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A Balanced Energy-Consuming and Hole-Alleviating Algorithm for Wireless Sensor Networks

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ABSTRACT In wireless sensor networks, energy balancing and energy efficiency are the key requirements to prolong the network lifetime. In this paper, we investigate the problem of energy hole, in which sensor nodes located near the sink or in some other parts of the network die early due to unbalanced load distribution. Moreover, there is a dire need to utilize the energy resource efficiently. For this purpose, balanced energy consumption and hole alleviation, and energy-aware balanced energy-consuming and hole-alleviating algorithms are proposed. These algorithms balance the distribution of load along with efficient energy consumption. An optimal distance and energy-based transmission strategy with least expected error rate is adopted to forward the data packets of different sizes. Furthermore, the data distribution between high-energy consuming nodes and low-energy consuming nodes in each corona is analyzed. This distribution enables the proposed algorithms to outperform their counterparts in term of network lifetime, balanced energy consumption, and throughput on the cost of increased end-to-end delay.

INDEX TERMS Wireless sensor networks, energy balancing, energy hole alleviation, throughput maximization, linear optimization.

I. INTRODUCTION

Wireless Sensor Networks (WSNs) consist of multiple sensor nodes which sense the parameters of interest and report to the sink(s). These networks have the diverse range of applications because of their data gathering capability in hostile, and remote areas [1]– [3]. Generally, deployed nodes are equipped with limited energy; hence, efficient energy consumption is of prime importance. [4], [5]. Sink(s) is the central entity of the network; hence, it is generally located at some central position. The data generated in network is forwarded towards the sink with multi-hop communication paradigm. The nodes nearer to the sink forward the aggregated data (data generated plus data received); hence, energy consumption of these nodes is relatively higher than the farther nodes. Moreover, due to random deployment there may occur the void holes in the network [6]. The presence of void hole further enhances the uneven energy consumption and leads towards the creation of energy holes. The void and energy holes disjoin the networks into disconnected regions, with substantial amount of unused aggregated energy. Hence, with the balanced energy consumption not only the problem of energy holes is reduced, but also the lifetime of the whole network is increased [7]– [10].

The sensor nodes report the sensed data to sink either in direct or in multi-hop transmission manner. Although, direct transmission is an easy way for reporting the data; however, if all nodes transmit data directly then the energy of farther nodes deplete much quickly. Similarly, in multi-hop transmission manner the farther nodes send data to its internal corona nodes. The data packets which are transmitted by the outer corona nodes is mainly distributed in the first radius of the sink. Therefore, the probability of energy hole is maximum near the sink. It is because that smaller is the transmission range more data is forwarded by the sensor nodes located near the sink. However, when the transmission range increases, most of the data is transmitted directly to the sink. Therefore, the load on the first corona nodes decreases and increases on the outer corona nodes. Therefore, it can be concluded that energy consumption is mainly dependent on the data size and the distance parameter [11].

Recently, the optimization techniques efficiently improve the network lifetime by balancing the energy consumption. In which the adaptive range adjustment strategy efficiently enhances the network lifetime [12]. An efficient transmission strategy plays an important role in maximizing the lifetime of a network, which is dependent on the life of sensor nodes. To maximize the network lifetime it is necessary to minimize the death rate of sensor nodes. The death of the sensor nodes is mainly caused by the exhaustion of energy due to unbalanced load distribution. The premature death of sensor nodes leads to serious energy and coverage holes problem. To avoid the energy hole problem around the sink, a wireless sensor network energy hole alleviating (WSNEHA) algorithm is proposed in [13]. The energy consumption of first radius sensor nodes is balanced by the algorithm. However, the energy consumption of sensor nodes located in the other regions is also very uneven. Moreover, there is dire need to utilize the energy resource efficiently. In order to achieve high throughput while being energy efficient, it is necessary to acquire an optimal distance which is free of location error. For this purpose, an energy condition mean square error algorithm is proposed in [17], which considers a distance-based metric to enhance the throughput. Although the algorithm achieves high throughput, though energy hole problem is emerged due to the iterative selection of sensor nodes.

Different algorithms are proposed in the literature and their design either focuses on balanced energy consumption or on high throughput. We consider both the aspects to enhance the throughput with energy efficiency. We propose a balanced energy consuming and hole alleviating (BECHA) algorithm [18] to level the load distribution of entire network. Our first contribution is to extend the work of WSNEHA algorithm by balancing the load of entire network. In second contribution i.e., an energy-aware balanced energy consuming and hole alleviating algorithm (EA-BECHA), our aim is to enhance the throughput by minimizing the packet drop ratio and prolong the network lifetime through efficiently utilizing the energy resource.

Rest of the paper is organized as follows. Section II represents a brief summary of literature review. Section III describes the system model, while the proposed algorithms are presented in section IV. Linear programming based mathematical modeling of simulation parameter are proposed in section V. The performance evaluation is given in section VI, and performance trade-off in section VII. Finally, the summary of contributions along with future work is concluded in section VIII.

II. RELATED WORK

In order to mitigate the uneven energy consumption different approaches are adopted not only to balance the overall energy dissipation but also to increase the network lifetime and throughput. The routing protocols are summarized in Table 1. A distributed coverage hole repair algorithm (HORA) for WSNs is proposed by Sahoo and Liao [14], which employs the node mobility of sensor nodes to reduce the energy hole problem. To maximize the coverage area by minimizing the overlapping region each sensor node checks its status of either cross triangle (CT), hidden cross triangle (HCT), and non-cross triangle (NCT) node. A mobile node is selected on the bases of higher degree of overlapping region and by the condition that its existing connectivity and coverage may not be disturbed. Therefore, the neighbor nodes with higher overlapping region will move first to repair the hole. The algorithm ensures no more coverage hole creation, outperforms in network lifetime and achieves more throughput. However, HORA is not suitable for delay sensitive applications due to the hole repair process.

Latif *et al.* [15], propose a spherical hole repair technique (SHORT) to repair the coverage and energy holes problem in underwater wireless sensor networks (UWSNs). The proposed technique is composed of three phases; knowledge sharing phase (KSP), network operation phase (NOP), and hole repair phase (HRP). Similarly, the nodes with higher degree of overlapping region are responsible for repair of energy and coverage holes. The results show good improvement in term of energy consumption and network lifetime with trade-off of high end-to-end delay.

An optimal distance-based transmission strategy (ODTS) using ant colony optimization (ACO) is proposed in [16]. The algorithm introduces two notions i.e., most energy efficient distance (MEED), and most energy balance distance (MEBD). The local optimal transmission distance is determined by MEED, while the global optimal transmission distance is achieved by balancing the load of all nodes through MEBD. Although, ODTS balances the energy consumption of entire network and efficiently utilizes the energy resource. Therefore, network lifetime maximization is achieved through energy balancing. However, the proposed algorithm is inefficient for random and sparse deployment; moreover, the energy hole problem is emerged due to the iterative selection of nodes.

Chen *et al.* [19], propose a power saving mobicast routing protocol for UWSNs to mitigate the energy hole problem, which is caused by the ocean current and non-uniform deployment of sensor nodes. To overcome the energy hole problem 3-D zone of relevance (3-D ZOR_t), 3-D zone of forwarding (3-D ZOF_{t+1}) and an apple peel technique is introduced. The energy hole problem is eliminated through expending the adaptive segments, while the energy efficiency is achieved by the collection of data through mobile autonomous underwater vehicles (AUVs). The algorithm efficiently maximizes the coverage area by covering the hole region, and also maximizes the packet delivery ratio. However, if the location of nodes is not predetermined then the algorithm will not perform well. Moreover the algorithm also pay cost due to message overhead.

A geographic and opportunistic routing protocol (GEDAR) based on depth-adjustment control strategy for recovery of void nodes is proposed by Countinho *et al.* [20]. GEDAR uses greedy forwarding strategy for finding the neighbors and adjust the depth of void nodes either by buoyancy-based or winch-based. Although, the algorithm outperforms in packet delivery ratio, and less number of re-transmissions. However, the geographic and opportunistic routing protocols are resilient to location error and leads to high end-to-end latency. Furthermore, the algorithm utilizes high energy due to multiple data packets sending to neighbors, and also due to void node recovery procedure.

To avoid the energy hole problem in UWSNs, the authors propose balanced routing (BR) scheme in [21]. To mitigate the energy hole problem around the sink, data of the 1^{st} corona node is allocated to the 2^{nd} corona node using two-hop transmission range $2r$. Although, the algorithm alleviates the energy hole problem in the first corona; however, the corona two which is the two-hop neighbor of sink treats as the one-hop neighbor of sink, which leads to load imbalance and creates energy hole problem.

In order to alleviate the energy hole problem, a mobile sink-based adaptive immune energy-efficient clustering protocol (MSIEEP) is proposed in [22]. The adaptive immune algorithm (AIA) based on energy dissipated is used to find the favorable number of cluster heads (CHs); moreover, AIA is also used to supervise the mobile sink about their sojourn location. Although, the algorithm efficiently utilizes the energy resource, prolongs the network lifetime with increased throughput. However, still the energy hole problem arises due to unbalanced load distribution.

