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AN ENERGY-EFFICIENT SECURE DYNAMIC ROUTING FOR CLUSTER-BASED WIRELESS SENSOR NETWORK

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Abstract:

Small sensor nodes with limited energy, memory, and compute capabilities make up Wireless Sensor Networks (WSNs). They are frequently used in hostile and unattended environments. Extending the network lifetime of WSNs is challenging and expensive. An energy-efficient routing technique is a critical issue in extending a network's network lifetime to achieve reliable data transmission in WSNs. Routing is the process of determining the most efficient path between source and sink nodes. The lifetime of nodes in a network is critical, and it must be improved by taking into account the Node's energy. This paper proposes an energy-efficient secure dynamic routing protocol for cluster-based WSN (CDR). First, the nodes are clustered based on the node location, following select cluster heads based on the energy and distance. Finally, the optimal path is selected for dynamic, secure routing to transmit sensitive data from the sensor node to the base station. Extensive simulations have validated the effectiveness of our proposed approach. The suggested routing strategy performs well compared to the existing routing scheme in terms of energy, packet delivery ratio, and time.

Keywords: WSN, dynamic routing, energy-efficient, node clustering

1. Introduction

Wireless Sensor Networks (WSNs) are made up of thousands of sensor nodes that are tiny in size, low in cost, and consume little power. WSNs are widely utilized in military surveillance, climatic and environmental monitoring, natural disaster warning and response, intelligent healthcare technology, and other sectors [1]. WSN is a vast network of low-power, intelligent, and multipurpose sensor nodes linked to base stations (BS) [2]. However, generic ad-hoc routing protocols in WSN have been limited because of the large number of nodes, low available data speeds, and different resource constraints. Instead, WSN routing systems enable resource-awareness and adaptivity to enhance network lifetime and overcome limited battery capacity [3]. WSN routing protocols are divided into two categories based on network structure: flat and hierarchical routing systems. Sensor nodes in a flat routing architecture can all act in the same way in the routing process. As a result, all sensor nodes are configured to send sensed packets to base stations directly. On the other hand, a hierarchical routing architecture divides the sensor nodes into clusters [4].

WSNs have gained a lot of attention to energy-efficient clustering routing protocols. The sensing nodes are grouped into smaller groups, known as clusters, in these protocols. In a cluster, one Node is given more communication responsibilities than the others. The CH is the particular Node, whereas member nodes are the other nodes. The CH receives the data from the member nodes. The CH then aggregates the data before sending it to the BS [5]. Figure 1 shows the cluster-based WSN.

