

A Study on Various Hierarchical Routing Structures Supporting Mobility Assisted WSN

Tilak S. Rajput¹, Shripad P. Mohani² and Samadhan C. Kulkarni³

¹⁻³Government College of Engineering, Jalgaon, India

Email: tilaksrajput@gmail.com, Shripad.mohani@gcoej.ac.in, samadhan.kulkarni@gcoej.ac.in

Abstract— Hierarchical routing outperforms other routing techniques, but has one major issue: hotspots near sink nodes, i.e., nodes near sink nodes, deplete the battery more rapidly. The mobile sink addresses this problem well. As the mobile sink moves through the network, the hotspot around it also moves, resulting in load balancing throughout the network. However, various overheads are associated with mobile sinks, such as location advertisement, path-finding, etc. This paper discusses different structures related to hierarchical routing that support sink mobility. Various design constraints and issues associated with mobile sinks are discussed. In the end, various routing protocols are summarized according to sink mobility pattern, position awareness, multi-sink support, protocol overhead, etc. The achievements and limitations of each protocol are also discussed.

Index Terms— Mobile sink, Mobile WSN, Hierarchical routing, Routing structures.

I. INTRODUCTION

In recent times, wireless sensor networks emerged as a promising technology for collecting sensory data from the real world. A small module known as a node is the fundamental element of WSN. It contains onboard sensors, controllers, communication modules, etc., all battery-operated. Therefore, WSN must be energy efficient to prolong the operating time of the node. Regarding energy efficiency, the methodology of data communication from source to destination node, plays an important role. Battery dependency is the utmost issue for WSN as it is directly related to the lifetime of the node [1-2]. Major studies suggest that inefficient routing is the main reason for battery drain out. To ensure the overall lifetime of WSNs, implementing energy-efficient routing algorithms in the network is an important factor [3].

Routing protocols are mainly categorized into three types: Flat routing, Location based routing, and Hierarchical routing. Flat routing assigns the same functionality to all nodes [4]. In location-based routing, the position information of a destination node is considered as a destination address, and information is flooded to nodes in that region [5]. Hierarchical routing divides the whole network into multiple regions; each region has a head node and member nodes. The head node collects the sensor data from member nodes and sends it to the base station [6]. The Hierarchical routing techniques outperform the flat and location-based routing techniques in terms of scalability, energy saving, and network lifetime, as suggested by literature in [7 - 9]. Hierarchical routing reduces the transmission of redundant data, which reduces energy consumption. As different nodes perform different tasks, the load is distributed equally throughout the network. Hierarchical routing incorporates MAC protocol; therefore, energy overhead due to collision is minimal.

One major shortcoming associated with hierarchical routing is this type of routing faces hotspot issue. Here, hotspots, referred to as sensor nodes around the Cluster Head (CH) (also called a sink), drain energy faster than other network nodes. It is caused by all the nodes' data traveling into the center towards the cluster head. After the depletion of all the neighboring nodes, the static sink (CH) itself is isolated from the network. Hotspot problems can be avoided using a Mobile sink; mobile sinks roam over the network and collect the sensed data from other nodes. Sink mobility also allows nodes to minimize the transmission overhead, such as destination and multi-hop address data; they can only transmit when the sink node is nearby. However, the sink sometimes moves randomly in the network; therefore, for data to be effectively transferred to the sink node, additional transmission protocols need to be periodically updated.

Another advantage associated with mobile sinks is that a distributed network can be readily accessible. Network connectivity also improves as data can be obtained from disconnected networks [16]. Sink mobility could be the best alternative in delay tolerant applications, as it reduces hop count and overhead during transmission, significantly reducing energy consumption. The sink mobility does have trade-offs. The continuous change in the location of the sink leads to the need to advertise new locations across the network continuously. This operation may sometimes be affected adversely, and the overhead of energy required to advertise a new location exceeds the energy needed for the static case. Some protocols redundantly disseminate data through multiple nodes to address this issue, but sometimes, it consumes the same overhead of energy.