Tunca *et al.* [23] present a virtual ring routing structure with mobile-sink approach to reduce the hotspot problem. To collect the data from nodes, mobile-sink moves in a predefined path. The recent sojourn location of sink is determined by the high-tier sensor nodes, whereas low-tier sensor nodes communicate with the high-tier nodes to take the recent location information of sink. Moreover, the anchor nodes which act as relay nodes to sink are also introduced to successfully forward the data packet to sink. The algorithm maximizes the network lifetime by utilizing the energy resource efficiently and also reduces the end-to-end delay. However, due to erroneous location information the algorithm results in low packet delivery ratio.

A weighted rendezvous planning (WRP) algorithm based on rendezvous points (RPs) is presented in [24] to reduce the traveling path and energy hole problem. A hybrid moving strategy using mobile-sink is adopted to collect the aggregated data from the RPs. The nodes advance their data to the nearest RPs using multi-hop transmission strategy. Similarly, weights are assigned to each node based on the hop-distance and number of packets in buffer. The selection of RP is conditioned to the weight factor i.e., the node with maximum weight factor is selected as RP. Although, network lifetime is achieved by minimizing the energy consumption. However, the algorithm performs inefficiently for data gathering in void regions. Furthermore, due to location error less throughput is achieved.

Lin *et al.* [25], Shamsan *et al.* [26], and Liao *et al.* [27] introduce clustering and mobile agents in WSNs for energy balancing. A virtual tree based cellular topology is presented to balance the uneven load distribution. In order to alleviate the energy hole problem and establish a reliable path for data delivery, the mobile nodes are moved to the hotspot region to collect the sensed data. Moreover, time slot is defined to avoid congestion in communication. The algorithm achieves network lifetime by balancing the load with the cost of high delay.

A general self organized tree-based energy-balance routing protocol (GSTEB) is introduced by the author in [28]. In order to balance the load distribution and minimize the energy consumption a three step technique is proposed, namely tree constructing phase, data collection and transmission phase, and information exchange phase. A root node is selected on the basis of high residual energy between the neighbors or itself, which is responsible for the collection and transmission of data packets. Network lifetime is achieved through efficient energy balancing, though with the cost of delay and message overhead.

An analytical model is presented in [29] which investigate two approaches i.e., hierarchical deployment, and data compression and aggregation. In order to balance the load distribution and mitigate the energy hole, a mobile-sink along with assisting nodes are introduced. The mobile sink collects the aggregated data from the assisting nodes which are at the top layer of normal node and responsible for the transmission of these leaf node data. Energy balancing is achieved with which energy hole problem is also reduced. However, the algorithm is inefficient for delay sensitive application. Similarly, an analytical model is proposed in [30] to evaluate the energy consumption, and network lifetime. The observations are considered during the entire network lifetime and also under given percentage of dead nodes. Moreover, with the proposed model spatio-temporal issues of emerging energy hole are investigated. The emerging time of death appearance and boundary of the energy hole is also determined. The analytical results of the scheme indicate efficient energy utilization and network lifetime longevity.

The use of mobile relay nodes is introduced by the author in [31] to remove the energy hole problem and to solve the issue of localization of sink. For this purpose, the entire network is divided into different clusters and mobile relay nodes are applied in the network to collect data from sensor nodes and transmit further to the sink. The relay nodes are considered as the mobile sink of sub-network regions. The algorithm is suitable for event-driven and continuous data delivery schemes. Moreover, with the help of mobile relay nodes energy efficiency, load balancing, and network lifetime maximization are achieved. However, the network become disjoint if the relay nodes are inefficient to transmit the data packets.

A two-fold game theoretic routing protocol, namely evolutionary game theory (EGT) and classical game theory (CGT) is proposed in [32] to balance the energy consumption of

TABLE 1. Comparison of routing protocols.

Protocol/ Deployment pattern	Feature (s)	Parameter (s) achieved	Parameter (s) compromised
HORA [12] **Random**	Energy and coverage hole repair, multihop transmission	Network lifetime, maximum hole recovered area, low mobility distance	Delay sensitive, high energy consumption
SHORT [13] **Random**	Energy and coverage hole repair, multihop transmission	Coverage area, hole recovered area, high packet delivery ratio, low mobility distance	Long end to end delay, more energy consumption
ODTS [14] **Uniform**	Energy balancing multihop transmission, ant colony optimization	Network lifetime, energy efficiency	Inefficient for random and sparse deployment, energy hole problem
Mobicast [17] **Random**	Energy and coverage hole, apple peel technique, multihop transmission	Energy efficiency, packet delivery ratio	Longer routing path, message overhead
GEDAR [18] **Random**	Recovery of void sensor nodes, energy and coverage hole	Packet delivery ratio, less number of re-transmission	High end to end delay, energy consumption, inefficient in sparse regions
BR [19] **Uniform**	Energy hole, network lifetime	Energy efficiency, network lifetime	Unbalanced load distribution, energy hole problem
MSIEEP [20] **Random**	Energy hole avoidance using mobile sink, clustering, multi-hop transmission	Energy efficiency, network lifetime, low packet drop ratio	Energy hole problem, load imbalance
RR [21] **Random**	Ring routing with mobile sink approach, high-tier and low-tier nodes, multihop communication, hotspot alleviation	Network lifetime, low delay, low energy consumption	Location error, low packet delivery ratio
WRP [22] **Random**	Weighted rendezvous points, mobile sink, multihop transmission, energy hole alleviation	Network lifetime, minimize energy consumption, alleviate energy hole problem	Location error, low packet delivery ratio, energy hole problem in void regions
EBMA [23] **Uniform**	Energy balancing, mobile agents, inter-cluster and intra-cluster	Energy balancing, energy hole alleviation, network lifetime	Location error, delay sensitive
GSTEB [26] **Random**	Tree-based energy balancing, time slot, beacon message	Network lifetime, energy balancing	Message overhead, delay sensitive, location error
AMEA [27] **Uniform randomly**	Analytical model based on hierarichal deployment and data aggregation, mobile agent, assisting nodes	Energy hole alleviation	High delay
DCFR [28] **Uniform**	Energy hole avoidance, multihop transmission	Energy efficiency, network lifetime longevity	Long transmission path, high packet drop ratio
ARCR [29] **Uniform**	Clustering, multihop transmission, relay nodes, mobile sink	Energy balancing, energy efficiency, network lifetime	High end to end delay
GTEB [30] **Random**	Energy hole, evolutionary game theory, classical game theory	Energy balancing, energy hole, network lifetime	Location error, low throughput
ELBAR [31] **Random**	Energy hole, multihop transmission	Packet delivery ratio, energy hole alleviation	Longer routing path, High end to end delay
SNAA [32] **Non-uniform**	Energy hole, sleep mode synchronization of nodes, optimal node selection, multihop transmission	Energy efficiency, network lifetime	High end to end delay

TABLE 1. *(Continued.)* Comparison of routing protocols.

HCR-I [33] **Random**	Energy hole alleviation using clustering, multihop transmission	Energy balancing, network lifetime	Transmission latency, high end to end delay
EHCB [34] **Random**	Energy hole elimination using clustering spatial analysis	Network lifetime, energy hole minimizing	Transmission latency, high end to end delay
HRDR [35] **Random**	Coverage hole repair, energy hole avoidance, multihop transmission	Coverage hole, network lifetime	Repair cost, energy consumption
EHKC [36] **Non-uniform**	Energy sink-hole problem, mobile sink, heterogeneous initial energy	Energy sink hole problem, network reliability, network lifetime	Delay sensitive, energy hole problem

entire network. The former takes the responsibility of energy balancing of different regions, while the latter is used at the nodes level balancing. The task of region level energy balance (RLEB) is to forward a uniform proportion of data packet to all sub-regions. Moreover, the algorithm defines a fitness function to recognize the switching probability between sub-regions which is expressed in term of gain and cost of consumption for advancement. While the node level energy balance (NLEB) is used to select one forwarder from N_K sensor nodes in the sub-region to advance the packet. The algorithm shows good improvement in network lifetime, packet delivery ratio, and average energy consumption. However, the geographic routing protocols are resilient to location error and the sensor nodes require positioning hardware.

In [33], the authors present a routing strategy to divert the data packet through specific angle around the energy hole polygon. The algorithm determines the area and angle of approximate polygon when an energy hole is emerged, whereas the range of polygon is determined by α_{min} and α_{max}. By indicating the hotspot region a hole core information (HCI) message is dispatched to its neighbors. To transmit the suspended data packet, a new route is determined and the useful information is disseminated through the diverted route. Despite the fact that the algorithm outperforms in throughput, though results in long end-to-end delay, more energy depletion and longer routing path.

A synchronization of nodes in adjacent annulus (SNNA) is introduced in [34] to balance the energy usage and mitigate the energy hole problem. In order to minimize the energy hole problem around the sink. The sensor nodes are deployed non-uniformly such as from low density to high density near the sink. Moreover, a synchronization based strategy is put forwarded to transmit and receive the data between adjacent annulus nodes. Each node in the network checks the residual energy and distance to find the optimal parent in the inner annuls. Furthermore, a sleep-mode scheduling mechanism is also introduced to minimize the energy consumption of entire network. Although, the algorithm maximizes the network lifetime. However, with trade-off of long end-to-end delay, and packet loss due to sleep-mode scheduling.