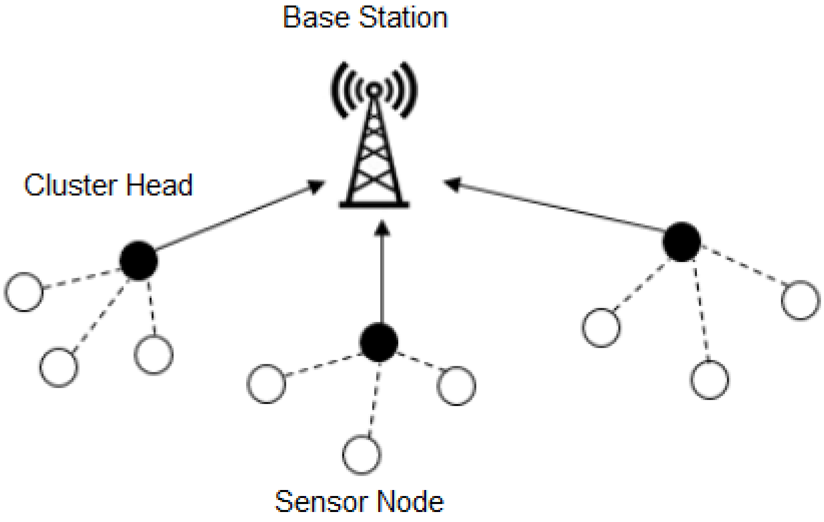

Figure 1 Cluster-based WSN

The data transfer from cluster heads to the BS might be done in a single hop or multi-hop approach. Clustering algorithms are divided into two categories: probabilistic and non-probabilistic. Clusters are created in a random order in probabilistic [6], resulting in imbalanced load distribution and energy usage. The non-probabilistic technique [7], on the other hand, selects cluster heads based on many parameters. Even though non-probabilistic methods outperform standard probabilistic methods, the dynamic nature of sensor nodes [8] means that enhancing energy conservation and routing robustness are still open issues for WSN.
This paper proposes an energy-efficient secure routing protocol for cluster-based WSN. It provides reliable communication between sensor nodes. This work contains three phases. First, the Node clustering is based on their location, following cluster head selection based on different parameters like energy and distance—finally, secure dynamic routing for sensitive data transmission.

The rest of the paper is organized as follows: Section 2 reviews various secure routing protocols used in WSN. Then, the proposed dynamic routing scheme is explained in section 3, and Section 4 analyzes the performance of the proposed work. Finally, section 5 concluded the paper.

2. Related Work

This section explains some previous cluster head selection methods and cluster-based secure routing schemes used in WSN.

Behera et al. [9] offer an efficient CH election strategy that rotates the CH location among nodes with greater energy levels than others. To choose the next set of CHs for the network, the algorithm analyses initial energy, residual energy, and an ideal value of CHs.

Hassan et al. [10] suggest a more energy-efficient clustering approach to extend the life of WSN-based IoT. First, for the overlapping balanced clusters, an ideal number of clusters is established. The balanced-static clusters are then constructed using a modified fuzzy C-means algorithm with a technique to reduce and balance the sensor nodes' energy usage. Finally, by combining a back-off timing mechanism for CH selection and a rotation mechanism for CH rotation, CHs are picked at ideal positions with rotation of the CH function among cluster members based on a new CH selection rotation algorithm.

Mehra et al. [11] introduced a fuzzy-based balanced cost CH selection technique that considers the residual energy, distance from the sink, and density of nodes in the region as inputs to the Fuzzy Inference System. To select the CH role, an eligibility index is calculated for each Node. This protocol achieves load balancing by evaluating the probability allocated to each sensor node when selecting the best candidate for the role of cluster coordinator.

Arunachalam et al. [12] suggest a Squirrel Search Optimization-based Cluster Head Selection Technique for extending the lifespan of sensor networks by incorporating a gliding component that aids in improved cluster head selection during the data acquisition and distribution phase. It calculates the fitness value of sensor nodes and organizes them in ascending order, with the cluster member being the Node with the lowest fitness value. Sensor nodes having a high fitness value, on the other hand, are confirmed as prospective cluster heads.

Ali et al. [13] create a novel Cluster Head Selection technique combined with a heuristic termed innovative ranked-based clustering to reduce sensor node communication and energy consumption while maximizing network lifetime. It constantly shifts between exploration and exploitation of the search process during run-time to obtain a better performance-to-cost ratio and significantly extends the network's life span. Furthermore, during cluster head (CH) selection, it considers residual energy, communication distance factors, and workload.

For WSN, Al-Otaibi et al. [14] create a hybridization of the metaheuristic cluster-based route discovery process. This method starts with a conceptual optimization with a levy distribution-based clustering procedure that uses a fitness function that includes four parameters: energy, distance to neighbours, distance to the base station, and network utilization. In addition, for optimal route selection, a water wave optimization with a hill-climbing based routing technique is carried out.