There are multiple scenarios in which mobile sink WSN is very helpful; one is a fire detection system for forest areas, in which numerous sensor nodes transmit sensed data to the mobile sink, which is mounted on the hands of firefighters, and they can take action on freshly available data [17]. Another scenario is where a doctor can acquire patients health live data on their handheld device when they visit a particular ward, in which the handheld device acts as a mobile sink. Habitat monitoring is another example of the mobile sink, where a mobile sink can be mounted on a robot or human. As the sink travels through the forest, the sensor nodes will transmit harvested data of wildlife movements in that region once the mobile sink reaches the range [18].

The above discussion substantiates sink mobility-assisted WSNs as a promising research field for various applications. It is essential to form a complete solution to address the problems of WSNs and new challenges associated with mobile WSNs. Mobile sink broadens the capabilities of WSN and caters to the dynamic properties of the network.

One of the crucial concerns of hierarchical routing is centralized control, and mobile sinks address that issue. The centralized network has now become a distributed network, and the central entity does not have the role of managing routes and control.

In this work, a detailed study has been performed on different hierarchical structures that support mobile WSNs. Protocols that support these structures, sink mobility, and position awareness of each protocol have been discussed. The design requirements and difficulties related to the issue of mobile sink routing are emphasized and described in order to give an understanding of the rationale behind and problems raised by mobile sink routing protocols.

The discussed hierarchical routing structures are summarized in table 1. The nature of virtual structures, the sink mobility pattern, position awareness, and information about multi-sink support is also summarized. Thorough overview of problems and their solutions are also discussed, in order to future directions. The discussed performance criteria are not included in the table, because we lack the quantitative metrics necessary to compare the approaches fairly under these conditions. Rather, each protocol's specific analysis is discussed under these protocols separately.

II. HIERARCHICAL STRUCTURES SUPPORTING MWSN

The most significant and widely adopted method for routing in WSNs with mobile sinks is hierarchical routing of mobile sinks. By establishing a virtual hierarchy of nodes and assigning distinctive responsibilities to the sensors, hierarchical routing techniques seek to reduce the overhead associated with advertising the location of the base station throughout the network. Area-wise clusters are formed, and one node is assigned the responsibility of the head node. The role of a head node is to collect data from member nodes and forward it to the base station by aggregating it.

The protocol structure to be formed under hierarchical routing can be formed in different structures like cluster-based, grid-based, tree-based, rail type, ring type, etc., as shown in Figure 1, which are reviewed in following sections. Some protocols also use a combination of two different structures that are also reviewed.

In this section, different hierarchical routing protocols are discussed with their application, advantages and drawbacks.

A. Grid-based approach

In this approach, nodes in the higher hierarchy level form a grid-like structure; basically, the points are nothing but crossing points of grids, as shown in Figure 1 (i). Grids can be in different shapes, such as triangular, hexagonal, rectangular, etc. Protocols like TTDD, CMR, and GBEER employ a grid-based approach.

- **TTDD: Two Tier Data Dissemination in Large Scale WSNs (TTDD)** [21]. The issue of effective and scalable dissemination of data in broad wireless sensor networks is the primary focus of the article, particularly when dealing with multiple mobile sinks. Previous approaches require sinks to persistently disseminate their location information across the entire sensor field, leading to excessive energy consumption and network overload. The results show that data can be efficiently delivered multiple sources to multiple mobile sinks in TTDD with high success rates (around 80-100%) and low delays (0.02-0.08 seconds). TTDD's performance is also scalable as the number of sinks and sources increases. The energy consumption increases sub-linearly with the number of sinks and almost linearly with the number of sources.