In [35], the authors present cluster head and relay selection mechanism to resist the energy hole problem caused by the first gradient sensor nodes. The procedure is performed in three phases i.e., identify the node that requires a relay, relay selection mechanism, and taking advantage of hybrid clustering and routing (HCR). Moreover, a cost function based on energy threshold is defined by the algorithm for selection of relay nodes. Results indicate good energy balancing and network lifetime longevity with the cost of high transmission latency and end-to-end delay.

In order to mitigate the energy sink-hole problem, a three-tier architecture composed of immobile sink, immobile sensor nodes, and mobile proxy sink is presented by the author in [36]. To minimize the imbalance load on sink neighbors, the sensor nodes deployed in the network are attached with heterogeneous initial energy, such that more energy is allocated to the sink proximal neighbors. Moreover, multiple mobile proxy sinks are responsible for the collection and distribution of data from sink neighbors to immobile sink. The algorithm takes advantage of mobile sink and alleviate the energy hole problem efficiently around the sink neighbors. However, the nodes located in a hop far away from the sink still facing the problem of unbalanced load distribution and energy hole problem.

A probabilistic coverage hole detection algorithm (HDRE) is proposed in [37] to maximize the network lifetime by avoiding energy hole. Sensor nodes with low residual energy die very early; consequently, yields to the emergence of more energy hole. To cope the limitation the algorithm takes decision on the probabilistic analysis and selects an optimal node to repair the coverage hole on the basis of residual energy. HDRE yields no more coverage hole and results in network lifetime longevity with the cost of repair and energy consumption.

The authors in [38] propose a relay node replacement strategy to eliminate the energy hole problem. The relay nodes are uniformly distributed in specific area with equidistant from the sink. The sensor nodes send their data to the relay nodes when their energy is less than a specific threshold. The relay nodes are responsible for data forwarding to the sink. Due to

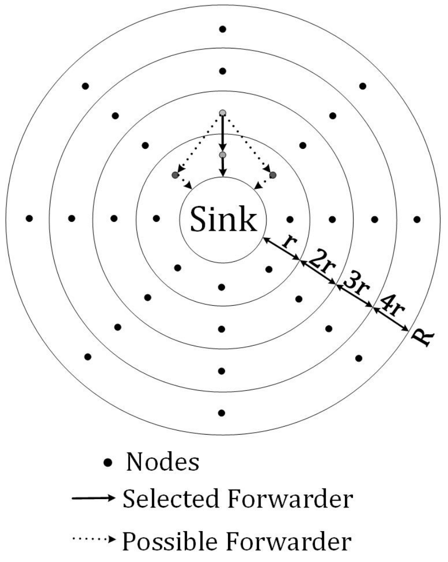

FIGURE 1. Network model of WSNEHA algorithm.

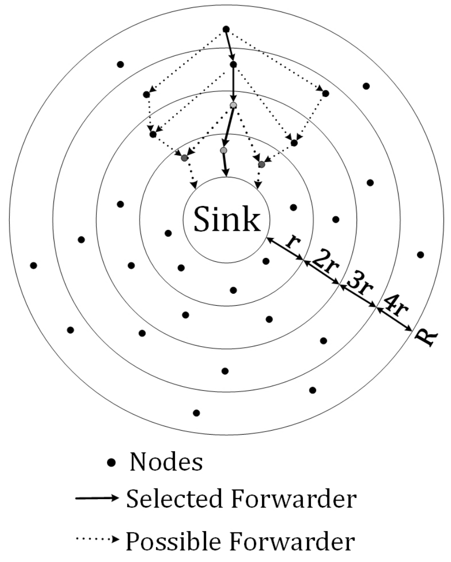

FIGURE 2. Network model of the BECHA algorithm.

the selection of relay nodes network lifetime longevity and energy balancing is achieved.

III. SYSTEM MODEL

We consider a WSN, similar to [6], [16] with network radius R and transmission radius r. The network is further divided into N concentric logical circles denoted as $C_1, C_2, \cdots, C_N$, each with thickness $t = \frac{R}{N}$, as shown in Fig. 1.

A. NODE ATTRIBUTES

Sensor nodes with density σ are deployed uniform randomly around a sink. The sink is free of energy constraint, while the sensor nodes are equipped with limited battery power source. Energy is majorly used in data transmission which is a precious and limited resource. Moreover, sensor nodes are stationary and have the same initial energy and maximum transmission range.

B. NETWORK TOPOLOGY

Let $K = \{k_1, k_2, \cdots, k_n\}$ is the set of sensor nodes, and $L = \{l_1, l_2, \cdots, l_m\}$ be the one-hop neighbors set of K. Let graph $G(t)$=$(V, E(t))$ with $|V| = K$ represents the graph at time t, where V is the set of vertices and E is the set of links at time t. Two sensor nodes i and j are neighbors when they are directly connected through an edge $E \in \{e_{ij}\}$. The data transmission is successful if every sensor node i is connected through a communication channel $\{e_{ij}\}$ with senor node j onward to sink. The flag $\wedge = 0$ indicates that the information is not disseminated to its neighbors.

C. ENERGY CONSUMPTION MODEL

The energy consumption model of receiving and sending b_o bits of data at a distance d is given as [11]:

$$\begin{aligned} E_{Tx}(b_o, d) &= \Re[\,C(\,2^{\frac{s}{\tau\Re}} - 1) + F\,]\,\tau, \\ &= [\,C_{base}\frac{(\,2^{b_0} - 1)}{b_0}\,d^{\alpha} + \frac{F}{b_0}\,]\,s, \end{aligned} \tag{1}$$

where E_{Tx} shows the overall energy consumed in data transmission. d is the distance between source node and neighbor nodes or sink. C_{base}, α, and F are the radio channel constants, s is the packet size, $\Re$ is the information rate. C_{efs} and C_{amp} are the amplifier energy which depends on distance parameter and bit error rate. If $\alpha = 2$ then $C_{base} = C_{efs}$ and if $\alpha = 4$ then $C_{base} = C_{amp}$. d_o is the reference distance ($d_o = \sqrt{\frac{C_{efs}}{C_{amp}}}$), respectively.

$$E_{Tx}(b_o, d) = \begin{cases} [\,C_{efs}\frac{(2^{b_0}-1)}{b_0}\,d^2 + \frac{F}{b_0}\,]\,s & \text{if } d \le d_o \\ [\,C_{amp}\frac{(2^{b_0}-1)}{b_0}\,d^4 + \frac{F}{b_0}\,]\,s & \text{if } d > d_o \end{cases} \tag{2}$$

$$E_{Rx} = \frac{F}{b_o}s, \tag{3}$$

where, E_{Rx} is the energy consumed on data reception.

IV. PROPOSED ALGORITHMS

Energy balancing is in direct relation with the network lifetime. The network lifetime can be prolonged efficiently by implementing good balancing strategy. For this purpose, we propose BECHA and EA-BECHA algorithms.

A. THE BECHA

Initially the sensor nodes are deployed, which are unaware of network information. After the network configuration each node is informed with a hello message which contains the information about sink and neighbors attributes i.e., Node ID, status of link, received signal strength and residual energy of neighbor nodes.

1) NETWORK MODEL

We consider a network model where nodes are deployed uniform randomly around a sink, as shown in Fig. 2. The nodes gather the information from environment and forward either to the next hop forwarding nodes or sink directly.

The data is forwarded to the neighbor nodes according to the energy level and distance parameter.

2) LOAD DISTRIBUTION

The sensor nodes in the outermost corona send data firstly to the internal neighbors. Similarly, the internal corona nodes are responsible for the transmission of aggregated data. The process iterates until the sink successfully receives the data packet. Therefore, more energy is consumed by the inner coronas' sensor nodes. Moreover, in each corona there exists maximum energy consuming and minimum energy consuming nodes. The BECHA algorithm is proposed to balance the energy consumption by distributing the load uniformly. The sensor node which participates more in the data transmission consumes energy quickly. The data packets of different sizes ΔD is calculated in [13] is simplified as:

$$\Delta D_t^x = \begin{cases} \Delta E b_o + F/(C_{efs}(2^{b_o}-1)d^2+2F) & \text{if } d \le d_o \\ \Delta E b_o + F/(C_{amp}(2^{b_o}-1)d^4+2F), & otherwise \end{cases} \tag{4}$$

where ΔD_t^x is the data packet which is allocated according to the energy level of neighbor nodes. Similarly, ΔE is the corresponding energy that is consumed on forwarding this data.

