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DESIGN OF A NOVEL REPTILE ROUTE PROBING-BASED OPTIMIZER FOR ANALYZING CLUSTER SELECTION AND ROUTING MECHANISM SUPERIORITY IN WSN FOR HEALTHCARE APPLICATIONS

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ABSTRACT
Applications of the Internet of Things (IoT) employing a Wireless sensor network (WSN) experience constraints like limited transmission range, restricted battery, and regular detachments owing to multi-hop data transfer. Because different solutions handle routing and clustering actions differently, providing limited energy consumption and better network lifetime was impossible. This work centers on efficiently collecting information from IoT nodes placed in a distributed environment and linked using WSN. We tackle these interlinked problems, routing and clustering, for IoT-based WSN in an extensive environment and introduce a better clustering and routing to tackle these problems jointly. Better clustering and routing techniques enable area-specific clustering with Superiority towards Cluster Selection and Routing Mechanism (SCSRM) obtained from the transmission range. During clustering, specific cluster heads are chosen to enable fail-over-proof routing, which is optimized using the Reptile Route Probing Algorithm (R^2PA) with Firefly features. Finding the shortest path comprising the fewest hops with alternate routing paths is the key to creating an effective routing path in healthcare applications. Modern benchmark protocols are used to compare the outcomes. Simulation and theoretical outcomes of the proposed system enable better network capacity, improved node density management, increased network lifetime and consistent network topology.

KEYWORDS: Wireless Sensor Network, Internet of Things, healthcare application, routing, clustering, cluster selection

1. INTRODUCTION

Numerous issues affect wireless sensor networks, such as energy efficiency, synchronization, security, longevity, and connectivity. One area for improvement arising from nodes' limited battery capacity is network segmentation, commonly called the hotspot issue. Clustering principles are applied to resolve these issues. The cluster-head (CH) selection procedure significantly lengthens the network's time in clustering. However, since the nodes have a restricted transmission range, multi-hop communication is needed in more expansive areas [1]. Most of the research done on WSNs treats clustering and routing as two different problems [2]. Rarely a few of the procedures employ multi-hop routing techniques. Not many protocols use a fixed node count as CH in a single-hop transmission [3]. In numerous methodologies, Cluster Heads are chosen arbitrarily and, as a result, may appear near one another. The CSMA/CA mechanism reduces network throughput because these Cluster Heads are within transmission range of one another [4]. To resolve this issue, it is essential to consider both clustering and routing as a unified and single issue. To make the solution scalable, a reliable method for selecting CHs and collecting data must be employed, and the amount of communication by cluster heads between sensor nodes and BS should be reduced [5]. Various protocols present today incorporate the identification of clusters, steady-state phase, synchronization, CH selection, aggregation of data, and discovery of routes. While this large number of steps uses up high energy, data transmission consumes only negligible power [6]. These actions require refining to extend the network's lifespan because WSN nodes are energy-constrained. [7]. One more limitation of present-day hardware devices is the restricted size of the packet buffer [8]. In the CH's network queue, data packets are buffered, and the packets will begin to be eliminated if their buffer size exceeds the CH's limit. Nodes are installed over a vast region to gather required information in a wireless sensor network. These nodes have devices powered by a battery and usually have a short range, so multi-hop communication is needed to collect and send information from Base Station (BS). One solution to overwhelmed this limitation is a clustering technique; however, this consideration is made with a single-hop communication viewpoint where every CH send data to BS directly. Anyhow, clustering and routing are likewise wanted for vast regions. A failed transmission of data will occur when any of the CH fails. This issue is called a hotspot issue. This happens because routing and clustering are performed separately [9]. The work provides an approach for clustering and routing based on the cluster's static regions where routing topology with the failover setup is considered during CH selection [10]. This work's proposed method addresses routing and clustering as a single issue. Clusters are formed by determining its transmission range and location. Following the CH and cluster identification, a routing method and a failover scenario for handling are suggested.

Existing modern optimizers (e.g., Dragonfly, Firefly, Grey Wolf, MFO) often struggle with high computation overhead, making them unsuitable for on-node or edge-level execution.
RRPO introduces: 1) Incremental re-optimization, 2) Fast local probing updates, 3) Minimal communication overhead for re-clustering. This supports near real-time adaptation of an essential requirement for healthcare WSNs that existing methods fail to satisfy. Healthcare WSNs carry heterogeneous traffic (critical alarms, periodic vitals, bulk logs). Few studies evaluate how cluster selection and routing affect high-priority, latency-sensitive packets versus background telemetry. Positioning a Reptile Route Probing–Based Optimizer to address these gaps will make a compelling contribution: emphasize how the algorithm handles dynamic healthcare-specific constraints (heterogeneous nodes, strict latency for alarms, mobility), demonstrate multi-objective superiority with broad baselines, validate on realistic scenarios (including testbeds), and integrate security/privacy and explainability. These are the key weaknesses in existing literature that your work should explicitly target and empirically resolve. The proposed Reptile Route Probing–Based Optimizer (RRPO) introduces several innovative contributions that directly address the persistent limitations in WSNs for healthcare applications particularly energy constraints, latency requirements, and the need for reliable, adaptive communication under dynamic conditions. Existing modern optimizers (e.g., Dragonfly, Firefly, Grey Wolf, MFO) often struggle with high computation overhead, making them unsuitable for on-node or edge-level execution. RRPO introduces: 1) Incremental re-optimization, 2) Fast local probing updates, 3) Minimal communication overhead for re-clustering. This supports near real-time adaptation of an essential requirement for healthcare WSNs that existing methods fail to satisfy. This method lowers the overhead associated with energy consumption, which results from a completely dynamic CH and clustering choice procedure. The chief contributions of the anticipated work:

1. A clustering and routing technique, Superiority towards Cluster Selection and Routing Mechanism (SCSRM), is energy-efficient for WSNs that address hotspot problems. This approach selects a CH using a less complex process that considers node connectivity and the total weight of the remaining battery. This technique utilizes the position of the WSN.
2. Additionally, we propose an optimization approach with Reptile Route Probing Algorithm (R^2PA) with Firefly features that provide any selected Cluster Head (CH) with alternate routing paths in the event of a possible failover.
3. The solution proposed is for WSNs on a large scale and compatible with multi-hop communication amongst devices installed in a large region, like healthcare sectors.
4. The remaining part of this work is presented below: 2nd section explains related works in the WSNs area, 3rd section explains the enhanced protocol for clustering and routing in WSNs in IoT, 4th section elaborates on the analysis and outcomes, 5th section expresses the conclusion.