Achievements and Limitations: The viability and benefits associated with creating a virtual grid structure to facilitate effective data dissemination across broad sensor networks are illustrated by TTDD. It outperforms the traditional sink-oriented data dissemination approach in terms of communication overhead and state complexity. The significant overhead of creating a unique grid for every source node is a challenge for TTDD, particularly in applications where a large number of sensor nodes contribute data.

- **CMR: Coordinate Magnetic Routing (CMR)** [20]. This study's primary goal is to develop a new and effective data distribution mechanism for wireless sensor networks with mobile sinks. The goal of the suggested technique is to remove the communication overhead associated with data distribution, using grid-based sensor network by combining coordinate routing and magnetic phenomena. The authors evaluate the performance of the CM algorithm through extensive simulations using the Georgia Tech Network Simulator (GTNetS). The results show that CM outperforms the ODDD scheme in terms of energy consumption, transmission success rate, and average end-to-end delay.

Achievements and Limitations: The simulation results demonstrate that in MSWSN, the CM algorithm provides safe and high-performance data transmission, making it a promising solution for real-world applications. The study is limited to a grid-based sensor network scenario.

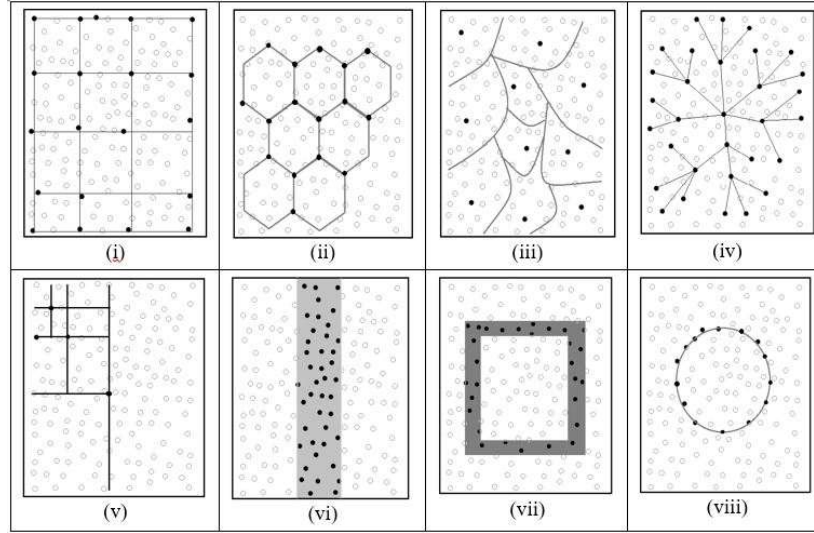


Fig. 1. Routing structure in hierarchical routing (i) Rectangular (ii) Hexagonal (iii) Clusters (iv) Tree (v) Quad tree (vi) Line (vii) Railroad (viii) Ring

- **GBEER: Grid-Based Energy-Efficient Routing from Multiple Sources to Multiple Mobile Sinks (GBEER)** [22]. This research explores the issue of data transmission from multiple sources to various mobile sinks in a large-scale wireless sensor network. The findings of the paper shows that GBEER outperforms the existing TTDD protocol in terms of total energy consumption, with variations in the number of sources, sinks, and sink speeds. GBEER consumes 5-6 times less energy than TTDD while maintaining a delivery success ratio above 90%.

Achievements and Limitations: GBEER can effectively and efficiently transmit data from multiple sources to multiple mobile sinks, making it a promising protocol for large-scale sensor network deployments. By creating and maintaining a standard grid structure, GBEER reduces the extra overhead associated with establishing distinct grids for each source (as in TTDD). Despite this, the nodes that make up the grid are probably hotspots and will likely die faster than other nodes.