Algorithm 1 BECHA

```
procedure Initialize all parameters
    $E_i :=\{E_1, E_2, E_3, \cdots, E_n\}$;
    $SetNeigh := \{a_1, a_2, a_3, \cdots, a_n\}$;
    $SetNeighDist := \{d_{11}, d_{12}, d_{13}, \cdots, d_{nn}\}$;
    GetInfo ($SetNeig, E_i, SetNeighDist$)
    for each node $i \in N$ do
        generate Rnd
        Find $MaxE_i r, MaxE_{i+1} r$;
        Find $MinE_i r, MinE_{i+1} r$;
        for $d_i < d_{i+1} \&\& MaxE_i r < MaxE_{i+1} r$ do
            if $MaxE_i > Th$ then
                Select $forwarder$;
                Update $SetForwd$
                $E_{avg} : E_{avg} - \Delta E_{i+1}$
                Update $SetE_i, MaxE_i r, MaxE_{i+1} r$
            else
                $break$;
            end if
        end for
    end for
end procedure
```

3) ENERGY CONSUMPTION

The energy consumption of sensor nodes is in direct relation with the distance and data size. More is the transmission distance and packet size more is the energy consumed by sensor nodes. While less amount of energy is consumed when the distance between the transmitter and receiver is minimum. The BECHA algorithm balances the energy consumption by allocating and forwarding the data packets of different sizes to each corona sensor nodes except the outermost corona. In multi-hop communication, it is obvious that there exist minimum energy consuming nodes and maximum energy consuming nodes. For this purpose data packet of different sizes is distributed according to the energy level of $i^{th} - 1$ corona nodes. Assume that a transmitting node t_1 sends data to a receiving node r_1 located at a distance S_1 from t_1. It can be concluded that more amount of data is transmitted if the destination changes to the receiver r_2, such that $r_2 < r_1$.

$$\Delta E = \begin{cases} (\Delta D_t^x(C_{efs}(2^{b_o}-1)d^2+2F)-F)/b_o & \text{if } d \le d_o \\ (\Delta D_t^x(C_{efs}(2^{b_o}-1)d^4+2F)-F)/b_o & otherwise \end{cases} \tag{5}$$

where, ΔE is the amount of energy which is consumed according to the data size and distance parameter.

B. THE EA-BECHA

The goal of EA-BECHA is to alleviate the energy hole problem by minimizing the energy consumption of those sensor nodes which are selected iteratively in each round. Consequently, the energy of nodes exhausts very early and causes energy hole problem. The analysis indicates that there exits maximum and minimum energy consuming nodes in each corona. Therefore, the energy hole problem is eliminated by allocating the data of maximums to minimum energy consuming nodes. The task is performed by selecting an optimal forwarder based on high residual energy and minimum distance from the sink. The EA-BECHA calculates the forwarding factor F_F of neighbor nodes, such as:

$$F_F \propto \frac{N_j^e}{d_{(i,j)}}, \quad \forall j = 1, 2, 3, \cdots, m, \tag{6}$$

where, N_j^e shows the energy of neighbor nodes j, and $d_{(i,j)}$ is the corresponding distance between i^{th} and $i^{th} - 1$ corona nodes. The F_F of all neighbor nodes is calculated according to Eq. 6. Where, the forwarder selected Fs in Eq. 7 shows that the neighbor node with high F_F is selected as the next hop forwarder.

$$Fs = argmax(F_F). \tag{7}$$

Similarly, in each corona the best forwarder is selected on the basis of high F_F. It is obvious that the energy consumption is high when the distance between the transmitter and receiver is maximum. Therefore, the optimal forwarder is selected on the bases of high residual energy and minimum distance from the sink. A routing path at a distance D between a sender and receiver consists of n hops, and $n - 1$ intervening optimal forwarder nodes [16]. The overall energy dissipation is minimum when each node transmits the data through optimal distance $d = D/n$. The total rate of dissipation is given as:

$$\begin{aligned}
E_{tot} &= (n)E_{Tx} + (n-1)E_{Rx} \\
&= \frac{D}{d}[C_{efs}\frac{2^{bo}-1}{b_o}d^{\alpha} + \frac{F}{b_o}] + (\frac{D}{d} - 1)\frac{F}{b_o}, \\
&= \frac{D}{d}C_{efs}\frac{2^{b_o}}{b_o}d^{\alpha} + (\frac{2D}{d} - 1)\frac{F}{b_o}, \\
&= \frac{2DF}{b_o d} - \frac{F}{b_o} + DC_{efs}\frac{2^{b_o}-1}{b_o}d^{\alpha}, \\
&\quad \times(\alpha - 1)C_{efs}\frac{2^{b_o}-1}{b_o}Dd^{\alpha-2} - \frac{2F}{b_o}Dd^{-2} = 0. \qquad (8)
\end{aligned}$$

By taking the derivative of Eq. 8 equal to 0, the energy optimal distance *EOD* can be deduced,

$$d_{EOD} = \sqrt[\alpha]{\frac{2F}{(\alpha - 1)2^{bo-1}C_{efs}}}. \qquad (9)$$

Algorithm 2 EA-BECHA

```
procedure Initialize all parameters
    $E_i := \{E_1, E_2, E_3, \cdots, E_n\}$;
    $SetNeigh := \{a_1, a_2, a_3, \cdots, a_n\}$;
    $SetNeighDist := \{d_{11}, d_{12}, d_{13}, \cdots, d_{nn}\}$;
    $SetForwd := \{f_1, f_2, f_3, \cdots, f_n\}$
    GetInfo ($SetNeig, E_i, SetNeighDist, SetForwd$)
    for each node $i \in N$ do
        generate Rnd
        Find $MaxE_ir, MaxE_{i+1}r$;
        Find $MinE_ir, MinE_{i+1}r$;
        Find $EOD$
        Calculate $F_F \propto N_j^e/d_{EOD}$;
        for $d_i < d_{i+1} \&\& MaxE_ir < MaxE_{i+1}r$ do
            if $MaxE_{i+1} > MaxE_i$ then
                if $E(f_i) > Th$ then
                    if $E_i > E_{avg}$ then
                        if $MaxE_{i+1}r < MaxE_ir$ then
                            Select $optimalforwarder$;
                        else
                            Select next $forwarder$;
                            Update $SetForwd$;
                            $E_{avg} : E_{avg} - \triangle E_{i+1}$;
                            Update $MaxE_ir, MaxE_{i+1}r$;
                            Update $E_i$;
                        end if
                    end if
                else
                    $break$;
                end if
            end if
        end for
    end for
end procedure
```

1) DATA DISTRIBUTION

The aggregated data is transmitted by the sensor nodes in an efficient manner to achieve both high energy efficiency and good energy balancing. The algorithm allocates data packets of different sizes according to the F_F of neighbors and select the neighbor with high F_F. Similarly, the process iterates for all coronas maximums and minimums energy consuming nodes.

2) ENERGY CONSUMPTION

The energy consumption of each sensor node is dependent on data size and distance between the transmitter and receiver. In EA-BECHA the energy consumption is efficiently reduced through the optimal forwarding strategy. The optimal forwarder is selected on the bases of optimal distance and high energy level.

V. LINEAR OPTIMIZATION

Linear optimization is widely used mathematical technique to find the optimal solution. In linear programming the objective function is followed by the set of constraints which formulate the solution [39]. The following parameters are mentioned to locate the optimal solution.

A. ENERGY CONSUMPTION

During the transmission phase of EA-BECHA, the data packets are transmitted to the sensor nodes with high F_F. The energy consumption on these transmissions is defined as: the energy which is consumed by transmitting and receiving l bits of data at a distance d. The cost function along with the set of constraints is defined as:

$$Min \sum_{r=1}^{r_{max}} \sum_{x=1}^{n} EC_x^r \quad \forall r \in R \wedge x \in N, \qquad (10)$$

such that,

$$C_1 : E_x \leq E_x^{ini} \quad \forall x \in N, \qquad (11)$$

$$C_2 : t \times E_{Tx_x}^r + t \times E_{Rx_x}^r \geq E_x^{min} \quad \forall x \in N, \qquad (12)$$

$$C_3 : E_x \leq E_{x-1} \quad \forall x \in N, \qquad (13)$$

$$C_4 : d_x \leq d_x^{min} \quad \forall x \in N, \qquad (14)$$

$$C_5 : Max \sum_{r=1}^{r_{max}} FF_x^r \quad \forall r \in R \wedge x \in N. \qquad (15)$$

Our main objective in Eq. 10 is to minimize the energy consumption EC of each node x. The summation of EC over r, accumulates the overall energy dissipation of x. Constraint in Eq. 11 shows the upper bound of energy i.e., each node is initialized with uniform initial energy. Constraint in Eq. 12 indicates that a minimum level of energy is required for successful communication, where t shows the total number of transmissions performed by each node to deliver a data packet. The inequality in Eq. 13 prevents the load disproportionality. Constraint in Eq. 14 depicts that a minimum transmission range is necessary for a successful communication. In order to achieve balanced energy consumption, it is necessary to select an optimal forwarder based on

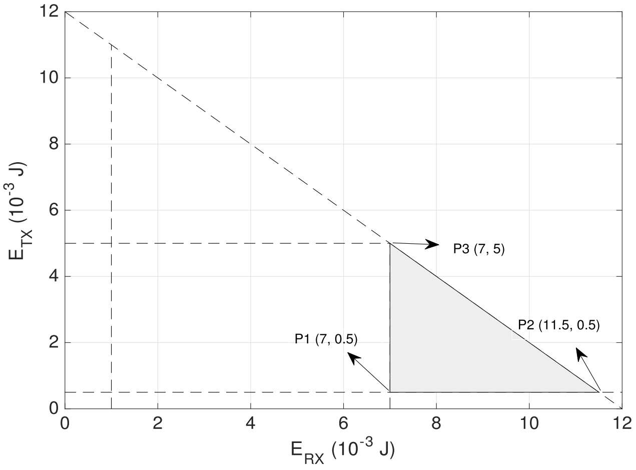

FIGURE 3. **Energy consumption: Feasible region.**

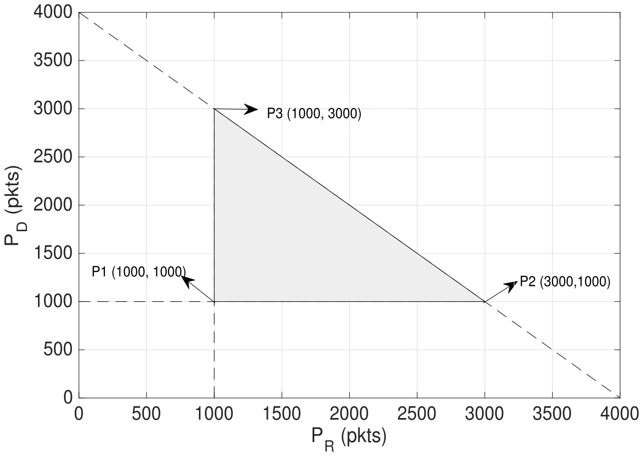

FIGURE 4. **Packets drop: Feasible region.**

maximum F_F. Eq. 15 deals with the selection of F_F based on high residual energy and optimal distance.

