An intelligent coverage optimization and link-stability routing for energy efficient wireless sensor network

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Abstract
In wireless sensor networks (WSNs), coverage is a significant indicator of the quality of service. However, full coverage is not feasible to achieve due to coverage holes (CH) in the targeted area. CH occurs for many reasons, such as energy depletion, occlusions and random deployment of nodes. Most of the existing CH restoration methods have huge limitations like high energy consumption (EC), low coverage ratio (CR) and less network lifetime. To address these issues, an Enhanced Mobile Sink-based Coverage Optimization and Link-stability Estimation based Routing (EMSCOLER) protocol is proposed in this paper. The proposed EMSCOLER provides a solution to the coverage restoration issue optimally and avoids network transmission faults. This work consists of two phases such as coverage restoration and Link Stability Estimation based Routing (LSER). Initially, the grid is constructed in the coverage area and randomly deploys the nodes over the grid based coverage area. Grid-based Red Deer Simulated Annealing (GRDSA) model detects the CH in the sensing field and moves the redundant nodes to the hole area to solve the restoration problem. LSER algorithm estimates the link quality and chooses the relay nodes for the transmission of data in order to maximize the whole network lifetime and provide an energy efficient routing. MATLAB tool is used for implementing the proposed protocol. The results of the proposed EMSCOLER are analysed using CR, EC, average residual energy (ARE), moving EC and network lifetime by comparing with the state of the art techniques. The proposed EMSCOLER approach achieved 98.53% CR, 5.842 J EC, 5.94 J moving EC, 0.1980 J ARE and 99.61% network lifetime. From the experimental analysis, the proposed method achieved better results than other techniques. Therefore, the proposed approach can effectively solve the coverage restoration problem and perform energy efficient routing.

Keywords Wireless sensor networks · Energy efficient · Coverage hole · Grid concept · Coverage hole restoration · Link stability estimation

1 Introduction

WSNs have fascinated much significant research attention because of their vast potential applications like environment monitoring, military surveillance, etc. [1, 2]. It consists of several small battery-operated sensor nodes (SNs), which are deployed randomly or manually in the Region of Interest (ROI) to sense the network area's physical condition. These sensor nodes gather the sensed data from the target area and forwarded it to the mobile sink (MS). However sensor failure may occur due to the manual deployment of static nodes. Moreover, the basic requirement of WSNs is the full coverage of ROI (target area) [3]. Thus, it is necessary to collect the data about the area and cover the ROI for its analysis. Due to some issues such as failure of SN, low battery life, exhaustion, maintenance of SN, random deployment of nodes, ambiguity in network topology and obstacles in the sensing field, the CH occurs in the target area [4, 5]. This CH is the region in ROI that is enclosed by none of the deployed sensors. Thus, the lack of network self-healing competence takes place. Also, it affects the performance of the whole WSN [6]. While a huge number of energy is left and wasted, the network

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lifetime soon ends up. Therefore, the detection of CH is significant for the effective performance of the network [7].

In WSN, various coverage-aware approaches have been proposed to extend the network lifetime and minimize the consumption of energy. These coverage aware techniques are divided into two types such as coverage aware-clustering and coverage aware scheduling algorithms [8]. The scheduling approaches improve energy efficiency and balance the network lifetime. These approaches exchange information between neighbours to identify the optimal nodes in the network to maximize the network lifetime [9]. By the scheduling procedure, EC in idle snooping can be decreased by enhancing the system lifespan, which is termed as the issue of link scheduling [10]. In WSN, the fuzzy-based routing approaches performed well to transmit data from source to destination. Intelligent dynamic fuzzy logic controller refreshment period of entries in neighbourhood matrices (IFPE) gathers the information about the neighbour node for choosing a better next relay node during data transmission [11]. The effective position routing protocols are employed in the multi-hop communication in which the information is conveyed to the sink node for reducing the end to end EC. The energy efficient MAC (medium access control) has turned off the invaluable hardware components. It is not probable to assure the entire energy exhaustion between all nodes owing to the inherent traffic of numerous to one structure [12]. An enhanced MAC protocol has been introduced to maximize the network lifetime and retain the energy in the network. Cross-layer collaboration among node module (CLCNM) is implemented for the enhancement of network lifetime [13]. These position-aware routing protocols are simple, scalable and position-aware [14]. But, when the number of nodes are enhanced in symmetrical evolution, the balanced energy exhaustion is accomplished. This obstructs the entire procedure; for this reason, the system lifespan is only based on both EC and node failure. In the node positioning, all nodes are linked to the sink node to control the connectivity. For the signal, the energy of transmission is not much considerable and also it is similar to the consumed energy through the elements of circuits as short distance internodes [15].

Using special nodes such as mobile agent, the problem related with the system lifespan can be resolved. The most effective mobile agent is proper for executing the various tasks and it acts as a cluster head [16]. The arbitrary mobile patterns are concentrated for accomplishing the coverage and sensing EC control. Here, it needs to manage the Equivalent sensing radius (ESR) [17]. However, it is a challenging task due to the inaccurate detection of its shape, size and position. If the CHs are detected accurately, then the way to solve the CHs with some SNs can be identified easily [18]. Moreover, in the recent years several

coverage restoration and routing approaches are introduced in the literature. But, the existing methods are based on the point coverage model; these techniques are not more efficient to restore the hole. Thus, the area coverage model is more applicable in WSN [19]. This model provides extensive network lifetime and less consumption of energy. However, in some approaches, the CR is very less; this degrades the performance of the whole network [20]. Therefore, EMSCOLER approach is proposed in this work.

1.1 Contribution

The key contributions of this paper are as follows:

i. GRDSA is the hybrid approach, which creates the CH in the sensing field and moves the redundant nodes to the hole area. It solves the CH restoration problem efficiently.

ii. LSER is proposed to find the optimal path by measuring the distance between the node and its neighbouring nodes based on their residual energy. Moreover, the stability of the link is estimated using some efficient metrics to choose the optimal path for the data transmission.

iii. EMSCOLER is the coverage optimization and routing approach, which enhances the CH restoration process and sends the packets in the optimal path to increase the network lifetime and decrease the EC. It overcomes the disadvantages in MSCOLER such as high EC and less coverage ratio.

iv. Extensive implementation is performed for analysing the efficiency of the proposed framework in terms of EC, CR, ARE, network lifetime and moving EC. Moreover, the proposed EMSCOLER is compared with existing methods to prove the efficacy of the proposed work.

Furthermore, this paper is structured with three sections as mentioned: Sect. 2 provides the recent related works. Section 3 presents the proposed methodology and Sect. 4 describes the experimental results and discussion. Section 5 concludes the paper.

2 Related works

Some of the recent related works are discussed as follows:

Wang et al. [21] proposed a mobile assisted node deployed strategy based on particle swarm optimization (PSO) for WSNs. The SNs were deployed randomly in the ROI and these nodes switch to the sleep mode or remain static after the process of deployment. The grid was constructed with equal size by partitioning the entire network to identify the sparse node regions, and then the coverage

rate of each grid was calculated. The candidate grids were chosen based on the lower coverage rate of the grid. PSO algorithm has been utilized for identifying a better deployment position of the mobile sensors.

