Enhanced Versions of PEGASIS Routing Technique for Wsns: a Survey

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Abstract: ***An efficient routing in Wireless Sensor Networks (WSNs) helps to utilize the network energy economically to escalate the lifetime of the network. PEGASIS is a forerunner for chain-based routing algorithm designed with aim to enhance network lifetime. But the algorithm suffers from problems like data redundancy, long link formations, large latency period and so on. Many researchers propounded the enhanced versions of PEGASIS to overcome one or more problems associated with it. This paper presents the literature survey of 45 such protuberant research papers spanning over last eighteen years to provide insight into the problems of chain-based routing algorithms. In this paper, an effort has been made to classify these chain-based routing algorithms for WSN based upon their features. The article dowries the strong and weak points of these enhanced versions proposed by each of fellow researchers. Such an exhaustive survey would surely be fruitful to provide more healthy and efficient solutions. Finally, some open issues concerning the future design of chain-based routing algorithms have also been presented.***

Index Terms: WSN, PEGASIS, Chain-based, Routing, Protocols, algorithms.

I. INTRODUCTION

WSN contains numerous small low-cost devices, called sensor nodes which are used to monitor different environmental conditions or track any event in cooperative manner. The sensor nodes communicate the gathered data to the sink or Base Station (BS) [1]. These networks can be employed in industry, home, wildlife, military applications in order to monitor or track any event [2][3][4]. Sensor nodes are capable to sense, process and communicate [5]. These nodes are laced with non-rechargeable power source (battery) which cannot be replaced. Therefore, some advanced methods are required to efficiently utilize these resources while achieving the overall goal of the network for longer period [6].

Sensor nodes devour their energy in each network operation i.e. sensing, processing, transmission and reception. Foremost amount of energy is primarily devoured in data transmissions[7]. As each sensor node is required to transmit its data to the sink, therefore, an efficient routing scheme can utilise the energy resource more effectively and enhance the network lifespan. Many investigators have proposed routing algorithms to optimize the energy utilization and network lifetime. Hierarchical routing algorithms have proved to more energy efficient and promising [8][9]. Hierarchical routing can be cluster based, chain based or hybrid of both methods. In cluster-based routing, all sensor nodes of the network arepartitioned into clusters. One node from a cluster act as Cluster Head (CH) which performs a duty to collect cluster data, aggregate the collected data and forward the data to sink. Other node act as member nodes which generates the data and forward it to CH [10]. In Chain-based routing algorithms, one node act as leader node who is responsible to forward chain data to the sink and other nodes except the end nodes of the chain transmits data to the subsequent node in the chain in direction of leader node [11]. LEACH (Low Energy Adaptive Clustering Hierarchy) and PEGASIS are two popular routing techniques which are considered as models for cluster-based and chain-based routing techniques respectively [12]. There are several surveys that are conducted on LEACH variants. But, very few number of surveys are available on chain-based routing techniques. Arora et al. have examined only twelve chain-based algorithms, the authors have not classified these algorithms into any category [13]. Marhoon et al. provided insight in nine chain-based algorithms and discussed merits and demerits of each algorithm [14]. Singh et al. discussed only nine algorithms which are limited in number [15]. These surveys are very limited in scope and are outdated. This paper presents a survey on the chain-based routing algorithms and classifies them into area division based, branching topology based and hybrid techniques-based chaining methods. The taxonomy for the PEGASIS modified algorithms surveyed in the paper is presented in figure1.

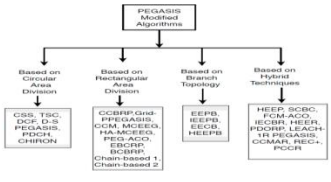

Figure 1: Taxonomy for PEGASIS modified algorithms

The main contributions of the paper are briefed as under:

1) An effort has been made to classify the chain-based routing algorithms depending upon their features. It will certainly provide a new perception for readers to

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comprehend chain-based routing. As far as we know, it is the first time for chain-based routing to be classified into four categories based on logical topologies.