1) GRAPHICAL ANALYSIS

Consider a scenario where test points are selected according to the system of inequalities in Eq. 12 to Eq. 15; $C_{efs} = 50\ nJ$, $C_{amp} = 50\ nJ$, $d = 60$, $P_{size} = 1024$. Now the test points are represented in Eq. 11 to Eq. 15 as:

$$1 \leq E_{TX} \leq 7.69, \tag{16}$$

$$0.5 \leq E_{RX} \leq 4.096, \tag{17}$$

$$1.5 \leq E_{TX} + E_{RX} \leq 12. \tag{18}$$

The test points provided in Eq. 16 to 18 construct the feasible region at points P_1, P_2, and P_3 as depicted in Fig. 3. Each vertex of feasible region shows an optimal solution. All points on the closed upper half plane validate the solution as:
at $P_1\ (7,\ 0.5) = 7.5\ nJ$,
at $P_2\ (11.5,\ 0.5) = 12\ nJ$, and
at $P_3\ (7,\ 5) = 12\ nJ$.
Therefore, it is proved that all the corner points satisfy the conditions of feasible region subject to the given constraints.

B. PACKETS DROP

During the transmission phase, the data packets are transmitted from source to destination through a wireless channel. Packets drop is difference between total number of packets sent by sensor nodes to the number of packets received by sink successfully. The packets drop may occur due to low link quality or due to the death of forwarder nodes. To minimize the number packets drop P_{Dr}, the cost function followed by the set of constraints is defined as:

$$Min \sum_{r=1}^{r_{max}} \sum_{x=1}^{n} cP_{Dr}{}_x^r \quad \forall r \in R \wedge x \in N, \tag{19}$$

where,

$$c = \begin{cases} 1 & \text{if } \textit{nodes/forwarders transmit packets to sink} \\ 0 & \text{if } \textit{nodes communicate with forwarders}, \end{cases} \tag{20}$$

such that,

$$C_1 : p_{link} \leq p_{good}, \tag{21}$$

$$C_2 : E_x \leq E_{x-1}^{min}, \tag{22}$$

$$C_3 : d_x \leq d_{x+1}^{max}. \tag{23}$$

Our aim in Eq. 19 is to minimize the overall P_{Dr} of entire network. The summation of P_{Dr} accumulates the packets drop of each node x in r rounds. The flag c in Eq. 20 is incremented each time when a data packet is handed over by the forwarder node to the sink. Constraint in Eq. 21 deals with the current status of link between a transmitter and receiver. The probability of current link will be greater than a minimum threshold i.e., p_{good}. If the link quality is less than p_{good} then the chances of packets drop increase. Constraint in Eq. 22 illustrates that a minimum energy level is required for both transmission and reception, while inequality in Eq. 23 suggests that the receiver would be in the transmission range for successful communication.

1) GRAPHICAL ANALYSIS

Consider a scenario, where test points are chosen according to the system of inequalities in Eq. 21 to Eq. 23, such as $P_{Dr} = 1000$ and packets reached $P_R = 2000$. Now the test points are represented as:

$$0 \leq P_{Dr} \leq 1000, \tag{24}$$

$$1000 \leq P_R \leq 2000, \tag{25}$$

$$1000 \leq P_{Dr} + P_R \leq 3000. \tag{26}$$

The assumed corner points in Eq. 24 to Eq. 26 construct the feasible region on the closed upper half plane at right side as depicted in Fig. 4. Each point validates the solution as:
at $P_1\ (1000,\ 1000) = 2000\ pkts$,
at $P_2\ (3000,\ 1000) = 4000\ pkts$, and
at $P_3\ (1000,\ 3000) = 4000\ pkts$.
Therefore, subject to the given constraints and intersection of corner points, the vertex of solution region is validated.

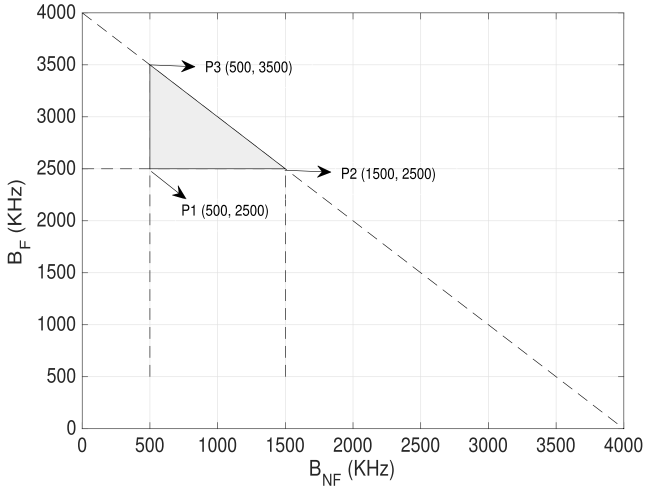

FIGURE 5. **Load distribution: Feasible region.**

C. LOAD DISTRIBUTION

In order to minimize the energy hole problem, it is necessary to balance the load distribution of entire network. Our aim is to level the traffic load in order to avoid early depletion of energy. The task is performed by forwarding the data to the nodes with high residual energy. Therefore, the objective function to level the load distribution LD is defined as:

$$Min \sum_{r=1}^{r_{max}} \sum_{x=1}^{n} LD_x^r \quad \forall r \in R \wedge x \in N, \tag{27}$$

such that,

$$C_1 : dp_x \le dp_x^{th} \quad \forall x \in N, \tag{28}$$
$$C_2 : E_x \ge E_x^{min} \quad \forall x \in N, \tag{29}$$
$$C_3 : d_x \le d_x^{min} \quad \forall x \in N. \tag{30}$$

The objective function is defined in Eq. 27 to level the data load between each corona maximum and minimum energy consuming nodes. Constraint in Eq. 28 shows that aggregated load of each node i.e., the data packet transmitted or received will be less than a specified threshold. The data packets of different sizes is transmitted to the sensor nodes, according to the energy level of forwarder nodes. Constraint in Eq. 29 shows a minimum energy threshold and the data packet only be transmitted by qualifying the condition. More data is transmitted only if the energy level is high and the distance between the transmitter and receiver is minimum.

1) GRAPHICAL ANALYSIS

Consider a scenario where the points are selected according to the system of inequality in Eq. 28 to Eq. 30 such as bandwidth allocated to forwarder nodes $B_F = 2500\ KHz$, $B_{NF} = 500\ KHz$. Now the test points are represented as:

$$500 \le B_{NF} \le 1000, \tag{31}$$
$$1000 \le B_F \le 2500, \tag{32}$$
$$1500 \le B_F + B_{NF} \le 3500. \tag{33}$$

The corner points provided in Eq. 31 to 33 construct the feasible region at points P_1, P_2, and P_3 as depicted in Fig. 5. Each vertex of feasible region shows an optimal solution. All points on the closed upper half plane validate the solution as:
at $P_1\ (500,\ 2500) = 3000\ nJ$,
at $P_2\ (1500,\ 2500) = 4000\ nJ$, and
at $P_3\ (500,\ 3500) = 4000\ nJ$.
Therefore, it is proved that all the corner points satisfy the conditions of feasible region subject to the given constraints.

D. END TO END DELAY

The time elapsed, during the data transmission from source to destination is termed as end-to-end delay. The end-to-end delay is composed of transmission delay, processing delay, queuing delay and propagation delay. We termed the transmission delay, processing delay and queuing delay as nodal delay, while consider the queuing delay as zero. In multi-hop transmission the end-to-end delay is high due to more processing time; moreover, it also increases with the increase in distance and density. Therefore, the cost function for minimizing the end-to-end delay $E2E$ is given as follows:

$$Min\ (c\ E2E), \tag{34}$$

where,

$$E2E = \begin{cases} N_D(i,j) + N_D(j,s) + P_D(i,j) + P_D(j,s) & if\ j \ne s \\ N_D(i,s) + P_D(i,s) & if\ j = s \end{cases} \tag{35}$$

such that,

$$C_1 : N_D \le N_D^{min}, \tag{36}$$
$$C_2 : P_D \le P_D^{min}. \tag{37}$$

The cost function is defined in Eq. 34 to minimize the overall $E2E$ delay, where N_D and P_D in Eq. 35 show the nodal delay and propagation delay. Similarly, the $N_D(i,j)$ is the delay occurred when the sensor nodes transmit data packets to the forwarder nodes and $N_D(i,s)$ is the latency occurred due to direct transmission. Constraints in Eq. 36 and Eq. 37 indicate that the N_D and P_D will be less than a minimum threshold for successful transmission. If the delay increases then the packet drop ratio increases.