To decrease network congestion, Farsi et al. [15] present a congestion-aware clustering and routing algorithm. By selecting the appropriate primary and secondary cluster heads, this protocol reduces end-to-end delay time. In addition, it increases network lifetime. A unique energy-efficient zone source routing strategy was proposed by Xu et al. [16]. A distributed energy region technique is developed for dynamically selecting the nodes in the network with the highest residual energy as source routing nodes. The source routing nodes then construct the best source routing path for each common Node, allowing partial nodes to participate in the routing process while balancing sensor node energy usage. In addition, an effective distance-based ant colony optimization technique is developed to find the global ideal transmission channel for each Node to reduce data transmission energy consumption.

El Alami et al. [17] suggest a sleeping-waking strategy for overlapping and nearby nodes to achieve energy efficiency in WSNs. As a result, data redundancy is reduced, and network lifetime is increased. Furthermore, unlike prior hierarchical routing algorithms, which required all nodes to gather and transmit data, this strategy requires the awake nodes to do these functions, which are critical to WSN energy consumption.

3. Methodology

Due to their characteristics, such as infrastructure-less deployment and resource-constrained nature, wireless sensor networks create several difficulties influencing the system's performance. The most difficult challenges, such as energy efficiency, proper cluster head selection, safe data transmission, and a lifetime of network improvement, necessitate serious consideration for WSN upgrading, which remains a tremendous effort.

This paper proposes an energy-efficient secure dynamic routing protocol for cluster-based WSN (CDR). First, the nodes are clustered based on the node location, following select cluster heads based on the energy and distance. Finally, the optimal path is selected for dynamic, secure routing to transmit sensitive data from the sensor node to the base station.

Base Station: A base station is often a network gateway, a sophisticated data processing/storage facility, or a human interface access point. It possesses limitless computing and communication power, limitless memory storage and a very long radio transmission range that can reach all nodes in a network. Sensor readings are collected, operations are performed on behalf of sensor nodes, and base stations manage the network. Base stations are believed to be trustworthy and tamper-resistant in some applications. As a result, they serve as essential distribution centres. Depending on the application, it can be placed at the network's centre position or in a corner position.

Sensor Node: A sensor node is a general wireless device with limited capabilities. Each Node has a limited amount of battery power, memory, and data processing capability, as well as a small radio transmission range. The base station generates a unique ID number for each sensor node.

Cluster Head: The cluster head is a more powerful sensor node that collects and integrates local traffic before sending it to the base station. The cluster head communicates directly with each other sensor nodes and relays data between the cluster members and the base station during data transmission.

Cluster: A cluster is collected of node members and a cluster head. A unique cluster ID number is assigned to each cluster. Cluster nodes connect directly with their cluster head, and no data is exchanged between sensor nodes.

Node Clustering and Cluster head Selection

This section explains node clustering and the cluster head selection process. Initially, the N number of nodes are randomly distributed in a (W * H) area with one base station located at the centre point of the area. Thus, all sensor nodes have the same initial energy, and the base station has unlimited energy and computing power. Algorithm-1 shows the node clustering and cluster head selection.

Algorithm1: Node Clustering and Cluster head selection
Step1: Deploy N number of nodes in MxM area
Step2: Create base station (BS) in the centre position of the network area
Step3: Split network area into four regions (R)
Step4: For i = 1 to |R|
Step5: NC_i = Count no of nodes in R_i
Step6: For j = 1 to $\|NC_i\|$
Step7: D = Compute the distance between NC_{ij} and BS
Step8: NR= Count no of neighbours nearest NC_{ij}
Step9: Engr = Get Current energy of Node
Step10: End For
Step11: C = Find optimal Node based on (D, NR, Engr)
Step12: Select C as Cluster Head (CH_i)
Step13: End For

In this algorithm, the network area is divided into four regions. First, the cluster head node is selected based on the distance, neighbours and energy level. Then, the cluster head is updated based on the packet delivery ratio of the CH.