2) A detailed analysis of various logical topologies for chain-based routing algorithms with their contributions and limitations has been presented in this paper.

3) A few important open research issues for the domain are recapitulated which will help the researchers to contribute further advances in the research field.

The remnant of this paper is organized as follows: Section 2 confers a basic concept of PEGASIS algorithm and its limitations. A detailed analysis of various enhancements of PEGASIS algorithm, their contributions and limitations are tabulated under different categories of chaining algorithms has been made in Section 3. Some open issues concerning the future design of chain-based routing algorithms are explored in Section 4. Finally, concluding remarks are given in Section 5.

II. POWER EFFICIENT GATHERING IN SENSOR INFORMATION SYSTEMS (PEGASIS) PROTOCOL

Lindsey et al. proposed a chain-based routing protocol for WSN in which node in the network transmits or receives data from its close neighbours. The chain of all alive sensor nodes in the network is formed. The chain is constructed, starting from the distant node from the sink, each node is connected to its nearest alive neighbour node using greedy method. While forming a chain, sensor nodes once associated in chain will not be reconsidered further for formation of the remaining chain. One node is chosen as leader which is accountable for the data transmission to the sink. Sensor nodes collect data from the proceeding node and aggregate it with its own data and send to the next sensor nodes till it encountered the leader node. Leader node selection is random. Each node become a leader using token passing technique. When any sensor node dies in the network, the chain is rebuilt in the same manner by omitting the dead nodes [11]. A-PEGASIS (ACO-PEGASIS) routing method improves upon PEGASISalgorithm by optimizing the chain length using Ant Colony Optimization (ACO) method [16][49]. E-PEGASIS (Enhanced PEGASIS) and RPB (Rotation PEGASIS Based) techniques further improves A-PEGASIS algorithm by exploiting the data redundancy in WSNs [17][18]. Singh et al. proposed a near optimal chain formation method using Biogeography Based Optimization (BBO) to obtain balanced energy consumption in the network [19].

A. Limitation of PEGASIS

PEGASIS is a centralised approach where all nodes transmit their location information to the sink which generates the chain routes. Each node in the network gets a chance to become a leader node which helps in uniform distribution of load and enhancing survivability of nodes. The total number of long distance transmissions is reduced to large extent, thereby saving large amount of energy and enhancing network lifetime. Despite these merits, it suffers from many demerits, as described below:

- The algorithm suffers from long transmission delay.
- It needs global information regarding location of nodes which adds communication overhead to the network.
- Chain needs to be reconstructed in case of node failure which adds extra burden on the network.
- Leader nodes are nominated on rotation basis irrespective of their remnant energy and distance to the sink. A leader node with low remnant energy may die while transmitting data to sink.
- When an elected leader node is placed far away from the sink, it consumes huge amount of energy and its health degrades suddenly resulting into instability in the network.
- Chain is formed with greedy method. Therefore, chain formed may not be of optimal length. There may exist long links in the chain which result into large energy consumption in the chain.
- If the network size is large and sink lies away from the sensor field, distance between the leader node and the sink increases many folds. Therefore, leader nodes consume huge amount of energy and the network become unstable. Thus, PEGASIS is not well suited for large networks.
- The protocol is not suited for dynamically changing topologies.
- In case of a node failure in the chain, data of all sensor nodes reaching failed node becomes useless.
- All sensor nodes generate and transmit data regularly. Lot of redundancy exists in the sensed data due to coherence, thus, wasting huge amount of network energy.

III. PEGASIS MODIFIED ROUTING ALGORITHMS

PEGASIS is a pioneer approach for increasing energy efficiency and lifetime of WSNs. However, it suffers from lots of demerits as discussed in Section 3.Many researchers in the field of WSN have proposed enhanced versions of PEGASIS. These enhancements can be categorised based upon the division of area, multiple branching of the single chain and hybrid techniques. Various modified versions of PEGASIS are classified as under:

A. Circular Area Divisions Based Chaining algorithms

In circular area division-based chaining algorithms, the entire sensor field is partitioned into co-axial circular layers. The chaining formation, leader selection or multi-hop criteria may vary from algorithm to algorithm. These variants are more scalable and energy efficient over PEGASIS.