1) GRAPHICAL ANALYSIS

Consider the scenario, where $P_D = 30\ ms$ and $N_D = 20\ ms$ according to Eq. 38 and Eq. 39 which is represented as:

$$0 \le N_D \le 20, \tag{38}$$
$$20 \le P_D \le 30, \tag{39}$$
$$20 \le N_D + P_D \le 30. \tag{40}$$

The intersection of corner points provided in Eq. 38 to Eq. 39 construct the solution region at upper right half plane, as shown in Fig. 6. Each test point in the feasible region validates the solution as:
at $P_1\ (20,\ 0) = 20\ ms$,
at $P_2\ (20,\ 30) = 30\ ms$,
and at $P_3\ (0,\ 30) = 30\ ms$.
Therefore, all the intersecting points validate the feasible region according to the given set of constraints.

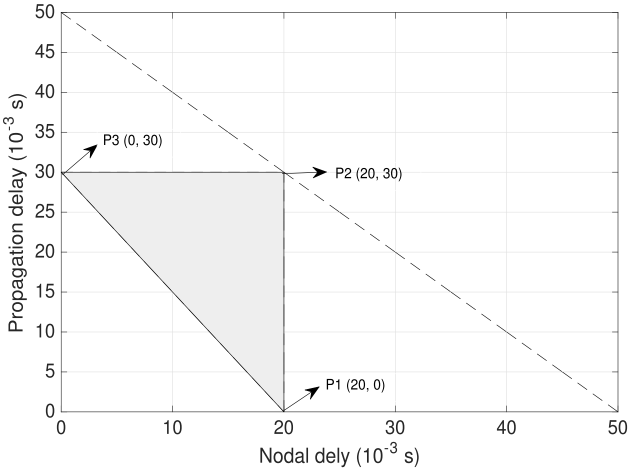

FIGURE 6. **End to end delay: Feasible region.**

E. THROUGHPUT

During the transmission phase, each node sends data to either sink directly or advances to the next hop forwarder nodes. Throughput is defined as, the number of packets successfully received at sink per unit of time. The data packets transmitted by the sensor nodes is counted as one successful transmission, while the data transmitted by the forwarder nodes as composite packet is also counted as one successful transmission. The objective function is defined as:

$$Max \sum_{r=1}^{r_{max}} \sum_{x=1}^{n} Np_x^r \quad \forall r \in R \wedge x \in N, \tag{41}$$

such that,

$$C_1 : E_x \leq E_x^{ini} \quad \forall x \in N, \tag{42}$$

$$C_2 : E_x \leq E_{x-1} \quad \forall x \in N, \tag{43}$$

$$C_3 : d_x \leq d_x^{min} \quad \forall x \in N, \tag{44}$$

$$C_4 : \sum_{r=1}^{r_{max}} \sum_{f=1}^{f_{max}} B_{F_f^r} \quad \forall r \in R \wedge \ f \in F. \tag{45}$$

Where, Eq. 41 is the objective function followed by constraints to maximize the successful packet delivery Np in each round. Constraint in Eq. 42 shows the energy bound i.e., nodes are attached with limited energy. Therefore, energy is the important constraint in the entire transmission process. Eq. 43 deals with the energy of outer and inner coronas nodes. Before the data transmission each node checks the energy of its forwarder nodes to avoid the load dis-proportionality. Whereas, constraint in Eq. 44 presents a distance metric threshold for successful communication. The aim of the induced Eq. 45 is to minimize the load on those nodes which participates more in the data transmission and have low residual energy level. Alternatively, the load is reallocated to proximal neighbors with high residual energy. Where, B_F shows the bandwidth allocated to the forwarder nodes with high energy level, and B_{NF} is the corresponding bandwidth allocated to non-forwarder nodes.

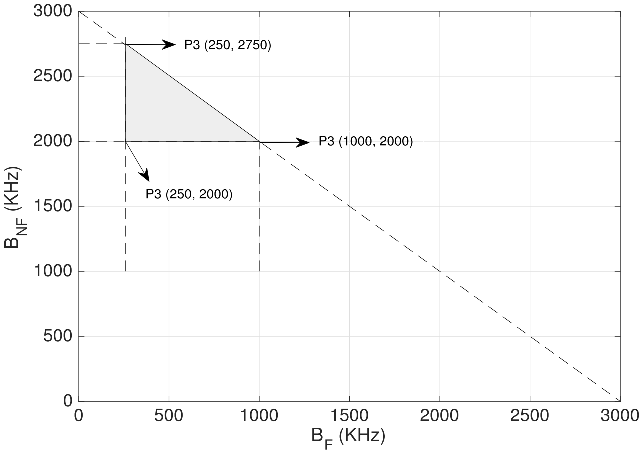

FIGURE 7. **Throughput: Feasible region.**

TABLE 2. **Simulation parameters.**

Parameter	Value
Network radius	$250m$
Transmission range	$60m$
Corona thickness	$30m$
Number of nodes	80
Initial energy	$1J$
C_{efs}	$50nJ/(bit.m^2)^{-1}$
C_{amp}	$50pJ/(bit.m^4)^{-1}$
d_o	$87m$
F	$50nJ.bit^{-1}$
b_o	$1bit$

1) GRAPHICAL ANALYSIS

Suppose a scenario with total bandwidth B between $2273\,KHz \ \ to \ \ 3000\,KHz$. The B allocated to B_F and B_{NF} according to Eq. 46, and Eq. 47 respectively:

$$273 \leq B_F \leq 1000, \tag{46}$$

$$2000 \leq B_{NF} \leq 2750, \tag{47}$$

$$2073 \leq B_F + B_{NF} \leq 3000, \tag{48}$$

The corner points considered in Eq. 46 to Eq. 48 generate the feasible region on upper right half plane at intersecting points P_1, P_2, and P_3 respectively:
at P_1 $(250, \ 2000) = 2060\ KHz$,
at P_2 $(1000, \ 2000) = 3000\ KHz$,
at P_3 $(250, \ 2750) = 3000\ KHz$.
Therefore, it is proved that all the points mentioned in Fig. 7 validate the solution under given set of constraints.

VI. PERFORMANCE EVALUATION

We perform simulations of our proposed protocols and compare with existing WSNEHA and ECMSE algorithms. The evaluation is measured in term of throughput, number of dead nodes, energy consumption, number of packets drop, data load on each corona nodes and end-to-end delay. The main parameter setting is summarized in Table 2.

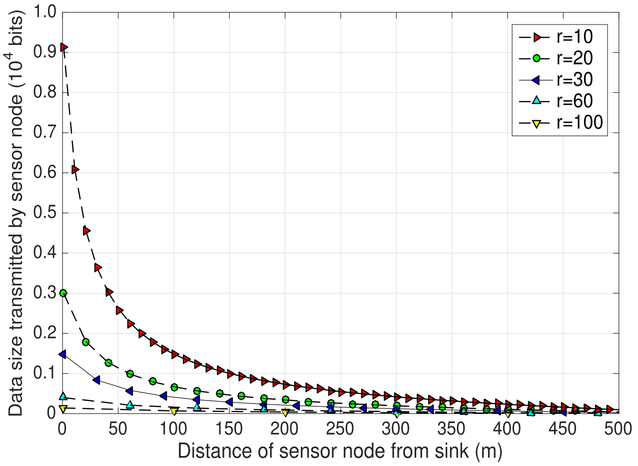

FIGURE 8. **The data size of sensor nodes increases with the decrease in transmission range and distance.**

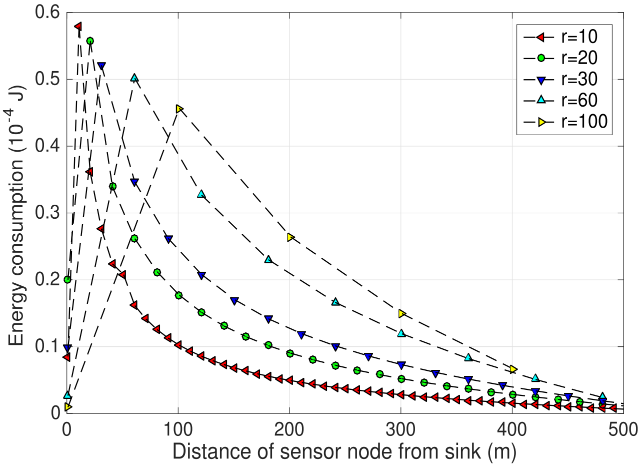

FIGURE 9. **Energy consumption of sensor nodes with varying distance and transmission range.**

TABLE 3. **Transmission range with energy consumption and data size transmitted.**

Transmission range	Data transmission	Energy consumption
$r = 10$	9 $kbit$	6 mJ
$r = 20$	3 $kbit$	5 mJ
$r = 30$	1 $kbit$	3 mJ
$r = 60$	0.5 $kbit$	2 mJ
$r = 100$	0.1 $kbit$	1 mJ

