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A Survey of Energy Efficient Routing Protocols in Wireless Sensor Network

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Abstract: *Wireless Sensor Networks (WSNs) have emerged as a prominent technology in various applications, including environmental monitoring, healthcare, and industrial automation. Energy efficient and reliable data routing is a fundamental challenge in WSNs due to the limited resources, energy constraints, and dynamic network conditions. This research paper presents a comprehensive survey of routing protocols in wireless sensor networks. Furthermore, the survey explores the strengths and weaknesses of different routing protocols, considering various factors such as network size, energy efficiency, scalability, and fault tolerance. It discusses the trade-offs involved in selecting a routing protocol and the impact of network dynamics on their performance. In this paper, the energy efficient routing protocols are surveyed with respect to their key features, and they are compared with each other. Challenging research issues of designing RL-based routing algorithms in WSNs are also discussed.*

Keywords: Wireless sensor network, Routing protocol, Reinforcement learning, Energy Efficiency.

Introduction

These days, wireless sensor networks can be thought of as one of the most broadly involved strategies for gathering and examining ecological data. Because of the energy restrictions of the sensor nodes in these networks, involving an ideal technique for steering and controlling wireless sensor networks can be compelling in expanding energy productivity and organization lifetime [1]. WSN has been seen as joining and correspondence between shrewd articles (things). Such sensors and actuators (for instance, home machines, surveillance cameras and sensors for natural observing) are normally fitted with different sorts of handsets, microcontroller gadgets, and conventions for correspondence of control and sensor data [1]. Such ongoing modules like sensors, are interconnected with each other to send detected data to the concentrated storehouses, in which the data is aggregately put away and open for clients with the option to get to.

Wireless sensor network is a famous region for research these days, because of huge possible utilization of sensor networks in various regions. Regularly, wireless sensor networks contain hundreds or thousands of these sensor nodes that are for the most part indistinguishable. These sensor nodes can impart either among one another or straightforwardly to a base station (BS) as displayed in figure 1. The sensor network is exceptionally circulated and the nodes are lightweight.

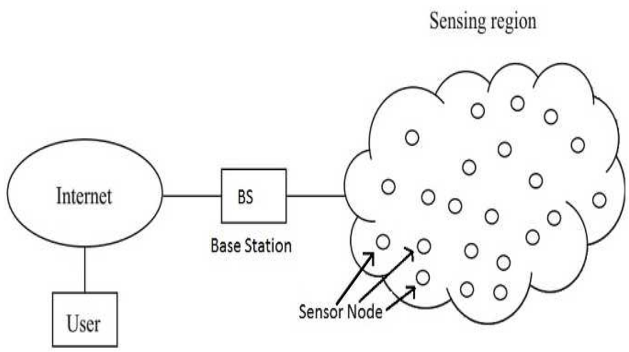

Fig. 1: Wireless Sensor Network.

II Architecture of WSN

Wireless Sensor Networks (WSNs) are self-coordinating networks that help multi-jump correspondence all through the organization. It is characterized as "a bunch of scattered portable sensor nodes utilized for noticing and recording the outer variables present in the climate and sorting out the accumulated data at a focal position" (Zhu and Wei, 2017). These networks are planned utilizing little equipment gadgets known as the bits or the wireless sensor nodes. The design of a sensor node is displayed in figure 2. The sensor node detects the powerful climate where it is sent, and accumulates the data for various applications, for example, modern observing, natural life fire following, agrarian checking, and protection framework. This data detected by the sensor node present in a particular group is in the crude configuration. This data is passed to the group head (nearby aggregator) to save the energy across the organization and is then sent to the base station. Base station processes the accumulated data and concentrates valuable data which is liberated from clamor and blunders. The base station at long last imparts this data to the distant areas by utilizing a web door. Sensors expect energy to play out its activity in the organization; this energy is given by the energy unit. Energy unit comprises of an energy source and energy reaping system. Energy source can be in any structure like electric or sun powered energy.