A) Concentric Circle Scheme (CCS) is a coaxial clustering approach for routing in WSN. Area between two coaxial circles is considered as layer.

A chain is formed of all nodes belonging to the same layer using greedy method. Cluster head is chosen in each layer. A multi-hop path [50] is established among all cluster heads to forward data to the sink. The nodes near sink always transmit data to the sink, thereby consuming more energy and shorting its life. CH in each chain are selected on rotation basis. Therefore, nodes with low remnant energy may be nominated as CH. The distance between two CHs in adjacent layers may not be optimum [20].

B) Track Sector Clustering Scheme (TSC) is an improvement over CCS algorithm. The algorithm reduces chain length in each layer by further dividing these layers into sectors. A chain is constructed in each sub layer of all sectors. The scheme minimizes the distance between CHs of adjacent layers. The drawback of the scheme is that the CH selection is not optimal since residual energy and distance to the sink or to CH of adjacent layer is not considered for selection [21].

C) Dynamic energy efficient Chain Formation (DCF) is another improvement over CCS algorithm. It follows layered approach like CCS. The policy of leader node selection is modified. Leader node in the highest level is elected on rotation basis in each round. First candidate leader nodes of lower layer are chosen in the communication range of the adjacent upper layer. The leader node is elected based upon the remnant energy and distance to the sink from the set of candidate nodes. The drawback of this co-axial clustering scheme is that it does not assure the reliable data transmission in case of leader node failure [22].

D) Diamond Shaped PEGASIS (D-S PEGASIS) is proposed for reliable data transmission in the network. The two cluster heads (leader nodes) are elected at each alternative layer for reliable connection. The disadvantage of the scheme is that it provides fault-tolerance at the cost of energy efficiency. Moreover, every alternate layer has only one leader node; so, failure of any CH in these layers will break the link and data of the network will not reach to the BS [23].

Table1. Comparison of Circular Area Division variants

Algorithm	Contribution	Limitations
CCS	• Transmission distance to the sink is largely reduced. • Energy efficiency is better.	• Nodes near sink carry more data to transmit. • Energy usage amongst all node is not balanced. • Suffers from energy hole problem. • CH selection is not optimal as node location and residual energy is not considered. • Distance between CHs of two adjacent layers need to be optimized.
TCS	• Tracks are further divided into sectors. • Parallel transmissions in different sectors reduce delay. • Distance between CHs of adjacent tracks is reduced and depend upon the size of the track.	• Low energy node may be selected as CH and die soon.
DCF	• CH of lower track is selected in the locale of CH of upper adjacent track with high residual energy. • Distance between two adjacent CHs is reduced.	• Distance between two adjacent CHs depends upon the neighbourhood size for the CH. • Less reliable data delivery.
D-S PEGASIS	• Make data delivery more reliable by selecting two CHs at every alternate layer.	• Failure of CH node of layer containing only one CH will cause data terminated before reaching to the sink.
PDCH	• One CH and one SCH are chosen for each chain, to balance the load within the chain. • Transmission distances are further reduced using multiple small branches of node.	• SCH selection of adjacent layer do not consider the distance between SCH of two adjacent layers.
CHIRON	• Chain length is reduced by forming multiple chains in each fan shaped area which reduces the transmission delays. • It is a distributive technique. Global knowledge of the network is not required to run.	• Network suffers from energy hole problem. • Not well suited for large scale networks.

E) PEGASIS Double CH (PDCH) protocol chooses two leader nodes instead of one with an aim to reduce delay and enhance network lifetime. Firstly, the entire sensor field is divided into levels like CCS. A chain is built at each level using greedy approach. The chain at each level consists of only those nodes which belong to that level. A leader node from each chain is elected based on remnant energy known as primary CH. Secondary CH (SCH) is chosen from each node with an aim to transmit chain data to secondary CH of upper level and so on. The selection of secondary CHs still needs to be optimized to reduce distances between the SCHs of adjacent levels [24].