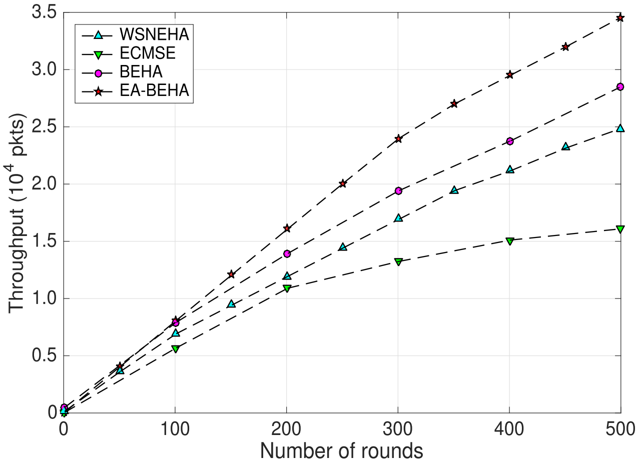

FIGURE 10. **Accumulative number of data packets delivered to sink.**

Sensor nodes except the outer most corona nodes receive cumulative load. The internal corona nodes forward the aggregated data packets as a composite packet to either sink directly or to the next hop forwarding nodes. In order to forward the aggregated data to sink, the sink proximal neighbors are selected as relays to sink. Consequently, the nodes die very early and causes energy hole problem. Despite the fact that WSNEHA algorithm balances the load between the sink proximal nodes, though energy hole problem emerges in the onward corona. Similarly, the network of ECMSE disjoints very early due to the iterative selection of nodes located near the optimal position. To extend the work of WSNEHA algorithm, BECHA is presented. Thereafter, EA-BECHA is proposed to overcome the limitations of ECMSE and BECHA algorithms.

A. DATA SIZE

Fig. 8 shows the data transmitted by sensor nodes with varying distance from the sink and with different transmission ranges r. In multi-hop communication manner if r is smaller then the data is mainly distributed in the first radius range of the sink. The sensor nodes located in this corona communicate directly to the sink and responsible for the transmission of aggregated data packets. Moreover, there exist some maximal energy consuming nodes which participate more in data transmission due to their closeness to the sink. If r is increased then the second corona nodes mainly participate in the load distribution. Similarly, by increasing r the packet load decreases on the inner corona nodes and increases on the outer corona nodes. The reason is that the sensor nodes act as relay to sink. Consequently, the energy of nodes exhaust more quickly and the energy hole problem is emerged. For instance, if $r = 10, 0.9 \times 10^4 bits$ of data is transmitted to the sink by the first corona nodes. Similarly, when r is maximum very low amount of data is transmitted to the sink. i.e., $0.04 \times 10^4 bits$.

B. ENERGY CONSUMPTION

Fig. 9 shows the energy consumption of sensor nodes with varying r and distance from the sink. It is observed that the sensor nodes at smaller distance will participate more in the data transmission as depicted in Fig. 8. Consequently, the energy exhausts very early due to their closeness. Similarly, if r increases the energy consumption become decreases. For instance, if $r = 10$, 0.9×10^4 $bits$ of data is transmitted with an energy dissipation of 6 mJ. Similarly, when r is maximum i.e., $r = 100$, 0.1×10^4 $bits$ of data is transmitted with energy consumption of 1 mJ as given in Table 3.

C. THROUGHPUT

Fig. 10 exhibits the higher throughput of EA-BECHA than that of BECHA, WSNEHA, and ECMSE. At the initial stages all the algorithms have same packet delivery ratio; however, the difference arises after 100 rounds. The

EA-BECHA algorithm outperforms because each time an optimal forwarder is selected to advance the data packet based on high F_F. As a result, more data is delivered to the sink i.e., 3.5×10^4 *pkts*. Hence, increases the throughput 28% more than WSNEHA and 99% more than ECMSE. On the other hand BECHA performs better than the existing schemes because of its good load balancing ability. The WSNEHA has low throughput due to the dis-junction of network caused by the maximal energy consuming nodes located in the 2^{nd} and onward coronas nodes. Hence, no more data is forwarded to the sink after the emergence of energy hole. The ECMSE performs worse because each time the forwarder nodes are selected iteratively near the energy optimal position, which results in the early exhaustion of energy and creates energy hole problem.

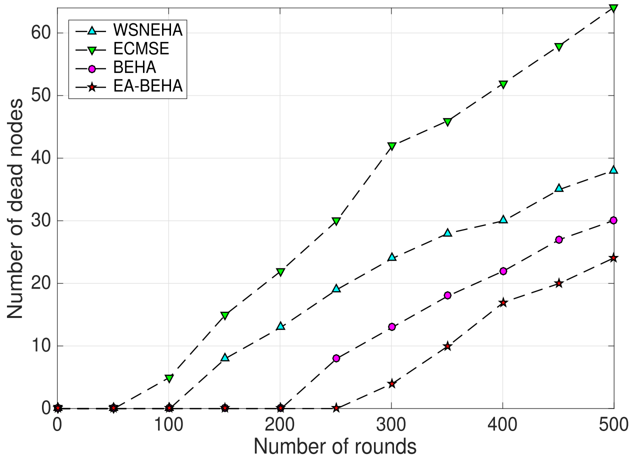

FIGURE 11. Number of dead nodes in each round.

D. NETWORK LIFETIME AND NUMBER OF DEAD NODES

The number of dead nodes in each round is shown in Fig. 11. It is clear from the figure that our proposed schemes outperform the ECMSE, and WSNEHA with considerable margins because of the balanced energy consumption and optimal forwarder selection strategy. The dead nodes ratio of ECMSE increases very sharply because of imbalance load distribution and also due to the selection of longer routing path. Consequently, more energy is exhausted in the transmission phase i.e., the first dead node emerges in 50^{th} round, and all nodes die in 500 rounds. Similarly, due to the energy hole problem caused by the maximal energy consuming nodes in the 2^{nd} corona and other region nodes, WSNEHA performs low as compared to the proposed algorithms. EA-BECHA further decreases the number of dead nodes as depicted in Fig. 11. It can be seen that the first dead node of WSNEHA appears in the 10^2 rounds because load of only first corona nodes is balanced; however, the sensor nodes of second and onward coronas still facing the load imbalance issue.

The BECHA algorithm shows improvement in the network lifetime longevity i.e., 13% and 110% more than WSNEHA and ECMSE. Moreover, the first dead node occurs in approximately 2×10^2 rounds. While the EA-BECHA outperforms in prolonging the network lifetime i.e., 58% more than WSNEHA and 166% high than the ECMSE. It is because the algorithm selects best forwarder for data transmission which is being energy efficient and energy balanced.

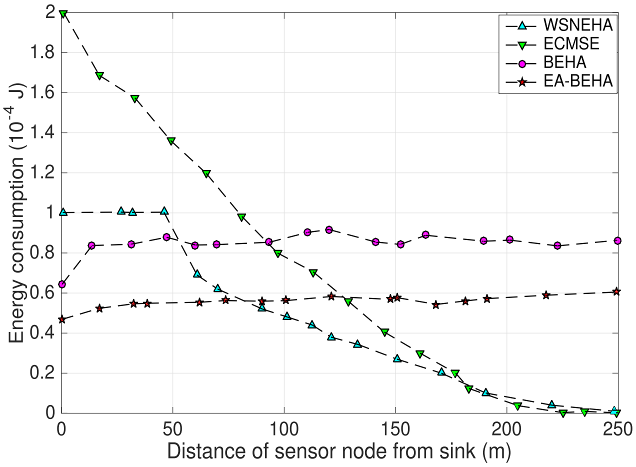

FIGURE 12. Energy consumption of sensor nodes located at various distances from the sink.

E. ENERGY UTILIZATION

Fig. 12 shows the energy consumption of sensor nodes with varying distance from the sink. The ECMSE consumes more energy in the initial stage because of iterative selection of sensor nodes. As it is clear from the figure that the energy of sensors in the first corona is balanced by WSNEHA algorithm. However, the remaining nodes of other coronas suffer the problem of imbalance load distribution which results in the early exhaustion of energy. Consequently, the energy hole problem is emerged and results in low network lifetime. The BECHA algorithm efficiently utilizes the energy resource and balances the load distribution of entire network. Whereas, EA-BECHA results in good utilization of energy resource i.e., 25% less than WSNEHA and 51% less than ECMSE. Because in each round an optimal forwarder is selected from the minimum energy consuming nodes which is responsible for the transmission of aggregated data. The method, iterates until the energy level of sensor nodes in each corona reaches an equilibrium state.

F. PACKETS DROP

The packets drop ratio of EA-BECHA is minimum than that of the ECMSE, BECHA, and WSNEHA algorithms i.e., in 500 rounds the packets drop ratio is 35% less than WSNEHA and 21% less than that of ECMSE as depicted in Fig. 13. It is because of low mortality rate of sensor nodes which results in energy hole avoidance. Moreover, the selection of forwarder nodes based on the optimal distance also resist the packets drop ratio i.e., the packet is transmitted to the forwarder nodes with low error rate. The ECMSE algorithm also performs well mainly because of minimum mean square error rate.

