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# A Review of Atypical Hierarchical Routing Protocols for Wireless Sensor Networks

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***Abstract**: Hierarchical routing in wireless sensor networks (WSNs) is a very important topic that has been attracting the research community in the last decade. Typical hierarchical routing is called clustering routing, in which the network is divided into multiple clusters. Recent advances in wireless sensor networks have led to many new protocols specifically designed for sensor networks where energy awareness is an essential consideration. Some types of atypical hierarchical routing includes chain-based,tree-based,grid-based routing and area-based routing. The most representative atypical hierarchical routing protocols are described, and qualitatively compared. In particular, the advantages and disadvantages of different atypical hierarchical routing protocols are analyzed.*

***Index Terms:** area-based, atypical hierarchical routing, chain-based, grid-based, tree-based, Wireless sensor networks.*

## I. Introduction

Wireless sensor networks(WSNs) consist of small nodes with sensing, computation and wireless communication capabilities. WSNs consist of a large number of low cost, low-power and intelligent sensor nodes and one or more sinks or base stations (BSs) [1], [2]. Those nodes are small in size and can perform many important functions, including event sensing, information processing,and data communication. The sensor sends such collected data, usually via radio transmitter, to a command center (sink) either directly or through a data concentration center (a gateway).As the network scale increases, the scalability of the network becomes a very important issue. WSN creates a local network hierarchy on one or more levels represented by nodes chosen by certain criteria that are aggregating and sending data to a central base station (BS).Most times it is not necessary to identify the exact location of the node and it's ID. Communication is done mostly from node to BS, the BS sends requests to obtain data from nodes. the answer of a particular node is not important, but the area of origin is. All data has to be aggregated by the cluster-head before reaching the BS.

Hierarchical architecture is proved to be an effective solution to the problem of scalability and energy efficiency. In a hierarchical architecture, the network is divided into different layers, and nodes in different layers perform different tasks. The typical hierarchical routing technique is clustering, in which the network is partitioned into multiple clusters and nodes undertake two different tasks,cluster heads (CHs) and ordinary nodes (ONs). An ON only delivers its sensed data to its related CH, while a CH is responsible for collecting the data from its ONs and transferring data to the sink via hierarchical routing.

Recently there arise some atypical hierarchical routings, which are variants of cluster-base routing and present special hierarchical architecture, including chain-based, tree-based, grid-based, and area-based routing. These types of atypical hierarchical routing are similar to the traditional clustering routing, but are more or less different in hierarchy division and communication scheme.In the past few years, an intensive research that addresses the potential of collaboration among sensors in data gathering and processing and in the coordination and management of the sensing activity were conducted. However, sensor nodes are constrained in energy supply and bandwidth. Thus, innovative techniques that eliminate energy inefficiencies that would shorten the lifetime of the network are highly required. Such constraints combined with a typical deployment of large number of sensor nodes pose many challenges to the design and management of WSNs and necessitiate energy-awareness at all layers of the networking protocol stack. Specifically, hierarchical routing protocols have proved to have considerable savings in total energy consumption of the WSN. In hierarchical routing protocols, clusters are created and a head node is assigned to each cluster. The head nodes are the leaders of their groups having responsibilities like collection and aggregation the data from their respective clusters and transmitting the aggregated data to the BS.

## II. Atypical Hierarchical Routing Protocols

**For Wsn**

In this section,analysis of few atypical hierarchical routing protocols of WSNs based on different logical topologies are done.

**A. Chain-Based Hierarchical Routing Protocols**

1) PEGASIS: PEGASIS (power-efficient gathering in sensor information systems) [4] is a pioneering chain-based hierarchical protocol. The main idea in PEGASIS protocol is for node to receive from and transmit to close neighbors and take turns for being the leader for transmission of data to BS. This approach distributes the energy load evenly among the sensor nodes. The nodes randomly placed in the field, organize themselves in the form of chain using greedy algorithm. Alternatively, BS computes this chain and broadcasts it to all the nodeIn PEGASIS, all nodes are organized into a linear chain for data transmission and data aggregation

2) CCS: CCS (concentric clustering scheme) [5] is centralized chain-based routing algorithm in which there exist multiple chains. The goal of CCS is to improve the energy efficiency of PEGASIS. The main idea of CCS is to consider the location of the BS to enhance its performance and to prolong the lifetime of the network. In CCS, the network is divided into a variety of concentric circular tracks which represent different clusters and each circular track is assigned with a level. The track nearest to the BS is assigned with level-1 and the level number increases with the increase of the distance to the BS. Thus, each node in the network is assigned with its own level.