2. RELATED WORKS

Various types of research concentrate only on clustering to streamline the energy in WSN nodes, like Balanced energy efficient network protocol focus on the node's residual battery for CH selection alone and Low Energy Adaptive Hierarchical Clustering (LEACH) [11] – [13]. Authors compare and contrast the outcomes of their studies with the algorithm. The outcomes show that the method has the most improved transmission rate with significant live nodes [14]. The provided method expects an equal dispersion of nodes with no dynamic clustering and random positioning. Choosing CHs through two separate methodologies [15]: The cluster member's (CMs) residual energy and periodic rotation of CH membership amongst cluster members [16]. Determination of a Cluster Head at a long distance from the Base Station is one of the significant actions resulting in farther-placed nodes' early death [17]. LEACH-extended Message Passing (LEACHXMP) can be used to overcome [18]. This technique uses a clustering-based procedure that considers factors like node density, the CH node's residual energy and the distance among nodes as criteria for selection. Orphan-LEACH protocol is a variant of the LEACH. This protocol was created on the presumption that the CH will be chosen randomly [19]. Thus, a portion of the CMs might never again stay associated with their CH and turn out to be orphans. O-LEACH recommends the idea of intermediate gateway nodes that gather information from members and transfer it to CHs. Based on FCFS, the gateway nodes are chosen. Nodes are selected by the gateway node devoid of considering the residual energy. It delivers improved energy efficiency and coverage compared to LEACH [20]. In any case, tracking down the data on orphan nodes is a significant limitation of this work. A few issues that should be settled are control overhead and data delivery delays. Minimal studies related to WSNs focus on clustering and routing as a solitary and confined issue [21]. For instance, the Joint Clustering and Routing protocol [22] utilizes gradient routing and back-of-timer to foster a network topology for gathering information in WSN in a more extensive environment.
Various approaches have been used in previous research to address hotspot issues. Even though multiple protocols like O-LEACH [23] and LEACH offer multi-hop routing solutions, the network faces inefficient energy consumption issues because

of the dynamic introduction of CH. So, clustering and routing should be considered together at the same time. It presumes that every node has the same chance of becoming CH and chooses the clusters through a probability model [24]. There are two stages in this protocol: one is the setup phase, and the other is the steady state stage. CH and cluster creation are selected at the start of the setup stage and data transfer occurs during the steady state. Here, we define a threshold equation for which every node will choose a random number from zero to one. The CH in the present round is below the threshold value [25]. If the node is not chosen as CH, it will likely be selected as CH in coming iterations. In the steady state stage, data is gathered and processed. The information is sent to the CH for every sensor node in a fixed time interval. After getting the information from its CM, CH compresses after aggregating it; at last, the base station will receive this information [26]. Particle swarm optimizations (PSO) is the most developed version of the enhanced particle swarm optimization strategy [27]. This strategy involves a c-mean for fuzzy clustering to tackle the nodes' death issues and to diminish the energy hole because of node location change and the effectiveness of the hotspot issue. Residual energy, distance towards BS and nodes density are the parameters included in Fuzzy inputs. The simulation outcomes provided a considerable count of live nodes when contrasted with different strategies [28]. Fuzzy-based data acquisition relies on an asymmetric key encryption scheme and slot-based scheduling strategy. To cut down on network overhead and energy consumption, fuzzy logic is employed to choose the CH [29]. Additionally, because of the significance of picking the proper route, which results in a decreased packet loss rate and latency, two CH types, namely dynamic and steady, have been presented. A stable Cluster Head is utilized to analyze and review route history. Data collection and routing are the two areas concentrated by the dynamic CH. After clustering and routing, the CH will begin to collect data in a fixed time based on factors such as the stability of the node, connection ratio, residual energy, and flexibility of the node [30]. Compared with other models, the simulation outcomes exhibited enhanced data collection, low latency, and less control overhead.

The surveyed literature establishes two complementary facts: (1) metaheuristic and hybrid optimizers can materially improve energy efficiency and routing performance in WSNs, and (2) healthcare/WBAN settings impose stringent, dynamic QoS, security, and explainability requirements that existing optimizers rarely satisfy in a holistic, deployment-ready manner. The Reptile Route Probing–Based Optimizer (RRPO) is therefore well-positioned to contribute meaningfully by combining (a) a novel, localized probe-and-adapt search strategy inspired by reptile behavior, (b) joint cluster-and-route multi-objective optimization tuned for healthcare priorities (latency, PDR, energy), (c) lightweight incremental re-optimization for real-time operation, (d) integrated security/privacy constraints, and (e) interpretable decision traces validated not only in simulation but also on representative hardware/testbed scenarios. Most contemporary metaheuristics (PSO, GA, ACO, WOA, GWO) use population dynamics that balance exploration and exploitation via global movement or probabilistic operators. RRPO augments this paradigm with a localized probe-and-retreat strategy inspired by reptilian reconnaissance: localized probes scan neighborhood link quality and energy state, then selectively retreat or commit based on multi-criteria probe scores. This yields three concrete advantages: 1) Faster, context-sensitive discovery of reliable routes: probes quickly detect high-quality short routes that global moves might overlook or only discover late in optimization; 2) Lower communication overhead: localized probing reduces frequent global information exchange, saving energy compared with population-wide broadcasts used in some meta-heuristics; 3) Better exploitation of local optima that are globally useful: whereas population methods can waste iterations exploring irrelevant areas, RRPO's probes emphasize locally robust solutions that translate to practical gains in PDR and latency.

3. METHODOLOGY

Assume that the base station (BS) and sensing nodes (SN) operate in the same sensing area. The goal of the SN is to gather the sense of the node's sensing statistics and transfer it to the BS. The following are the network's properties: Every cluster is created with a bunch of nodes; a cluster contains cluster members and a CH that can communicate information straightforwardly to the CH. Through multiple hops, the CH conveys the BS with the data. Every node has T_{min}, a base transmission range in the minimum, and an information transmission range (T_d), which details the sensing devices' character details at T_{min} levels. Throughput is determined as packet count acquired by BS and initiated from the nodes. A first-order radio scheme is employed to transmit the data. In the methodology proposed, energy disbursed for H-bit data transmission, $E_{tx}\ (H,d\ )$ is provided as:

$$E_{tx}\ (H,d\ )=(E_{ele}+E_d\ .\ d^e).\ H \quad (1)$$

Here, the energy degenerated for single-bit transmission circuit is E_{ele}, and amplification energy is E_d. The energy transmitted over a distance d is d^e, and path loss exponent is e. For multi-path space, the e value is 4; for free space, the e value is 2. Therefore, $E_{tx}\ (H,d\ )$ is the overall energy emanated for the H-bit packet transmission.