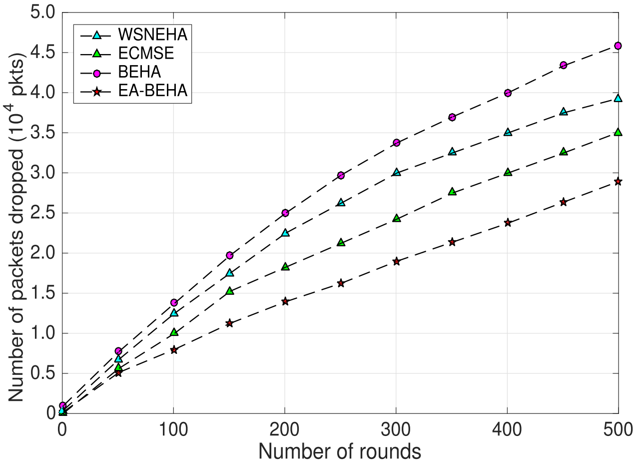

FIGURE 13. Number of packets drop in each round.

In contrast to the EA-BECHA and ECMSE, the WSNEHA and BECHA result in more packets drop because of erroneous location. As a result the packets are transmitted by sender nodes, while not received at the destination.

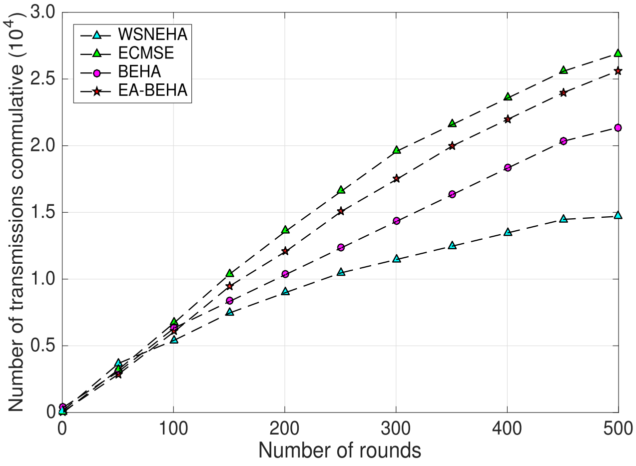

FIGURE 14. Accumulative number of transmission to deliver the data packets.

G. NUMBER OF TRANSMISSIONS

The number of transmissions is mainly dependent on the number of hops, and total number of re-transmissions. Fig. 14 illustrates the number of transmissions that are required to forward the data packets to the sink. Initially, all the algorithms have approximately same number of transmission. However, it diverges after 100 rounds mainly because of forwarders selection criteria. The WSNEHA shows less number of transmissions because no more data is transmitted when the network becomes disjoint. Contrary, to the discussed algorithm, BECHA depicts high number of transmissions because each time the data packet is handed over to the adjacent neighbors which is selected between the local maximum and local minimum threshold. The EA-BECHA shows moderate number of transmissions because the higher priority nodes suppress the transmission of low priority nodes. Therefore, the algorithm indicates good improvement and gives moderate number of transmission with high packet delivery ratio. The ECMSE has more number of transmissions because of two reasons 1) more number of re-transmissions, and 2) due to longer routing path selection.

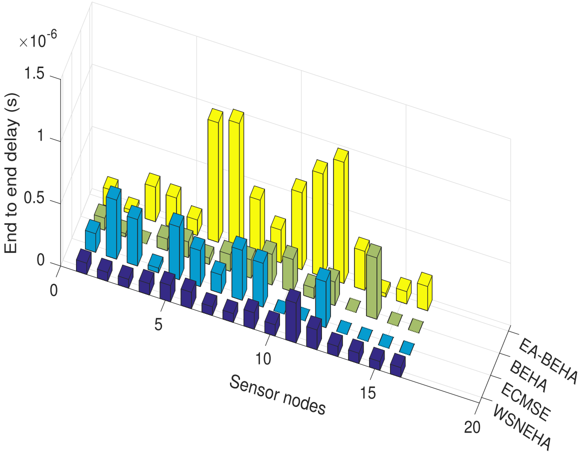

FIGURE 15. Average end-to-end delay of sensor nodes during data delivery.

H. END TO END DELAY

The comparative analysis shows that the WSNEHA algorithm has low latency rate i.e., $0.2 \times 10^{-6}s$ as compared to the ECMSE and proposed algorithms as illustrated in Fig. 15. The ECMSE algorithm has high delay is mainly because of more number of re-transmissions and error coping. Furthermore, the BECHA and EA-BECHA have high delay because of the selection strategy. Each time an optimal forwarder is selected for the delivery of data packets. Consequently, the algorithms take more time for data delivery. In high traffic scenario the proposed algorithms perform inferior than that of WSNEHA. Moreover, it is also clear from the figure that the propagation delay is low when the distance between the nodes and sink is minimum, and conversely.

I. LOAD DISTRIBUTION

Fig. 16 shows the data packets distributed to each corona nodes. As depicted in figure that the data load is distributed uniformly between the sink proximal neighbors. It is because of the fact that each time the node with high residual energy is selected as forwarder node. However, WSNEHA algorithm shows dis-proportionality in data distribution among nodes in onward coronas when r is low. The ECMSE, distributes the data load unevenly between each corona nodes. As shown in Fig. 16 that there is immense data load on inner coronas nodes i.e., 1.6×10^3 *pkts*. Moreover, the unequal load is distributed to the sensor nodes lie on the energy optimal position. Contrary to the existing algorithms, the load balancing is achieved by the proposed algorithms. It is because of the good balancing ability and efficient forwarder nodes selection strategy.

TABLE 4. Performance trade-off of proposed algorithms with existing algorithms.

Protocols	Technique	Parameters achieved	Cost to pay
WSNEHA	Energy hole alleviation	Balanced load distribution and energy hole alleviation around sink	Unbalanced load distribution in 2^{nd} corona and other regions, low throughput, location error, packets drop
ECMSE	Data forwarding using optimal distance	Throughput, less number of retransmissions and packets drop ratio	Energy hole problem, unbalanced load distribution, end to end delay
BECHA	Energy hole alleviation and energy balancing	Balanced load distribution, network lifetime	Energy consumption, low throughput with more packets drop
EA-BECHA	Energy balancing and energy hole alleviation using optimal forwarder selection mechanism	Energy balancing, network lifetime, throughput	End to end delay

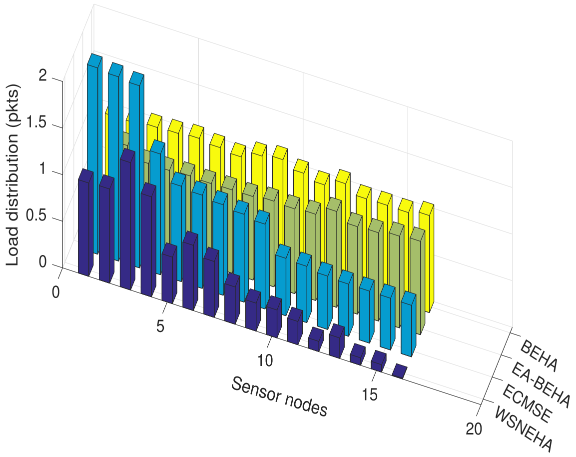

FIGURE 16. Data packet delivered to sensor nodes.

VII. PERFORMANCE TRADE-OFF

In this section the improvements and limitation of proposed algorithms with existing algorithms are discussed. The comparative analysis of proposed with previous algorithms show good improvement in energy consumption, network lifetime, throughput and packet drop ratio as given in Table 4. We achieved network lifetime and throughput by balancing the load distribution uniformly. Such as EA-BECHA prolongs the network lifetime with 58% more than WSNEHA and 166% more than ECMSE with energy efficiency of 25% and 51%, respectively. Similarly, the throughput is enhanced with 28% and 99% with less number of packet drop ratio i.e., 35% and 21%. On the contrary, EA-BECHA has higher end to end delay mainly because of processing time for selection of forwarder nodes i.e., 110% higher than WSNEHA and 90% high than that of ECMSE algorithm. Similarly, BECHA has high end to end delay of 20% and 10% than that of the existing algorithms.

VIII. CONCLUSION AND FUTURE WORK

Energy balancing and energy hole problem are the key issues in maximizing the lifetime of a network. In WSNs due to unbalanced load distribution sensor nodes die very early which leads to energy hole problem. Moreover, due to erroneous location information the data is not successfully delivered to the neighbor nodes causing low throughput. To balance the energy consumption efficiently and alleviate the energy hole problem, we propose BECHA. Thereafter, EA-BECHA is presented to enhance the throughput and minimize the packets drop ratio. This work mainly adopts optimal forwarding strategy to utilize the energy resource efficiently. Moreover, our forwarder node selection mechanism reduces the overall transmission distance. Thus, balances the load distribution and achieves energy efficiency. Moreover, due to low expected error rate the EA-BECHA achieves high packet delivery ratio with less number of packets drop. Finally, the simulation results indicate effectiveness of the proposed algorithm which shows superiority in network lifetime and throughput on the cost of increased end-to-end delay.

In future work we intend to apply this strategy in UWSNs. The energy hole detection and alleviation would be more challenging when the mobility of deployed nodes is considered in 3-D underwater environment. An adaptive mechanism for the selection of transmission range and forwarding nodes will be followed to avoid energy hole problem. Moreover, to reduce the end-to-end delay an optimal setting for holding time would also be considered. Furthermore, the incorporation of buffer-aided relays would be an interesting aspect to explore.

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