Cluster-based Routing Protocols for Heterogeneous Wireless Sensor Networks: A Review

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ABSTRACT—

Wireless Sensor Networks (WSNs) are rapidly emerging in a variety of applications and have become a hot research area. WSNs includes many small sensor nodes that communicate with each other through routing protocols. Primarily, such network's performance depends on the routing protocols that are divided into different categories such as flat routing, cluster-based routing, and location-based routing. Clustering becomes an important branch of routing protocols in WSNs among these groups. Since, it achieves high energy-efficiency and scalability. This protocol can utilize more number of sensor nodes to form the clusters and select the Cluster head (CH) to accumulate the data from the other cluster members. Then, the accumulated data are sent to the Base Station (BS) or another CH through the routing path. This is said to be cluster-based routing protocol. This paper explains the detailed survey on cluster-based routing protocols for WSNs. It also discusses the benefits and disadvantages of WSN clustering-based routing protocols. Eventually, a full review is completed and few approaches are proposed to boost network performance as potential directions.

Keywords—Wireless sensor networks, Sensors, Routing, Clustering, Cluster formation

I. INTRODUCTION

WSNs holds number of wireless sensor nodes which communicate with their environment through wireless channels to collect and transmit necessary environmental information to the BS through a single-hop or multihop transmission [1]. These nodes are usually fitted with a densely distributed battery, processor, memory and radio in the given region for a particular purpose. WSN's emerging applications are military, farming, weather forecasting, monitoring of health care, smart transportation, and home automation. There are two characteristics of the sensor network: homogeneous and heterogeneous WSNs. All sensor nodes are equipped with equal capacity hardware in homogeneous WSN, whereas in heterogeneous WSN only advanced nodes need more hardware. Heterogeneous WSNs are well known and prevalent in real-time applications to extend the life and performance of the network[16]. Efficient routing becomes an essential issue in such networks due to the limitations on the battery, transmission bandwidth and processing ability.

Routing is a process of finding a path from the origin node to the destination node. Most of the recent energy-efficient routing protocols designed for heterogeneous WSNs are focused on clustering techniques for WSNs which are effective in scalability and energy conservation [2-3]. WSN routing protocols are primarily responsible for the creation and maintenance of energy-efficient routes. In addition, they have few features that make them complicated or distinct from traditional routing protocols. Originally, IP dependent routing protocols that is not possible in WSNs, since the IP nodes cannot be delegated to the IP address. Such networks where information from several sensor nodes is sent to the BS are also unique with respect to data flow. In fact, data redundancy in data traffic can be provided by the sources as many sensors can produce the same data in different regions. At last, routing protocols should tackle network barriers such as limited power, bandwidth, and so on.

Different routing protocols are introduced for WSNs with the common goal to accomplish the optimal trade for energy consumption, latency and bit data rate. Routing protocols can be categorized into different types according to the establishment of the routing paths, network topology, protocol functionality, initiator of transmissions and choice of next hop. The network topology based routing protocols are further classified into flat-based, cluster-based and location-based routing protocols. Each sensor node plays equivalent role in the flat-based routing protocol whereas they have different roles in the cluster-based routing protocols. So, cluster-based routing protocols can increase energy consumption and scalability as well as the network life compared to the other types of routing protocols.

A cluster-based routing is an energy-efficient method in which nodes with a high energy level are randomly chosen for processing and transmitting data while nodes with a lower energy level are used to sensing and transmit data to the CHs[15]. This cluster-based routing protocol property gives scalability, maximization of lifetime, and minimization of energy. Such protocols play a key role in achieving specific goals for implementation. Low-Efficiency Adaptive Clustering Hierarchical (LEACH) protocol is the most well-known cluster-based routing protocol that has the advantage of easy implementation and effectively balances network loads [4]. For many subsequent clustering protocols, the basic concept of the LEACH protocol was an encouragement. The main objective of this protocol is to select the sensor nodes as CHs by rotation, thus distributing high-energy dissipation to all sensor nodes in the network when communicating with the BS. LEACH's functionality is divided into rounds where each round is divided into two phases: set-up and steady state. The clusters are configured in the set-up stage, while the data is transmitted to the BS in the steady-state phase. Every node decides whether or not to become a CH for the current round during the set-up phase. This decision is based on the network's estimated percentage of CHs and the number of times the node has so far been a CH. The node choosing a random number between 0 and 1 makes this decision. When a node is successfully selected by CH, it transmits a signal of ads to the other nodes. Other nodes can decide which cluster they will join for this round based on the advertisement's received signal strength and send a membership message to their CH. In addition, CH rotation is performed at each round to distribute energy load evenly among sensor nodes through the generation of a new phase of advertising. Sensor nodes sense the data in the steady-state phase and transmit it to the CH. The CH compresses the data from the nodes belonging to the respective cluster and transmits directly to the BS an aggregated or fused packet.