Xue et al. [22] introduced a random-vector-functional-link-based link quality prediction (RVFL-LQP) algorithm for the estimation of the link quality. The link quality metric was selected as the signal-to-noise ratio (SNR) to evaluate the stability of the link. Based on the wireless link characteristics analysis, the raw SNR sequence was decomposed as stochastic as well as time varying sequence. The prediction model of variance of stochastic sequence and time-varying sequence has been constructed by the RVFL. Finally, the prediction on SNR probability-guaranteed interval boundary was performed using LQP.

Yarinezhad [23] developed a novel routing algorithm called Nested Routing to solve the issues in mobile sink for WSNs. Based on the virtual ring-shaped architecture and the mobile sink; this routing algorithm performed the transmission of data. The virtual architecture was considered for the nested Routing and it has many nested rings. Based on the geographic routing algorithm, all the messages were sent from the source to the destination by choosing the shortest transmission path. In the network, the high collisions and EC were occurred due to the frequent updates of sink position.

A novel distributed self-healing algorithm has been proposed by Khalifa et al. [24] and named it as distributed hole detection and repair (DHDR) for CH detection and recovery. The already deployed nodes were used for handling the hole detection as well as repair in a simultaneous manner in the network. ACH has been detected dynamically by the position as well as size of redundant node estimation using DHDR. The appropriate nodes were chosen from the surrounding area by this algorithm. The void area of hole was restored without disturbing their existing connectivity or coverage by relocating the chosen nodes. The EC was minimized and the coverage was maximized by sharing the data and among nodes.

Gou et al. [25] introduced a novel optimization approach for the CH repair among heterogeneous WSNs nodes. A multi-factor collaborative hole repair optimization algorithm (FCHROA) performed the healing process more effectively. The hole area was covered by constructing the Pearson-like fuzzy matching relationship among two nodes such as mobile node (MN) and virtual repair node (VPN). The VPN position has been resolved by the Delaunary triangulation with bulge vertices. Moreover, the node of criticality, residual energy and the nodes relative distance were considered for the generation of multi-factor synergy matching decision table among the VPN as well as the MN. The finite distance movement was performed by the MN based on the obtained decision table to recognize the CH repair optimization.

So-In et al. [26] developed a novel distributed deployment algorithm termed as CH-healing algorithm (CHHA) for WSNs. The CHs were healed to increase the area coverage and decrease the moving distance of total SN. After the completion of SNs deployment in the network, the CHs were detected by the CHHA that consist of hole-boundary SNs according to the computational geometry. A concept was applied by the CHHA distributed deployment feature to virtual forces for decision making to move the mobile SNs to restore the CHs.

Zhang et al. [27] proposed an effective CH detection algorithm based on the simplified Rips complex for WSNs. The issue of high complexity was addressed using this hole detection algorithm. The nodes were classified by correlating the Turan's theorem with concept of degree and clustering coefficient; besides, the redundant node determination rules (DRs) were designed to sleep the redundant nodes. Then, the redundant edges were removed by the generation of redundant edge deletion rules. Therefore, the Rips complex was simplified efficiently based on these two steps and identified the CH effectively.

Feng et al. [28] suggested a CH detection and repair algorithm for the network disconnection solution. According to the maximum simple subnet, the network topology was analyzed by this algorithm dynamically. Also, the hole area's boundary node was determined and the polygon area of the boundary node was estimated. Further, in the CH area, the cluster nodes were generated by activating the valid inactive nodes. Using this way, the CH was healed and managed the network's communication as well as connectivity.

Huang et al. [29] proposed an advanced Delaunay method to detect CH in ROI. The redundant nodes were considered for covering the hole area, for that these nodes were identified initially. In the redundancy map, the redundant nodes number of occurrences was assumed for the energy parameters and basic distance. This assumption was taken to find the optimal redundant nodes in the coverage area. Based on the run distance and the average remaining energy, the cooperative incomplete game was devised in order to perform the healing process and achieved better coverage.

Verma and Sharma [30] developed CH Detection and Restoration strategy based on node decentralized and localized algorithm. It has provided the solution for the network hole identification and healing process. Crucial Intersection Points (CIPs) was a new concept introduced for coverage restoration problem. Localized algorithms based on CIPs to identify the CH and location calculation algorithm based on perpendicular bisection to restore the CH were the two stages in this strategy. After the hole in

the coverage area was restored, the data was transmitted from the source node to the sink. Moreover, this approach was highly scalable and distributable. Both the non-convex as well as convex hole has been detected effectively.

Vasim Babu et al. [31] presented adaptive source location privacy preservation approach using randomized routes (ALPP-RR) for routing in WSN. In this research, the clustering operation has been performed using Integration of Distributed Autonomous Fashion with Fuzzy If–then Rules (IDAFFIT) algorithm. Based on Principle component analysis, the secure data aggregation was performed with end-to-end integrity as well as confidentiality. This approach obtained better network lifetime and secure routing.

Almomani et al. [32] proposed dynamic and reactive reliability estimation with selective metrics mechanism (DRESM) to estimate the link reliability for routing. The fuzzy weighted logic multi-objectives was used to develop the notion of multi-criteria next relay node selection. Moreover, Status Information Distribution and Outgoing Traffic Control Management (IDOTM) were proposed to gather the fresh data regarding the neighbour nodes and manage the outgoing traffic in the network. The multi-objective routing protocol performed better data transmission using optimal path.

From the literature, various researches have focused only on CH restoration solution. However, the EC and CR are not considered in these techniques. If the EC is high, then it decreases the network lifetime and degrades the entire performance of the network. Moreover, if the CR is computed, then the accuracy of the CH restoration can be identified effectively. Therefore, energy efficient optimization approach is required for the restoration process. The optimization technique has the ability to change the coverage restoration issue into non-constrained optimization problem. Also, the link stability estimation approaches assisted the routing performance in finding a better path to avoid data loss and congestion. A multi-objective link reliability estimation found the near to optimal path for the transmission of data. However, the existing routing approaches have many disadvantages, such as high EC and difficulty in finding the optimal path for transmission. Thus, the grid based coverage optimization and efficient routing technique is introduced in this work to solve the problem of coverage restoration and find the optimal path for transmission.

3 Proposed methodology

In this paper, EMSCOLER protocol is proposed to solve the CH issue and avoid faults during data transmission in the network. Two phases are comprised in the proposed

work, namely GRDSA and LSER that performs coverage restoration and link quality estimation. In the first phase, the grid-based network coverage is performed using GRDSA to restore the hole area with the redundant nodes. In the second phase, the relay nodes are chosen by LSER for the transmission of data. The proposed EMSCOLER increases the network lifetime and provides energy efficient routing. Figure 1 illustrates the structure of the proposed EMSCOLER.

