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Research Article

Energy Measure Semigraph-Based Connected Edge Domination Routing Algorithm in Wireless Sensor Networks

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In wireless sensor networks (WSNs), batteries are used as power source which is limited, and replacement of the battery is difficult. Since communication between nodes consumes most of the node power, topology-based power control is essential for reducing energy consumption. It is necessary to use optimized topology-based energy control model, so the selected nodes are used to generate a virtual backbone, which reduces unwanted routing of data. The virtual backbone for optimized topology can be created by connected dominating set (CDS) of graph theory. However, generating the virtual backbone by using the CDS algorithm is an NP-hard problem because of larger network size. To overcome this problem, in this paper, a novel distributed connected edge dominating set-based semigraph model (S-CEDS) is proposed. The performance ratio of the proposed S-CEDS is measured as $(4 + \ln\Delta')$ $|\mathrm{opt}|$, where $|\mathrm{opt}|$ represents the network size. The proposed S-CEDS is implemented using the ns-2 simulator and evaluated with conventional routing protocols such as AODV and DSDV. The results show that the proposed S-CEDS approach increases throughput and network lifetime. Also, it reduces energy consumption and average number of hops required for data transmission.

1. Introduction

Wireless sensor networks (WSNs) have caught the eye of researchers, as a result of the major developments being made in the field of embedded systems [1, 2]. WSN refers to the group of dedicated sensor nodes which are spatially dispersed and deployed. Deployed sensors measure environmental conditions like temperature, pressure, humidity, and sound. WSNs are similar to wireless ad hoc networks because they do not rely on any fixed infrastructure, as formation of their network will be done spontaneously with wireless connectivity. In WSN, the most demanding task is the conservation of energy. The major work of sensor nodes is classified as sensing, processing the sensed data, and communicating the sensed information with the peers. Since the communication module consumes most of the sensor energy, it could be controlled by effective topology construction. But WSNs are ad hoc in nature, so this makes the task of topology construction and designing the routing protocols a challenging one. However, this can be achieved with virtual backbone overlay network modeling in WSN. In this model, the selected nodes are considered for virtual backbone construction, and CDS (connected dominating set) of graph theory is used for making the virtual backbone by considering the network as the graph and sensor nodes as the vertices of the graph [3, 4]. This is done because the CDS can extend the lifetime of the wireless network, thus keeping the energy depletion and deportation rate at a minimum.

An interconnected subset of nodes that are put up in the entire network to aid routing is called the virtual backbone [5, 6]. In WSNs, the nodes can use these backbones for communication between them since there is no established architecture for centralized control.

We can define a dominating set (DS) of a network as a small subset of nodes such that each node either belongs to the subset or to the neighbor of some elements in that subset. The CDS, which is formed by connecting the nodes of the DS, is essentially responsible for the passage of messages from one node to another. The source node, which is not a part of the CDS, may send its message to the nearby CDS nodes which in turn send it towards the destination node. In case if the destination node is a part of the CDS, it gets the message directly from a neighbor who belongs to the CDS.

One of the noticeable issues in WSN is data collision, which is caused by flooding centred routing protocols [7]. It can also be resolved by virtual backbone formation. In addition, another thriving research domain involves trying to minimize the size of the CDS. Since the size of the network is proportional to the energy competence and probability of transmission failure, the backbone network size should be kept smaller [8, 9].

In our earlier research [9], we proposed a semigraph contiguous prevalent set (SCPS) algorithm for the semigraph structure. In addition, the SCPS construction scheme maintains the best performance ratio:

$$(2 + \ln \Delta_a)|\mathrm{opt}|, \tag{1}$$

where $|\mathrm{opt}|$ is the size of any optimal adjacent dominating set (ADS) and Δ_a is the maximum adjacent degree of all nodes of the network. Moreover, the SCPS algorithm has $\mathrm{O}(n^2)$ time complexity and $\mathrm{O}(n^2 + n\log n + n^2|A|)$ message complexity, where A is an ADS obtained using the SCPS algorithm.

This paper puts forth the idea of a new distributed connected edge dominating set-based semigraph model (S-CEDS), which is responsible for engendering a size and power effective network formation. This executes the routing and reduces the control messages with fewer interventions. The distributed connected edge dominating set (CEDS) is constructed in a sparse network for the fixed node environment. This scheme is implemented in two stages and constructs the CEDS using a semigraph. The first phase involves the construction of an edge dominating set (EDS) in a disseminated manner, which is labelled as a pseudo-dominating set (PDS) as few of the elements may have been removed from the last dominating set. In the second phase, we construct a semigraph-based connected edge dominating set. This omits some of the selected PDS nodes to decrease the size of the CEDS with no deprivation in handling or connectivity. The results of the simulation exhibit S-CEDS is a better solution than the already existing connected dominating set (CDS) construction algorithms in terms of size and construction costs. Based on the proposed algorithm, the performance ratio is $(4 + \ln \Delta')|\mathrm{opt}|$. The time complexity can be measured as $O(m)$, where m is the maximum number of edges in the semigraph model. The message complexity is measured as $O(mn + m\Delta')$ which is linear, where "n" is the total number of vertices and Δ' is the maximum edge degree of the semigraph.