F) Chain-based hierarchical routing protocol (CHIRON) is a routing protocol designed to minimize the problems of data transmission delay and redundant transmissions associated with chain routing. The sink divides the whole sensor field into fan shaped smaller areas using BeamStar concept. The fan shaped area is further divided into smaller

group of nodes depending upon strength of signal received by each node from the sink. Several numbers of small chains are created using greedy method in each fan shaped area to reduce data transmission delay and redundant paths. A node with maximum residual energy is elected as leader node of each smaller group. Parallel data transmissions are performed in each group of small chains. Then, the leader nodes collectively communicate their aggregated chain data to the sink in leader-by-leader transmission manner. The area division in the algorithm is uneven which results into imbalance of energy load and degrades the network performance [25].

The contributions and limitations of all the prominent circular area-based techniques are tabulated in Table 1. From the table, it is observed that these techniques have better energy efficiency and more scalable as compared to PEGASIS. Moreover, by dividing the network into tracks and sectors, data is exchanged in local regions and redundant paths are largely reduced. All of these techniques suffer from energy hole problem as nodes near sink bear responsibility to communicate data to the sink and consume more energy.

B.Rectangular Area Division Based Chaining Algorithm

In rectangular area division-based chaining algorithms, the entire network is divided into equal sized rectangular strips. The size of rectangular strip may be adjusted according to approximate node density in the sensor field to control number of nodes in the chain. The chaining formation, leader selection or multi-hop criteria may vary from algorithm to algorithm.

A) Chain-Chain Based Routing Protocol (CCBRP) partitions a WSN into multiple chains with each chain having equal number of nodes. The proposed protocol uses greedy method for chain formation. Initially, parallel data transmissions take place in all chains. The nodes in the chain transmit data to the leader node. Further, one chain is built between all leader nodes of the network using greedy method. Then, all leader nodes communicate their chain data to the second level leader node, which is randomly selected from the set of first level leader nodes. This node lumps its own data with the received data and frontwards it to the sink [26]. The drawback of the technique is thatthe nodes near the sink are responsible for forwarding data to the sink, thereby quickly deplete the batteries and degrade the overall performance of the network.

B) Grid-PEGASIS routing protocol divide the sensor field into small virtual grids. Each grid is assigned a unique ID. Each node finds its association with Grid ID. A chain is formed in each grid among the nodes associated with the grid. Then data from each grid is forwarded to the sink in multi-hop manner. The leader node from each chain transmits data to the end node of other chain of next grid. In this way. Communication distances are further minimized. But, the drawback of the technique is that the node having the responsibility to send data to the sink is selected randomly which may degrade the network performance [27].

C) Chain-Cluster based Mixed routing (CCM) is a hierarchical routing algorithm inspired from LEACH and PEGASIS both. Initially, the algorithm divides the WSN into rectangular equal sized strips (considered as clusters). The nodes associated with a single strip form chain in a self-organized manner. The CH for each chain is chosen based on its remnant energy. The data transmission phase of the algorithm runs in two steps. Firstly, the CH of each chain receives cluster data in the similar way to PEGASIS. Secondly, a voted node is chosen with the responsibility to forward data of all chains to the sink [28].

D) Multi Chain Energy Efficient Greedy (MCEEG) is a hierarchical routing protocol. The sensor field area is splintered into sub regions like CCM. PEGASIS routing protocol is individuallyapplied in each sub region to form chain. This approach results into short length parallel chains. The transmission distances between the nodes of each chain are reduced, thereby saving energy in data transmissions. Further, to improve energy efficiency, the sink is mobile and moves from one Terminator Node (TN) to another to collect the data. However, the proposed protocol still uses extraneous hops, which adds extra delay and increases the energy consumption in sensor nodes. Therefore, the investigators proposed HA-MCEEG protocol which avoids extraneous hops to improve stable operative period and the network lifespan [29].