Assumptions The following assumptions are made for our WSN environment:

- A massive target area is covered with a huge amount of homogeneous SNs. These SNs are static except sink node. SNs are placed randomly in the 2D monitored area.
- The communication between the nodes is performed through the radio signals.
- The location information of each SN is known by itself using GPS (Global Position System).
- Link stability estimation path is used to find the optimal path for the transmission of data from the source node to the MS.
- If any nodes in the target region is not sensed and do not communicate with MS or other nodes, then the corresponding area is said to be coverage hole.
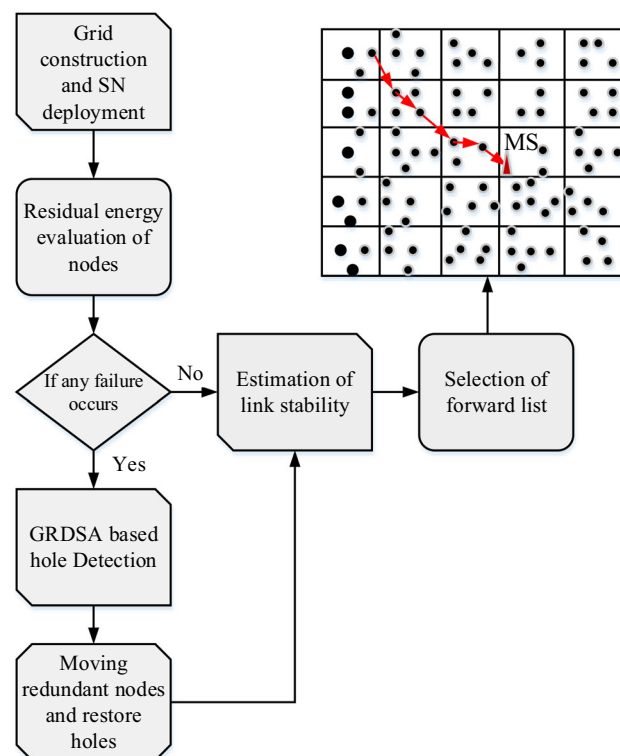

Fig. 1 Proposed EMSCOLER structure

3.1 Construction of grid

When the nodes are placed, the logical grid of $p \times q$ cells is constructed by partitioning the entire sensor field. The cells in the constructed grid have a square area of equal size that comprised of SNs. The SN computes the ID of each cell $[I_k, I_l]$ based on its location (k, l) and it is expressed as:

$$I_k = \left[\frac{k - k_0}{\delta}\right], \quad I_l = \left[\frac{l - l_0}{\delta}\right] \tag{1}$$

where, the network initialization stage's location information is represented as k_0, l_0 and the cell size of a grid is denoted as δ. To make the process simple, let as consider the cell ID as positive. The area is said to be fully covered, if the CR of the network is one and any point in the sensing region is within the limit r_s. S_n node sensed the center point of grids' (G_i) probability sensing $(B_{h,k}(G_i, S_n))$ is given as:

$$B_{h,k}(G_i, S_n) = \begin{vmatrix} 1 & M_r - c \geq d(G_i, S_n) \\ e^{-\rho, \delta^\alpha}, & M_r - c < d(G_i, S_n) < M_r + c \\ 0 & M_r + c \leq d(G_i, S_n) \end{vmatrix} \tag{2}$$

where, the nodes' maximum sensing radius is denoted as M_r, the ambiguous monitoring capabilities of measuring nodes is represented as c and α, ρ are the nodes intruder sensed probability value. The distance among the node S_n and the grid center point is computed as $d(G_i, S_n)$. At least one node sensed the center point of grid is defined as:

$$N_p(G_i) = 1 - \prod_{n=1}^{A_k} \left(1 - B_{p,k}(G_i, S_n)\right) \tag{3}$$

The probability that all G_i in the monitored region is sensed by minimum one node to γ, which is the indication of network coverage ratio.

$$\gamma = \frac{\sum_{i=1}^{A_p} B_{p,k}(G_i)}{A_p} \tag{4}$$

3.2 Energy model

The node's energy in the network may vary frequently from the initial deployment. The degradation occurs mainly due to some of the common factors such as sensing range and the communication range. Therefore, the residual energy of each node in hole restoration area is computed during the relocation time of redundant nodes, or else the healing process may be performed by the low energy nodes. If the low energy nodes carry out the restoration process, then it leads to the extra hole in the network. The initial energy of SNs is 2 J and the size of the packet send from source to the destination is 1024 bit. The radio energy

model is used to compute the EC of each node [33]. Each node consumes certain amount of energy to send A-bit message to a distance Dis and it is defined as:

$$En_{Tk}(A, D) = \begin{cases} A \times En_{ec} + A \times \varepsilon_{fs} \times Dis^2, & Dis \geq Dis_0 \\ A \times En_{ec} + A \times \varepsilon_{mp} \times Dis^4, & Dis \geq Dis_0 \end{cases} \tag{5}$$

where, the radio electronics EC is represented as En_{ec}, the distance threshold value about the transmission model of SN is represented as l_0 and the EC of amplifier while transmitting the data is denoted as ε_{fs} and ε_{mp}. Equation (6) computes the energy spends by the radio for receiving A-bit message and it is as follows:

$$EC_{ck}(A, Dis) = A \times En_{ec} \tag{6}$$

And the threshold value l_0 is computed using the following equation,

$$l_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \tag{7}$$

3.3 CH detection and restoration using GRDSA

The target area is assist to be covered when the SNs are placed within a sensing range. The CH can be identified based on the nodes in the coverage area. If the SNs not sensed the data and not communicate with other SNs or MS, then the CH is determined. In this work, GRDSA is proposed to determine the CH and to restore the nodes to the hole area. GRDSA is the hybrid approach, which is the combination of Red Deer algorithm (RDA) and Simulated Annealing (SA) algorithm. RDA is a recent evolutionary algorithm, which randomly initializes the red deers (SNs). Based on the roaring ability of the red deers, the best optimal solution is selected. Moreover, it has the high capacity of local search, so it can easily determine the CH area. SA is based on the physical process of metallurgical annealing and it can transform the worst solution to the highly optimized solution. Thus, it can move the redundant nodes efficiently to the CH to solve the restoration problem. The steps of GRDSA for the CH detection and restoration are as follows:

Here, the red deer is the SNs. Initially, an array of variables is formed that need to be optimized. The array can be termed as red deer and it is represented as RD. It is a counterpart of solution. The initial population is generated as R_{pop}. A red deer is an $1 \times k$ array in R_{var} dimensional optimization issue and it is expressed as:

$$RD = [S_1, S_2, S_3, \ldots, S_{R_{var}}] \tag{8}$$

For each red deer, the fitness function is calculated as:

$$fitness\ function = f(RD_{EC}) = f(S_1, S_2, \ldots, S_{R_{var}}) \qquad (9)$$

Based on the fitness value, the best RD and the remaining are identified. The best (male) red deer is denoted as R_{best} and the remaining red deer is represented as $R_w(R_w = R_{pop} - R_{best})$.

The fitness function of each node is computed based on the energy. If $f(RD)$ of the neighbour node is better, then update the position of RD and the equation is given as:

$$best_{new} = \begin{cases} best_{old} + p_1 \times ((UB - LB) * p_2) + LB, & if\ p_3 \geq 0.5 \\ best_{old} - p_1 \times ((UB - LB) * p_2) + LB, & if\ p_3 < 0.5 \end{cases} \qquad (10)$$

where, the current position is represented as $best_{old}$ and the new position is denoted as $best_{new}$, p_1, p_2 and p_3 are the randomly generated values using uniform distribution between 0 and 1, the search space is limited for generating the possible neighbourhood solution as lower bound and upper bound, which is represented as LB and UB respectively.