This protocol also uses a Multiple Access Time-Division (TDMA)/Code-Division Multiple Access (CDMA) to reduce collisions between clusters and intra-clusters. The network re-enters the set-up phase after a certain duration and enters another round of CH selection. It uses single-hop communication, however, and can therefore not be used in large-scale networks. CHs are also selected based on probability; therefore, uniform distribution cannot be guaranteed and load balancing cannot also be achieved. Many clustering-based routing protocols have been developed for WSN over the past decades to optimize the lifespan of the network and reduce energy consumption. This paper discusses various clustering-based routing based on LEACH protocols. It also focuses on the merits and limitations of these protocols and displays them in tabular form.

The rest of the article is organized as follows: Section II presents the survey in WSN on various clustering-based routing protocols. Section III focuses on the merits and limitations of the surveyed protocols in a comparative analysis. Section IV concludes the discussion and suggests the future enhancement.

II. SURVEY ON ENERGY-AWARE ROUTING PROTOCOL FOR WSN

For clustered heterogeneous WSN, Smaragdakis et al. [5] suggested a Stable Election Protocol (SEP). This protocol's main objective was to extend the time interval before the initial node's death. This protocol was based primarily on each node's weighted option probabilities of becoming CH based on the residual energy in each node. Also, by using the characteristic parameters of heterogeneity such as the percentage of advanced nodes

and an additional energy factor between advanced and normal nodes, the stable region of clustering hierarchy process has been improved.

Qing et al. [6] proposed a new heterogeneous WSN system for Distributed Energy-Efficient Clustering (DEEC). In DEEC, the CHs were selected based on the probability based on the ratio between each node's residual energy and the network's average energy. Based on their initial and residual power, the epochs of being CHs for nodes varied. The nodes were chosen as CHs with high initial and residual energy.

Zhou et al. [7] proposed a new model for heterogeneous WSN with energy and computational heterogeneity. The energy dissipation and the optimum number of clusters in these networks were also obtained under a mathematical model that provides guidance for the development of clustering protocols. In addition, a novel energy-efficient protocol has been designed to ensure secure transmission and enhance the LEACH protocol clustering scheme. The CH selection algorithm was performed in this protocol on the basis of an Energy Dissipation Forecast and clustering Management (EDFM) model that takes into account the level of residual energy and energy consumption in all nodes.

Jun et al. [8] proposed a new LEACH-SC (Selective Cluster) routing protocol in WSN. A new method has been used in this protocol to select the CHs, i.e. an ordinary node can select a CH closest to the center point between the node itself and the sink. Once the CHs have been elected, data that includes their node ID as the CH ID and location information to inform non-CH nodes were transmitted and advertised. Then the non-CH nodes recorded all the information from CHs within the transmission range. Then, the node can discover the CH closest to the midpoint between itself and the sink and join the cluster.

Babaee et al. [9] suggested a WSN-based Best Path Cluster Routing (BPCR) protocol which transmits data via the best route rather than the shortest route. This protocol's main objective was to reduce the rate of packet failure and improve energy efficiency in high-traffic networks. In this protocol, by calculating the BPCR value in each node within the network, the best path for data transmission was discovered. The BPCR value has three elements like the rate of arrival, the rate of failure and the rate of recovery.

Haseeb et al. [10] proposed a protocol for Adaptive Energy-aware Cluster-based Routing (AECR) to improve energy conservation and performance in data delivery. Initially, on the basis of node distribution, balanced size clusters were created and random cluster formation was avoided. Then, both inter-and intra-cluster routing paths were optimized to improve the performance of data delivery when balancing data traffic on built forwarding paths. In addition, CH's position between nodes was dynamically shifted by exploiting the network condition to reduce excessive energy consumption and improve load distribution.

Hosen & Cho [11] proposed a protocol for WSN on Energy Centric Cluster Routing (ECCR). The CHs were selected in this protocol based on the higher node ranks. The rank was defined by the residual energy and the member nodes average distance. The CH was acting as the caretaker for CH selection in the next round, where the information of the rank was piggypacked along with the local data transmission during intra-cluster communication, according to the data aggregation and data transmission. As a result, the number of control messages for the selection of CH and the formation of clusters was reduced.