3.1. Problem statement

Some prior research should have included the selection of a routing path during the CH selection process. Therefore, frequent disconnections, routing topology and ineffectual CH selection surfaced. It was found that raising the nodes transmission range to 100 from 10 meters reduces the number of clusters. The existing LEACH protocol employs none of the routing mechanisms. So, the existing protocol uses a novel routing method where CH finds one more CH with distance lower than distance from

CH which is an extended version of the existing LEACH mechanism, i.e., Superiority towards Cluster Selection and Routing Mechanism (SCSRM) for healthcare applications. The relay node is the recently chosen CH in the routing path. However, several examples demonstrate that the edge length between the CH exceeds the node's highest transmission range.

3.2. Network protocol

The distributed responsibilities of CHs and BS form the basis of superiority towards cluster selection and routing mechanisms (SCSRM) in the healthcare sector based on routing and transmission. The BS defines the underlying backward, equal and forward nodes of all node present and initial sub-area distribution. Broadcasting of the TDMA (time-division multiple access protocol) to the nodes, data transmission to BS and data collection are all managed by the CHs. This approach is explained in the following sections. CM/CH and clustering process are selected in the S-CSRM setup phase. Every one of the cluster's nodes behaves as a contender node to be chosen as the CH. In the data transmission stage, each CH collects data from its members through a multi-hop communication, aggregates it, and transfers it to the BS. S-CSRM aims to carry out CH selection and clustering therefore network's lifetime is expanded effective via inter-cluster routing. The fundamental concept of fixed-area-based clustering is utilized to simplify clustering, CH choosing procedure and inter-cluster routing amongst CH. Each node distinguishes its backward and forward nodes concerning its BS for inter-cluster routing. This data is used while routing discovery and in selecting CH.

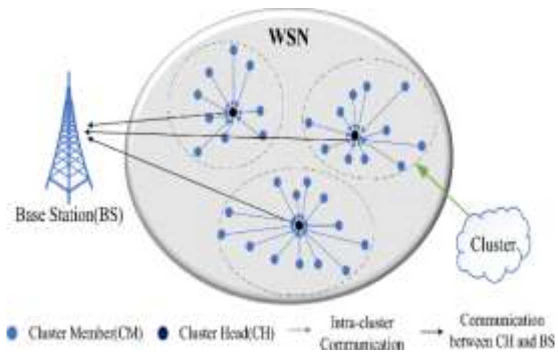

Fig 1: Node Clustering

3.3. Clustering

In S-CSRM, the fixed-area selection process is used in healthcare sectors to quicken the process of finding backward and forward nodes, clustering, and choosing the CH. This information benefits both the CH determination and the robust network topology creation. Backward nodes *B*, forward nodes *F* and area *A* are set to 0 as the initial values. BS finds the first hop neighbors through calculation, then sends a message to region (1) nodes inside Tr_d. After getting the message, the region (1) nodes fix BS as forward node and transfers message inside Tr_d. Then, region (1) sends the message, it will be set as the forward node by region (2) and send the message to the region (3). This procedure will end when there are no backward nodes in the K^{th} area (last area). Multiple K - 1 areas may send a message to a node; that node fixes its forward node ID after getting the first message in the K^{th} region. It then records the list of forward nodes after receiving the second and third forward nodes. The BS sends a "TEMP" message to every node in the network enquiring if they have configured their backward or forward nodes when the broadcast messages have finished reaching all (K) regions. Nodes will send an "ACK" message if they have received data; otherwise, they will transmit an "ERR."

In the process of CH determination, backward, forward and equal nodes are found and utilized during topology creation. CH was chosen given the weight accumulated and broadcasts its schedule to its associated nodes; then, an update in network topology will be made. Then, the briefest way is recognized from source CH to BS for directing the traffic. Energy dissemination and data transmission begin alongside the next stage's alternative routing path determination technique. Phase 2 begins once more after one round of data transmission. This procedure goes on until all nodes in the network face death.

3.4. CH selection probability with S-CSRM

For the node (x), there should be a single forward node (u). The node (x) functions as the backward node. The node(u)'s probability P to be chosen as the node (x)'s forward node is:

$$\prod_{u}[1\text{-}P(x,u)] \cap u \in F(x) \qquad (2)$$

For node (x) is the sole CH that sends data to node (u), we can give the probability as:

$$P_{CH}\,(x)\text{=}[1\text{-}\prod_{u}(1\text{-}P(x,u))] \cap u \in F(x), \quad A(x) \neq A(u) \qquad (3)$$

Here $P(x, u) = P_{CH}(u).P(F(x))$. According to this equation, if node (x) needs to be chosen as a CH, it needs to pose node (u) likelihood of CH node. In network generation, the condition needed is: If there is no backward node for node (x), it specifies the node (x)'s region is the last (K^{th} region), then the node (x)'s to CH is provided below:

$$P_{CH}(x)=P(x,m) \cap N_B(x)=0 \cap N_F(x) \neq 0 \quad (4)$$

Here, the node (x)'s equal node is m, from a different region but is within the same area.

3.5. Node functionality analysis with S-CSRM

We can determine the quantity of node (x)'s forward nodes using trigonometric calculations. If the transmission range radius represents T_{r_d}, area's boundary and node is $d(x)$, and angle is $\theta/2$. Then,

$$\frac{\theta}{2} = \arccos\frac{\Delta\, d(x)}{T_{r_d}} \quad (5)$$

The sector's region is provided in Eq. (6):

$$R(x) = \frac{\theta}{2} * Tr_d^2 \quad (6)$$

The forward region is attained by deducting triangle region from the complete area and provided as:

$$R\big(F(x)\big) = R(x) - b.\ \Delta\, d(x)\sqrt{Tr_d^2 - \Delta\, d(x)^2} \quad (7)$$

Here, the right-angle triangle's perpendicular line is b. The node (x)'s forward node count is computed as given below:

$$N_F(x) = \rho.\ A(F(x)) \quad (8)$$

Here, the count of nodes per unit area is ρ. Likewise, for computing the node (x)'s backward node count:

$$\frac{\phi}{2} = \arccos\frac{T_{r_{min}} - \Delta d(x)}{T_{r_d}} \quad (9)$$

Here, the right-angle triangle's angle is $\frac{\phi}{2}$; it is utilized to compute the node (x)'s backward nodes count. Thus, using the below equation, we can find the node (x)'s backward node count:

$$N_B(x) = \rho\left[\phi.\ T_{r_d}^2 - Tr_{min}.\ d(x)\Big).\ \sqrt{Tr_d^2 - (T_{r_{min}} - \Delta\, d(x)^2}\right] \quad (10)$$