- HPDD: Hexagonal Path Data Dissemination (HPDD) [23]. HPDD implements a hexagonal structure rather than a rectangular grid used in TTDD, as shown in Figure 1 (ii). Results of the paper show that the hexagonal structure performs better than the rectangular, while it resembles other protocols as per GBEER. Achievements and Limitations: Though it outperforms GBEER, it suffers the same hotspot problem as GBEER. HPDD performs better in advertising the sink route and providing a shorter data path.
- HexDD: Honeycomb Tessellation (HexDD) [24]. The HexDD protocol overlays a virtual honeycomb tessellation on the underlying sensor network. Based on their positions, sensor nodes are linked to hexagonal cells. The honeycomb's three diagonal border lines serve as a sink for query processing and data caching. HexDD forwards data along boundary lines and toward the center via geographic routing. To address network routing flaws, the authors also present a fault-tolerance technique. HexDD performs better than the other protocols in terms of latency, energy consumption, and data delivery ratio—especially in situations where there are a lot of moving components and routing holes.

Achievements and Limitations: Even in the context of fluctuating network conditions and faulty communication links, HexDD can achieve a high data delivery ratio, low latency, and low energy consumption due to its virtual architecture and fault-tolerance mechanism. The only limitation is that the author assumes sensor nodes have limited mobility.

B. Cluster based Approach

In this approach, the network is divided into multiple sectors known as clusters, as shown in Figure 1 (iii); each cluster employs a high-tier node among the member nodes and is named a Cluster Head. Its mechanism is more complicated than grid type approach, but more optimized network is achieved.

- HCDD: Hierarchical Cluster-based Data Dissemination [25]. It is used to determine Cluster Head (CH), an integrated hierarchical structure for all source nodes is created, similar to GBEER and HPDD. To determine CH, the Max-Min algorithm is incorporated [26]. There is no need to change the position of member nodes to transfer data between nodes and CH.

Achievements and Limitations: One of the crucial advantages of HCDD is that it uses a distributed clustering approach that does not require the position of the member nodes. The overhead associated with the distributed network is significantly large, and if the cluster head nodes' batteries are about to run out, it leads to the failure of the network.

- EEMSRA: Energy Efficient Mobile Sink Routing Algorithm (EEMSRA) [27]. It is another successor of the LEACH [28] protocol; LEACH CH is selected randomly according to the availability of energy in the sensor node. EEMSRA addresses key problem of hotspot by periodically selecting CHs. CH must create a TDMA schedule so that each member node can transmit data in that particular time slot only to avoid a collision. Thus, EEMSRA is a cross-layer protocol synchronized with the MAC layer. In order to provide the network time to adjust routes before the sink arrives at the cluster, the sink announces its next projected cluster visit. Therefore, we can say that EEMSRA employs controlled sink mobility.

Achievements and Limitations: In EEMSRA, all member nodes have to follow a TDMA schedule that results in avoidance of collision. As it incorporated MAC layer scheduling, therefore, it may not support a wide range of devices. It is very successful in addressing the hotspot problem.

- MSRP: Mobile Sink-based Routing Protocol (MSRP) [29]. In MSRP, cluster heads provide data aggregation once it is collected from member nodes. To coordinate the successful transmission of data, the sink and the nearby cluster heads follow a TDMA schedule identical to EEMSRA. Mobility is controlled in this protocol. Achievements and Limitations: The collected data aggregated by the CH can't be retrieved until the sink is closer than a predetermined distance threshold; as a result, MSRP is suitable only for delay-tolerant applications. Furthermore, data from some parts of the network will likely not be accessed because the protocol does not ensure that the sink will reach every cluster head within a set amount of time.

C. Tree Based Approach

In the Tree-based approach, a tree-like structure is formed by overlaying nodes, as shown in Figure 1 (iv). The control hierarchy originates from the root to the leaves. Therefore, we can call a TREE-based network a centrally controlled network.