After the position update, the percent of R_{best} is chosen as R_{com}, which is the commander (neighbour node). The following equation is used to evaluate the number of R_{com} is given as:

$$R_{com} = round\{\lambda.R_{best}\} \qquad (11)$$

where, the initial value of the algorithm is denoted as λ which ranges from 0 and 1. Then, the number of stag is measured as:

$$R_{stag} = R_{best} - R_{com} \qquad (12)$$

where, the number of stags in regard to the male population is represented as R_{stag}.

The distance between $best_{new}$ and the neighbour nodes is calculated using the following equation:

$$d_n = \left(\sum_{i \in I} \left(stag_i - hind_j^i \right)^2 \right)^{1/2} \qquad (13)$$

where, the distance between the ith stag and hind is represented as d_n. Then, find the neighbour node of S. For each temperature, several iterations are performed till it reached to low. Thus, the solution is obtained and detects the hole area. Then, the redundant nodes are identified based on the available energy. The thermodynamic law is used for the node energies' probability distribution at a given temperature t.

$$PD(RE) = e^{-RE/(bt)} \qquad (14)$$

where, the Boltzmann's constant is denoted as b and the remaining energy of nodes is represented as RE. Based on Metropolis algorithm, the new energy of the node is computed if the energy of the node is high then move that

node to the hole area. If the energy is not decreased, then the difference between the fitness function is computed in each step and it is given as:

$$\psi = f(R) - f(R') \qquad (15)$$

Using the following equation, p_l can be evaluated:

$$p_l = \exp\left(-\frac{\psi}{T}\right) \qquad (16)$$

If the sensor node energy is low, then do not consider that node and compute the energy of the nearby nodes until the hole area is covered by the active nodes. Thus, the redundant SNs are moved to the CH and solved the coverage restoration problem efficiently. Table 1 provides the pseudocode of proposed GRDSA.

3.4 Routing using link quality estimation (LSE)

The optimal transmission distance d_{op} can be resolved by the optimal energy scheme, which selects the optimal node s_{qe}. The available next hop forwarder is chosen based on the nodes' ARE. Let as consider, the node 'n' needs to transmit the data to MS. Therefore, first get the neighbour nodes with high ARE and choose them as the forward candidate to send the data to MS. Here, node '$n + i$' is one of the neighbour of 'n' having high ARE and are closer to the sender node 'n'. Thus, this node is selected as forwarding candidate (FC). Likewise, the neighbour nodes with high ARE is selected as the FC and provide rank for each FC according to their distance from each node's ARE. The equation for rank calculation is given as:

$$L(n + i) = \begin{cases} (d_{n+i} - d_n)\left[\dfrac{1}{d_{n+i} - d_{op}} + (re_{n+i} - v) \right] \\ \qquad (n + i) \in fc(n), \quad -S \leq i \leq S \end{cases} \qquad (17)$$

where, the residual energy of node $n + i$ is represented as RE_{n+i}, the energy threshold value is denoted as v, $d_{n+i} - d_n$ indicates the distance between node n and neighbour node $n + i$ and $fc(n)$ denotes FC of node n. The FC with highest rank is chosen as the next forwarder. Then, the energy efficient MAC protocol is utilized to provide a channel for the communication between the source and destination. B-MAC is a low power and flexible protocol based on CSMA [34]. It is simple in design and implementation. It avoids the collision and has a small core. Moreover, it provides the principle functions and interfaces that assist in the dynamic changes of parameters to compromise with the varying communication environment.

The effectiveness of the routing protocol is evaluated according to the link stability estimation accuracy. This LSE provides the optimal path for the transmission of data

Table 1 Pseudocode of GRDSA

Algorithm 1: Algorithm forProposed GRDSA approach

Initialization: red deer population R_{pop}, SA initial temperature T_0, maximum iterations

Choose forwarder list L (h) from adjacent nodes A (h) to start with transmission timer

Generate array of variable R_{var} and initial population R_{pop}

    for each SN, compute the fitness value using equation (9)

        if R_{best} is higher than R_w

       then

       update the position of R_{best} as R_{com}

       end if

    end for

Compute the neighbour nodes using equation (11)

    for each pair of SNs

        Evaluate two nodes distance using equation (13)

          If increases the distance of two nodes

$f(R) = \min(\alpha)$ // objective function

          for each solution R

        Identify the neighbours of R

          if the energy of R is reduced $R < 0$

         Obtain the solution

         Else

         if $\exp\left(-\dfrac{\psi}{T}\right)$ then

          Requires to minimize the temperature if it not reached the balance

        End if

      End for

    for each failure sensor

        Evaluate $\max(\alpha)$, a low distance nodes   // determination of redundant nodes

          if sensor $R = \max(\alpha)$

         Shift R to the hole position

         End if

    End for

from source to the MS. Some of the metrics such as Expected Transmission Time (ETX), Required Number of Packets (RNP), Link Quality Indication (LQI) and Received Signal Strength Indicator (RSSI) are used for the estimation of the link stability. The description of these metrics is as follows:

ETX: In the bi-directional packet transmission, this parameter is utilized because it estimates the stability of the link effectively. It computes the number of transmission needed for transmitting a packet over the link. The primary goal of ETX is to minimize the transmission count for packets. If the transmission count minimizes, then the EC also decreases.

$$ETX = \frac{1}{dr_f \times dr_r} \tag{18}$$

where the forward delivery ratio is represented as dr_f and the reverse delivery ratio is denoted as dr_r. Then, the computation of ETX path is performed by adding all the value of *ETX* for each single link and the equation is given as:

$$ETX(p) = \sum_{k \in p} ETX_k \tag{19}$$

RNP: It has the similar range with ETX. It is the ratio of number of transmitted and retransmitted packets to the number of successfully received packets within a coverage area. It computes the quality of link in both forward and
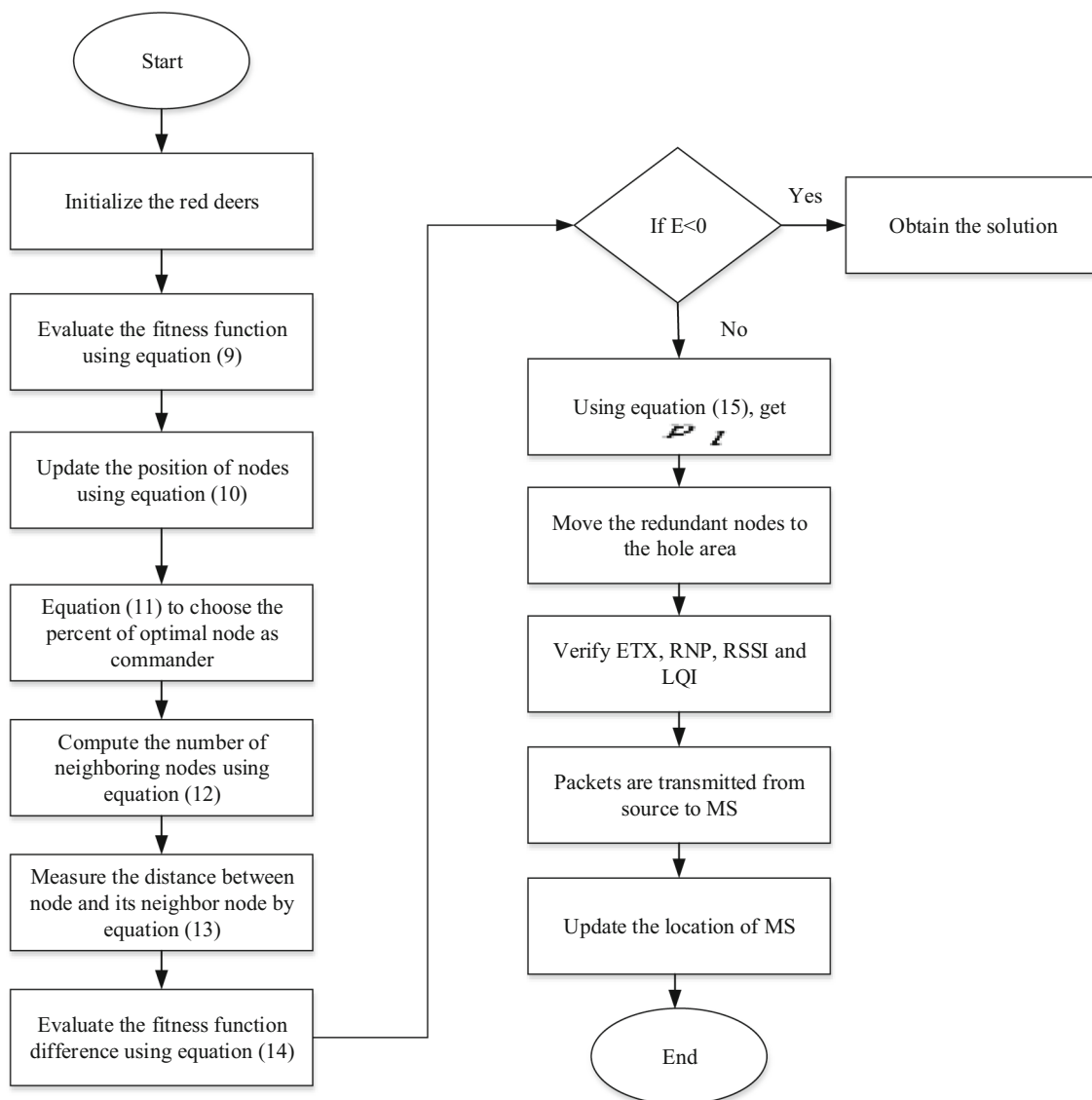

Fig. 2 Proposed EMSCOLER flowchart

backward direction. If the RNP value is less, then it indicates that the link quality is better. The following equation computes the RNP as,

$$RNP = \frac{Number\ of\ packets\ send \times Number\ of\ packets\ received}{Number\ of\ packets\ received} - 1$$

(20)

RSSI: It is the received radio signals' computed energy. 802.11 standards are utilized for developing this RSSI and it is the convenient metric. Equation (21) defines the path loss model based on the distance and it is as follows:

$$p_{loss}(d) = p_{loss}(d_0) + 10e \lg\left(\frac{d}{d_{ref}}\right) + X_\tau$$

(21)

where X_τ be the Gaussian distribution of random variable with mean value equivalent to 0, the distance between the source and the destination is represented as d, the path loss exponent is denoted as e and the reference distance is denoted as d_{ref}, which is equivalent to 1 m. The condition $C = B_t - p_{loss}(d_{ref})$ is obtained by the received signal power C in the distance d_{ref}. After obtaining this condition, the RSSI is computed as,

$$RSSI = C - 10e \log d$$

(22)

LQI: The link quality between the nodes is verified by this LQI. The error in the successful received packets is measured using this parameter. LQI is defined as,

$$LQI = (Y_{cor} - k).l$$

(23)

where the correlation value is represented as Y_{cor} ranges from 50–110, in which the maximum value considered as 50.

Thus, the link stability is estimated to broadcast the data from source to the MS based on these parameters. Then, the optimal path is selected for the efficient data transmission. Thus, the efficient routing is performed using the proposed EMSCOLER. Figure 2 represents the flowchart of the proposed EMSCOLER protocol.

4 Experimental results and discussion

The experimental setup and the proposed EMSCOLER performance are evaluated in this section. The performance of the proposed EMSCOLER is compared with the state of the art approaches such as CORONA, MS based Coverage Optimization and Link-stability Estimation Routing (MSCOLER), Virtual Centripetal Force-based Coverage Enhancing Algorithm (VCFCEA), and Overlap-Sense Ratio based Coverage Enhancing Algorithm (OSRCEA) [35].

4.1 Experimental setup

MATLAB is the simulation platform used for analysing the proposed work. In a grid based coverage area, the experiment is performed and several numbers of SNs are deployed randomly. Table 2 shows the experimental metrics considered for this work. Using these parameters, the network initialization is performed.

The performance of the proposed EMSCOLER routing protocol is estimated based on some of the performance metrics, which is discussed in the below subsection.

4.2 Evaluation metrics

Some of the performance metrics considered for the evaluation of proposed EMSCOLER are coverage ratio, EC, moving EC, ARE and network lifetime. The definition of these performance metrics are provided below:

Energy consumption (EC): It is the total energy consumed by the SNs in the network for the entire process. It is computed by the following equation:

$$EC_{kwh/node} = \frac{Q_w * E_{\left(\frac{usage}{node}\right)}}{1000_{\left(\frac{W}{kW}\right)}}$$

(24)

where the energy consumption is denoted as EC, power in Watts is represented as Q_W and the energy usage per node is depicted as EC.

Coverage ratio (CR (%)): It is the proportion of region covered by redundant nodes over the primary coverage area.

Moving EC: It is the energy consumed by the moving redundant nodes at the time of hole restoration.

