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RESEARCH ARTICLE

An Overview of Energy Efficient Hierarchical-Based Routing Protocols for Internet of Things

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ABSTRACT

Wireless sensor networks (WSNs) are a common datacollection with detecting mechanisms for a variety of submissions, including environmental monitoring, agriculture, health, military, and smart transportation. Every sensor node gathers information from its surroundings and transmits it to the Base Station via a wireless link, either single-hop or multi-hop. The main energy ingestion factor in the network is dominated by the data collection and forwarding capabilities of the sensor nodes. Designing energy-efficient protocols is a significant topic of research because many sensor nodes are outfitted with low-power batteries that are challenging to replace. Various routing methods are suggested and looked into to address this issue. The main goals of hierarchical-based routing in WSNs are preserving the residual energy of each sensor node, extending the network lifetime, and assuring communication among the sensor nodes. In this study, an attempt is made to evaluate the various hierarchical routing protocols. The majority of these sensor nodes, known as cluster-head (CH) or leaders, are in charge of gathering and processing data before sending it to the sink, while other nodes, known as member nodes, are in charge of sensing the sensor field and sending the sensing data to the head nodes. Head nodes selection is done in the first layer of the two-layer hierarchy-based routing architecture, and routing is done in the second layer. Picking a suitable hierarchical routing protocol is crucial besides challenging issues. The paper's main objective is to evaluate several recently created hierarchical-based routing protocols in WSNs, which were extended to include other published routing protocols including The Low Energy Adaptive Clustering and is extended to other presented routing protocols like Power-Efficient Gathering in Sensor Information Systems (PEGASIS), Energy Efficient PEGASIS-Based Algorithm (EEPB), Hierarchal PEGASIS, PEGASIS Double CH, Improved EEPB, and Mobile sink improved energy-efficient PEGASIS-based routing protocol.

Key words: Energy efficient PEGASIS-based algorithm, Energy efficient hierarchical routing protocols, Low energy adaptive clustering, Mobile sink improved energy-efficient PEGASIS-based routing protocol, Power-efficient gathering in sensor information systems, Wireless sensor networks

INTRODUCTION

Wireless sensor networks (WSNs) are gorgeousmore and more appealing and intended for anextensive range of applicationsbecause of advancements and improvements in Micro-Electro-Mechanical System and wireless communication technology, including disaster management, security surveillance, habitat monitoring, medical and health, and industrial automation.[1,2] Therefore, WSNs have succeeded in connecting the physical world, computing world, andhuman nation.

A WSN is made up of a hugeamount of small sensor nodes that sense information and are spread across a large area, which includes a memory processor, battery, and A/D converter relating to a sensor and radio transceiver to form an ad hoc network. Figure 1 shows sensor node architecture in WSN. Data from these sensor nodes is gathered by one or extra strong sinks or base stations (BSs). All sensor nodes can sense information, analyze data, and communicate wirelessly but have a limited power supply.

Section 2 of this paper provides an overview of hierarchical routing protocols in WSN. In addition to section 3 discusses some of the objectives of

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WSN Clustering Protocols. Also, Section 4 presents several hierarchical routing protocols proposed by researchers, and finally, section 5 concludes.

OVERVIEW OF HIERARCHICAL ROUTING PROTOCOLS

Data entering the network in a WSN must be routed, which is the responsibility of the network layer. When compared to multi-hop networks, single-hop networks permitstraight communication between the source node and sink. Data packets sent by the source node in multi-hop networks are relayed by the network's intermediate hops before arriving at the sink. Routing tables must be maintained in all of these scenarios for smooth operation, and they are governed by various routing protocols. Network construction, communication originator, routing direction formation, protocol operation, and next-hop choice are a few factors used to categorize routing strategies in WSNs. Additionally, there are three categories into which routing protocols grouped by wireless network design are divided:

Flat protocol

Nodes are organized consistently and also have a similar role, i.e. every node in the network is at the same level. FLAT protocols are supplementary classified as pro-active, reactive, or hybrid.[3]

Hierarchical protocols

With these protocols, nodes are grouped into clusters, and the node with the greatest amount of energy is designated as the cluster's cluster-head (CH). The cluster leader plans events both inside and outside of the cluster. To save energy when delivering data packets from the CH to the BS, CHs must collect data from the cluster's nodes and eliminate redundancy in the data they collect.[4,5]

Location-based protocols

Based on where they are in the network, nodes are recognized. Signal strength determines how far apart sensor nodes must be; the stronger the signal, the closer the nodes must be. Some protocols in this category, such as Geographic and energy aware routing and Greedy Perimeter Stateless Routing,[6,7] permit nodes to enter sleep mode if there is no activity at that node.

