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Energy-Efficient Clustering and Routing Protocols in Wireless Sensor Network: A Survey

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***Abstract*—**Wireless Sensor Network (WSN) has increased the interest of researchers in several challenging characteristics. The most vital challenge in these networks is energy minimization. One of the most accepted solutions in constructing the energy-efficient WSN is to cluster the networks. In clustering, the nodes are split into some clusters and few nodes are elected to be cluster heads. In a clustered WSN, the normal nodes can transmit their sensed data to the cluster head. Then, the cluster head can aggregate and transmit those data to the base station. Typically, clustering involves different merits such as scalability, energy-efficiency and minimizing routing delay. In this article, a detailed comparative survey on energy-efficient clustering and routing protocols in WSN is presented. At first, energy-efficient clustering and routing protocols proposed for WSN in previous researches are studied in detail. After that, a comparative and state-of-the-art analysis is carried out to identify the limitations in those protocols and suggest a novel improvement on clustering and routing protocol with increased network lifetime and reduced energy consumption.

***Keywords*—**WSN, Clustering, Routing protocol, Cluster head, Data aggregation

I. INTRODUCTION

WSN is a network that consists of many sensor nodes that are equipped with a limited battery. Each sensor node can collect and process the sensed data by transmitting it to the sink nodes based on the multihop communication manner. These networks are used in different applications such as tracking and monitoring. Normally, WSN is distributed in harsh surroundings with limited access to individuals. Thus, WSN must operate in a self-configured and autonomous mode with the ability for constructing a network in an ad-hoc manner. There is a need for a design in which the transmission to a base station is as low as possible and all the decisions are made at the node level since WSN is energy-constrained and data transmission consumes high energy.

Clustering the nodes is a well-known two-layered method that splits the network into two layers and the nodes positioned in similar layer are assembled into the same clusters [1]. Among those nodes, few are selected to be the head of each cluster called cluster head for efficiently distributing the management processes among the nodes. Since a huge amount of data provided by the nodes in WSN is analogous, the clustering uses the correlation among the data and aggregates them to reduce the network load and energy consumption [2]. Typically, the cluster head has the responsibility of collecting the data from normal nodes and aggregating and transmitting them to the base station. Also, it has different advantages such as high scalability, robustness and less energy consumption, network load [3].

One of the most important clustering and routing protocols is Low Energy Adaptive Clustering Hierarchy (LEACH) [4]. The major objective of this protocol is to rotate the cluster head among all the nodes for balancing the network load. Over the past decades, several clustering routing approaches have been proposed for WSN in which power management is the fundamental objective. These clustering routing protocols are normally split into three steps such as cluster formation, cluster head selection and data transmission. The major aim of each protocol is selecting the cluster head with reduced energy consumption of the network. In this article, a comprehensive and state-of-the-art survey on the energy-efficient clustering and routing protocols in WSN is presented. Initially, the most significant protocols proposed in previous researches are reviewed in detail. Then, the advantages and the shortcomings of each protocol are discussed in such a way their limitations encouraged to further improve on those protocols.

The remaining article is structured as follows: Section II presents the previous energy-efficient clustering and routing protocols for WSN in detail. Section III discusses their advantages and disadvantages. Section IV concludes the

review and suggests improvements in clustering and routing protocols.

II. SURVEY ON ENERGY EFFICIENT CLUSTERING AND ROUTING PROTOCOLS

Improved LEACH routing protocol [5] was proposed for enhancing the conventional LEACH protocol. In this protocol, the cluster head selection was modified by considering the dynamic change of the node's energy and so the frequent re-clustering was reduced. Temporarily, a vice cluster head was established for each cluster during the communication process that has the objective of reducing the energy consumption for re-clustering and prolonging the network lifetime.

An Energy-Balancing unequal Clustering Approach for Gradient-based routing (EBCAG) was proposed [6] to balance the energy consumption of cluster heads. In this protocol, the nodes were partitioned into the clusters of unequal size and a gradient value i.e., node's minimum hop count to the sink was maintained by each sensor. The size of clusters was decided by the gradient value of its cluster head and the data collected from the cluster members must pursue the direction of descending gradient to reach the sink.

Constructing Optimal Clustering Architecture (COCA) was proposed [7] in which the easy-to-deploy unit-based network framework was applied. Based on this, an optimal number of units was obtained to minimize the total energy consumption of all sensor nodes. After that, an iterative algorithm was proposed to determine the number of clusters within each unit. Additionally, the energy holes in the network were mitigated by designing an effective energy-aware head rotation and inter-communication routing protocols.

A Stable Energy Efficient Clustering Protocol (SEECP) [8] was proposed to balance the load among nodes by using energy-aware heuristics. The major aim of this protocol was selecting the cluster head in a deterministic manner and providing full network coverage with a balanced load among nodes. In this protocol, a predetermined number of cluster heads were chosen based on the node's residual energy. Also, the energy dissipation of cluster heads was decreased by a threshold-based inter-cluster data transmission algorithm. Moreover, numerical computations were performed to select an optimal radius around the base station for dual-hop communication that reduces the energy consumption of distant cluster heads.

An Energy-Efficient Heterogeneous Ring Clustering (E2HRC) routing protocol [9] was proposed to solve the energy balance problem in WSN. In this protocol, nodes were split into different levels according to the different locations and also several ring domains were split based on different levels that reduce the energy consumption by transmitting and receiving data packets. Then, a clustering algorithm was proposed in which the clustering probability model was used for splitting the network into different sized heterogeneous clusters according to the node residual energy and relative node location in the cluster. Also, a cluster head rotation mechanism was applied to avoid energy holes creation in the network.