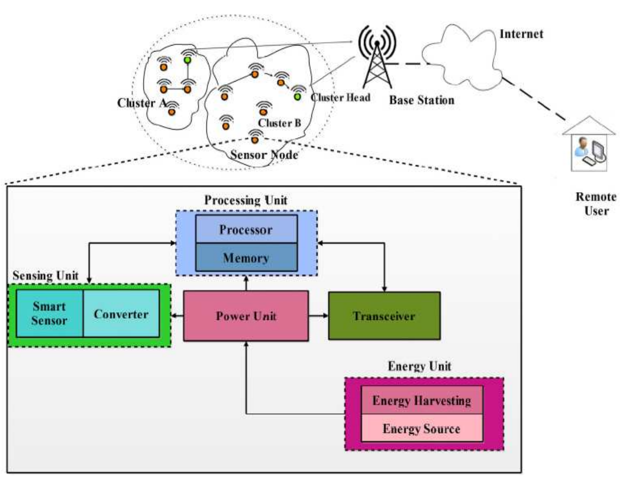

Fig. 2: Architecture of WSN

This energy is implanted in the sensor as battery. Energy collecting approach deals with the energy to further develop network execution where ordinary wellsprings of energy can't be utilized. The battery goes about as a power unit associated with the detecting unit, handling unit and handset. Detecting unit comprises of a shrewd sensor and converter. A shrewd sensor decides or faculties the contribution from the unfavorable climate. This info can be as strain, heat, speed increase, light. At greatest times, the information is as a simple sign. This simple sign is switched over completely to a computerized associated with the handling unit. Detecting unit send the data about the detected data to the handling unit for additional handling. The handling unit is partitioned into two sections: processor and memory. Processor centers around the execution of a guidance. Memory is associated with the processor and stores the outcome as well as the guidance data. There is an association between handling unit and handset. The handled data is passed to the handset for transmission. The handset is utilized for transmission of detected contribution to its adjoining node. 3.

III Routing in WSN

WSNs have a great potential for process, manufacturing and industrial applications, although it has several challenges. For example, during excessive data transmission especially in data gathering applications, some nodes deplete their energy before other nodes leading to the creation of routing holes that disconnect some nodes from the others; and thus, lose the coverage of significant part of ROI. Manual fixing is impossible in many applications; thus, various researches are made for detecting holes and their causes and their impact on network performance while providing solutions. The main factors affecting network efficiency of WSNs can be summarized in the following:

- The limited sensor node energy.
- The long duration of sensor operation.
- The many-to-one traffic flow due to centric data collection process to the sink or BS.
- The environmental factors or the nature of the monitored environment such as forest or battlefield.
- The random deployment of sensor nodes in many applications.

Sensor networks can be deployed in a variety of ways according to the application environment. For example in environmental applications, especially forest fire detection, and volcanic events, the inspected area is vast and perilous for human involvement. Other similar examples, such applications include tracking the enemy movements in a battlefield or in detecting the impact of various dynamics of glaciers on global warming. However, in other applications where the inspected area is safe, like habitat, healthcare and most of the industrial applications, the nodes are deployed manually in predetermined locations. Moreover, typically human interference in wireless sensor network field is difficult after the deployment stage. Therefore, sensor networks are expected to operate for an extended period of time without being attended by individuals. The same network protocol may perform differently under different frequency allocations moving to a higher frequency region will cause more attenuation to the desired signal while minimizing interference, possibly boosting the overall performance. On the other hand, propagation delay and packet duration are effective, since a channel that is sensed to be free may nonetheless contain interfering packets. And packet length probably affects collision rate and the efficiency of re-transmission (throughput). Finally, power control and intelligent routing can greatly help in limiting interference and maximizing network lifetime [16].

IV Energy Efficiency Routing

A number of factors may influence how energy-efficient sensor networks are, including its structure, the data aggregating mechanisms, and the used routing protocols. The current study describes the effect of each factor on the network's energy efficiency in such a case.