This study focuses on network-based hierarchical routing protocols. The node selection makes hierarchical routing more energy efficient by assigning sensing information to low-energy nodes and data processing and transmission tasks to high-energy nodes. As a result, increased longevity, scalability, and energy savings are possible. Cluster-based routing is another name for hierarchical routing. Block, grid, or chain cluster-based hierarchical routing protocols are the most common.[8,9] Figure 2 displays a categorization of network structure-based routing protocols.

OBJECTIVES CLUSTERING PROTOCOLS OF WSNS

Clustering goals are used to meet the needs of various applications in WSNs. The following are the various network clustering objectives.[10]

Scalability

Sensor nodes are split into several clusters with different levels of assignment in a clustering routing scheme. The CHs are in charge of data aggregation, information dissemination, besides network organization, while the member nodes

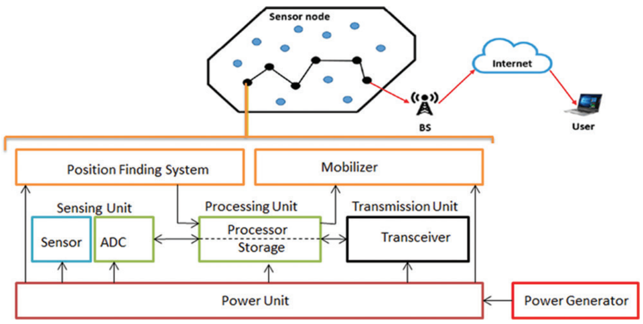

Figure 1: Sensor node architecture in wireless sensor networks

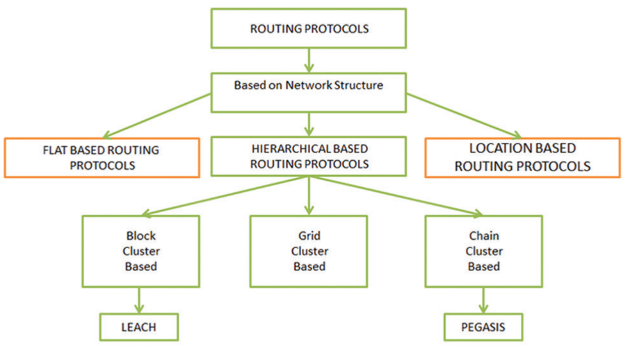

Figure 2: Network structure-based routing protocol taxonomy

are in charge of sensing events and collecting information in their surroundings. The routing table kept at each sensor node might be smaller due to clustering topology, which can localize the route established surrounded by the cluste.[11-13]

Data aggregation

This is an operative procedure for WSNs to exclude energy.[14-16] Aggregating data from various nodes allows for the removal of duplicate transmission and the provision of fused data to the BS. Clustering data aggregation is the most often used method of data aggregation/fusion, in which each CH aggregates the acquired data and delivers the fused data to the BS.[17] To send combined data by multiple-hopping over other CHs, CHs are often placed in a tree topology. This significantly reduces energy consumption.[17]

Less load

Due to the large amount of redundant data that sensors might provide, data aggregation or fusion has become a key principle and objective in WSNs. Combining data from many sources to reduce duplicate data transfers and create a rich, multidimensional image of the targets under observation is the main objective of data aggregation or fusion.[18] All cluster members only submit data to the CHs, and the CHs aggregate the data, which significantly reduces transmission data and saves energy.

Energy efficiency

Data aggregation aids in the reduction of transmission data and the conservation of energy in clustering routing schemes.In addition, clustering thru intra-cluster and inter-cluster connections can lower the number of sensor nodes carrying out long-distance communications, allowing the network to use less energy overall. Furthermore, in a clustering routing scheme, only CHs perform data transmission, which can save a significant amount of energy.[19,20]

Reduced latency

Whenever a WSN is divided up into clusters, only CHs are responsible for data transmissions outside of the cluster. The mode of only sending data out of the cluster aids in avoiding node collisions. Latency is reduced as a result, which can reduce hops from the data source to the BS and thus latency.

Load balancing

Is significant attention in WSNs for extending network lifetime.[21,22] For Sensors cluster construction, it is typical to contemplate distributing sensor nodes evenly throughout clusters, with CHs handling data processing and intra-cluster management. Furthermore, multi-path routing is a technique for load balancing.