Dynamic Routing:

This section explains the proposed dynamic routing for improving network performance. This routing is used to find the optimal best path, which leads to the extended lifetime of the network. Algorithm-2 shows the dynamic routing

Algorithm-2 Dynamic Routing
Step1: BS generate the salt key (SK)
Step2: BS distribute SK to each cluster head (CH)
Step3: If Node has any sensed message
Step4: Transmit the message to CH
Step5: CH checks the BS communication range
Step6: If CH is nearest to BS, then
Step7: CH send message to BS
Step8: Else
Step9: Send a message to the nearest CH
Step10: Continue until BS reaches.
Step11: End IF
Step12: End IF

Dynamic Encryption and Decryption

This section explains the proposed dynamic encryption and decryption algorithm for secure message transmission. Initially the salt key is randomly generated based on the combination of numbers and alphabets. The size of the salt key is based on the length of plain text. Algorithm-3 explains the encryption process.

Algorithm-3 Data Encryption
Input: Plain Text (PT)
Output: Encrypted Text (ET)
Step1: n=Length(PT)
Step2: Set base= 0123456789ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz
Step3: salt= randomly select n characters from base
Step4: v1 = 0
Step5: for i = 0 to n
Step6: v2=(ascii(salt(i))+ascii(PT(i))+v1)%256;
Step7: ET=ET+(char(v2))
Step8: v1=v2;
Step9: end for
Step10:Return ET, salt

For example let *Plain Text =My Secret* and *salt = ppqPeRhpp* Table 1 explains the encryption process.

Table 1 Encryption Process

Salt	PT	V1	V2	ET
P	M	0	189	½
P	y	189	166	¦
Q		166	55	7
P	S	55	218	Ú
E	e	218	164	¤
R	c	164	89	Y
H	r	89	51	3
P	e	51	8	
P	t	8	236	ì

Encrypted text = ½¦7Ú¤Y3 ì

Algorithm-4 explains the decryption process.

Algorithm-4 Data Decryption

Input: Encrypted Text (ET), Salt

Output: Decrypted Text (DT)

```
Step1:  v1=0
Step2:  v2=256+ascii(ET(0))-ascii(salt(0)-v1)%256
Step3:  DT=DT + char(v2)
Step4:  for i = 1 to n
Step5:     v2=(256+ascii(ET(i))-ascii(salt(i)))-ascii(ET(i-1)))%256;
Step6:     DT=DT+(char(v2))
Step7:  end for
Step8:  Return DT
```

Table 2 shows the decryption process.

Table 2 Decryption Process

Salt	ET	V2	DT
p	½	77	M
p	¦	121	y
q	7	32	
P	Ú	83	S
e	¤	101	e
R	Y	99	c
h	3	114	r
p		101	e
p	ì	116	t

Decrypted text = My Secret

4. Experimental Result

This section explains the performance evaluation of the proposed approach. The proposed dynamic routing is implemented using Java (version 1.8), and the experiments are performed on an Intel(R) Pentium(R) processor with a speed of 2.30 GHz and 4.0 GB RAM using Windows 10 64-bit Operating System.

The network topologies were varied based on a different number of nodes from 100 to 300. To establish the dynamic network topologies, all the nodes were distributed randomly over the sensor field. The initial energy for each Node is set as 5J. The proposed CDR is compared with RRP (Ring Routing Protocol) [18] and GCRP (Grid-cycle routing protocol) [19]. The comparison among protocols was performed concerning node energy, average end-to-end delay and packet delivery ratio.

Table 3 shows the energy consumption result for different number of nodes.

Table 3 Energy Consumption Result

No of Nodes	RRP	GCRP	CDR (Proposed)
100	2.3	2.1	1.5
150	2.5	2.2	1.8
200	3	2.5	2.1
250	3.5	3	2.3
300	3.7	3.1	2.8

Figure 2 shows the energy consumption comparison. When increasing the number of nodes, the energy consumption also increases due to the number of nodes concerned in data forwarding. The proposed CDR consumes less energy compared to the other two routings.