A novel Energy-Aware Clustering and Routing Protocol (EA-CRP) was proposed [10] for aggregating the data in WSN. The main objective of this protocol was to diminish the energy consumption among all the nodes. In this protocol, a novel multilayered framework was employed that splits the network into the number of layers. Also, a multihop routing algorithm was proposed for inter-cluster communications based on the tradeoff between distance and energy of relaying nodes.

A Modified Threshold-based CHR (MT-CHR) protocol [11] was proposed in which a new probability of being a cluster head for any node was computed. Also, a novel expression for threshold energy was proposed that delays the first node die-out and avoids any data loss in the network. Centralized Density and Threshold-Based Cluster Head Replacement with Adaptive Data Distribution (C-DTB-CHR-ADD) protocols were proposed [12] to optimize the energy consumption by minimizing the number of re-clustering processes, preventing the cluster head nodes early die-out, deactivating few nodes placed at the dense regions from cluster's participation and decreasing long-distance communications. In this protocol, nodes in the dense clusters were assigned into the sleeping mode according to the specific node active probability. Also, the base station was concerned about setting up the required clusters and informed the sensor nodes with their respective active probability.

To distribute the energy consumption between nodes, a new density-based relaying protocol [13] was proposed in which the network field was partitioned into equally-sized layers where each layer was divided into equal clusters. Then, a density-based algorithm was proposed that considers the number of nodes in each cluster. Moreover, an energy-aware relaying algorithm was proposed that utilizes a free space channel propagation model to select the relay nodes according to their energy and locations among others.

A Balanced Power-Aware Clustering and Routing Protocol (BPA-CRP) was proposed [14] in which four broadcast ranges were assigned for each node. In this protocol, the network field was split into equal-sized layers and clusters. The clustering algorithm was used to facilitate any cluster for processing multiple rounds without any requirement for set-up overhead. Also, a routing algorithm was introduced in which the forwarder node has the ability to relay the collected data from the layer towards the base station and the

exhausted nodes which act as cluster heads or forwarders were prevented by using the "Only Normal" operation mode. Further, appropriate node death-handling rules were designed to ensure that each node dies efficiently without any data loss.

III. RESULTS AND DISCUSSIONS

In this section, a comparative analysis of the merits and demerits of different energy-efficient clustering and routing protocols whose functional information is discussed in the above section is presented. Table 1 shows the merits and demerits of the above mentioned energy-efficient clustering and routing protocols in WSN.

Table 1. Comparison of different clustering and routing protocols in WSN

Ref. No.	Protocol	Merits	Demerits	Performance Metrics
[5]	Improved LEACH	Frequent re-clustering is reduced.	The amount of messages created by this protocol was high.	Number of rounds=30: Consume energy=200 Time=500sec: Number of nodes alive=72
[6]	EBCAG protocol	Minimum energy consumption of the network.	This protocol was based on WSN with uniform distribution which is practically not feasible.	Number of nodes=800: Network lifetime=24 (rounds until 5% of nodes die) Number of rounds=400: Number of nodes alive=100
[7]	COCA	Simple and minimized energy consumption.	The decision of the cluster head rotation frequency was difficult and the computational complexity was high.	Network size=$12\times10^4 m^2$: Network lifetime=3000round
[8]	SEECP	Better performance in terms of load balancing, energy efficiency and stability period.	The mobility of nodes, cluster heads and the base station are not considered which may degrade the network performance.	Number of rounds=500: Energy variance=0, Number of nodes alive=100, Average energy=0.05
[9]	E2HRC routing protocol	Better average energy consumption.	The network lifetime was not efficiently increased.	Number of nodes=30: Packet loss ratio=0.79, Average power consumption=1.08mW
[10]	EA-CRP	Reduced communication overhead.	The network lifetime was not efficiently analyzed.	Number of rounds=180: Number of nodes alive=142 Initial energy for each node=2J: Round until the last node dies=1800
[11]	MT-CHR	Improved network functionality abilities	The network lifetime was not efficiently increased.	Network dimension=400: Network utilization=62%, Network lifetime=530rounds Number of rounds=600: Number of nodes alive=70
[12]	C-DTB-CHR-ADD	Significant improvement in network lifetime.	Each node should dependent on the threshold probability to decide whether it will act as a cluster head or not.	Number of rounds=1000: Number of nodes alive=100 Network dimension=400 m: Network lifetime=960rounds, Network utilization=64.5 %
[13]	New density-based relaying protocol	Reduced long-distance communication between nodes.	The performance was not effective.	Number of rounds=600: Number of nodes alive=96,
[14]	BPA-CRP	Increased network lifetime.	The selection of the forwarder nodes was only based on its energy and the number of measurements during data aggregation was high.	Number of rounds=700: Number of nodes alive=25 Initial energy for each node=3J: Network lifetime=4500rounds

IV. CONCLUSION AND FUTURE SCOPE

In this article, a detailed comparative survey on energy-efficient clustering and routing protocols in WSN is presented. Through this comparative analysis, it is noticed that the previous protocols have the objective of minimizing the energy consumption of sensor nodes by clustering the

network efficiently. Among those protocols, BPA-CRP has better performance in terms of energy efficiency and network lifetime than all other protocols. Even though, few limitations are observed in this protocol. Therefore, the future extension of this study could be focused on the further enhancement on BPA-CRP by using Quality-of-Service (QoS)-aware clustering and improved data aggregation schemes to achieve higher energy conservation and network lifetime in WSN.

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