Fault-tolerance

Because WSNs can be applied in a variety of dynamic situations, sensor nodes may face energy depletion, transmission failures, hardware malfunctions, malicious attacks, etc. It is anticipated that numerous small sensor nodes would be used in applications like storm simulation and tracking. As a result, fault tolerance in WSNs is a major challenge.[23] Effective fault-tolerant techniques are essentialto be implemented into WSNs as CHs are typically required in these types of applications to prevent the loss of important data from crucial sensor nodes. Re-clustering is the most logical technique to recover from a cluster failure, although it typically interferes with the existing process. Assigning a CH backup is a workable plan for overcoming a CH failure.

Avoiding energy holes

Multi-hop routing is typically employed to transfer gathered data to a sink or a BS. In those networks, each node transmits both its traffic and traffic that has been relayed from other nodes. No matter the MAC protocol, sensor nodes closer to the BS are required to send more packets than nodes farther away.[24] Because of such, even though many surviving nodes still have plenty of energy, the nodes nearest to the BS exhaust their energy fastest, leaving a hole nearby, dividing the entire network, and preventing other nodes from delivering data to the BS. Energy holes are what this is.[25] Node distribution, load balancing, and energy mapping and assignment are the three categories that compose up energy hole avoidance systems, often known as energy consumption balancing mechanisms.[26]

Network lifetime

In WSNs, network lifetime must be taken into account because sensor nodes, particularly in hostile environments, have limited power supplies, computing power, and transmission bandwidth. Nearby sensor nodes to the majority of the sensor nodes in the clusters must be more likely to be CHs. In addition, the energy-aware idea aims to choose routes in inter-cluster communications that are anticipated to lengthen network lifetime, and routes made up of nodes with greater energy resources ought to be chosen.[27,28]

Quality of service (QoS)

WSN network submissions and features make the QoS necessary. It is typically necessary to have efficient sampling, little latency, and temporary precision. It is challenging for all routing protocols to fulfill all QoS necessities since a few demands break one or more protocol principles. Instead of supporting QoS, current clustering routing techniques in WSNs focus more on boosting energy efficiency. QoS measurements are necessary for many real-time applications, including monitoring emergent events and tracking battle targets.

PROPOSED HIERARCHICAL ROUTING PROTOCOLS

The main Hierarchical Routing proposed for WSNs to increase energy-efficient will be described in this section, as illustrated in Figure 3:

The low energy adaptive clustering (LEACH)

LEACH protocol is a block-based routing protocol. The chain-based routing protocol revolution began with this protocol. The design is built on a distributed clustering method, and throughout the work period, all sensor nodes cooperating via a first-order radio model continue to bargain about that will succeed the selected cluster leader. Every sensor node will have a 1/p chance of becoming the next CH in each round of the CH selection process. The node number, which runs from 0 to 1, influences the choice of which node will be the subsequent cluster leader. The node number, which runs from 0 to 1, determines which node will be the subsequent CH. The node is classified as a CH for the current round if the value is smaller than a predetermined threshold T (n); otherwise, it is regarded as a regular node. The threshold is as surveys:

$$T(n) = \begin{cases} \dfrac{P}{1 - P\left(r \bmod \left(\dfrac{1}{P}\right)\right)}, if\ n \in G \\ 0, otherwise \end{cases} \quad (1)$$

Where,

- *P*: CHs desired percentage of
- *r*: The current round
- *G*: The set of nodes that did not act as CHs in the most recent rounds.

The result is, saving energy and increasing network lifetime due to the unsettled CH node procedure that consumes node energy. The CH is chosen by the self-organizing Leach protocol either at random or according to parameters like energy. The task of collecting data from the nodes, aggregating it, and delivering it to the BS will fall to the CH,[29] as illustrated in Figure 4.