The rest of the paper is organised as follows: Section 2 gives an overview of related work on the connected dominating set. Section 3 explains about the basics of semigraph-based virtual backbone construction. Section 4 gives insight into authors' contribution. Section 5 elaborates the proposed semigraph-based connected edge dominating set construction. Optimality analysis of the proposed system is given in Section 6. The simulation environment along with results and discussion is given in Section 7. Section 8 explains the hardware implementation of the proposed S-CEDS. Finally, Section 9 discusses conclusion and future work.

2. Related Work

In [10], the authors proposed a modified algorithm that can calculate the minimum connected dominating set for ad hoc networks. The results from the simulation show that the modified approach is capable of performing better than the approach which already exists for larger networks. In [11], greedy redundant connected dominating set (GR-CDS) with greedy strategy was introduced in order to produce an optimal size of the CDS which has a time complexity of $O((\Delta^2 + \log n)n)$. Also, an algorithm pruning for connected dominating set (P-CDS) was formulated to make the CDS a little smaller, with the time complexity of $O(n^2)$. This brings down the size of the CDS algorithm, at the cost of little performance time. In [12], an effective colour-theory-based energy efficient routing (CEER) algorithm which is based on a colour-theory-based dynamic localization (CDL) algorithm was put forward. The CEER focuses on picking those members of the cluster which are closer to the anchor. This is achieved by contrasting their RGB values. The sensor node which has the greatest level of energy is selected as the next hop. The results clearly exhibit that the proposed routing algorithm in comparison with the energy saving dynamic source routing (ESDSR) in mobile wireless sensor networks can nearly save up to 50–60% energy.

In [13], a distributed connected dominating set (CDS) construction algorithm was proposed in order to efficiently create a CDS in a single phase in large ad hoc networks. The distributed single-phase connected dominating set (DSP-CDS) depends on its uniform processing in the single phase in terms of power, and any modifications in the network topology are handled easily without trouble. DSP-CDS can use several parameters such as CDS size, diameter, and the number of rounds to converge to maintain the performance of the algorithm.

In [14], a novel approach based on the total dominating set and bipartite theory of graphs called TD algorithm was proposed. This constructs the CDS, a virtual backbone of ad hoc wireless networks. The TD algorithm stated that there exists an entirely substantiated connection between the total dominating set, the Y-dominating set of the bipartite graph, and the CDS. It is also proven that this approach performs better than any other latest development while finding the solution to the dynamic problems faced in the graph optimization platform. This is verified by conducting simulation over various vital factors, including large transmission ranges and dense network area.

In [15], the authors proposed a new degree-based greedy approximation connected pseudo-dominating set using 2 Hop Information (CPDS2HI) which is centralized. It can be observed from the simulation that the algorithm is capable of building CDS that is smaller in size and with lesser message complexity $O(\Delta n)$ in contrast to preexisting methods across a range of distribution of sensor nodes. In [16], the redundancy connected dominating set (RCDS), an efficient centralized algorithm, was proposed. This method constructed a relatively optimal connected dominating set on a virtual backbone network efficiently within $O(\Delta n)$. A relatively optimal connected dominating set can be constructed as follows: firstly, to get the MISs, we will have to build a simple sequence algorithm. Later, by including new nodes, a CDS can be constructed using maximal independent sets (MISs). CPDS2HI retains the performance ratio of $(4.8 + \ln 5)|\mathrm{opt}| + 1.2$, where $|\mathrm{opt}|$ being the size of the optimal CDS of the network.

In [17], a brand new distributed greedy approximation algorithm based on degrees was proposed. The time and message complexities of the algorithm were found to be $O(D)$ and $O(nR)$, respectively. The proposed algorithm generates size and power effective network by using the semigraph-based connected edge dominating set. The virtual backbone is constructed by selecting the nodes with the highest edge degree, and S-CEDS reduces the control message overhead and transmission inference. Furthermore, the performance ratio of the proposed S-CEDS is measured as $(4 + \ln \Delta')|\mathrm{opt}|$, where $|\mathrm{opt}|$ represents the network size.

3. Semigraph Virtual Backbone Model

Representing wireless sensor network as a semigraph model improves the battery efficiency of the sensor node. Because of the reduced number of hops for effective routing, the flexibility of deploying nodes, identification of network obstacles, and the selection of cluster head and cluster formation are made with reduced complexity. Figure 1 shows the representation of the graph model, and Figure 2 shows the associated representation of the semigraph model. In Figure 2, a small circle in between two end vertices represents a middle vertex of any of the edge E which will not be the middle vertex of any other edge E'. And the middle vertex of an edge E is an end vertex of an edge E'. A small tangent to the circle will be drawn at the end of the edge E'.