Table 2 Simulation parameters

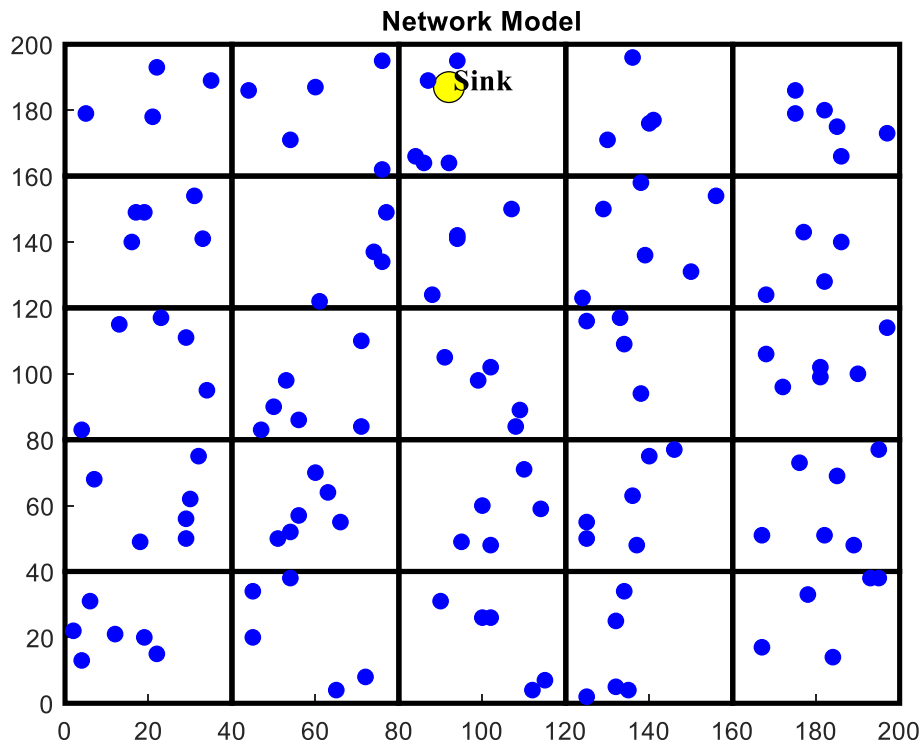| Parameters	Descriptions
Number of static nodes	20–100 nodes
Node deployment	Random
Sensor field	200 m × 200 m
Shape of the monitored area	Square
Initial Energy	2 J
En_{ec}	60 nJ/bit
ε_{fs}	10 pJ/bit/m^2
ε_{mp}	0.0013 pJ/bit/ m^4
Mobile Sink	1
Grid size	40 m
Sensing range	50 m
Communication range	60 m
Radius of the hole	25–50
Packet size	1024 bit

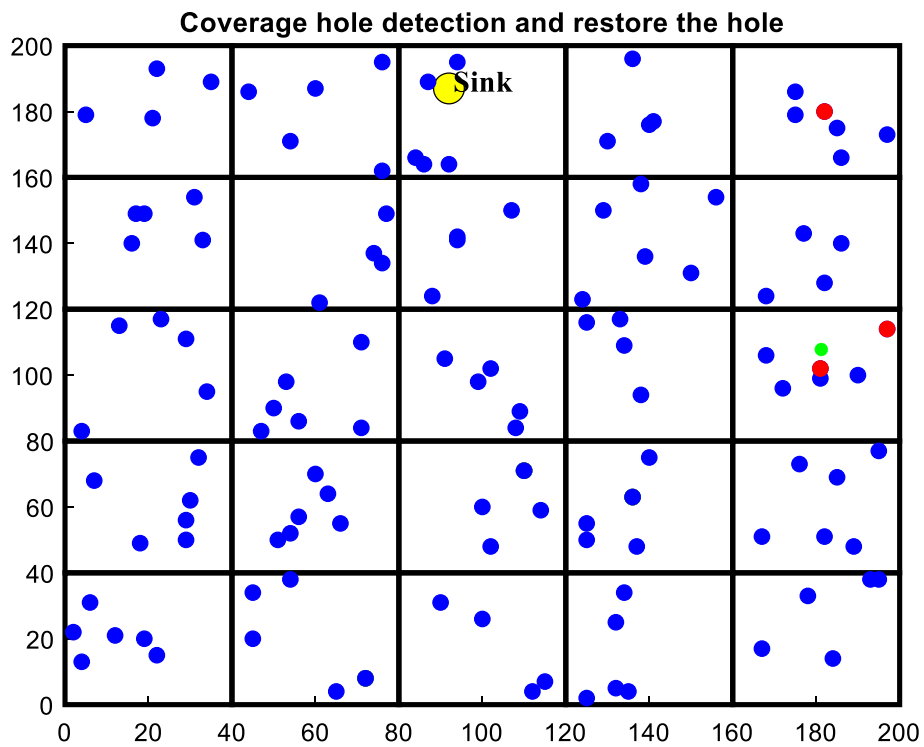**Fig. 3** Grid construction and SN deployment

Fig. 4 Hole detection and restoration

ARE: It is defined as the available energy computation after the simulation completed.

Network lifetime: It is the execution time of the network during the task performance. It defines the period until the first node consumes the energy in the specific sensor network. If the EC is less, then the network lifetime extends. The network lifetime NL_t is computed by the following equation,

$$NL_t = \min_i \left[\frac{\sum_{j=1}^{i} C_{ij} * x_j}{y_i} \right] \tag{25}$$

where $y_i = n$, $i = 1, 2, ..., n$, where the coverage area is denoted as n. Then, compute the value of both coverage matrix C_{ij} and node life x_j to obtain the accurate estimation. The equations for the computation of C_{ij} and x_j are given as:

$$C_{ij} = \begin{cases} 1 & \textit{if SN monitors TN} \\ 0 & \textit{otherwise} \end{cases} \tag{26}$$

$$x_j = \frac{En_0}{En_n}, \quad 1 \le j \le i \tag{27}$$

where the sensor node is indicated as SN, the target node is denoted as TN, the initial energy is represented as En_0 and the energy consumption rate of node n is denoted as En_n.

4.3 Experimental results and analysis

The performance of the proposed EMSCOLER is analysed in terms of coverage ratio, EC, ARE, moving EC and network lifetime. Initially, the grid is constructed in the coverage area with the equal size of cells. After the construction of grid, the SNs are deployed in the grid based coverage field randomly.

Figure 3 shows the constructed grid and the deployment of SNs in the grid structure. Then, the CH is detected and restored, which is shown in Fig. 4. Let as consider the redundant nodes to move in the hole area in order to heal the CH. First, the MS is placed at the grid point middle and then moved to the coverage area in a direction of counter clockwise and it is shown in Fig. 5.

Two metrics such as link quality EC and CR are used in this work to measure the EMSCOLER performance for sending and receiving the data packets and the maximum iteration is 1000. Figure 6 shows the CR attained by the proposed EMSCOLER and the existing approaches. The proposed EMSCOLER attained the CR for several numbers of nodes such as 20, 40, 60, 80 and 100 are 94.08%, 95.07%, 96.06%, 97.05% and 98.53% respectively. The MSCOLER technique obtained the CR for 20, 40, 60, 80 and 100 nodes are 92%, 93.5%, 94%, 95% and 98% respectively. The CORONA obtained the CR for 20, 40, 60, 80 and 100 nodes are 87%, 89%, 92%, 94% and 97% respectively. The OSRCEA routing approach obtained the CR for 20, 40, 60, 80 and 100 nodes are 86%, 88%, 91%, 92.5% and 95.5% respectively. The existing VCFCEA approach attained the CR for 20, 40, 60, 80 and 100 nodes are 78%, 81%, 84%, 84.5% and 85.5% respectively. Thus, the CR attained by the proposed EMSCOLER is higher than the existing approaches.