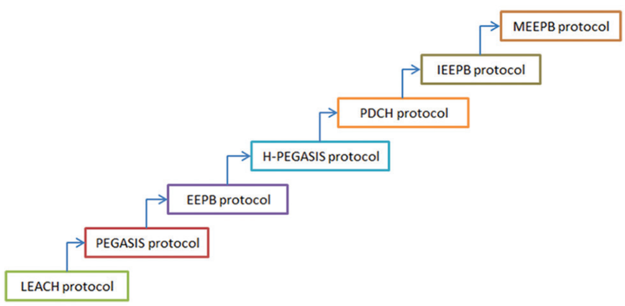

Figure 3: Hierarchical routing protocols improvement stages

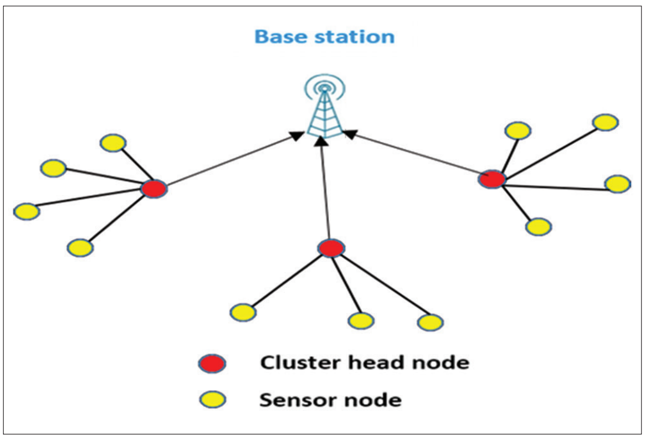

Figure 4: Low energy adaptive clustering protocol

Characteristics of the LEACH protocol

- Balancing energy dissipation by giving each node an equal chance of becoming a CH
- Leach employs TDMA, which prevents CHs from colliding
- Outperforms traditional routing protocols.

Drawbacks of the LEACH protocol

- Ineffective for large-scale network deployments.
- Additional overhead on CH nodes as a result of the dynamic clustering process.

Protocol for power-efficient gathering in sensor information systems (PEGASIS)

The PEGASIS protocol, a chain cluster-based routing system with analtered mode of operation than the Leach protocol, surpasses the Leach protocol. According to the first-order radio model, the nodes participating in the PEGASIS protocol are also in communication with one another. There are various requirements for the PEGASIS protocol that may be divided into two main sections:

- Chain formation

As shown in Figure 5, the procedure for building a chain of sensor nodes is based on a generous algorithm to guarantee communication between each sensor node and its closest neighbor. Send the data at the chain's end, that has been gathered in advance to the leader node or the node that is most nearby to the BS. Always start the chain at the farthest node.[30]

- Gathering and collecting data
- During the following phase, every node will combine its data with that of its neighbors before sending the combined data to the following node in a growing procedure. This information will be sent to the BS by the leader. In addition, a separate leader node in an altered place is randomly selected and used in each round[30-32]
- The leader will design a control token passing plan for a certain round to move data from a far-off node to the closest one, then to the BS. As exposed in Figure 6.

Features of the PEGASIS protocol

- Energy savings due to the shorter distance between nodes. As a result, the process of transmitting and gathering data will have used less energy

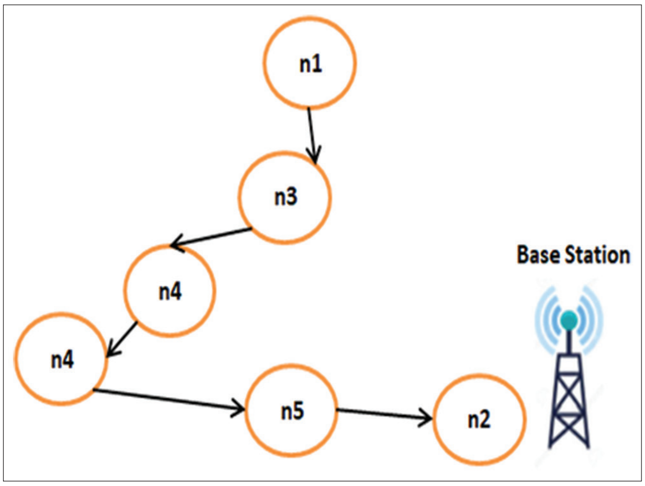

Figure 5: Power-efficient gathering in sensor information systems protocol chain

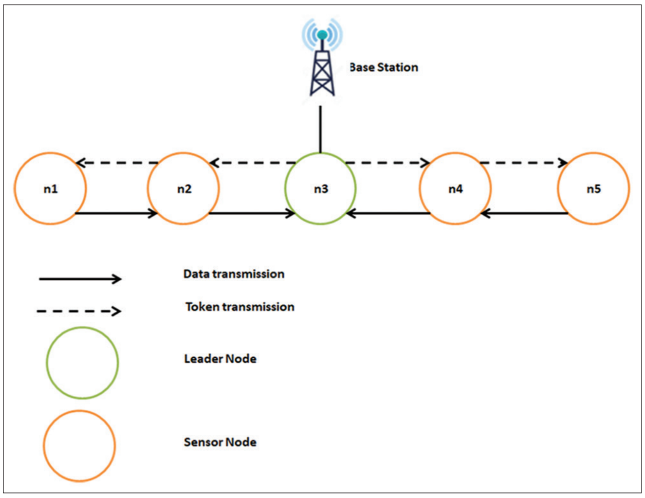

Figure 6: Control token passing approach in the chain-based

- Because of the volume of messages received by the leader node, energy is saved more effectively
- Reduce the number of messages by having the final node in a chain send the Final message as a single message to the BS.

