2E delay statistical analysis of our scheme with rival schemes. Although, we have increased the number of ordinary nodes dynamically to observed time consistency during simulation for RREQ and RREP messages. The results captured during simulation showed consistency in terms of time. Moreover, the route advertisement of EGN nodes in the network minimized network overhead, which allows the ordinary node to share their collected data in a unicast communication environment with destination nodes. The unicast communication of our scheme not only minimizes network overhead, but also maintain consistency in end to end (E2E) delay. Therefore, the E2E results of the proposed scheme surpasses the rival scheme with better result statistics.

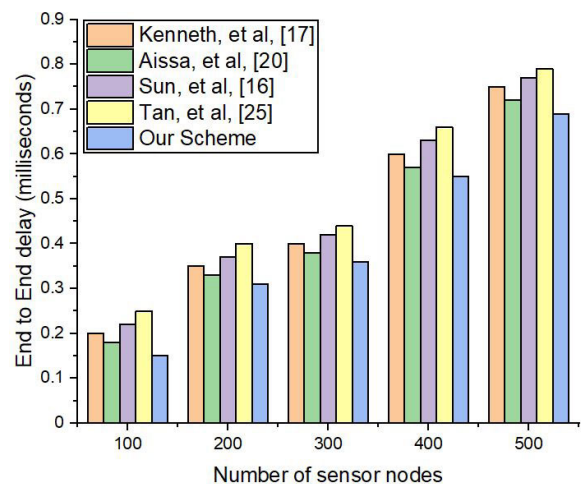


FIGURE 8. End to End analysis statistics of our scheme with its rival schemes.

**I. PACKET LOST RATIO RESULTS ANALYSIS OR PACKET DELIVERY RATIO**

The performance reliability of our scheme was also observed for packet lost ratio. The packet lost ratio analysis were made

during simulation by varying the number of nodes in the network. The route advertisement of EGN node plays an important role to improve the packet lost ratio. The route advertisement of an EGN node in their vicinity not only minimizes computation cost and network, but it also improves the packet lost ratio in terms of unicast communication of ordinary to share their collected data with destination node. The packet lost ratio observed during simulation results against our scheme had better result statistics over the existing scheme. The unicast communication of ordinary nodes based on advertising route selection information, enables the ordinary nodes to respond each incoming RREQ/RREP message in an operational network. The graphical statistic for packet lost ratio are shown in figure 9.

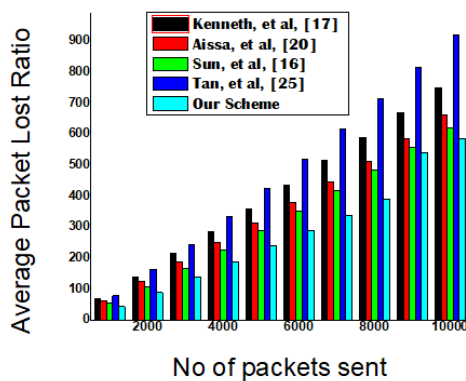


FIGURE 9. Packet lost ratio analysis statistics of our scheme with its rival schemes.

## V. CONCLUSION

In this article, an energy gauge nodes (EGN) based deployment infrastructure and communication mechanism is presented to prolong lifetime of the resource limited networks. The proposed scheme uses various intelligent EGN nodes to perform different activities such as residual energy  $E_r$  computation, identification of ordinary nodes energy levels, optimal route advertisement etc. Due to their built-in configuration, EGN nodes have the capacity to categorize ordinary nodes based on their residual energy  $E_r$ . The categorization process is based on SPR, RTT and RREP values which are collected from the neighboring nodes deployed in its closed proximity. The  $E_r$  value of the responding node  $C_i$  (RREP) is examined by the concerned EGN to identify its category i.e., powerful, normal or critical. If  $E_r$  of 10 nodes which are linked to an EGN is below the defined threshold value then built-in configuration is applied by EGN to ensure a prolonged sleeping cycle of ordinary nodes with their  $E_r \in normal$  or  $critical$  level. Apart from critical phase, the aforementioned process is repeatedly applied in both powerful normal categories. The proposed EGN based load balancing infrastructure ensures the operational capabilities of active nodes until failure of maximum nodes i.e., networks remain operational for maximum possible duration. Simulation results performed in Omnet++ validate the effectiveness of the

proposed scheme against the existing schemes in terms of throughput, network lifetime, E2E delay, PLR and energy consumption.

In the future, we are looking to extend the proposed EGN nodes scheme to IoT network infrastructure. Moreover, we also want to apply some cryptographic techniques to the proposed model to prepare a complete package for IoT networks.

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## COMPLIANCE WITH ETHICAL STANDARDS CONFLICT OF INTEREST

All authors declare that they have no conflict of interest.

## ETHICAL APPROVAL

This article does not contain any studies with human participants or animals performed by any of the authors.

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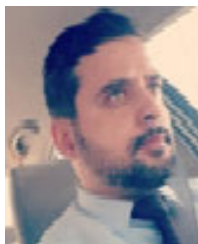
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