In WSN, a semigraph $SG = (V, X)$ corresponds to a network of nodes, where vertices set $\{V\}$ represents the sensor nodes and the set of edges $\{X\}$ represents the communication link between the sensor nodes. Any element in the edge set $\{E\}$ is defined as a nonempty subset $\{V\}$ with two or more vertices (aka the $n-$ tuples set).

A virtual backbone semigraph $SG = (V, X)$ is obtained from the graph by reducing the cardinality of the edges.

The definitions used to frame the semigraph in the wireless sensor network are listed below.

Definition 1 (dominating set [18]). A dominating set (DS) for a graph $G(V, E)$ is a subset $S \subseteq V$ such that each node in $\{V - S\}$ adjacent to at least one node in S.

Definition 2 (connected dominating set [19]). A connected dominating set (CDS) is a connected subgraph of a dominating set.

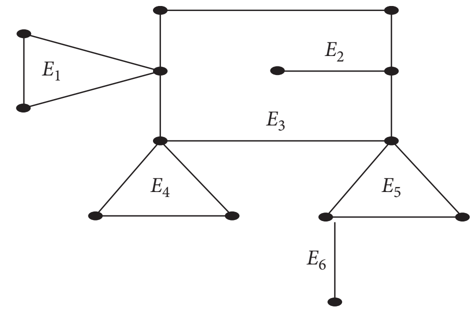

Figure 1: Graph model.

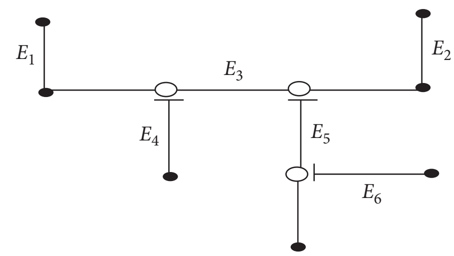

Figure 2: Semigraph model.

Definition 3 (semigraph [19]). A semigraph for the network is determined as $SG = (V, X)$ for an edge $E \in X$ and the node $v \in V$, and the edge degree $\mathrm{ed}(E)$ for "E" is determined by the following function:

$$\mathrm{ed}(E) = \sum (\deg_{e} v - 1), \quad (2)$$

where $\deg_e v$ is the edge degree of a vertex v.

For a given subset $\{F\}$ of $\{X\}$, $\langle F \rangle$ is the sub-semigraph of SG induced by F.

Definition 4 (maximum edge degree [20]). The maximum edge degree of edges of semigraph is represented as Δ'.

Definition 5 (edge dominating set (EDS) [20]). A set $\{F\}$ of edges in the semigraph $SG = (V, X)$ is referred as the edge dominating set if it satisfies the condition that it should be adjacent to at least one edge in "F" from the edges in {X–F}. The edge domination number of $\gamma'(S)$ is the minimum cardinality of an edge dominant set of the semigraph SG.

Definition 6 (connected edge dominating set (CEDS) [21]). An EDS F of a semigraph SG is a connected edge dominating set if the induced sub-semigraph $\langle F \rangle$ is connected. The minimum cardinality of a connected edge dominating set is denoted as $\gamma'_c(S)$ (aka the connected edge domination number).

4. Motivations and Contributions

The researchers use virtual backbone construction for WSN infrastructure to reduce the unwanted routing of data. However, the virtual backbone generated by CDS is NP-hard because of larger in size. To generate size and power effective network, a semigraph-based connected edge dominating set is constructed as a virtual backbone. By selecting the nodes with highest edge degree for backbone construction, S-CEDS reduces the control message overhead and transmission inference. Furthermore, the performance ratio of the proposed S-CEDS is measured as $(4 + \ln \Delta')|\text{opt}|$, where $|\text{opt}|$ represents the network size framed using S-CEDS.

The foremost contribution of the proposed S-CEDS is mentioned below:

(i) S-CEDS is built by considering maximum edge degree nodes which create a persistent virtual backbone with availability of routes.
(ii) A virtual backbone with smaller size is created even with random distribution of sensor nodes.
(iii) The time complexity is measured as $O(m)$, where m is the maximum number of edges in the semigraph model, and the message complexity is measured as $O(mn + m\Delta')$.
(iv) The proposed system has the best performance ratio $(4 + \ln \Delta)|\text{opt}|$, where $|\text{opt}|$ represents the network size framed using S-CEDS
(v) The network performance of conventional routing protocols AODV and DSDV is analysed with the constructed S-CEDS backbone using ns-2 simulator.

5. Proposed Semigraph-Based CEDS Construction

This section introduces a novel S-CEDS algorithm for virtual backbone construction. The route discovery and path selection in the wireless sensor network were performed using the S-CEDS construction algorithm. A simple edge degree algorithm is implemented to perform CEDS with lesser data packet complexity.

The construction of S-CEDS was performed through two stages:

(i) Generation of EDS.
(ii) Development of S-CEDS based on the semigraph structure.