Drawbacks of the PEGASIS protocol

- Long communication distances between nodes cause high delays. As a result, more energy will be consumed
- Limited scalability
- Ineffective for time-varying topology.

Energy efficient PEGASIS-based algorithm (EEPB)

The EEPB protocol is superior to the PEGASIS protocol. By addressing the issue of long chains generated by the distance among nodes induced by the greedy algorithm employed in the PEGASIS protocol, which leads to high energy consumption and rapid node death, EEPB seeks to address the drawbacks of PEGASIS.[33] As indicated in the accompanying Eqs. (2), and (3), the EEPB protocol resolves this issue by establishing a distance limit that resolves to calculate the formatted chain's average chain length.

$$D_{average} = \sum_{p=1}^{h} \frac{Dp}{h} \quad (2)$$

$$Dthreshold = \alpha \times Daverage \quad (3)$$

Where:

- Daverage: which is the chain's average distance
- h is the hop number of the formed chain
- Dp: is the distance between each link in the chain that is constructed, where (P = 1, 2, 3, h)
- An LL problem is more likely to arise if the distance in the middle of the end node of a created chain and an innovative demanded node to join with that chain of nodes is greater than the D threshold
- Dthreshold: is the distance for the threshold
- α: is a user-defined constant.

EEPB bases its selection of the leader node on two variables: the node's remaining energy and the distance between the middle of the nodes and the BS. Following the establishment of the chain, the information transmission stage starts by collecting data incrementally from each node until it reaches the leader node, which is in charge of transmitting the data to the BS. Power will be conserved and distributed equally among nodes as a result.[34,35]

Characteristics of the EEPB protocol

- Using a distance threshold, keep the network away from the phenomenon of long links.

Drawbacks of the EEPB protocol

- Uncertainty about the distance threshold will be caused once again by the problem of long links
- Unsuitable leader selection occurs when the residual energy of nodes and the distance between them are not taken into account when selecting the leader node.

Hierarchal PEGASIS (H-PEGASIS)

H- PEGASIS is a more advanced version of the PEGASIS protocol. It was created to reduce the delay of transmission packets to the BS. It intends a description of data collection issues by taking energy and delay metrics into account. Simultaneous data messages are spread to reduce delay. Signal coding, such as CDMA, is used to avoid collisions. Only nodes that are physically apart are permitted to broadcast data simultaneously in order to prevent signal interference. The chain forms a tree-like hierarchy with CDMA-capable nodes, and each selected node transmits data to the node of the upper hierarchy. This ensures parallel data transmission and significantly reduces latency.[33]

Characteristics of the H-PEGASIS protocol

- Reduce the time it takes for packets to be transmitted to the BS.

Drawbacks of the H- PEGASIS protocol

- Only spatially disconnected nodes are permitted to transmit data at the same time.

PEGASIS double CH (PDCH)

The procedure of doubling the CH will have a positive impact on the entire network by reducing traffic and avoiding high delays. Usually, the PEGASIS protocol employs a single CH to communicate with the BS. Currently, using a double CH is preferred over a single CH, as illustrated in Figure 7. The method of increasing the number of CHs is based on a hierarchical communication system between CHs at each layer.[34,36] The CH selection stage begins after the chain formation process is completed, and nodes are chosen as primary CHs, secondary CHs, or

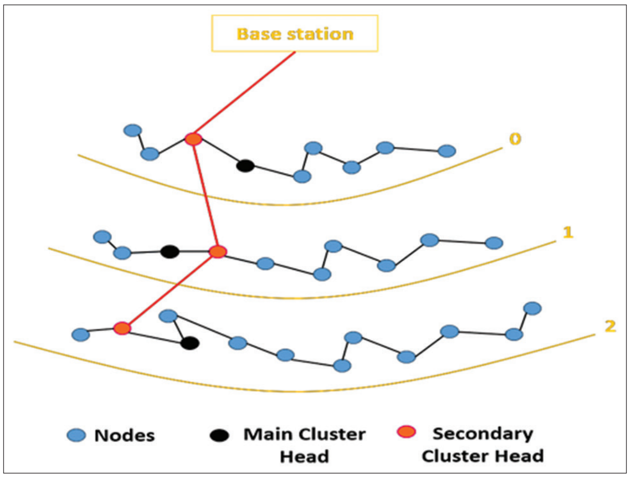

Figure 7: Double cluster head

regular nodes based on their weights. Node weights W can be discovered or determined by separating their residual energy by their distance from the BS, as shown in the following Eq. (4).The network selects the node with the highest weight as the primary CH. Following the selection of the primary CH, each node in the chain computes its distance from the assumed parent node, p1, and compares it to the distance from the sink node, p2. If the distance p2 > p1, the node is considered a secondary CH; then, it is a regular node in the chain.

$$Wn = En/Dn \quad (4)$$

Where denotes a node's residual energy and which measures the distance between the sink and the sensor node.