E) PEGASIS ACO (PEG-ACO) protocol divides the network into rectangular layers like CCM. Nodes associated with same layer are assumed to form a single cluster and an ACO-based chain is formed in each cluster [30]. These layers can either be horizontal or vertical. The nodes which are distant from the BS when selected as leader node will dissipate large amount of energy and therefore, may die soon.

F) Energy-Balanced Chain-Cluster Routing Protocol (EBCRP) is a distributed routing algorithm. It divides the network into equal sized rectangular areas. Nodes associated with each area are considered as a single cluster. Chain in a cluster is formed using ladder algorithm instead of greedy approach. Therefore, long distance transmissions are reduced to some extent. CH of each cluster is carefully chosen depending upon the remnant energy and is accountable to transmit cluster data to the sink directly. Direct communication to the sink consumes a large amount of CH energy and degrades network performance [31].

G)Chain-Based1 routing protocol divides the network into equal sized strips in the direction of the sink. Chain is built amongst all nodes of the strip using greedy approach. The end node of each chain closest to the sink (terminator node) is responsible for data transmission to sink. The chain is updated if any node in it become dead. Nodes near the sink in each chain die quickly because they consume much higher energy for direct data transmission to the sink and make network unstable. Another Chain-based2 algorithm is proposed which is an improvement over Chain-based1 to

reduce number of direct transmission to sink. A main chain is constructed between the terminator nodes of the chains. The terminator node with highest energy is selected as leader node of the main chain and is responsible to transmit data to the sink. Both the algorithms are not scalable [32].

Table 2. Comparison of Rectangular Area Division variants

Algorithm	Contribution	Limitations
CCBRP	• Partition the network into multiple chains of equal number of nodes. • Parallel data transmissions in all chains. • Multi-hop leader by leader node relay of data to the sink.	• Nodes near sink have more data to transmit and deplete their batteries quickly.
Grid-PEGASIS	• Long link formations are avoided.	• Single chain adds delay in data transmission. • Leader node is chosen randomly.
CCM	• CH of each chain is elected based on the residual energy. • Transmission delay is reduced to some extent.	• Voted CH consumes more energy as compared to other nodes.
MCEEG	• Sink is mobile and collect data from the terminator node of each chain. • No need to elect CH of a chain. • Long distance transmissions are greatly reduced. • Saving energy in data transmissions.	• Greedy approach is used for chain formation. • Energy consumption in the chain is more due to long link formation.
HA-MCEEG	• Avoid extraneous hops. • Improve stability period and network lifetime.	• Overhead to form chain is increased.
PEG-ACO	• Optimal length chains are formed using ACO. • Long distance transmissions are reduced.	• CH selection is not optimal.
EBCRP	• Distributive approach. • Chain length is optimized using ladder algorithm. • Energy hole problem is reduced to some extent.	• CH communicates directly to the sink. • Not suitable for large size networks.
Chain-Based1	• Only terminator nodes are transmitting chain data to the sink. • The maximum distance between the pair of nodes in a chain depend upon the strip width.	• Node near sink become dead quickly and creates energy hole. • Chain in each strip is built using greedy method.
Chain-Based2	• Number of direct transmissions to the sink is reduced by constructing a main chain between the terminating nodes of the strip chains.	• Once the nodes start dying, the distance between the terminating nodes may increased due to random deployment of WSN.

A comparison of rectangular area-based variants of PEGASIS is given in Table 2. It is observed from the table that the large size rectangular area like a strip results into long chains which introduced long delays in the chain and CH of each strip consume more energy in communicating data to a static sink. In such cases, mobile agents or sink with responsibility to collect data from CHs, gives better performance of the network. But, it may add extra cost for these devices in setting up WSN.

C.Branching Topology Based Algorithms

In branch-based topology, small branches of nodes are formed along with the backbone chain. The main idea for these algorithms is based upon the fact that that long-distancetransmissions consume more energy;therefore, distance of data transmission need to be reduced. All sensor nodes except the leader node communicate with their neighbour nodes. Aslong-distance communications are removed makingthese algorithms more energy efficient as compared to PEGASIS.