The return $\{F\}$ variable provides the edge dominating sets for the input positions of wireless sensor network nodes. To finalize the EDS, the highest edge degree of first $m/\Delta' + 1$ edges is added to $\{F\}$. The above measured number is lower bound for γ_c' [22]. The edges and vertices are framed in the network, and an interconnection between several edges was framed using the Algorithm 1, which finds the connected edge dominant set.

Theorem 1. *F is an EDS.*

Let $\{F\}$ be the set of all edges obtained from Algorithm 2. Since $m/(\Delta' + 1)$ is the lower bound for EDS, the line 11 of Algorithm 2 considers the highest edge degree of the first $m/(\Delta' + 1)$ edges. Also, from line 14, each edge E_i is $X - F$ adjacent to some edge in $\{F\}$. Hence, $\{F\}$ is an EDS.

The H value returned generates the possible number of connections between the edge dominant sets generated using Algorithm 2, whereas the nodes in the wireless sensor networks are grouped as a connected edge dominant set. The semigraph model provides many possible links between the nodes in the network. It helps frame an energy-efficient shortest relaying path.

Theorem 2. *H is a CEDS.*

Let H be the set of edges obtained in line 9 of Algorithm 1. In the input of Algorithm 1, the set H is an EDS which is the output of Algorithm 2. Furthermore, from the condition given in line 4 of Algorithm 1, $\langle H \rangle$ is connected. Therefore, H is a CEDS.

6. Optimality Analysis of the Proposed S-CEDS

In the following section by using theorems, the performance ratio, time complexity, and message complexity of the proposed S-CEDS are discussed.

Theorem 3. *Let H be the S-CEDS obtained from the CEDS construction algorithm.*

Then, $|H| \le (4 + \ln \Delta')|\text{opt}|$. In a semigraph S, $|\text{opt}|$ represents size of any CEDS.

Proof. Let $|F|$ be the size of an EDS of a semigraph S. Then, from [21, 22], $|F| \le (3 + \ln \Delta')|\text{opt}|$, where Δ' is the maximum edge degree of the network. In Algorithm 1 from line 4 to 6, to connect a node in V, we add at least one edge E_i so that the induced sub-semigraph is connected.

Therefore,

$$|H| \le |F| + |\text{opt}| \le \left(3 + \ln \Delta'\right)|\text{opt}| + |\text{opt}|. \tag{3}$$

Hence, $|H| \le (4 + \ln \Delta')|\text{opt}|$.

Theorem 4. *$O(m)$ is the time complexity of the S-CEDS algorithm.*

The complexity analysis of the proposed S-CEDS algorithm (Algorithms 1 and 2) gives time complexity and message complexity $O(m)$ and $O(mn + m\Delta')$, respectively, where Δ' is the maximum edge degree of semigraph S.

Proof. In Algorithm 2, the EDS is constructed with a time complexity $O(m)$ [22], and in Algorithm 1, the CEDS is constructed with the same time complexity $O(m)$ in semigraph S. Therefore, the time complexity of the proposed S-CEDS construction algorithm is $O(m)$.

Next, the total number of messages is counted to find message complexity of the proposed S-CEDS. The message complexity of EDS construction is $O(mn)$ [14], and on each edge, the condition given in the line 14 of Algorithm 2 is satisfied, for all n nodes of the network. Also the message complexity of CEDS construction is $O(m\Delta')$ [22], where Δ' is the maximum edge degree of the network. Hence, the total message complexity of the proposed S-CEDS algorithm is $O(mn + m\Delta')$.

Input: An EDS F of a connected semigraph $SG(V, X)$ obtained from Algorithm 2.
Output: S-CEDS $H \subseteq X$ of the semigraph $SG(V, X)$.
CEDS $H \longleftarrow F$, $V \longleftarrow \{v_1, v_2, \ldots, v_n\}$, $X \longleftarrow \{E_1, E_2, \ldots, E_m\}$
for $i = 1$ to m do
  for every edge $E_i \in X - H$ do
    If E_i satisfies the following conditions
      (i) Each edge E_i in $X - H$ adjacent to at least one edge E in H
      (ii) The induced sub-semigraph $\langle H \rangle$ is connected, then
      add E_i to H
    end if
  end for
end for
return H

Algorithm 1: Generation of S-CEDS for the semigraph model.

Input: A connected semigraph $SG(V, X)$ with $|V| = n$ and $|X| = m$.
Output: EDS $F \subseteq X$ in the semigraph S.
$\mathrm{ed}(E_i) \longleftarrow \phi$, $F \longleftarrow \phi$, $V \longleftarrow \{v_1, v_2, \ldots, v_n\}$, $X \longleftarrow \{E_1, E_2, \ldots, E_m\}$
Let $E_i = \left\{(v_1, v_2, \ldots, v_j)/v_j \varepsilon V,\ j \geq 2\right\}$
for $i = 1$ to m do
  for all $v_j \in E_i$ and $j \leq n$ do
    $\mathrm{ed}(E_i) \longleftarrow \sum_j \deg_e v_j - 1$
  end for
end for
for $i = 1$ to m do
  Sort the edge in the descending order of $\mathrm{ed}(E_i)$
end for
add first $m/(\Delta' + 1)$ edges to F
  for $i = 1$ to m do
    for all edge $E_i \in X - F$
      If E_i satisfies the following conditions
        (i) $|E_i \cap E_j| > 1$, for some $E_j \in F$
        (ii) The battery level of one of the node $v \in E_i$ should be higher
      Then add E_i to F
      end if
    end for
  end for
return F

Algorithm 2: Generation of EDS.