3) EBCRP: EBCRP (energy-balanced chain-cluster routing protocol) is a distributed hierarchical algorithm with chain-cluster topology for WSNs. The routing scheme is based on the idea that each node delivers equal data and only short-distance communication is performed among different nodes. Only neighbor nodes communicate with each other except CHs. The implementation of EBCRP can be partitioned into three phases: 1) chain-cluster formation; 2) cluster-head selection; and 3) steady-state. In the chain-cluster formation stage, the network is divided into multiple rectangular sections which are equivalent to different clusters, and a routing chain is created in each rectangular section by the ladder algorithm instead of the greedy algorithm. Thus, the long-distance communication is removed. In the cluster-head selection stage, several nodes act as CHs and communicate with the BS in rotation. The CH selection is performed according to the residual energy of different nodes.

**B. Tree-Based Hierarchical Routing Protocols**

1) EADAT: EADAT (energy-aware data aggregation tree) [45] is an energy-aware distributed heuristic. The main goal of this algorithm is to tackle the problem of energy shortage by considering energy-aware data-centric routing. Large-scale wireless sensor networks are expected to play an increasingly important role in future civilian and military settings. Collaborative microsensors could be very effective in monitoring their operations. This aggregation tree can be used to facilitate data-centric routing. The main idea is to turn off the radio of all leaf nodes to save power, and thereby extending the network lifetime. Therefore, in order to save the number of broadcasting messages, only the non-leaf nodes in the tree are in charge of data aggregation and traffic relaying. The algorithm is initiated from the sink by broadcasting a control message. The sink is assumed the root node in the aggregation tree. If a sensor node receives a control message for the first time, it sets up its timer which counts down when the channel is idle. The timer is associated with each sensor.

2) BATR: BATR (balanced aggregation tree routing) [7]is a typical tree-based routing algorithm. Its goal is to find an optimal path based on a balanced tree, in which each node consumes the equal amount of energy. It is assumed that the BS is aware of the location information of all nodes in advance by special equipments such as GPS, and performs the task of routing computing. The routing algorithm begins with the BS as the root node, and then creates the relationship of parent and child with other nodes. This algorithm chooses the minimum weighted edge as much as the number of child nodes, and adds the new node to the tree. This means that data will be delivered from the node of the tree to the new node..

3) PEDAP: Power-efficient data gathering and aggregation protocol (PEDAP) [8] is a tree-based routing protocol.PEDAP prolongs the lifetime of the last node in the system while providing a good lifetime for the first node, whereas its power-aware version provides near optimal lifetime for the first node although slightly decreasing the lifetime of the last node. Another advantage of our protocols is they improve the lifetime of the system even if the base station is inside the field, whereas LEACH and PEGASIS cannot.The objective of PEDAP is to maximize

the network lifetime, which is defined by the number transmission rounds. The minimum energy cost tree is uses to data transmission. This tree is constructed by a centralized manner using Prim's minimum spanning tree algorithm. When data transmission is performed, the root of the tree structure acts as the CH. Each node receives data from its child nodes, aggregates the data with its own and delivers it to its parent node.

4) ETR: ETR (enhanced tree routing) [7] is a typical tree-based routing scheme. ETR is an improvement of the tree routing (TR) [8], which is a simple routing protocol for a moderate tree-like network and follows only parent-child links starting from root node to leaf node. ETR was proposed to implement balance between performance and cost. In ETR, it is assumed that each node has an updated neighbour table which has the address of its immediate one-hop neighbours. This neighbour table is important to identify the alternate path to the sink with the number of hops less than the actual path. ETR introduces an important parameter named network depth of a node, which represents the minimum number of hops from the node to the root node using only parent–child links.

**C. Grid-Based Hierarchical Routing Protocols**

1) PANEL: As a grid-based hierarchical algorithm in WSNs, PANEL (position-based aggregator node election protocol) uses the geographical position information of the nodes to determine the aggregators of the nodes. . As its name indicates, PANEL uses the geographical position information of the nodes to determine which of them should be the aggregators. Like other aggregator node election protocols, PANEL also ensures load balancing in the sense that each node is elected aggregator nearly equally frequently. The salient feature of PANEL that makes it novel and different from other aggregator node election protocols is that besides synchronous applications.The most distinctive feature of PANEL is that it can satisfy both synchronous and asynchronous applications. In PANEL, the network is divided into several geographical clusters.

2) TTDD: TTDD (two-tier data dissemination) approach is a grid-based protocol in which there exist multiple mobile sinks. Initially a grid structure is established when the network is divided into multiple cells with several dissemination nodes. Such dissemination nodes are responsible for relaying query message to proper sources.Whenever sinks require specific data, they query the whole network by a flooding manner until such queries are relayed to the source nodes. A source, at one crossing point of the grid, propagates data announcements to reach the other dissemination points by greedy geographical forwarding. When the message arrives at a node that is closest to the crossing point, it stops. This propagation process continues until the message reaches the boundary of the network. All sinks can move from one cell to another and each sink locally floods query messages within the cell to find the nearest agent node of the source. When a sink plants to move out of reach from communication with a primary agent node, it selects an immediate agent node which acts as a bridge between the primary agent node and the sink.