- **SEAD: Minimum Energy Asynchronous Dissemination to Mobile Sink (SEAD) [30].** In SEAD, Steiner trees are implemented and replicas of intermediate points are selected focusing minimum-cost in terms of energy. Separate trees are implemented for each source, same as TTDD. It also utilizes advertisement of sinks' position and the next sector to be visited so that mobility is transparent to overlaying structures. Therefore, position awareness is necessary in this protocol.
Achievements and Limitations: As the Steiner tree algorithm is implemented in this protocol, it is possible to define the second-tier structure more efficiently in SEAD. Significant overhead is required to define a separate tree for each branch.
- **QDD: Quad-tree Based Data Dissemination (QDD) [31].** Whole network is divided into successive quadrants in QDD, as shown in Figure 1 (v). The center of successive quadrant acts as higher tier node. Until the second-tier nodes accuracy is satisfactory for immediate access to the structure, the quadrants are further subdivided recursively into smaller quadrants. If any member has a query or data is ready to send, it sends it to the center point of that sub-quadrant.
Achievements and Limitations: A minimal amount of overhead is needed to form a quad-tree structure. The hotspot problem is not addressed in this protocol.

D. Area Based Approach

Rather than creating intricate structures, these methods identify the high-tier nodes as those within a defined boundary. Minimum overhead is needed in this type to construct a hierarchy. Rather than altering the structure, the hotspot issue is addressed by specifying an area size that is large enough to distribute and reduce the extra burden on the high-tier nodes.

- **LBDD: Line Based Data Dissemination (LBDD) [32].** In LBDD, the whole network is divided into two parts by a vertical strip defined by the protocol, as shown in Figure 1 (vi). The nodes inside the strip are known as inline nodes. All sensor data is sent to the inline node. The sink then sends a query regarding data, and it is forwarded until the node storing the data is reached.
Achievements and Limitations: The structure is very simple to establish. Because the source nodes and the sink may readily access the line structure; such operations have little overhead. The line must be broad enough to tolerate hotspot problems. Flooding the line will result in a significant increase in the overall energy usage for large networks.

TABLE I: SUMMERY AND COMPARISON OF HIERARCHICAL ROUTING PROTOCOL WITH STRUCTURES

Protocol	Position Awareness	Sink Mobility Pattern	Type of structure	Multi sink support	Structure Accessibility	Data Aggregation
TTTD [21]	Y	R	Rectangular	Y	Easy	Y
CMR [20]	Y	R	Rectangular	Y	Moderate	N
GBEER [22]	Y	R	Rectangular	Y	Moderate	N
HPDD [23]	Y	R	Hexagonal	Y	Moderate	N
HexDD [24]	Y	R	Hexagonal	Y	Moderate	Y
HCDD [25]	N	R	Clusters	N	Hard	N
EEMSRA [27]	Y	C	Clusters	N	Hard	Y
MSRP [29]	Y	C	Clusters	Y	Hard	Y
SEAD [30]	Y	R	Tree	Y	Easy	N
QDD [31]	Y	R	Quad-tree	Y	Moderate	N
LBDD [32]	Y	R	Line	Y	Hard	N
RAILROAD [33]	Y	R	Rail	Y	Moderate	N
RING ROUTING [34]	Y	R	Ring	N	Moderate	N
MGRP [35]	Y	R	Hybrid (Grid & Cluster)	N	Easy	Y
EGRR [36]	Y	P	Grid	N	Moderate	N
EADA [38]	N	P	Hybrid (Grid & Tree)	N	Moderate	Y
Shared Tree [39]	N	R	Hybrid (Cluster & Tree)	Y	Hard	N

- **Railroad: Railroad [33].** The networks arrangement dictates the geometry of the rail, which is a closed loop made of a strip of nodes, as shown in Figure 1 (vii). When a node is ready with the data, it forwards it to a nearby railroad node. The rail segment that is centred on the rail node with the shortest communication range width is known as a station, and it is built by the rail node that receives the meta-data. When a station node is ready with data, the sink requests the rail to share data and notifies the source about its location. The source node is able to send the relevant data straight to the sink.