From equation (3), the upper bound for the S-CEDS is $(4 + \ln \Delta')|\mathrm{opt}|$, where $|\mathrm{opt}|$ represents the size of any CEDS. The performance ratio of the SCPS based on equation (1) is $(2 + \ln \Delta_a)|\mathrm{opt}|$, where $|\mathrm{opt}|$ is the size of any optimal adjacent dominating set (ADS) and Δ_a is the maximum adjacent degree of all nodes of the network [9]. For any semigraph with γ' and γ_a, represent edge domination number and adjacent domination number of SG, and then $\gamma' \leq \gamma_a$ [23]. Thus, we conclude that the performance ratio of S-CEDS is $(4 + \ln \Delta')|\mathrm{opt}|$.

7. Simulation of S-CEDS Using ns-2

The semigraph-based topology is constructed for wireless sensor network using the ns-2 simulator [24]. The performance of the proposed semigraph topology is compared with the graph topology. To verify the efficiency of the proposed topology, conventional routing protocols like DSDV and AODV were used. The performance metrics like throughput, end-to-end delay, packet delivery ratio, packet loss, overhead, and jitter are measured for the proposed system. The parameters for ns-2 simulation are given in Table 1.

The performance of the proposed S-CEDS is evaluated by measuring the various performance metrics with different combinations. Throughput is a measure of maximum bandwidth utilized by the network. The efficiency of the network is purely based on the increase in throughput. From Figure 3, the proposed semigraph model with AODV routing protocol provides the maximum throughput rate of 435 kB/s.

Table 1: Parameters for ns-2 simulation.

Parameters for simulation	Values
MAC type	802_11
Queue type	DropTail/PriQueue
Antenna	Omni antenna
Queue length	500
No. of nodes	50
Routing protocol	Flooding
Maximum network coverage area	2000 ∗ 2000 meters
Packet size	1 kB to 100 kB
Simulated time	16 seconds
Initial energy	1000 (J)
Tx power	1.015 (J)
Rx power	0.015 (J)

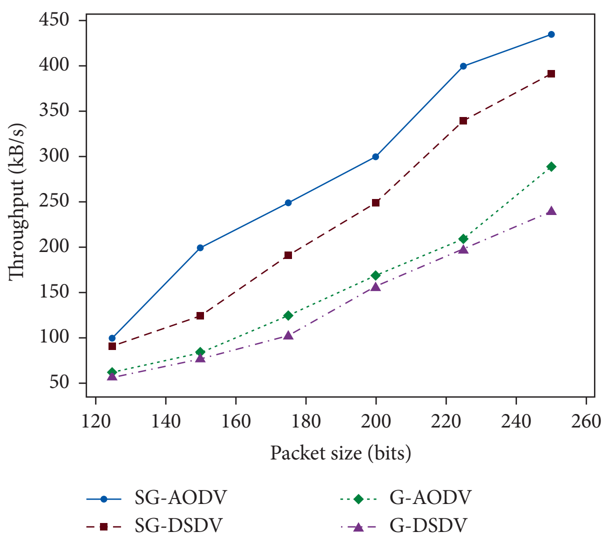

Figure 3: Throughput.

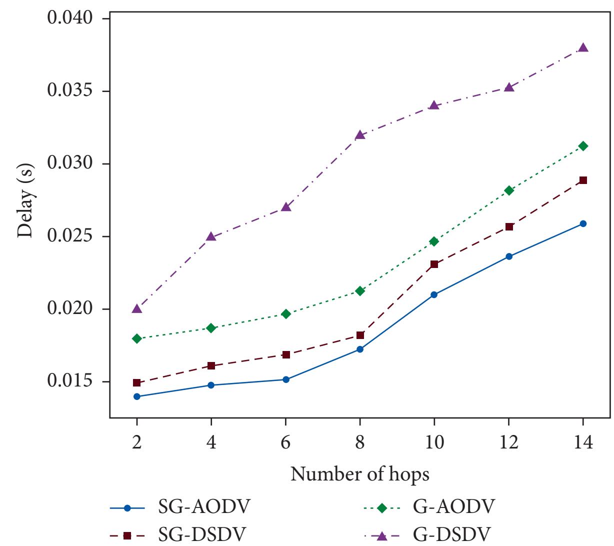

Figure 4: End-to-end delay.