The conditions needed for a node to attain the position of a CH are:

$$x_{CH} = \begin{cases} N_F(x) \neq 0,\ N_B(x) \neq 0 & \text{for all } x \in \text{region} < K \\ N_F(x) \neq 0,\ N_B(x) = 0 & \text{for all } x \in \text{region} < K \end{cases} \quad (11)$$

3.6. Routing

BS starts routing by sending the update message to every node in all regions (1). Once the data is received, every node in the region (1) broadcasts messages within their data transmission range after setting BS as their forward node (remote location of the healthcare sector). After receiving messages from nodes over region (1), the nodes over region (2) set these nodes as forward nodes. Region (1) nodes set region (2) nodes as backward nodes and send the "ACK" message back in T_{r_d}. Until every node in various regions sets its forward and backward nodes, this process keeps going. Nodes with the most significant Euclidean distance for encompassing the most considerable length of area in one hop are given preference when choosing a forward node. It is essential to observe that the T_{r_d} of nodes determines data transmission, while the lowest transmission range, $T_{r_{min}}$, determines the formation of clustering regions. Fig 1 displays a basic topology that the network's BS created. The BS initiates the one-hop neighbor in the first step. This comprises CH nodes seven, eight and nine. Every CH maintains a routing table that contains information like its backward and forward nodes. Every node transfers a message for route update to backward CH nodes (four, five, six). Likewise, CH nodes (four, five, six) transfer a message for route update to backward nodes (one, two, three). In a routing table, the backward and forward nodes are maintained for all the nodes. A message regarding an update will be sent if there is a CH change in any region. To manage the failover scenario, if nodes five and four fail, node two will be chosen as the forwarding node by node 1. The final step involves route discovery and selection following network topology generation and CH selection. This step offers the best possible route for data transmission from source to sink while focusing on energy-efficient, failover and load-balancing scenarios.

3.7. Optimizing with firefly hybridization and R^2PA

The binary optimization issue contains limited resolutions from 0 to 1. A binary vector represents every solution or agent, where a zero value denotes that the feature isn't chosen, and one value shows that the selected feature is accepted. The solution vector's size corroborates the various features in a specific dataset. During every iteration in FF, the chosen feature subset has to be assessed. Therefore, it is a challenging task, particularly in the wrapper-based approaches. The FF presented was first created to address issues with continuous optimization. Algorithm 1 describes the re-designed algorithm R^2PA with FF to resolve the problems in FF. Before being assessed, each solution vector is transformed into a binary form of 0*s and* 1*s*. The transfer function in S-shape is employed to accomplish this conversion. This function allows for selecting a specific feature in a solution vector. Numerous researchers have utilized this function and consider it reliable. Eq. (12) represents the transfer function in S-shape.

$$S(x)= \frac{1}{1+e^{-x}} \tag{12}$$

Eq. (13) is used to update the agent's feature during the conversion process.

$$P_d^{t+1}= \begin{cases} 1 & \text{if } S\left(P_d^{t+1}\right)>\text{rand} \\ 0 & \text{if } S\left(P_d^{t+1}\right)\leq \text{rand} \end{cases} \tag{13}$$

Here, agent's updated feature subset is P_d^{t+1}, random number among 0 and 1 is provided as rand and transfer function in Eq. (13) is $S(P_d^{t+1})$. Fig 2 illustrates a comprehensive summary of the framework proposed.

3.8. Fitness function

In this section, the algorithm evaluates the quality of the solution. As it is a wrapper-based method, a learning algorithm has been employed. The classification accuracy is found using K-NN. The amount of classification and feature error are the features in the fitness function. FF aims to decrease the number of features while improving accuracy. Instead of using accuracy, we used classification error. This is due to the need to reduce the error and feature count. The function for evaluating feature subset is given in Eq. (14).

$$fitness= \gamma * \ \lambda+(1-\gamma)* \ \frac{|f|}{|F|} \tag{14}$$

Where the quantity of features is given as $|f|$, in the given dataset $|F|$ represents the count of features, the classification error is λ, and a parameter that provides a relative contribution among the number of features and the classification error is given as $\gamma \in [0, 1]$.