Energy Efficiency- This concept could be formally defined as the functionality of sensor networks which extend for the longest time possible. Within ideal data aggregating schemes, all sensors need to have expended the same amount of energy in each data gathering round. A data aggregation scheme is energy efficient if it maximizes the functionality of the network. Assuming that all sensors are equally important, the energy consumption of each sensor should be minimized. This idea is captured by the network lifetime which quantifies the energy efficiency of the network [1, 3].

There are a number of crucial factors to measure the performances of data aggregating algorithms, such as the life span of networks, data accuracy and latency. Taking into consideration that these measures are defined differently according to their applications, these concepts can be formally defined as follows:

Network lifetime- It is a certain number specified by system designers. To exemplify, whenever the application is determined by the time of node cooperation, the life time is described as the number of rounds performed before draining the energy of the 1st sensor [4].

Data accuracy- This concept is defined according to the particular applications that the sensor networks are designed for [4].

Latency- It is the delay that occurs in terms of transmitting data, routing, and aggregating data. Its measurements take form of the time delay that takes place between receiving data packets at the sink and generating data at source nodes [4].

V Classification of Existing WSN Routing Protocols

In the past, wireless sensor network control and routing protocols have been based on static approaches. Figure 3 shows the general classification of these methods. In many applications of wireless sensor networks, it is not possible to assign a global identifier to each node due to their large numbers. However, sensor nodes are usually randomly distributed in the environment. This process makes it difficult to select some specified nodes in order to send them dedicated commands or to communicate with them privately. Routing protocols can use data aggregation and routing based on aggregation results to improve network performance and save energy. This approach called data-centric protocols sends a query to some desired area and waits for the response data to be received. By contrast, hierarchical protocols use clustering techniques. The main purpose of hierarchical routing is to conserve the energy of sensor nodes by engaging them in an intra group communication and performing aggregation to reduce the number of transmitted messages to the source node.

Often, location information is needed to calculate the distance between two specific nodes in order to estimate energy consumption. Because addressing procedures, such as IP, do not exist for sensor networks, spatial information can be used to route them. In another approach called location-based protocols, data can be sent to a specific location, reducing the number of data transfers significantly to reduce energy consumption. This method also supports dynamic network topology.

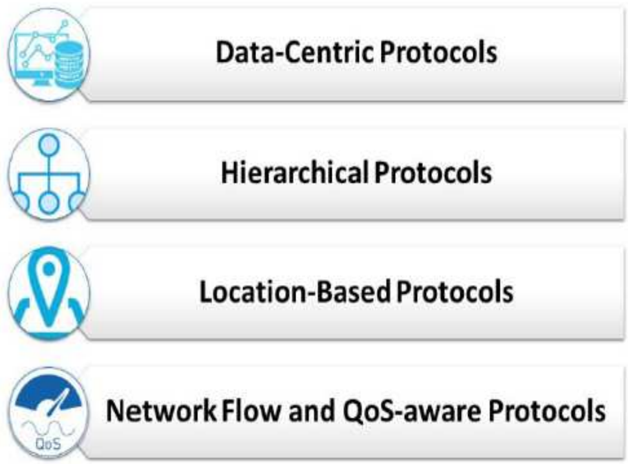

Fig. 3: Classification of existing wireless sensor network routing protocols

Some of the previously reported routing protocols are aware of network flow and QoS. These protocols, while adjusting routes on the sensor network, take into account the delay requirements in the end-to-end transmission process. Routing methods in wireless sensor networks also underwent many changes when the approach of using artificial neural networks and deep learning emerged in the world.

VI LEACH Protocol

Combined with the limited energy of sensor nodes, many effective algorithms have been designed, among which, the most classical one is the low energy adaptive cluster hierarchical protocol (LEACH). The idea of this algorithm was to select cluster head nodes randomly in a cyclic way, it's shown in figure 4. The cluster head nodes collected data from member nodes and sent them to the base station. In that way, the energy consumption can be evenly distributed to each node of the network [11].

LEACH routing protocol was a low power adaptive clustering routing algorithm designed by Heinzelman (MIT, Department of Electronics and Computing) for WSN in 2000. The concept of "wheel" was introduced into the working process of LEACH protocol. Each round was divided into three phases: cluster head selecting phase, clustering phase and stable communicating phase. In the cluster head selecting phase, all nodes ran for cluster head nodes in a specific method.