3) HGMR: HGMR (hierarchical geographic multicast routing) is a typical grid-based hierarchical protocol which combines the advantages of two previous locationbased hierarchical protocols, GMR and HRPM . This is location-based multicast protocol. This protocol incorporates the key design concepts of the Geographic Multicast Routing (GMR) and Hierarchical Rendezvous Point Multicast (HRPM) protocols. HGMR decompose the multicast group into subgroup. HGMR apply the local multicast scheme of GMR to forward data packets along multiple branches of the multicast tree in one transmission. In HGMR, the multicast group is divided into subgroups using the mobile geographic hashing: the deployment area is partitioned into a number of equal-sized square sub-domains called cells and each cell comprises a manageably-sized subgroup of members. GMR is used to improve the forwarding efficiency while HRPM is used to reduce the encoding overhead. In HRPM, the whole network is hierarchically partitioned into multiple cells using the mobile geographic hashing idea. Each cell has an Access Point (AP) which manages the location information of the destinations in the corresponding cell.

**D. Area-Based Hierarchical Routing Protocols**

1) LBDD: LBDD (Line-based Data Dissemination) is a typical area-based routing protocol, in which the network is divided into two equal parts by a vertical strip or line of nodes. The nodes on this strip or line are referred to as inline nodes. This line acts as a rendezvous region for data storage and lookup. It assumes that each node knows its geographic location and network geographic boundaries. The core part of this protocol is the concept of a rendezvous region which decouples data dissemination operation. Therein, the vertical line acts as the rendezvous region, and it is located at the center of the sensing field.

2)  VLDD: Virtual Line-based Data Dissemination (VLDD) [61] is proposed to achieve energy-efficient and reliable data transmission. VLDD designs a Virtual Line Structure (VLS) for data storage. The VSL is a specific area for data collection and information delivery. When a source node receives the location information of a mobile sink group, it calculates the entry point of the VLS. If an entry node receives data packets from a source, it delivers the data to its neighbour node of the VLS. Then, the neighbour node transmits the data to its neighbour node of the VLS. Ultimately, the data reach the exist node of the VLS. When a sink in a group wants to obtain data packets from VLS, it sends a query packet toward VLS and follows one of two cases by the flag value, True or False. When a sink has False value in its flag, it means that the LS finished the group region calculation. Then, the sink obtains data packets from the VLS.. To process this case, two steps are performed. In the first step, the sink obtains the current location information of the actual sink group region from the LS agent. In the second step, the sink achieves the location of the new VLS and sends a query to the new VLS.

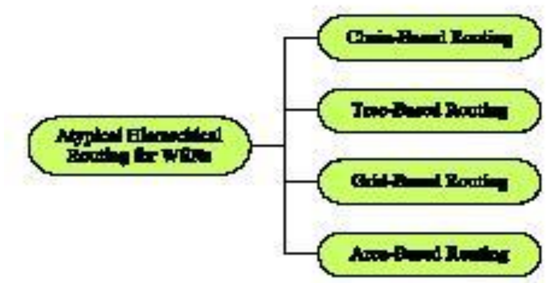

Fig. 1.   Classification of hierarchical routing for WSNs.

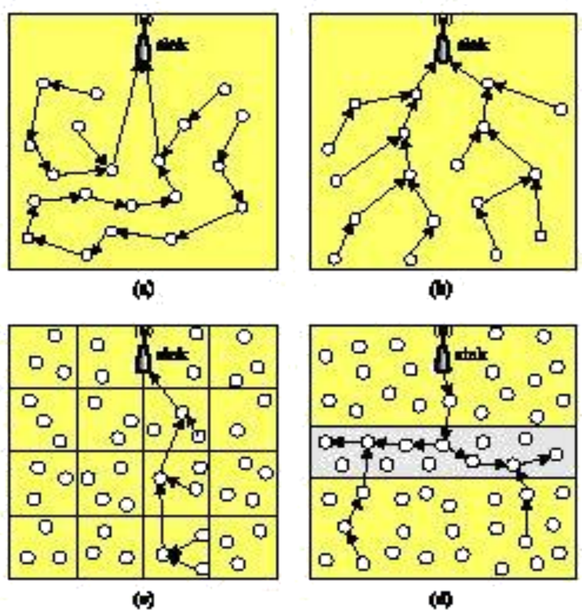

Fig. 2.   Different topologies of atypical hierarchical routing for WSNs (a) Chain-based topology. (b) Tree-based topology. (c) Grid-based topology (d) Area-based topology.