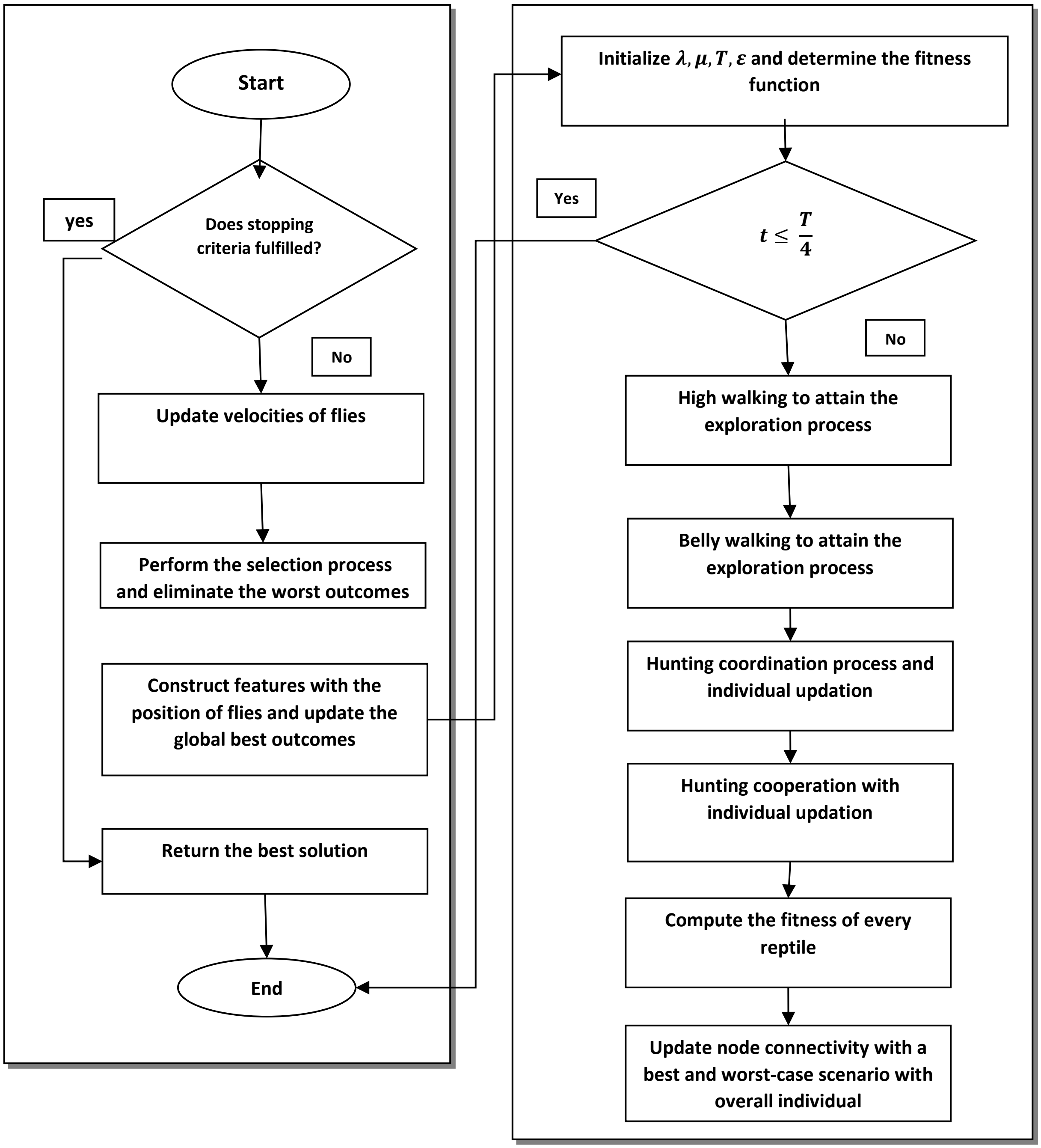

Fig 2: Flow Diagram Of R^2PA Optimizer Model

Algorithm 1:

1. Set T, μ, λ and ε as initial values.

2. Set iteration value, population initialization as random value with i={1,…,N} for $X_i^{(t)}$*;*

3. Attain fitness function and best outcomes with reptile sense;

4. Repeat process

```
for i=1 to N do
    for j=1 to N do
        Update hunting operator;
            Update percentage difference;
                Update reduction function;
    if t≤ T/4 then
        Update exploration;
        else if (T<t< T/2) then
         Update exploration;
         else if (T<t<3 T/2) then
            Update hunting coordination;
                else
             Update hunting coordination based on features; //from fireflies
         end if
     end for
  end for
set t=t+1;
until t>T
Attain global solution
```

4. Numerical results

An outcome comparison is made between the proposed S-CSRM protocol and the current protocols like LEACH, ERP, HEER and SEED. Compared to these protocols, the S-CSRM protocol performs more effectively, especially when the lifetime of the networks is compared. It is essential to define the word "round" as it applies to this context before going into more detail. A round is the duration of which the cluster organization, node setup, data transmission and CH selection procedures are finished. MATLAB 2020a is utilized to carry out the simulations, and Table 1 contains information on the parameters used in each simulation. Cluster creation needs high-energy consumption processes in existing LEACH protocol. However, S-CSRM establish sub-clustering beforehand based on the smallest possible transmission range. Every node within sub-area chooses the subsequent CH by applying cumulative weights to several factors, including connectivity and residual battery. All member nodes then start to send and receive data by the TDMA schedule in healthcare sectors. The fact that S-CSRM uses more node energy for data transfer than advertising, cluster formation, and network resetting is significant to note.

Table 1: Parameter Setup

Parameters	**Value**
Sink	100
Total nodes	300
Energy	1J
Area	500*500m
Packet size	2000 bits
Control packet	200 bits
Transmission energy	50 nJ/bit/m2
Receiver energy	50 nJ/bit/m2
Aggregation energy	10nJ/bit/m2
Amplifier (free space)	100nJ
Amplifier (multi-path)	0.0015nJ

4.1. Throughput

The network lifetime is observed to reduce with increasing area size for a fixed amount of transmission range and clusters. The above condition is correct for every protocol, including LEACH, ERP, HEER and SEED. Figure 3 shows how node density affects the various S-CSRM, LEACH, ERP, HEER and SEED area sizes. When comparing the S-CSRM to the LEACH, the network lifetime is longer in S-CSRM. When the nodes increase, the network's lifetime improves and stabilizes as the node count rises. This is because increased node density in given area promotes increased inter-packet communication for CH selection and clustering, reducing the energy required for data transmission.

This results from each node receiving its CH turn faster and using up energy more quickly. In addition, the nodes are more widely distributed and use huge energy to transmit data to CH. In contrast, network lifetime decreases again at larger node density values, i.e., five hundred and more. This is because the CH has to act as a relay node for a greater node number and transmit data from a more significant number of CMs. As a result, both protocols' overall network lifetimes decrease. Comparing the S-CSRM approach to the LEACH methodology, a similar increase in PDR is seen in Fig 6 and Fig 7.

4.2. Node state analysis

The results of S-CSRM protocol demonstrate that there are two thousand three hundred five hundred a seven thousand four hundred rounds for 0.26 *J*, 0.5 *J*, *and* 1*J* of initial node energy, which displays the die-out pattern for nodes in the S-CSRM protocol with varying initial energy levels. Tables 8 to 10 provide node movement periods for LEACH and S-CSRM protocols at variou0s initial energy levels. Fig 9 demonstrates that the S-CSRM protocol has a far longer control packet lifetime than the LEACH protocol. CMs in different clusters encounter data packet collisions even though the CH provides them with a TDMA-based data transfer schedule. Consequently, in ERP, LEACH packets reaching BS drops. The network's nodes cannot send data since there are fewer disconnected nodes in any given round in LEACH than in S-CSRM. S-CSRM protocol offers total connectivity and an alternative routing method in multi-hop communication. As a result, more packets reach the BS at a higher throughput. The transmission range grows as the CHs increase. This can be found in Fig 11, where the LEACH and S-CSRM methods are based on average E2E delay. This is because, instead of using probabilistic clustering with unknown CH positions, the network uses the transmission range to build clusters limited to a maximum edge length. The various phases each protocol executes account for all these differences in the network's lifetime under multiple protocols. S-CSRM does not use dynamic clustering; instead, it creates clusters initially. Compared to other protocols, this lengthens the protocol's network lifetime.