A) Energy Efficient PEGASIS-based Protocol (EEPB) is a PEGASIS inspired algorithm. In this, a modified leader node selection technique has been proposed. Leader node is selected based on remnant energy and remoteness to the sink. Therefore, healthier node is elected as leader node which may not die soon. Moreover, a concept of threshold distance for establishing link in the chain has been introduced. All links in the chain have distance less than the threshold. Thealgorithm helps to enhance network performance in terms of minimizing energy consumption and maximizing duration for reliable network operation. The drawback of the proposed technique is that no method is proposed to define the threshold distance. Therefore, adopted threshold may cause long link formations again [33].

B) Improved EEPB (IEEPB) is an improvement over EEPB. In this algorithm, the distance is calculated twice. An isolated node nearest to rear node of chain is chosen as new node. Two types of spans are calculated before adding new node to the chain; the span between the rear node and new node and the span between new node and closest node in the chain. Then, the new node is connected either to rear node or to a closest chain node such that span between the two nodes is minimum. In this way, instead of single straight chain, multiple branches of chains are formed, thereby reducing total length of the chain significantly. A weighted election method is proposed for the leader selection which includes normalised distance to the sink and residual energy [34].

C) Energy Efficient Chain Based (EECB) is a PEGASIS modified approach. The Chain formation is initially started in the similar way as that of PEGASIS. The rear node of the chain finds nearest isolated node,SN, in the network. If the extent between the rear node and SN is greater than the threshold distance,SN finds a closest node from the set of connected nodes, otherwise a link is formed between the rear node and SN [35]. Leader node is designated based upon remnant energy and distance to the sink. The drawback of the algorithm is that long chain is formed in the network which causes delay in transmitting data to the

sink. Nodes near the sink are more likely to be selected as selection criteria is dependent upon distance to the sink. Therefore, these nodes will die earlier and can create bottleneck of the network [36].

Table 3. Comparison of PEGASIS variants based upon branching topology

Algorithm	Contribution	Limitations
EEPB	• Leader node is elected based upon remnant energy and remoteness to the sink. • No link exists in the chain greater than threshold distance.	• No method is proposed for finding threshold distance.
IEEPB	• An isolated node is either connected to end node of chain or to any connected node whose so ever is minimum. • Long distance transmissions are reduced.	• Overhead associated to calculate distance between end node and all isolated node to find nearest node. • Overhead associated to calculated distance of selected isolated node with all connected nodes.
EECB	• Threshold distance is taken as average distance of all nodes. • Reduces overhead, as need of calculating two types of distances each time is reduced to some extent.	• Suffers from energy hole problem.
HEEPB	• Optimizes chain using HBO and ACO method. • Enhance network lifetime.	• Still suffer from long transmission delays.

D) Hybrid EEPB (HEEPB) is a hybrid method to optimize chain formation using HBO and ACO. The algorithm is designed with an aim to achieve energy efficiency in WSNs. The results of the proposed approach are better as compared to EEPB and IEEPB [37].

From table 3, it observed that all the branch-based techniques suffer from long transmission delays which is required to be reduced for delay sensitive applications.

D.Hybrid Techniques Based Chaining Algorithms

These algorithms are designed to make use of the advantages of one or more techniques along with PEGASIS. The foremostobjective of these algorithms is tocurtail delay in data transmission, minimize energy utilization and exaggerate the network lifespan.

A) Hybrid Energy Efficiency Protocol(HEEP) is a hybrid approach of cluster based and chain-based routing in WSN. The whole network is partitioned into chains of clusters. The main objective of the algorithm is to reduce energy utilization in CHs of clustering technique and delay incurred due to long chain in PEGASIS [38].

B) SCBC (Sector Chain Based Clustering) is a PEGASIS inspired technique. The algorithm divides the whole WSN into sectors. The chain in each sector is formed like IEEPB and avoid long link formations. The sink selects the CH for each chain depending upon the remnant energy and distance to the sink. It also elects the secondary CH for the primary CH depending upon residual energy, distance to the sink and distance between them. The secondary CH is chosen to forward data of primary CH to the sink [39]. The algorithm suffers from long latency period. Moreover, sink takes decision for CH and secondary CH in each round which involves a large communication overhead.The drawback for the technique is that cluster and chains within the clusters are not optimally formed resulting into undue wastage of energy.