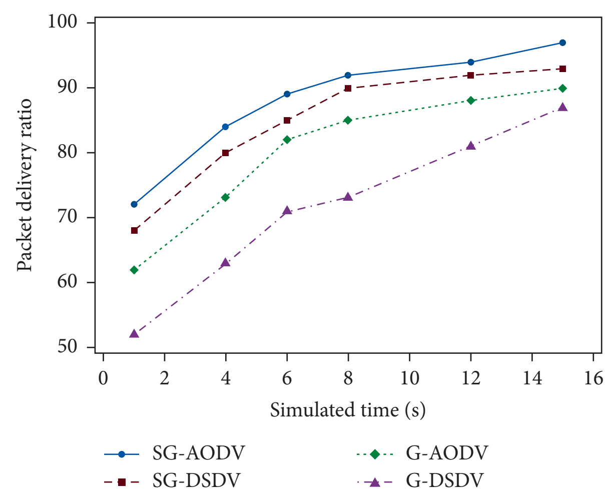

Figure 5: Packet delivery ratio.

The DSDV routing protocol uses the table-oriented approach, in which identifying an alternate route causes delay. It may reduce the performance of the entire network. AODV, an on-demand routing protocol, provides a more efficient path in this situation. Moreover, the semigraph model assists the AODV protocol to frame multiple possible links between the sender and the receiver. The connected edge dominating set assists the network to mount a possible low-cost route to the destination, so the efficiency of the system increases with semigraph and AODV combination.

End-to-end delay is the measure of time taken by the data packet to reach the destination from the source node in a unidirectional communication mode. The end-to-end delay and retransmission rate majorly affect the throughput of the network. Figure 4 shows the end-to-end delay plot for the network. Here, AODV outperforms with the DSDV routing algorithm when it is evaluated on graph and semigraph topologies. Combining with the semigraph model, the AODV protocol provides an average delay of 0.0188 s. The graph model with the DSDV protocol provides the maximum delay of 0.0301 s. The packet delivery ratio (PDR) refers to the successful transmission of data between the communication ends. Packet loss causes retransmission which in turn increases the delay in the network. The PDR is directly affected by the number of retransmissions. Figure 5 shows the packet delivery ratio of the simulated environment. The delivery ratio is calculated by the rate of successful transmissions in the given initial simulation time. The semigraph with AODV routing protocol provides 97 percent delivery rate in WSN.

The congestion in the network increases when the signal-to-noise ratio (SNR) increases. The SNR value is represented in decibel. When SNR increases, the bit error rate decreases. The bit error rate is the measure of the total number of bits transmitted with the error bits received due to congestion in the network. Figure 6 represents the bit error rate of the network with graph and semigraph implementation. A less bit error rate defines the quality of the channel and capability of the protocol to overcome the congestion in the network.

End-to-end delay describes the time taken by a packet that propagates from source to destination, whereas jitter measures the variation of delay between consecutive packet reception due to packet drop and increase in the bit error rate. The jitter may also be caused due to the imbalanced

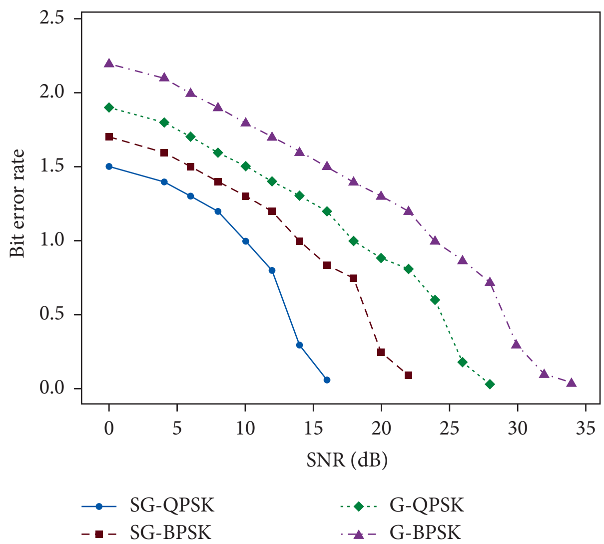

Figure 6: Bit error rate.

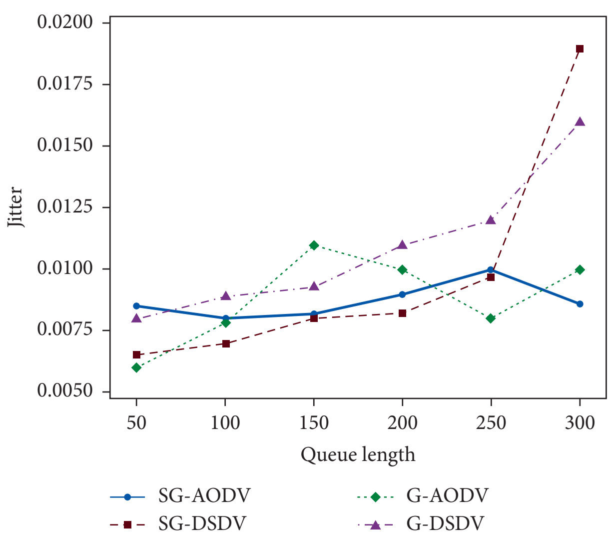

Figure 7: Jitter.

traffic in the network. The delay at the initial stage of transmission will not be the same always. The traffic at the middle or at the end of the path varies from other segments of the path. So the jitter plays an important role in measuring the quality of service in the network. Figure 7 shows the jitter measured in the network using the graph and semigraph model. The jitter is measured in the units of the millisecond. Increase in queue length may increase packet loss due to router buffer overflow. Increase in traffic proportionately increases the possibility of congestion in the network.