Achievements and Limitations: By building stations, railroads reduce the requirement for massive broadcasts on the rail structure, giving them an edge against LBDD and facilitating the scaling of the protocol.

- Ring Routing: Ring Routing [34]. This structure incorporates a ring-like circle with a width of one node. The ring encloses a network hub that has been predetermined globally. Using geographic routing to forward packets to the network centre, the sink notifies the ring of its location. Therefore, the sink's current position is always known to ring nodes.

Achievements and Limitations: Ring Routing is an efficient protocol since the ring structure is readily accessible, and the suggested hotspot mitigation approach has a low overhead. Quick data distribution is made possible by the simple and quick acquisition of new sink location data from the ring.

E. Hybrid Approaches

As indicated by name, these types of protocols incorporate two or more structures.

- MGRP: Multi-tier Grid Routing (MGRP) [35]. This type of routing combines cluster and grid-based approaches. Similar to the quad-tree approach of QDD, a recursive quadrature is constructed. Moreover, rather than the centre of each quadrature acting as a data dissemination centre, each quadrant acts as a cluster. A CH is selected randomly based on residual energy and changed periodically to mitigate the hotspot problems.

Achievements and Limitations: As first grid structure is formed and then clusters are constructed, the accessibility of the network becomes easier. However, a huge amount of overhead is associated with the formation of such a complex structure.

- EGRR: Real-Time Routing Protocol Based on Expect Grids (EGRR) [36]. The flooding overhead is minimized in this protocol compared to EAR2 [37]. Data is forwarded across the Expect Grid (EG) built within an Expect Area (EA) by the nearest node in the EA that receives it. The nearest grid crossing point is where the sink gets its data. This technique prevents long-term broadcasts.

Achievements and Limitations: Expect regions and grids together to lessen the sink advertisement broadcasts. The second-tier structure is constantly changed, which results in the minimization of the hotspot problem.

- EADA: Energy Aware Data Aggregation (EADA) [38]. This protocol combines an on-demand data dissemination tree with a grid structure. The node with maximum residual energy performs the role of gateway node. The mobile sink floods the interest zone with data inquiries via gateways restricted on a circle sector. The inquiry is responded to with data aggregated at the gateway node and follows the same route as that of the inquiry.

Achievements and Limitations: By constructing a tree for each inquiry, the load on the grid is increased, which leads to an increase in the overall energy consumption. The hotspot problem is somehow mitigated in this protocol.

- Shared Tree: Shared Tree [39]. A cluster-based infrastructure is arranged using this protocol into a common shared tree. The source nodes send queries to the shared tree root in order to retrieve the topological position of the mobile sink, which the root node receives on a regular basis.

Achievements and Limitations: Although the clustering technique is tedious, the network will require less energy once the clusters are formed because of the shorter routes made possible by the shared tree routing table sharing mechanism. However, the hotspot problem is not mitigated in this protocol.

III. CONCLUSION

Extensive survey of protocols supporting sink mobility in controlled and uncontrolled manner with different routing structure has been done. To provide further insight into the motives and underlying mechanisms, certain challenges encountered by mobile sinks and the design constraints for a mobile sink routing protocol are explored in detail. It is observed that overhead associated with sink mobility has been addressed by some protocols. However, high-tier nodes are still susceptible to hotspot problem. Different structures exhibit different level of susceptibility to hotspot problem.

The network structures like clusters and grid have better accessibility as they exhibit well defined structure throughout the network. However, hotspot problem is an important concern in such a complex network as overhead is huge. By using the root as a message relay node, sink advertisement process is simplified. By dividing the load on the top-tier nodes among several nodes in particular geographic areas, Area- Based techniques lessen the hotspot issue at the trade-off of poor accessibility.

The performance of the current WSN architectures can be significantly improved by mobile sinks; for this reason, creating effective distributed routing solutions is an appealing field of study. In order to direct future researchers, we also included a thorough overview of the outstanding problems and their accompanying difficulties in this study.

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