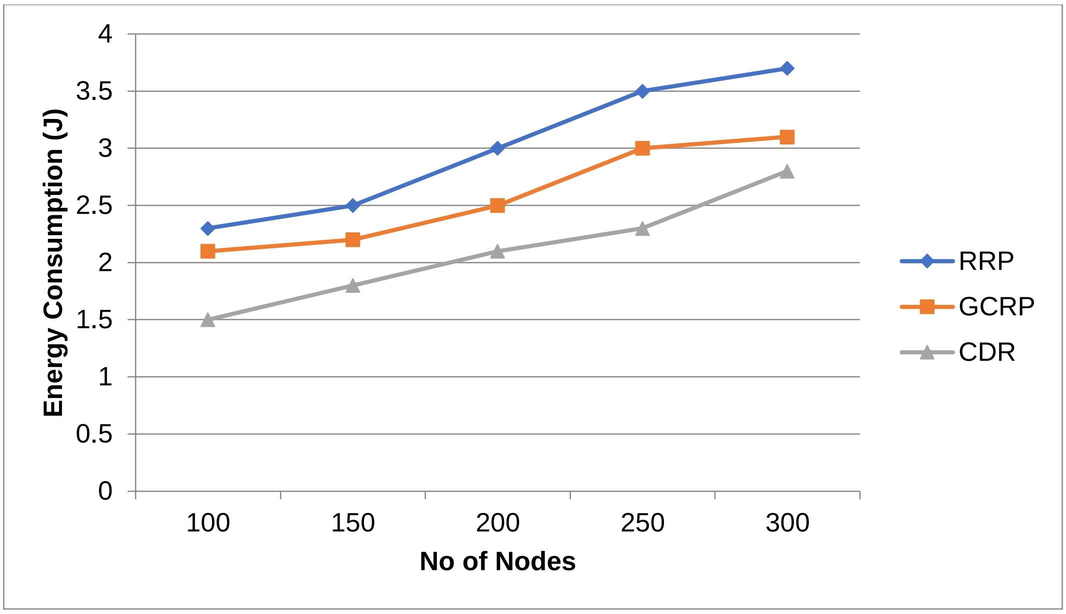

Figure 2 Energy Consumption Comparison

Table 4 shows the average end-to-end delay result.

Table 4 Average End-to End Delay Result

No of Nodes	RRP	GCRP	CDR (Proposed)
100	55	30	25
150	59	38	28
200	62	42	37
250	70	50	40
300	75	58	42

Figure 3 shows the average end-to-end delay comparison graph. The proposed method takes less time to send packets compared to other methods. However, the delay is increased when the number of nodes is increased.