Thus, many benefits will be provided, by giving the CH the task of gathering data from nodes, a CH will arise in the form of the main CH and a secondary CH, as displayed in Figure 7, for example, decreasing the delay in the transmission and reception process between nodes. As anoutcome, each node's load is balanced, and the network lifetime is increased.[36,37]

Characteristics of the PDCH protocol

- Minimize dynamic cluster formation overhead
- Distributing the energy load among the nodes will increase the network's lifetime.

Drawbacks of the PDCH protocol

When the double CH is located as follows, time delay and unbalanced load distribution occur:

- The first CH is located far away from the second CH and in different directions
- When the location of the double CH is far from the BS.

Improved EEPB (IEEPB)

IEEPB protocol, whichrisesto the shortcomings of EEPB. When EEPB constructs a chain, the threshold used is inexact and difficult to determine. As a consequence, a "long chain" is formed. Furthermore, when EEPB chooses the leader, it disregards the node energy and the distance between the BS and the node that optimizes the leader selection. IEEPB estimates the distance of two nodes twice and, using these comparisons, determines the shortest path to join two nearby nodes. By using a threshold,[38] the chain construction is simplified to avoid the formation of "long chains." When selecting the appropriate leader, IEEPB also considers the node's energy and the distance between the BS and the node, as shown in the following Eqs (5), (6), (7), (8).

$$Dbs = dToBS/dave \quad (5)$$

Where *dTo BS* is the distance between the sensor node and BS and d is the average distance between sensor nodes and BS.

$$Ep = Einit/Ei \quad (6)$$

Where *Ep* is the Portion energy, *Einit* is the initial energy of node *i*, and: is the residual energy of node *i* for round *n*.

$$Wi = W1Ep + W2\ Dbs \quad (7)$$

$$W1 + W2 = 1 \quad (8)$$

Where Wi isthe combined weight of each node and *w1 + w2* is the coefficient of weight factors.

- If *w1 > w2* then indicates that residual energy is the most useful factor in choosing the leader node
- If *w1 < w2* then indicates that the distance between the node and the BS is the most useful criterion to choose the leader node.

The leader node will ultimately be determined by the node with the lowest weight.[34]

Characteristics of the IEEPB protocol

- Long links are avoided
- Efficient leader node selection takes into account two factors: residual energy and distance between nodes when executing the process of assigning a weight coefficient to each node.

Drawbacks of the IEEPB protocol

- High loads on single chains due to the distance between the sink node and the chain
- Large delays.

Mobile sink enhanced energy-efficient PEGASIS-based routing protocol (MIEEPB)

MIEEPB is superior to IEEPB because it incorporates sink mobility into a multi-chain model, allowing for the construction and application of smaller chains, reducing the load on the leader nodes.[39] Similar to the earlier protocol IEEPB, MIEEPB makes use of the first-order radio model to enable effective communication between sensor nodes. Data is also sent between nodes through token passing, using MIEEPB multi-chain and double CH extensions. The primary and secondary CHs are also chosen using the weighting algorithm. Finally, by defining the sojourn time and location, MIEEPB employs a mobile sink. The mobile sink node divides the WSN area into multiple regions, such as four regions, and takes into account that the sink node completes one course around each of the four sojourn places once every round, as illustrated in the following Eq. (9).

$$Ts=\sum_{i=1}^{4}\left(Ni\right) \quad (9)$$

Subject to:

$$_{ij}\begin{cases} D & if\ i\quad j \\ 0 & otherwise \end{cases}$$

Where T_S represents the entire sojourn time of one sequence, $x_{i,j}$ represents the number of bits spread between chain leaders and the sink i, j represents the sink potential locations where $i = 1$, $j = 4$ as an example for four chains, Ni represents the number of divided regions in WSN, and D reflects the total amount of data that was transmitted between the sink and chain leaders during the sojourn.

MIEEPB is a multi-chain model called has limited and continuous fixed path mobility of sink nodes, and probable locations that maximize network lifetime while efficiently utilizing the energy of wireless sensors.