The packet loss ratio is the ratio between total number of packets transmitted and the successful reception of the same. Figure 8 shows the packet loss ratio (PLR) with respect to time. The average packet loss ratio is about 0.12 percent in the semigraph model with the AODV routing protocol. The retransmission rate and packet loss rate is higher when implementing the DSDV routing protocol. Packet loss leads to retransmission,

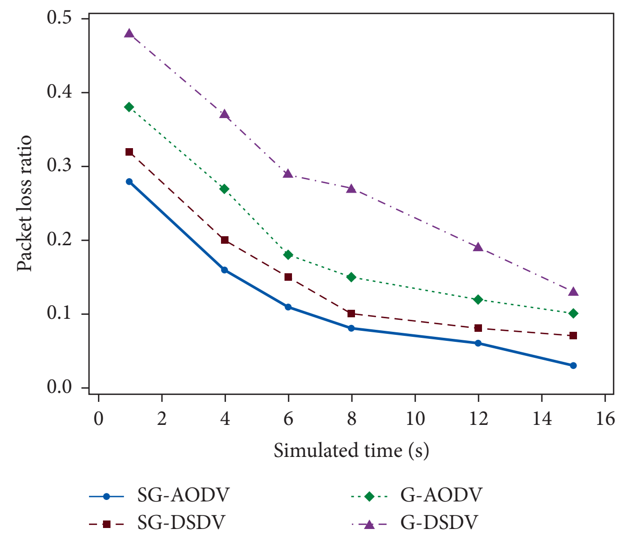

Figure 8: Packet loss ratio.

which may not affect the throughput but increases the power consumption, which reduces the network lifetime.

The normalized routing overhead is the measure of the total number of routing control packets required per data packet in the transmission path. Here, the overhead is measured under varying queue length and shown in Figure 9. The increase in overhead increases the consumption of energy in the selected path. Generally, cost of the path is determined by calculating overhead incurred by the link. Changes in the overhead were measured about 0.12 seconds when comparing the AODV algorithm in semigraph model and graph model. The small increase in the overhead leads to increase in network power consumption. If the overhead and bit error rate increase together, it affects the network throughput which in turn leads to the overall performance degrade.

The energy consumption with varying queue size is given in Figure 10. Energy is measured in joules. Each packet transmitted consumes some joules of energy in the network. The consumption of energy increases when the same data packet is retransmitted several times due to the packet drop in the network.

Table 2 shows the average values of measured performance metrics for graph and semigraph model.

The proposed semigraph model with AODV routing protocol was developed as a hardware model to check the performance of the network in the real-time environmental condition. The transmission delay is calculated for hardware implementation and shown in Figure 11. The delay is compared with the semigraph model and the graph model with the AODV routing protocol.

8. Hardware Implementation of the Proposed S-CEDS

The semigraph and graph models have been implemented in the hardware to measure the real-time performance.

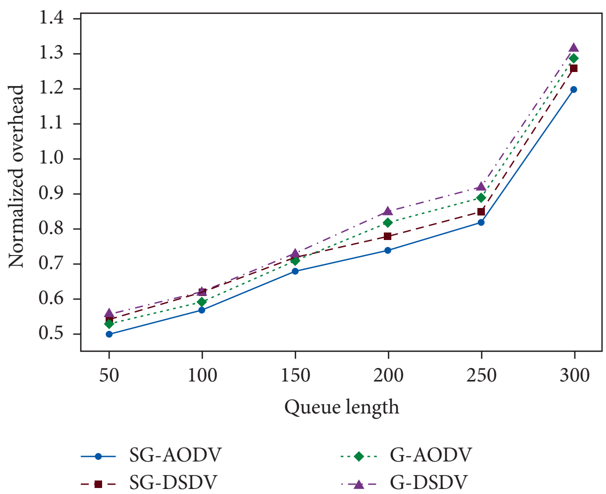

Figure 9: Normalized overhead.

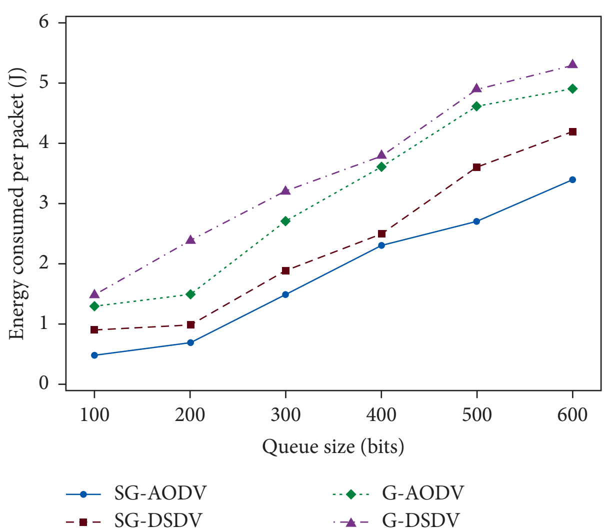

Figure 10: Energy consumption.