## III. Comparison Of Different Protocols For WSNs

**In this section,the performance of different protocols is compared.**

### A. Comparison of Performance of Chain-Based Hierarchical Routing Protocols

1) Energy Efficiency: Large energy depletion is generated in chain-based routing protocols, including PEGASIS, CCS, and EBCRP due to long-distance communication between the chain leaders to the sink, Thus, these routing protocols suffer from low energy efficiency. CHIRON uses a short-haul and multi-hop data transmission manner, which obviously decreases energy consumption for long-distance communication.

2) Scalability: It is clear that long chain will result in large transmission delay, so chain-based routing protocols suffers from the problem of scalability. Especially, there exist only one chain in PEGASIS, so the problem of scalability of this protocol is very serious.The protocols CCS,EBCRP,CHIRON suffers from large delay caused by too many communication hops, so this kind of topology shows its limitation of scalability.

3) Delivery Delay: In chain-based topology, such as PEGASIS, CCS, and EBCRP, the long chain structure suffers from large transmission delay. However, the chain-based routing protocol CHIRON uses a short-haul and multi-hop data transmission style, which can effectively reduce the chain length and redundant transmission paths, accordingly reduce the transmission delay.

4) Load Balancing: In chain-based routing protocols, including PEGASIS, EBCRP, and CHIRON, although nodes near to the leaders have much more communication load, all nodes act as the leader in turn. This can achieve load balancing to some extent. However, energy expenditure in CCS is not balanced because data delivery uses a relay style and the tracks closer to the BS have more data to relay.

5) Algorithm Complexity: As a chain-based topology, PEGASIS assumes that all nodes achieve global knowledge of node positions to select closest neighbours. This is a complex operation course. Moreover, the data transmission in long chain increases the algorithm complexity. Nevertheless, in CCS, EBCRP, and CHIRON, no global knowledge is needed and data depletion is limited in a smaller area. Accordingly, the algorithm complexity of these protocols is decreased.

6) Implementation Cost: Most routing protocols need low implementation cost. In chain based routing protocols, including PEGASIS,CCS,EBCRP, and CHIRON the implementation cost is low.

### B. Comparison of Performance of Tree-Based Hierarchical Routing Protocols

1) Energy Efficiency: Long-distance transmission doesn't exist in tree-based topology, so the energy efficiency of this topology is improved compared with that of chain-based topology. But the energy expenditure is decreased to some extent in the case of tree-based topology BATR

2) Scalability: This kind of topology shows its limitation of scalability.,since these protocols suffers from large delay caused by too many communication hops.

3) Delivery Delay: Tree-based routing protocols, such as EADAT and BATR, suffer from large delay caused by the long distance data transmission path. In PEDAP, the transmission delay is lessened due to the fact that the tree formation mechanism can reduce the path length.

4) Load Balancing: PEDAP can contribute to load balancing to some extent, due to the residual energy is considered. However, BATR and ETR can't realize real energy consumption balancing, because residual energy of nodes is not taken into account.

5) Algorithm Complexity: In the tree-based protocol of BATR and PEDAP,energy expenditure is decreased to some extent.Clearly the algorithm complexity is increased compared with that of EADAT and ETR.

6) Implementation Cost: Most routing protocols need low implementation cost.But PEDAP exhibits large Implementation cost.

Table 1.Comparison on different protocols for WSN

| PROTOCOL | CLASSIFICATION | ENERGY EFFICIENCY | SCALABILITY | DELIVERY DELAY | LOAD BALANCING | ALGORITHM COMPLEXITY | COST |
|---|---|---|---|---|---|---|---|
| PEGASIS | Chain-based | Very low | Very low | Very Large | Moderate | High | Low |
| CCS | Chain-based | Low | Low | Large | Bad | Moderate | Low |
| EBCRP | Chain-based | Low | Low | Large | Moderate | Moderate | Low |
| CHIRON | Chain-based | Low | Low | Small | Moderate | Moderate | Low |
| EADAT | Tree-based | Low | Low | Large | Moderate | Low | Low |
| BATR | Tree-based | Low | Low | Large | Bad | Moderate | Low |
| PEDAP | Tree-based | Low | Low | Moderate | Good | Moderate | Large |
| ETR | Tree-based | Moderate | Moderate | Moderate | Bad | Low | Low |

## VI. Conclusion

Routing in sensor networks has attracted a lot of attention in the recent years and introduced unique challenges compared to traditional data routing in wired networks. The main objective behind the routing protocol design is to keep sensors alive as much as possible, thus prolonging the lifetime of network. In the past, much effort has been made in designing effective hierarchical routing protocols for WSNs based on different logical topologies.

In this paper, a review of logical topologies and hierarchical routing is provided. Hierarchical routing for WSNs is divided into five categories, including cluster based, chain-based, tree-based, grid-based, and area-based topologies. In this paper,various hierarchical routing protocols for WSNs have been discussed. After that, hierarchical routing protocols for WSNs have been compared according to several performances.

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