Characteristics of the MIEEPB protocol

- Appropriate for time-sensitive applications
- Decreases the network overhead
- Reduce the distance between nodes
- Sink mobility will mitigate the loads on the nodes that are nearest to the sink node
- Decreasing the delay in delivering data
- Decrease the load on the leader node in a single chain as in IEEPB.

Drawbacks of the MIEEPB protocol

- Sink mobility is not appropriate for communicating with randomly moving nodes in the network; this will increase delay, congestion, and overhead.

CONCLUSION

In this study, a review of WSN routing methods is offered. The objective of all of them is to maintain data delivery while extending the life of the sensor network. Because sensor nodes have limited energy resources, energy economy is the key issue while designing routing protocols for WSNs. Keeping the sensors operational for as long as feasible will lengthen the lifetime of the WSN, which is the main objective of the routing protocol design. The sensor nodes' primary energy consumption is data. By incorporating sensor nodes in multi-hop communication inside a specific cluster, energy-efficient hierarchical protocols including LEACH, PEGASIS, EEPB, H-PEGASIS, PDCH, IEEPB, and MIEEPB, which are detailed in this study, can effectively maintain the energy usage of sensor nodes. WSN designers may find this survey useful in choosing an acceptable.

REFERENCES

1. Amutha J, Sharma S, Nagar J. WSN strategies based on sensors, deployment, sensing models, coverage and energy efficiency: Review, approaches and open issues. Wireless Pers Commun 2020;111:1089-115.
2. Zhu J, Lung CH, Srivastava V. A hybrid clustering technique using quantitative and qualitative data for wireless sensor networks. Ad Hoc Netw 2015;25:8-53.
3. Arora VK, Sharma V, Sachdeva M. A survey on LEACH and other's routing protocols in wireless sensor network. Optik 2016;127:6590-600.
4. Heinzelman WR, Chandrakasan A, Balakrishnan H. Energy-Efficient Communication Protocol for Wireless Microsensor Networks. In: Proceedings of the 33rd Annual Hawaii International Conference on System Sciences; 2000. p. 1-10.
5. Handy MJ, Haase M, Timmermann D. Low Energy Adaptive Clustering Hierarchy with Deterministic Cluster-Head Selection. 2002 In: 4th International Workshop on Mobile and Wireless Communications Network. MWCN; 2002. p. 368-372.
6. Bulusu N, Heidemann J, Estrin D. GPS-Less low-cost outdoor localization for very small devices. IEEE Pers Commun 2000;7:28-34.
7. Savvides A, Han CC, Strivastava MB. Dynamic Fine-grained Localization in Ad-Hoc Networks of Sensors. In: Proceedings of the 7th Annual International Conference on Mobile Computing and Networking; 2001. p. 166-179.
8. Naeimi S, Ghafghazi H, Chow CO, Ishii H. A survey on the taxonomy of cluster-based routing protocols for homogeneous wireless sensor networks. Sensors 2012;12:7350-409.
9. Tang F, You I, Guo S, Guo M, Ma Y. A chain-cluster based routing algorithm for wireless sensor networks. J Intell Manuf 2012;23:1305-13.
10. Amutha J, Sharma S, Sharma SK. Strategies based on various aspects of clustering in wireless sensor networks using classical, optimization and machine