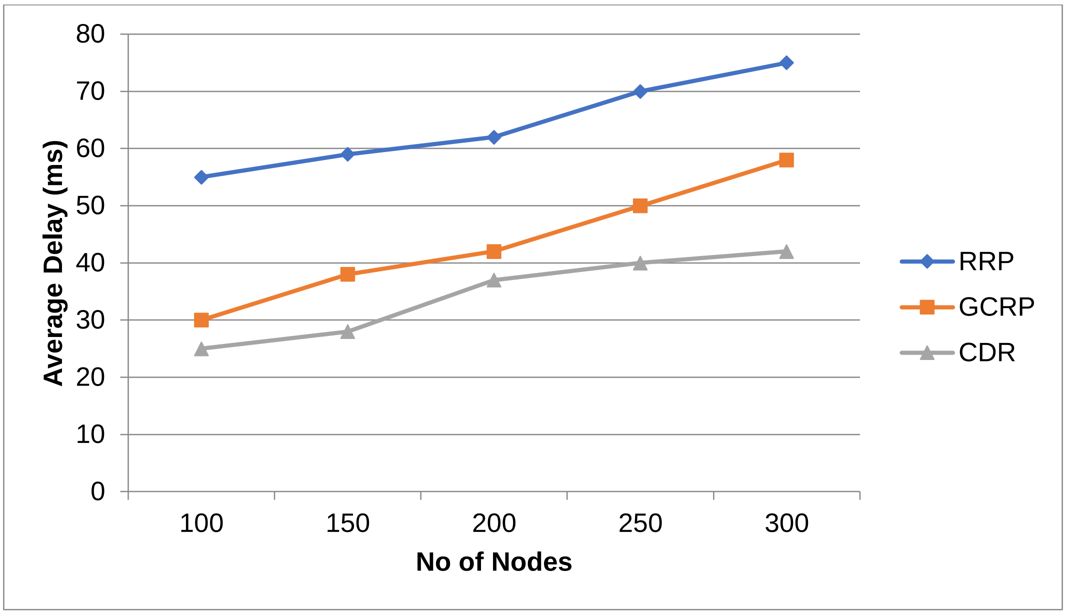

Figure 3 Average End-to-End Delay Comparison

Table 5 shows the packet delivery ratio result.

Table 5 Packet delivery Ratio Result

No of Nodes	RRP	GCRP	CDR (Proposed)
100	63	85	90
150	60	80	89
200	55	78	85
250	43	70	81
300	40	62	79

Figure 4 shows the packet delivery ratio comparison for the different number of nodes. When the number of nodes increases, the packet delivery ratio will decrease because more nodes send data and generate traffic. The proposed CDR produce a high packet delivery ratio compared to other methods.

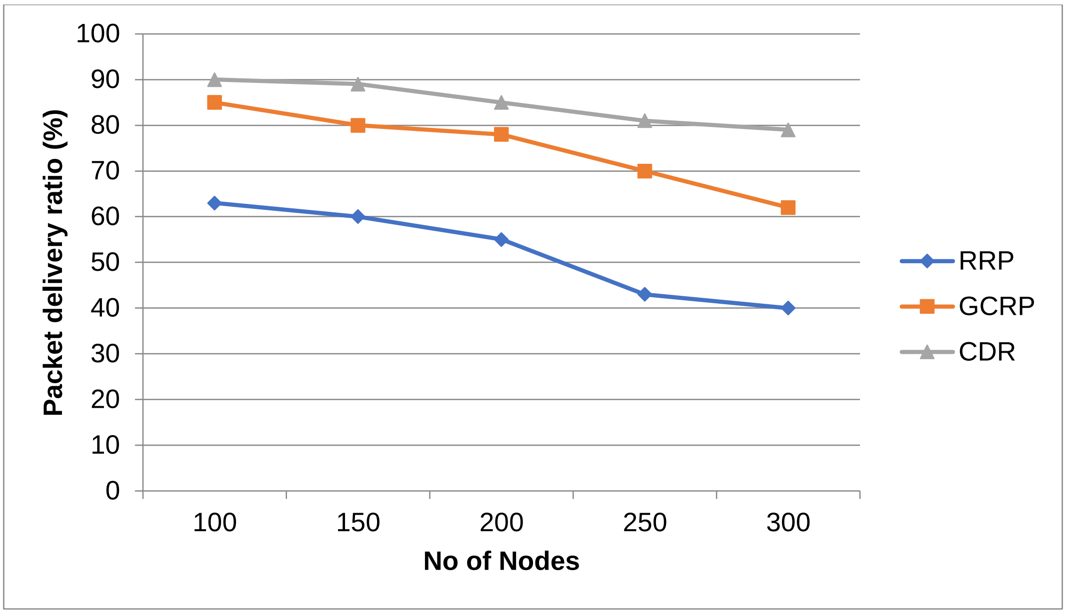

Figure 4 Packet Delivery Ratio Comparison

5. Conclusion

This paper proposes a cluster-based secure dynamic routing for WSN. The main objective of this paper is to reduce energy consumption and secure data delivery. It uses energy, distance to the base station and the number of neighbours based parameters for cluster head selection. The cluster head is used to transmit data packets from the sensor node to the base station. The proposed work reduces energy consumption and delay and increases the packet delivery ratio.

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