4.3. Transmission range

The outcomes presented in Fig 12 for LEACH and ERP protocols show that fewer clusters and hop counts are produced as the transmission range increases. For each area, there is an optimal cluster value. Table 2 to Table 3 demonstrates that for all initial energy nodes, the highest number of packets that could reach BS, when the transmission range was 100 $m \times 200\ m$ area. The nodes' transmission range determines the number of clusters that develop. While LEACH performs better than S-CSRM for lesser transmission ranges, the outcomes are similar. However, S-CSRM is feable in forming clusters based on the transmission range for a particular area of 200 $m \times 200\ m$. In contrast, LEACH is unable to do so and produces additional clusters. When T goes beyond 70 meters, LEACH does not change cluster count, whereas S-CSRM can adapt to more excellent transmission ranges with efficiency.

4.4. Routing analysis

The proposed protocol generates an optimal clustering region and is flexible enough to change transmission ranges. However, the hop count does not change after a specific transmission range. By designating CHs and fixed area clusters, S-CSRM improves clustering and routing topology development. Still, LEACH's variable area size leads to an increase in the average hop for longer transmission ranges. The transmission path produced by S-CSRM is effective than ERP and increases with a more extensive transmission range. In each round, there are 100% of connected nodes for S-CSRM; in LEACH, it is nearly 100%, and in LEACH, it is 90–95%. The cause is that each cluster has a set transmission range covering every node. However, some nodes stay disconnected from LEACH, and the network lifetime decreases because of gateway nodes. LEACH achieves good node connectivity because it is designed to reduce unconnected nodes.