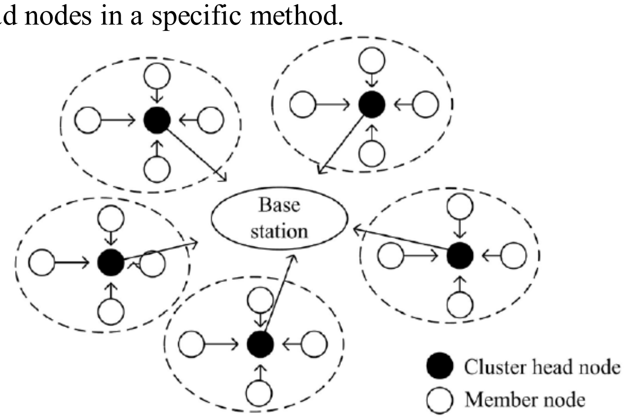

Fig. 4: Clustering diagram of LEACH protocol.

The unselected nodes chose a appropriate cluster head to participate in the cluster a in the clustering phase. In the stable communicating phase, the member nodes transmitted data to the cluster heads. The cluster heads then sent them to the base station. Cluster head selecting phase and clustering phase were the core parts of the LEACH protocol. The details are described as follows:

- Each node generated a random number between [0] and 1.
- Each node got a threshold T(i) according to the following formula, which we can get in [7].

$$T(i)=\begin{cases}\dfrac{P}{1-P\times\left[r \bmod\left(\dfrac{1}{P}\right)\right]} & i\in G\\ 0 & \text{otherwise}\end{cases}$$

Where, P was the percentage of cluster heads in all nodes, r was round, G was the set of nodes that had not been selected as cluster head.

- The nodes whose random number was less than the threshold were selected as cluster heads and sent the massages to other nodes. Remarkably, those selected nodes could not be cluster heads in the after rounds.
- The unselected nodes chose a cluster head according to the strength of the received information to participate in the cluster.
- The cluster heads generated a time division multiple access (TDMA), and sent them to their member nodes.
- Member nodes collected the around data then sent to their cluster heads on the basis of TDMA.
- The cluster heads fused the data and then sent them to the base station [12].

In the LEACH protocol, the balanced distribution of the load in the network saved the energy consumption caused by communication. The method of being cluster head circularly could distribute the load to different nodes in turn. It could also prolong the system lifetime. Cluster heads fused the data from member nodes reduced the amount of data. However, there were still some shortcomings in LEACH protocol. Scholars had put forward different improvement methods for different problems. In LEACH protocol, no matter how far the cluster head was from the base station, it was necessary to send the data directly to the base station. The energy consumption for data transmission showed exponential relationship with the distance. When the distance was over a certain level, the energy consumption would increase sharply. The author in [13] took an improvement by selecting a sub-cluster head in each cluster. It allowed the cluster head far away from the base station to transmit data by multi-hops through the sub-cluster head, so as to reduce energy consumption for long distance transmission. In [14], a self-guided adaptive clustering method was proposed to prolong the lifetime of network by allowing or prohibiting nodes to participate in the clustering phase. Some nodes in dense clusters were allowed to enter dormant mode. It could reduce the communication with cluster heads. Thus, it prolonged the network lifetime. This paper introduced an improved algorithm, optimized clustering LEACH protocol based on energy and distance of cluster head (O LEACH). The algorithm took two steps to improve the LEACH. Firstly, optimize the cluster head selecting to prolong the stability period. Then optimize the clustering phase to average energy consumption among clusters.

VII FUZZY Logic Based Routing in WSNS

Fuzzy logic has been used to deal with many real-world problems. Fuzzy logic allows us to measure uncertainty defined by linguistic variables and presented in the form of multi-valued logic between 0 and 1. Fuzzy systems have the ability to make decisions based on conclusions drawn from fuzzy rule base which consists of fuzzifier, inference engine, fuzzy rule base and defuzzifier. A set of fuzzy rules are defined in the form of propositions in Fuzzy rule base that contains linguistic variables representing words or sentences.