learning techniques: Review, taxonomy, research findings, challenges and future directions. Comput Sci Rev 2021;40:1-43.
11. Abbasi AA, Younis M. A survey on clustering algorithms for wireless sensor networks. Comput Commun 2007;30:2826-41.
12. Akkaya K, Younis M. A survey on routing protocols for wireless sensor networks. Ad Hoc Netw 2005;3:325-49.
13. Chidean MI, Morgado E, Del Arco E, Ramiro-Bargueno J, Caamano AJ. Scalable data-coupled clustering for large scale WSN. IEEE Transa Wirel Commun 2015;14:4681-94.
14. Rajagopalan R, Varshney PK. Data aggregation techniques in sensor networks: A survey data aggregation techniques in sensor networks: A survey recommended citation recommended citation data aggregation techniques in sensor networks: A survey. IEEE Commun Surv Tutor 2006;8:48-63.
15. Çam H, Özdemir S, Nair P, Muthuavinashiappan D, Sanli H. Energy-efficient secure pattern based data aggregation for wireless sensor networks. Comput Commun 2006;29:446-55.
16. Guleria K, Verma AK. Comprehensive review for energy efficient hierarchical routing protocols on wireless sensor networks. Wirel Netw 2019;25:1159-83.
17. Ozdemir S, Xiao Y. Secure data aggregation in wireless sensor networks: A comprehensive overview. Comput Netw 2009;53:2022-37.
18. Li C, Zhang H, Hao B, Li J. A Survey on routing protocols for large-scale wireless sensor networks. Sensors 2011;11:3498-526.
19. Shankar T, Shanmugavel S, Rajesh A. Hybrid HSA and PSO algorithm for energy efficient cluster head selection in wireless sensor networks. Swarm Evol Comput 2016;30:1-10.
20. Katre SS, Gosavi SK. Challenges and issues in wireless sensor network-a review. Int Res J Eng Technol 2018;5:2856-60.
21. Singh SK, Singh MP, Professor A, Singh DK. A survey of energy-efficient hierarchical cluster-based routing in wireless sensor networks. Int J Adv Netw Appl 2010;2:570-80.
22. Yadav KR, Pal V, Singh G, Yadav RP. An efficient load balancing clustering scheme for data centric wireless sensor networks. Int J Commun Netw Secur 2012;1:24-8.
23. Chitnis L, Dobra A, Ranka S. Fault tolerant aggregation in heterogeneous sensor networks. J Parallel Distrib Comput 2009;69:210-9.
24. Li J, Mohapatra P. Analytical modeling and mitigation techniques for the energy hole problem in sensor networks. Pervasive Mob Comput 2007;3:233-54.
25. Tran-Quang V, Nguyen Huu P, Miyoshi T. A transmission range optimization algorithm to avoid energy holes in wireless sensor networks. IEICE Trans Commun 2011;94-B:3026-36.
26. Ishmanov F, Malik AS, Kim SW. Energy consumption balancing (ECB) issues and mechanisms in wireless sensor networks (WSNs): A comprehensive overview. Eur Trans Telecommun 2011;22:151-67.
27. Younis M, Youssef M, Arisha K. Energy-aware management for cluster-based sensor networks. Comput Netw 2003;43:649-68
28. Hou YT, Shi Y, Sherali HD, Midkiff SF. On energy provisioning and relay node placement for wireless sensor networks. IEEE Trans Wirel Commun 2005;4:2579-90.
29. Jiang S. LEACH Protocol Analysis and Optimization of Wireless Sensor Networks Based on PSO and AC. In: 2018 10th International Conference on Intelligent Human-Machine Systems and Cybernetics (IHMSC); 2018. p. 246-50.
30. Ghosh R. Comparative performance analysis of routing protocols in wireless sensor network. Int J Sensor Netw Data Commun 2016;5:1-5.
31. Lindsey S, Raghavendra CS. PEGASIS : Power-Efficient GAthering in Sensor Information Systems. In: Proceedings, IEEE Aerospace Conference; 2002. p. 1125-30.
32. Lindsey S, Raghavendra CS. PEGASIS: Power-Efficient Gathering in Sensor Information Systems. In: Proceedings, IEEE Aerospace Conference; 2002.
33. Rana H, Vhatkar S, Atique M. Comparative study of PEGASIS protocols in wireless sensor network. IOSR J Comput Eng 2014;16:25-30.
34. Vhatkar S, Nanade A, Atique M. Performance Evaluation and QoS Analysis of PDCH and MBC Routing Protocols in Wireless Sensor Networks. In: IFIP International Conference on Wireless and Optical Communications Networks, WOCN; 2017. p. 101-9.
35. Hussein AA. Improvements of PEGASIS routing protocol in WSN improvements of PEGASIS routing protocol in WSN. Int Adv J Eng Res 2019;2:1-14.
36. Linping W, Zhen C, Wu B, Zufeng W. Improved Algorithm of PEGASIS prOtocol Introducing Double Cluster Heads in Wireless Sensor Network. In: 2010 International Conference on Computer, Mechatronics, Control and Electronic Engineering; 2010. p. 148-51.
37. Xiao Y, Lu D. A Double Heads Static Cluster Algorithm for Wireless Sensor Networks. In: 2010 the 2nd Conference on Environmental Science and Information Application Technology; 2010. p. 635-8.
38. Li T, Ruan F, Fan Z, Wang J, Kim JU. An Improved PEGASIS Protocol for Wireless Sensor Network. In: 2015 3rd International Conference on Computer and Computing Science (COMCOMS); 2016. p. 16-9.
39. Thakur S, Singh B. Mobile sink-based multi-chain pegasis protocol for improving the lifetime of WSNs. Int J Innov Res Electr Electron Instrum and Control Eng 2016;4:71-4.