Rhim et al. [12] proposed a Multi-Hop Graph-based Energy-Efficient Routing (MH-GEER) protocol in WSN to distribute a balanced rate of energy consumption between clusters and extend the lifespan of the network. This protocol covered the choice of node clusters and multi-hop routing inter-cluster. The phase of clustering was based on centralized cluster formation and distributed selection of CHs similar to the LEACH protocol. The routing phase was used to build the multi-hop dynamic route between CHs and BS.

Sharma & Bhondekar [13] proposed a Traffic and Energy Aware Routing (TEAR) scheme with enhanced CH selection to enhance the stability period. The nodes in the network were considered with random levels of heterogeneities in energy and traffic. Also, the traffic requirement of the node was considered when selecting the CHs along with its energy levels.

III. COMPARATIVE ANALYSIS

A comparative analysis of the merits and limitations of different cluster-based routing protocols is presented. The Table 1 gives the merits and demerits of the cluster-based routing protocols which are studied in above section.

Table.1 Comparison of Different Cluster-based Routing Protocols for WSNs

Ref. No.	Protocols	Merits	Limitations	Performance Metrics
[4]	LEACH	Reduced inter- and intra-cluster collisions and less delivery delay.	It is not applicable for large scale networks. Also, energy efficiency and scalability were very low.	Number of rounds=1000: Throughput=370kbps; Number of nodes alive=98; Number of packets received from CHs=4.3×10^7; Failure rate=6%
[5]	SEP	High cluster stability and network lifetime.	Energy efficiency was still low and the amount of packets delivered to the BS was less.	Number of rounds=1000: Throughput=400kbps; Number of nodes alive=100; Number of packets received from CHs=6×10^7
[6]	DEEC	Improved network lifetime and reduced delay.	Less cluster stability and the amount of packets delivered to the BS was less.	Number of rounds=1000: Number of nodes alive=100; Number of packets received from CHs=6.5×10^7
[7]	EDFM	Balanced energy consumption and improved network lifetime.	Still, packet delivery ratio was not efficient.	Number of rounds=1000: Number of packets received from CHs=7.3×10^7
[8]	LEACH-SC	Reduced packet failure rate.	The performance was degraded while increasing the network size.	Number of rounds=1000: Failure rate=4%; Number of nodes alive=31
[9]	BPCR	Reduced overall network energy consumption.	The BPCR value was fixed for each node.	Simulation time=200sec: Energy consumption=60J; Number of survival nodes=100
[10]	AECR	Energy efficient and reduced computational overhead.	Packet delivery ratio was still not efficient.	Number of nodes=300: Network lifetime=740sec; Energy consumption=0.175J; Network throughput=76kbps; Network delay=0.055sec
[11]	ECCR	Energy efficient and prolonged network lifetime.	The clusters of ECCR were static and it was not appropriate for large-scale networks.	Number of rounds=1000: Number of CHs=9; Residual energy of nodes=20J; Number of alive nodes=100
[12]	MH-GEER	Efficient load balancing and network permanence.	The other nodes excluding CHs had lowered residual energy while using MH-GEER.	Load balancing=$493.02J^{-1}$; Residual energy=97.68mJ

[13]	TEAR	Better performance in terms of stability period.	Less efficient routing under multi-heterogeneity, high data transmission delay due to high traffic and poor energy balancing in multi-hop data transmission.	Stability period: Mean=1870; Standard deviation=99

IV. CONCLUSION

WSNs have a great deal of interest in civil and defense applications. Such functions include monitoring of atmospheric conditions, battlefield and safety, etc. A huge number of sensors are needed in these applications and therefore require careful infrastructure and network management. Clustering-based routing protocols have been popular methods in WSNs to maintain scalability. In this article, various cluster-based routing protocol's merits and limitations are focused and represented in tabular form. Based on the contrast between different protocols, it is clear that TEAR protocol is useful in enhancing WSN efficiency by considering heterogeneities of both energy and traffic. However, few limitations are addressed such as less effective routing under multi-heterogeneity, high data transmission delay due to high traffic and weak energy balancing in multi-hop data transmission. As a result, it would require further research to solve these TEAR protocol problems and increase the lifetime of the network. In future, an enhancement of TEAR protocol could propose by considering coverage region including energy and traffic to provide more realistic routing in heterogeneous WSN scenarios. Also, a data aggregation method could propose to reduce the amount of network traffic. As well, energy-harvesting aided nodes would deploy to adjust the transmission power and thus energy efficiency increases in multihop transmission.

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