Figure 7 represents the EC by the proposed EMSCOLER and the existing approaches. The proposed EMSCOLER consumed the energy for 20, 40, 60, 80 and 100 nodes are 4.654 J, 4.852 J, 5.149 J, 5.446 J and 5.842 J respectively. The MSCOLER technique consumed the energy for
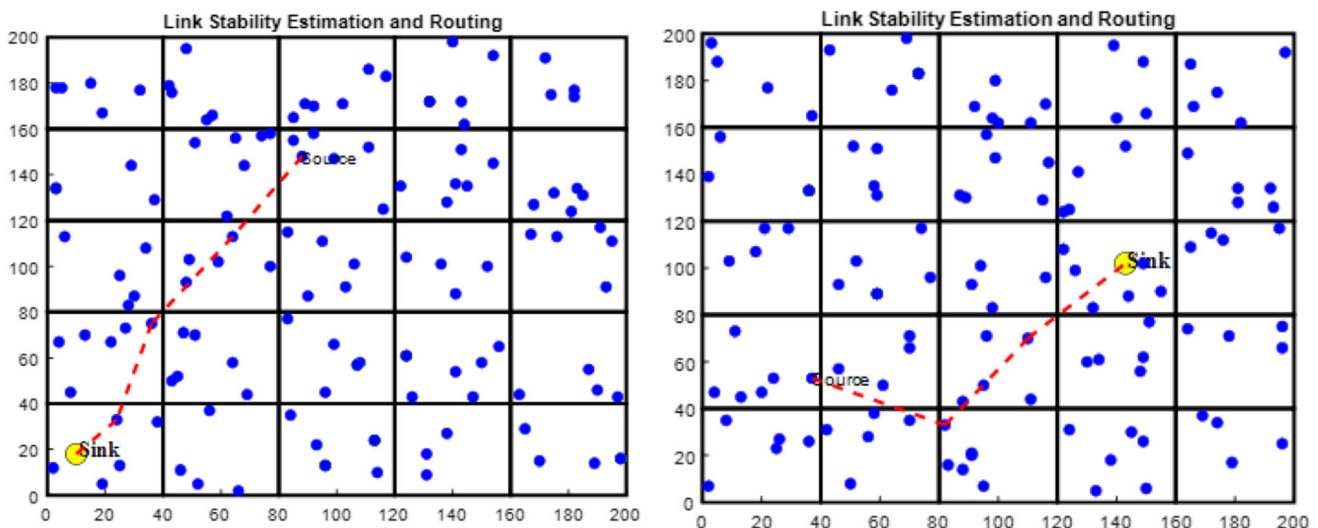

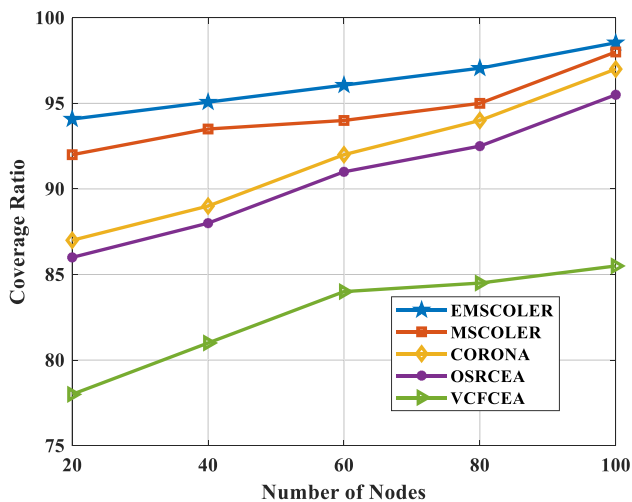**Fig. 5** Link stability estimation and routing using proposed EMSCOLER

Fig. 6 CR of proposed EMSCOLER and the existing approaches

Fig. 7 Performance analysis on EC of proposed EMSCOLER and the existing approaches

20, 40, 60, 80 and 100 nodes are 6 J, 5.95 J, 6.1 J, 6.5 J and 7.85 J respectively. The energy consumed by COR-ONA for 20, 40, 60, 80 and 100 nodes are 8 J, 10 J, 10.25 J, 11 J and 11.95 J respectively. The consumed energy by OSRCEA routing approach for 20, 40, 60, 80 and 100 nodes are 9 J, 11.5 J, 12 J, 13 J and 14 J respectively. The EC of existing VCFCEA approach for 20, 40, 60, 80 and 100 nodes are 12 J, 13.75 J, 14 J, 14.25 J and 16 J respectively. Thus, the energy consumed by the proposed EMSCOLER is lower than the existing approaches for the transmission of packets and this will increase the network lifetime. Moreover, the shortest distance to the MS is computed to generate the forwarder list, which is helpful for the selection of optimal path. Therefore, the energy is not affected by the location updating of MS.