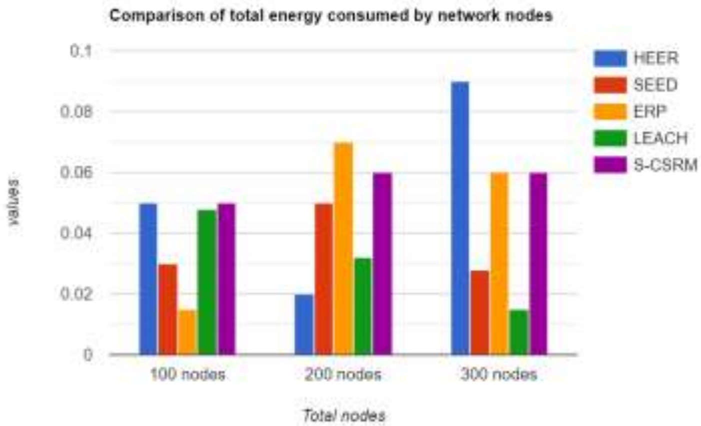

Fig 3: Total Energy Consumed By Network Nodes

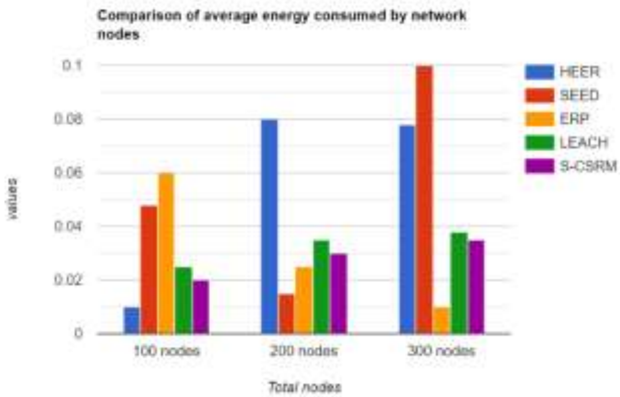

Fig 4: Avg. Energy Consumed By The Nodes

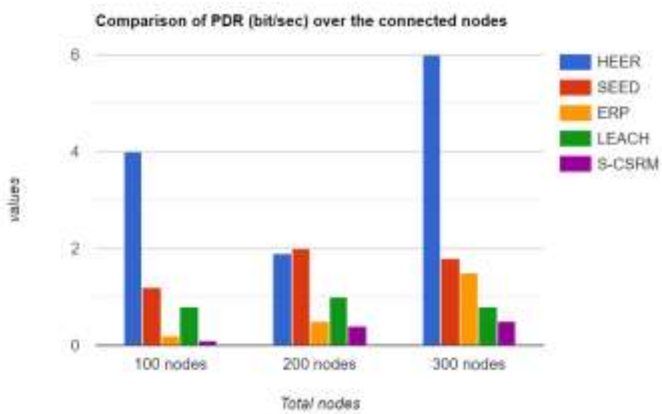

Fig 5: PDR Computation

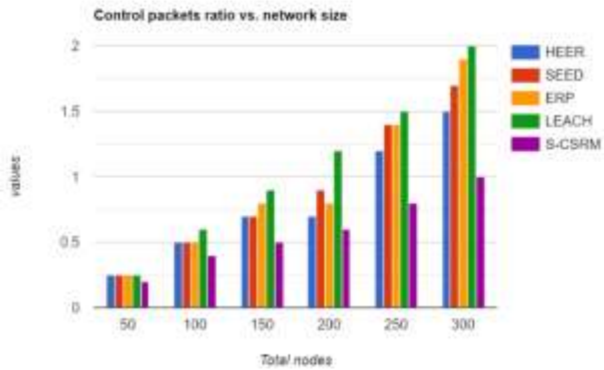

Fig 6: CPR Analysis

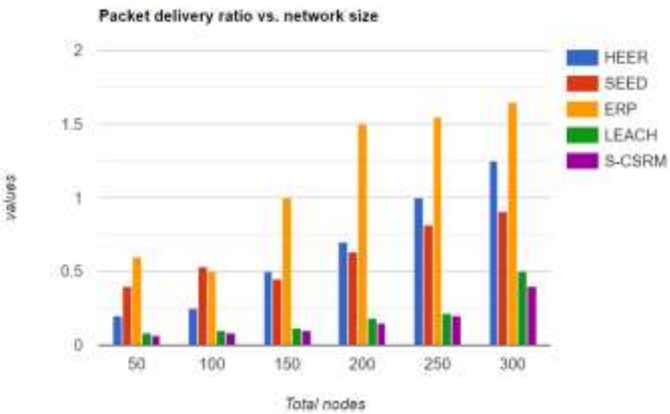

Fig 7: PDR Vs. Network Size

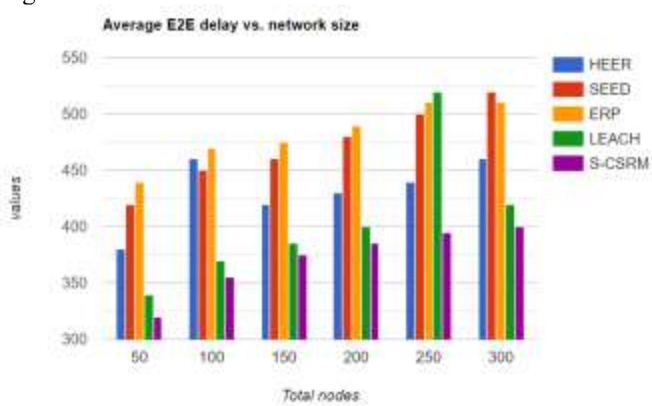

Fig 8: Avg. Delay Vs. Network Size

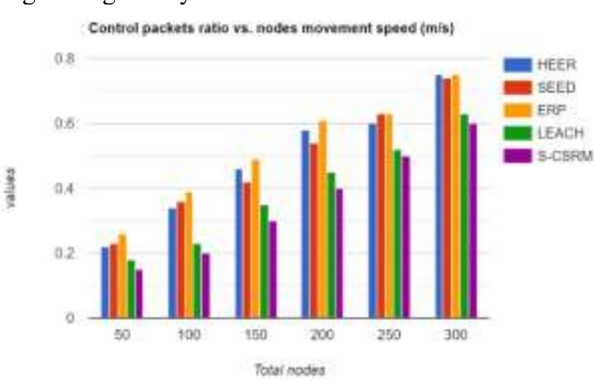

Fig 9: CPR Vs. Node Movement Analysis

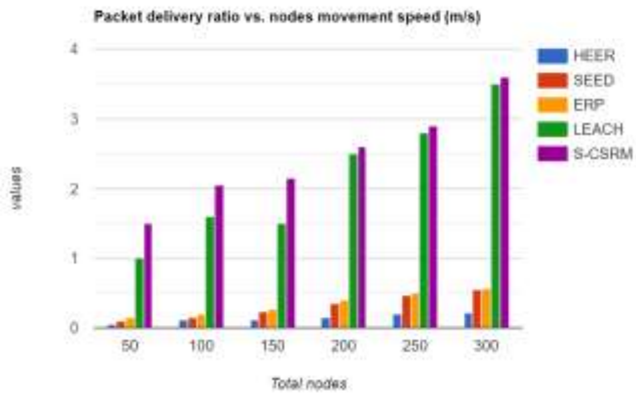

Fig 10: PDR Vs. Nodes Movement Analysis

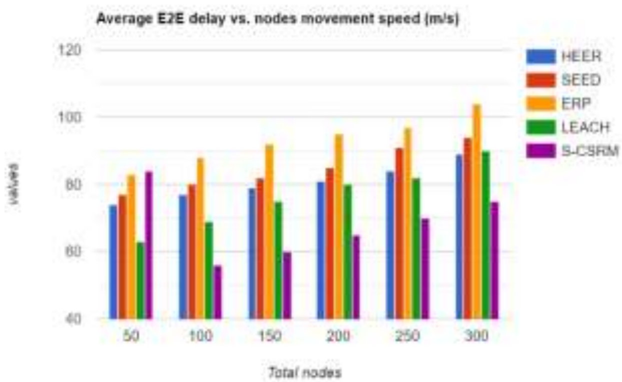

Fig11: Average Delay Vs. Nodes Movement Comparison

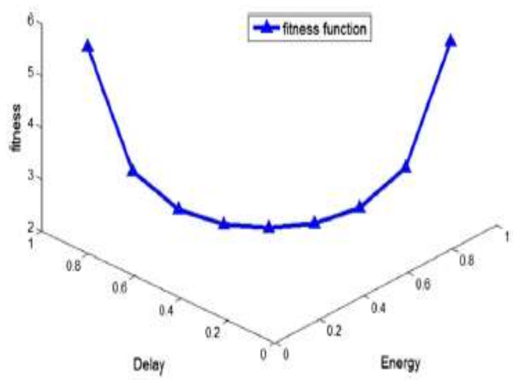

Fig 12: Fitness Function

5. Conclusion

The proposed S-CSRM work handles routing and clustering as one unified issue. An energy-efficient solution was not found because these two problems were handled independently in earlier research. An enhanced clustering-based approach was developed with effective traffic routing in a multi-hop situation, taking into account the geographical position of nodes. The failover condition was considered throughout the model's creation. The findings show that compared to the LEACH and ERP with S-CSRM, the proposed method offers a much longer network lifetime. This algorithm can be elongated to encompass scenarios with both BSs and nodes. Healthcare facilities, retail centers, and stadiums are additional locations where random node placement and distribution possibilities can be explored in real life. Thus, the network energy and total capacity is more optimally achieved.

Declarations

Ethical Approval

The proposed work is based on simulation and algorithmic modeling using publicly available concepts and does not involve human participants, animals, or sensitive data; hence, ethical approval is not required.

Competing Interests
The authors declare that they have no competing interests.
Conflict of Interest
The authors declare that there is no conflict of interest.
Authors' Contributions
Pushpavalli Kathirvelu: Conceived the idea, performed literature survey, and developed the proposed methodology.
Arasakumar Murugesan: Assisted in model design, simulation, and technical validation.
Balaji Subbiah: Contributed to performance analysis, results interpretation, and manuscript refinement.
All authors reviewed and approved the final version of the manuscript.
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Availability of Data and Materials
The work is based on simulations; no new datasets were generated. Any supporting information related to implementation can be made available by the authors upon reasonable request.