C) Hadjila et al. proposed a hybrid of clustering and chain-based approach (FCM-ACO) to route data in a WSN with an aim to exaggerate network lifespan. The proposed algorithm uses fuzzy c-means clustering to split the entire network into pre-decided number of clusters and forms chain in each cluster using ACO method. The leader nodes are elected based upon the remnant energy. The leader node of each cluster transmits the cluster data to the sink in multi-hop manner. For multihopping, a single chain is constructed between all leader nodes and the sink using ACO method. The technique suffers from many drawbacks. Firstly, redundant data transmissions consume huge amount of the network energy. Secondly, load on the leader nodes is comparatively more as compared to other sensor nodes. Thirdly, distance between the leader nodes may be large since distance between adjacent cluster and leader node is not considered while selecting it [40].

D) Energy Efficient Chain Based Routing (IECBR) is a hybrid of chain-based and cluster-based approach. The algorithm initially selects the CHs from the network such that these nodes are nearest to the sink. Thereafter, CH is selected based upon remnant energy and remoteness to the sink. Each CH creates a chain among the member nodes of its cluster, beginning with the remotest node from the CH and chain is formed in greedy way. Then, another chain is formed between the CHs to transmit data to the sink. The algorithm reduces the number of long chains which in turn reduces the delay. Despite the merit, it suffers from long link formation as chains are formed using greedy method [41].

E) Hamilton Energy-Efficient Routing Protocol (HEER) is a delay cognizant routing technique for WSNs. The aim of the protocol is to devise energy efficient paths in the network to forward data to the sink. The algorithm initially divides the network into clusters which remain fixed throughout the network operational period. The benefit to keep clusters static is that the overhead incurred while reforming the clusters iseliminated. A Hamilton path is created in each cluster using greedy method[42].

F) PDORP (PEGASIS-DSR Optimized Routing Protocol) is a routing algorithm using PEGSIS-DSR routing. A hybrid optimization using Genetic Algorithm (GA) and Bacterial Foraging Optimization (BFO) is used to optimize the routes. It uses a concept of directional transmission and cache in routing. The main goal of the algorithm is to reduce delay and increase the energy efficiency in the network [43].

G) LEACH-1R PEGASIS is a hybrid routing using LEACH-IR and PEGASIS for WSN. The proposed algorithm takes the advantage of clustering as well as chaining. The purpose is to reduce the delay of PEGASIS by forming short chains in the clusters and enhance energy efficiency using clustering approach. CH of each clusterin

LEACH-IR initiates the process of chaining by finding farthest node from it. The chain in each cluster is formed using greedy method [44].

H) Cluster-Chain Mobile Agent Routing (CCMAR)is a cluster-based data aggregation in WSN. CHs are elected depending upon their residual energy in a communication radius R. Other sensor nodes are associated with adjoining CH based upon received signal strength. CH of each cluster take the responsibility to form chain within the cluster and act as leader node. A Mobile Agent (MA) is introduced to collect data from all CH to reduce the transmission distances. MA is assigned a duty to communicateaggregated data to the sink [45].The next node for MA route is selected depending upon node residual energy, path loss between two nodes and detected signal energy level.

I) Reliable and Energy-efficient Chain-cluster based routing protocol (REC+) is a routing algorithm which makes the use of clustering and chaining mechanisms to achieve reliable data transmission. LEACH and other clustering algorithms make a strong assumption that all nodes can directly reach the sink [46]. However, the assumption adds unreliability in data transmissions, therefore the algorithm drops the assumption.It puts forward a method to find best place of CH and cluster formation to reduce network energy consumption and intra-cluster delay. The number of hops to CH for each node in the cluster is calculated carefully before electing CH of a cluster in order to make the connections more reliable. The algorithm also considers the multi-hop transmissions for intra-cluster data transmission as well as for inter-cluster transmission to enhance network lifetime and scalability [47].