Table 2: Efficiency of the network.

	Semigraph		Graph	
	AODV	DSDV	AODV	DSDV
Throughput (kBps)	435	392	290	240
Energy (J)	1.85	2.35	3.1	3.51
Packet delivery ratio	88	84.6	80	71.2
Packet loss ratio	0.12	0.15	0.37	0.28
Delay (seconds)	0.0189	0.0205	0.0231	0.0301

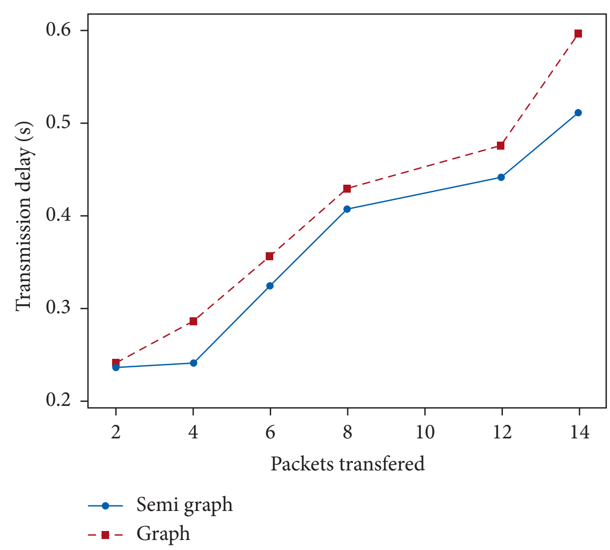

Figure 11: Transmission delay in the hardware model.

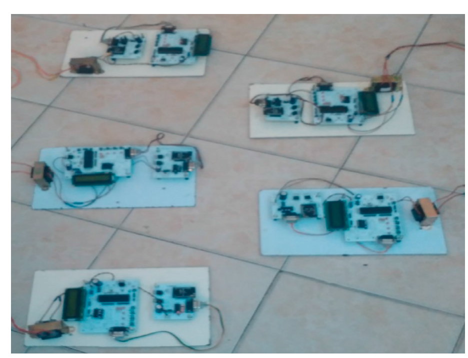

Figure 12: Hardware implementation.

Nodes are created using PIC 16F877A microcontrollers. To generate the wireless link between nodes, Tarang P20 802.15.4 (a standard wireless transponder) is used. Ten nodes have been placed to form a network. Semigraph- and graph-based topologies are constructed to check the response time of the node. Figure 12 shows the hardware setup.

The delay that is measured by varying packet sizes in the hardware environment is given in Table 3. The delay generated in the hardware environment is closely related to the simulated delay output. Due to the real-time environmental collisions, an additional delay will be generated than the simulated result.

The data rate measured between the sender and receiver node through the Wi-Fi network is given in Table 4. The data rate is affected due to the flooding in the Wi-Fi network. The sender and receiver nodes were placed in the fixed distance,

Table 3: Delay measured in the hardware environment.

Packet size (in bits)	Delay (in ms)	
	Semigraph	Graph
8	34090	36492
12	36226	37476
16	37471	38194
20	38055	40847
24	40562	44584
30	41481	43317

Table 4: Data rate measurement.

Distance (meters)	Bandwidth (MBps)	
	Semigraph	Graph
25	1.32	0.92
30	1	0.84
35	0.87	0.76
40	0.58	0.51
45	0.4	0.35

and the data rate is recorded by transferring the data packet through the router node.

9. Conclusion

Virtual backbone construction for WSN infrastructure reduces the unwanted routing of data. However, the virtual backbone generated by CDS is NP-hard because of larger in size. To overcome this problem, we proposed a novel distributed connected edge dominating set-based semigraph model (S-CEDS) which generates size and power effective network. The proposed S-CEDS method reduces the connected edge domination number $\gamma_c'(S)$. By taking $m/(\Delta' + 1)$ edges for CEDS construction, the approximation ratio of proposed algorithm is $(4 + \ln \Delta')|\mathrm{opt}|$, where $|\mathrm{opt}|$ represents the network size and Δ' is the maximum edge degree of the semigraph. The conventional wireless network protocols such as AODV and DSDV are simulated with two network topologies such as graph (CDS) and semigraph (S-CEDS). This is implemented by using an ns-2 simulator, and the parameters like remaining energy, bit error rate, jitter, throughput, end-to-end delay, and packet delivery ratio are measured. The result shows the proposed S-CEDS generates size and power effective network. In future, S-CEDS can be extended to support fault tolerance with malicious nodes. [24]

Data Availability

There are no synthetic data used for this research.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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