References
[1] L. Abualigah et al., "Aquila optimizer: A novel meta-heuristic optimization algorithm," *Comput. Ind. Eng.*, vol. 157, p. 107250, 2021.
[2] L. Abualigah et al., "The arithmetic optimization algorithm," *Comput. Methods Appl. Mech. Eng.*, vol. 376, p. 113609, 2021.
[3] S. A. F. Aghda and M. Mirfakhraei, "Improved routing in dynamic environments with moving obstacles using a hybrid fuzzy-genetic algorithm," *Future Gener. Comput. Syst.*, vol. 112, pp. 250–257, 2020.
[4] A. Arulmurugan, S. F. Waris, and N. Bhagyalakshmi, "Analysis of cluster head selection methods in WSN," in *Proc. 6th Int. Conf. Inventive Comput. Technol. (ICICT)*, IEEE, 2021.
[5] W. Fang et al., "MSCR: Multidimensional secure clustered routing scheme in hierarchical wireless sensor networks," *EURASIP J. Wirel. Commun. Netw.*, vol. 2021, no. 1, pp. 1–20, 2021.
[6] H. R. Farahzadi et al., "An improved cluster formation process in a wireless sensor network to decrease energy consumption," *Wireless Netw.*, vol. 27, no. 2, pp. 1077–1087, 2021.
[7] T. Kaur and D. Kumar, "Particle swarm optimization-based unequal and fault tolerant clustering protocol for wireless sensor networks," *IEEE Sens. J.*, vol. 18, no. 11, pp. 4614–4622, 2018.
[8] W. Kiran, S. Smys, and V. Bindhu, "Enhancement of network lifetime using fuzzy clustering and multidirectional routing for wireless sensor networks," *Soft Comput.*, vol. 24, no. 15, pp. 11805–11818, 2020.
[9] M. Mohan, V. Tamizhazhagan, and S. Balaji, "A perspicacious multi-level defense system against DDoS attacks in cloud using information metric & game theoretical approach," *J. Netw. Syst. Manage.*, vol. 31, no. 85, 2023. doi: 10.1007/s10922-023-09776-7.
[10] D. K. Shah and T. Amgoth, "Renewable energy harvesting schemes in wireless sensor networks: A survey," *Inf. Fusion*, vol. 63, pp. 223–247, 2020.
[11] P. Sood, "A fuzzy logic-based clustering algorithm for WSN to extend the network lifetime," *J. Global Res. Comput. Sci.*, vol. 9, no. 6, pp. 19–25, 2018.
[12] H. Singh and D. Singh, "Multi-level clustering protocol for load-balanced and scalable clustering in large-scale wireless sensor networks," *J. Supercomput.*, vol. 75, no. 7, pp. 3712–3739, 2019.
[13] P. Feng, D. Qin, P. Ji, M. Zhao, R. Guo, and T. M. Berhane, "Improved energy-balanced algorithm for underwater wireless sensor network based on depth threshold and energy level partition," *EURASIP J. Wirel. Commun. Netw.*, vol. 2019, no. 1, pp. 1–15, 2019.
[14] N. Ayoub, M. Asad, M. Aslam, Z. Gao, E. U. Munir, and R. Tobji, "MAHEE: Multi-hop advance heterogeneity-aware energy-efficient path planning algorithm for wireless sensor networks," in *Proc. IEEE Pacific Rim Conf. Commun., Comput. Signal Process. (PACRIM)*, Aug. 2017.
[15] G. S. Arumugam and T. Ponnuchamy, "EE-LEACH: Development of energy-efficient LEACH protocol for data gathering in WSN," *EURASIP J. Wirel. Commun. Netw.*, vol. 2015, no. 1, p. 76, 2015.
[16] J. Roberts and J. Toft, "Finding vulnerabilities in IoT devices: Ethical hacking of electronic locks," M.S. dissertation, Sch. Elect. Eng. Comput. Sci., KTH Royal Inst. Technol., Stockholm, Sweden, 2019.
[17] A. Aldweesh, A. Derhab, and A. Z. Emam, "Deep learning approaches for anomaly-based intrusion detection systems: A survey, taxonomy, and open issues," *Knowl.-Based Syst.*, vol. 189, Feb. 2020.
[18] L. Ferran, L. Maglaras, S. Moschoyiannis, and H. Janicke, "Deep learning for cyber security intrusion detection: Approaches, datasets, and comparative study," *J. Inf. Secur. Appl.*, vol. 50, Feb. 2020.

[19] X. Ge, N. Fu, Z. Baig, G. Teo, and A. Robles-Kelly, “Deep learning-based intrusion detection for IoT networks,” in *Proc. 24th IEEE Pacific Rim Int. Symp. Dependable Comput. (PRDC)*, Dec. 2019, pp. 256–265.
[20] H. Hassan, A. Gumaei, A. Alsanad, M. Alrubaian, and G. Fortino, “A hybrid deep learning model for efficient intrusion detection in the big data environment,” *Inf. Sci.*, vol. 513, pp. 386–396, Mar. 2020.
[21] J. Deng, M. Lee, and H. Wang, “IoT data feature extraction and intrusion detection system for smart cities based on deep migration learning,” *Int. J. Inf. Manage.*, vol. 49, pp. 533–545, Oct. 2019.
[22] C. Yin, S. Zhang, J. Wang, and N. N. Xiong, “Anomaly detection based on recurrent convolutional autoencoder for IoT time series,” *IEEE Trans. Syst., Man, Cybern. Syst.*, early access, Feb. 7, 2020.
[23] Y. Wang, M. Su, M. Zhang, and J. Nie, “A deep hierarchical network for packet-level malicious traffic detection,” *IEEE Access*, vol. 8, pp. 201728–201740, 2020.
[24] J. Yang and F. Wang, “Wireless network intrusion detection based on improved convolutional neural network,” *IEEE Access*, vol. 7, pp. 64366–64374, 2019.
[25] T. Otomo, D. Liu, and A. Nayak, “DL-IDS: A deep learning-based intrusion detection framework for securing IoT,” *Trans. Emerg. Telecommun. Technol.*, 2019.
[26] Y. Li, Y. Xu, Z. Liu, H. Hou, Y. Zheng, Y. Xin, Y. Zhao, and L. Cui, “Robust detection for network intrusion of industrial IoT based on multi-CNN fusion,” *Measurement*, vol. 154, Mar. 2020.
[27] S. Kunang, S. Nurmaini, D. Setiawan, and B. Y. Suprapto, “Attack classification of an intrusion detection system using deep learning and hyperparameter optimization,” *J. Inf. Secur. Appl.*, vol. 58, Mar. 2021.
[28] Sherubha, “Graph-based event measurement for analyzing distributed anomalies in sensor networks,” *Sādhanā (Springer)*, vol. 45, no. 212, 2020. doi: 10.1007/s12046-020-01451-w.
[29] Sherubha, “An efficient network threat detection and classification method using ANP-MVPS algorithm in wireless sensor networks,” *Int. J. Innov. Technol. Explor. Eng. (IJITEE)*, vol. 8, no. 11, pp. 2278–3075, Sep. 2019.
[30] Sherubha, “An efficient intrusion detection and authentication mechanism for detecting clone attack in wireless sensor networks,” *J. Adv. Res. Dyn. Control Syst. (JARDCS)*, vol. 11, no. 5, pp. 55–68, 2019.