J) Position-based Chain Cluster Routing protocol (PCCR) designed for strip area WSN. The algorithm partitions the strip WSNinto several belt-shaped region considered as clusters. CH for each cluster is chosen based upon remnant energy and position. A backbone chain is constructed amongst all CHs of a single strip to forward data to sink. The algorithm enhances the network lifespan effectively[48].

The contributions and limitations of all prominent hybrid chain-based techniques are tabulated in table 4. It is observed that in combining different types of techniques with chain-based routing further improves the performance of the algorithms.

Table 4. Comparison of PEGASIS variants based upon Hybrid techniques

Algorithm/ Reference	Contribution	Limitations
HEEP	• Take advantage of clustering to form multiple chains in the network.	• Number of nodes in each chain is not fixed.
SCBC	• Divide the network into sectors. • Branched Chain is constructed in each cluster using IEEPB. • CH nodes lying away from the sink, transmit data to the sink in multi-hop manner.	• Node near sink has more data to transmit and will die soon.
FCM-ACO	• Cluster are formed using FCM technique and remain fixed. • Optimized chain is formed in each cluster using ACO technique. • CH of each cluster is chosen based upon residual energy.	• Waste energy in transmitting redundant data. • Suffer from energy hole problem. • Distance between two CHs of adjacent sectors is not considered.
IECBR	• Clustering approach is used to form multiple chains in the network.	• Chains are formed using greedy method.
HEER	• Hamilton Path is created in each cluster using greedy method. • Number of clusters are fixed and remain unchanged during the whole network life.	• Chain formation method is not optimal.
PDORP	• Take advantage of Genetic Algorithm (GA) and BFO to optimize the chains.	• Use directional antennas which adds the cost to the sensor node.
LEACH-1R REGASIS	• For network division LEACH-1R clustering method is used. • Multiple chains are formed in the network.	• Chain in each cluster is formed with greedy method.
CCMAR	• Network is divided into dynamically formed clusters. • Mobile agent is used to collect data from each CH.	• The path for the mobile agent is not optimized.
REC+	• Reliable data transmission. • For Intra-cluster communication the adjustable transmission antennas are used. • Number of hops to CH node is limited which helps to enhance network reliability.	• High overhead incurred to find CH and Cluster formation in each round.
PCCR	• Save CH energy by chain formation between all CHs.	• Suitable only for strip shaped WSN

IV. OPEN ISSUES

From the survey of PEGASIS and its variants presented in the paper, it is observed that substantialendeavours have been made in delineatingefficacious chain-based routingalgorithms for WSNs. However, still there is lot of prospective to enhance current routing methods. A few imperative open issues are recapitulated as given below:

- Data redundancy needs to be exploited to further enhance network efficiency.
- Most of the techniques do not consider reliable network connections. Failure of a single node may cause loss of data sent to it by other nodes. Therefore, fault tolerance design of protocols is still a challenge.
- Adoption of mobile sink or mobile agent nodes can increase the energy efficiency of the network. Path for these mobile agents can be made efficient to reduce delays.
- There is lot of scope in combining different types of techniques with PEGASIS to tap the merits of each technique.
- It is required to minimize large latency period introduced due to long chains.
- Many algorithms are not suitable for large networks as they are not scalable. The scalability of such algorithms need to be investigated.
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V. CONCLUSION

Transmission over long distances in WSN consumes much higher energy and effect the node lifetime. But, the problem is solved to some extent when data is transmitted to its closest node in the chain as proposed in PEGASIS. The PEGASIS modified techniques have been briefly surveyed in this paper. More precisely, chaining algorithms are categorised into circular area division based, rectangular area division based, branching topology based and hybrid algorithms. The algorithms in each category have been discussed in detail along with their merits and demerits. Finally, some open issues have been explored. This paper certainly provides understanding of various types of chaining algorithms for the readers. It will helpthem in understanding the gaps in research and orient their work in the right direction.

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