Figure 8 represents the moving EC of different moving nodes. The CH is created by the failure nodes and some of the redundant nodes are utilized to restore the hole in the sensing field. The energy consumed by the proposed EMSCOLER and the existing techniques are based on the number of moving nodes. The EC is less for the lower count of nodes. The proposed EMSCOLER consumed the moving energy of 3, 5 and 10 moving nodes are 2.97 J, 3.96 J and 5.94 J respectively. The existing MSCOLER, CORONA, OSRCEA and VCFCEA consumed the moving energy for 3 nodes are 4 J, 6 J, 8 J and 9 J respectively. For 5 moving nodes, the existing MSCOLER, CORONA, OSRCEA and VCFCEA consumed the moving energy of 8 J, 10 J, 12 J and 15 J respectively. For 10 moving nodes, the existing MSCOLER, CORONA, OSRCEA and VCFCEA consumed the moving energy of 12 J, 13 J, 17 J and 23 J respectively. From the analysis, the proposed EMSCOLER consumed less energy for the moving nodes than the other techniques.
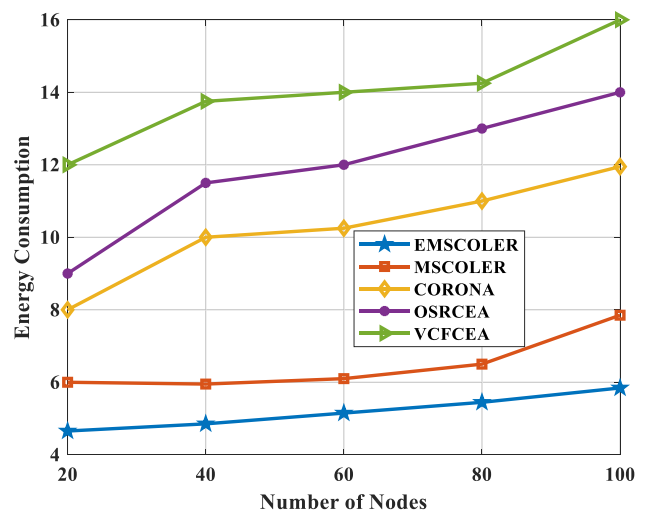
Figure 9 illustrates the ARE of proposed EMSCOLER and the existing methods. The ARE attained by the proposed EMSCOLR for 0, 500, 1000, 1500, 2000, 2500 and 3000 rounds are 0.3961 J, 0.3466 J, 0.297 J, 0.2772 J, 0.2574 J, 0.2475 J and 0.1980 J respectively. While the existing MSCOLER attained for 0, 500, 1000, 1500, 2000, 2500 and 3000 rounds are 0.35 J, 0.3 J, 0.25 J, 0.24 J, 0.2 J, 0.18 J and 0.095 J respectively, the existing CORONA obtained the ARE for 0, 500, 1000, 1500, 2000, 2500 and 3000 rounds are 0.32 J, 0.285 J, 0.22 J, 0.2 J, 0.19 J, 0.15 J and 0.07 J respectively. For 0, 500, 1000, 1500, 2000, 2500 and 3000 rounds, existing OSRCEA attained the ARE of 0.25 J, 0.22 J, 0.2 J, 0.19 J, 0.12 J, 0.1 J and 0.048 J respectively. The existing VCFCEA obtained the ARE for
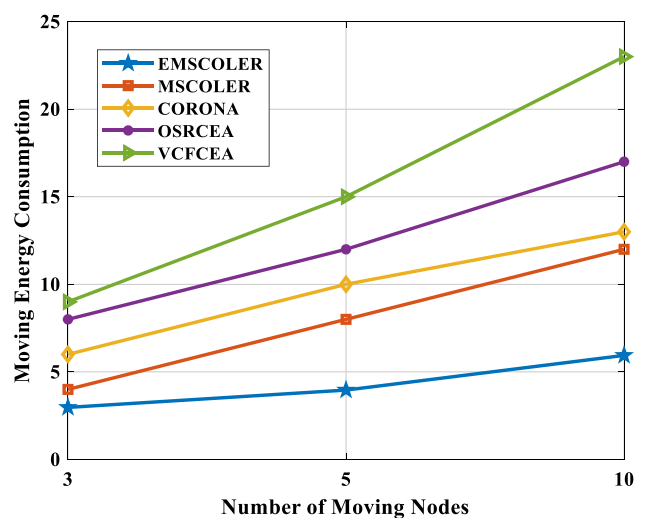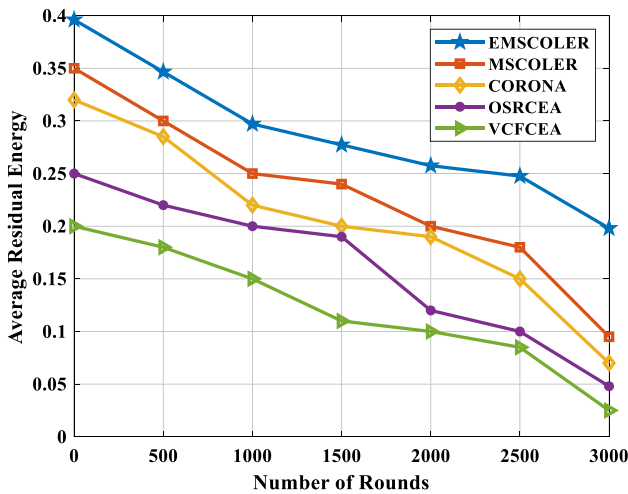

Fig. 8 Moving EC

Fig. 9 Comparison analysis of ARE

0, 500, 1000, 1500, 2000, 2500 and 3000 rounds are 0.2 J, 0.18 J, 0.15 J, 0.11 J, 0.1 J, 0.085 J and 0.025 J respectively. Form the simulation result analysis, the remaining energy reached by the proposed EMSCOLER is greater than the existing approaches. The residual energy will be decreased if the number of packet count increased, because the energy consumed by the large number of packet count is high.

Figure 10 represents the network lifetime of proposed EMSCOLER and the existing routing protocols. The proposed EMSCOLER achieved the network lifetime for 20, 40, 60, 80 and 100 nodes are 97.80897, 98.30799, 98.80702, 99.30604 and 99.60546 respectively. The existing MSCOLER, CORONA, OSRCEA and VCFCEA attained the network lifetime for 20 nodes are 95.85, 92 90.5 and 86 respectively. For 40 nodes, the network
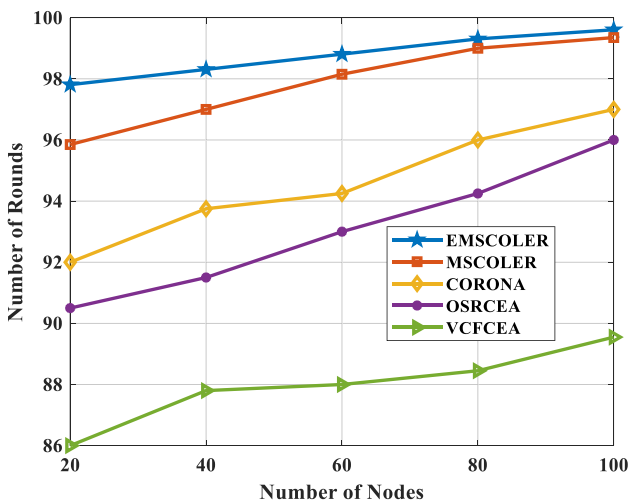

Fig. 10 Analysis of Network Lifetime

lifetime obtained by the existing MSCOLER, CORONA, OSRCEA and VCFCEA are 97, 93.75, 91.5 and 87.8 respectively. For 60 nodes, the network lifetime attained by the existing MSCOLER, CORONA, OSRCEA and VCFCEA are 98.15, 94.25, 93 and 88 respectively. The network lifetime obtained for 80 nodes by the existing MSCOLER, CORONA, OSRCEA and VCFCEA are 99, 96, 94.25 and 88.45 respectively. For 100 nodes, the existing MSCOLER, CORONA, OSRCEA and VCFCEA achieved the network lifetime of 99.35, 97, 96 and 89.55 respectively. Thus, the performance of EMSCOLER is better than the existing approaches in terms of network lifetime.

5 Conclusion

In this paper, the coverage optimization and link quality estimation based routing is implemented for the reliable transmission of data. CH in WSN is the major issue as it affects the network lifetime and the quality of link at the time of routing. EMSCOLER approach is proposed in this paper, for CH restoration and estimation of link stability for routing. The proposed approach efficiently identifies the CH, restores the hole by the redundant nodes and measures the link quality using some parameters. The grid based coverage area is used for nodes deployment. The nodes are static except the sink node and placed randomly in the grid based coverage area. MS is placed at the center point of grid and moves in the counter clockwise direction. GRDSA is the optimization approach, which performed the CH detection and restoration process. It restored the CH more efficiently by moving the redundant nodes to the hole area. LSER estimated the quality of the link using the parameters like ETX, RNP, RSSI and LQI. These parameters assist to identify the quality of the link and optimal path for the packet transmission. MATLAB is the simulation platform for analysing the proposed EMSCOLER and compared with existing protocols in terms of coverage ratio, EC, moving EC, ARE and network lifetime. The proposed EMSCOLER approach achieved 98.53% CR, 5.842 J EC, 5.94 J moving EC, 0.1980 J ARE and network lifetime as 99.60546. From the results analysis, the proposed EMSCOLER consumed less energy and maximized the network life while compared with existing MSCOLER, CORONA, OSRCEA and VCFCEA approaches. Therefore, the performance of the proposed EMSCOLER is better than the existing routing approaches.

Declarations

Conflicts of interest No conflict of interest.

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