Fuzzy input is mapped to the fuzzy output by the inference engine on the basis of fuzzy rule base. The linguistic fuzzy rules can be defined to represent the dynamic nature of the system as given by the human experts. Fuzzy logic is suitable for formulating the multi-objective function for routing in WSNs [13].

Fuzzy logic is a computational paradigm that deals with uncertainty and imprecision by using linguistic variables and fuzzy rules. Fuzzy logic has been applied to various domains, including routing in wireless sensor networks (WSNs). Fuzzy logic-based routing algorithms aim to make routing decisions based on imprecise and uncertain network conditions.

In the context of WSNs, fuzzy logic-based routing algorithms can consider multiple factors and make routing decisions based on the linguistic variables defined in the system. Here is a general overview of how fuzzy logic can be applied to routing in WSNs:

Define linguistic variables: Linguistic variables are used to represent network parameters or metrics in a linguistic form. For example, variables like "battery level," "network congestion," or "link quality" can be represented using linguistic terms such as "low," "medium," or "high." These linguistic variables and terms help capture the imprecision and uncertainty associated with network conditions.

Define fuzzy rules: Fuzzy rules map the input variables (e.g., network parameters) to output variables (e.g., routing decisions). These rules encode the knowledge and heuristics required to make routing decisions. For example, a fuzzy rule could state: "IF battery level is low AND network congestion is high, THEN select a longer but energy-efficient route."

Fuzzification: Fuzzification involves converting crisp input values into fuzzy values based on the linguistic terms defined in Step 1. This process assigns membership degrees to linguistic terms based on the degree of similarity between the input values and the linguistic terms.

Fuzzy inference: Fuzzy inference applies the fuzzy rules to the fuzzy input values to obtain fuzzy output values. This step involves evaluating the antecedents (IF parts) of the fuzzy rules and combining their consequences (THEN parts) using fuzzy logic operators.

Defuzzification: Defuzzification converts the fuzzy output values into crisp output values. This step involves aggregating and summarizing the fuzzy output values to obtain a single, crisp routing decision.

Fuzzy logic-based routing algorithms in WSNs can consider various network parameters, such as energy levels, link quality, congestion, and distance, to make intelligent routing decisions. By using linguistic variables and fuzzy rules, these algorithms can handle uncertainties and imprecision's associated with network conditions, adapt to changing environments, and optimize routing paths based on different objectives, such as energy efficiency, latency, or reliability.

VIII RL Based Routing in WSNs

Reinforcement Learning (RL) is an unsupervised learning technique which is a type of machine learning. Q-learning is a kind of RL that has been successfully applied by the researchers to deal with various routing issues in WSNs. Q-learning finds an optimal solution based on the value of function Q(s, a) known as Q-value, where 'a' represents some action taken by agent at state's' then reward 'r' is received by the agents from the environment representing the quality of action 'a' at state's'. it is an iterative process and reward 'r' is used to update the Qvalue and evaluates the next state and reward. The process continues to learn the environment till it finds optimal solution [13].

Reinforcement learning is one of the learning methods used in this field. Based on Markov's decision process [16], it tries to assign a suitable amount of reward (or punishment) to each agent by considering a reward for each action, so that the agent learns what to do in each state in order to maximize the total accumulated reward [17], [18]. With this method, there is a parameter, called the discount factor that has a value between zero and one indicating that the reward of current stages should always affect the calculation of total reward more than the reward of expected future stages [19]. This can be expressed by Equation 2

$$R_t = r_{t+1} + \gamma r_{t+2} + \gamma^2 r_{t+3} + \gamma^3 r_{t+4} + \cdots = \sum_{i=t}^{\infty} \gamma^{i-t} r_{i+1}$$

Where, R_t is the amount of the received reward from time t based on future rewards. r_t+1 indicates the received reward at time t+1 and γ is the discount factor. A typical Reinforcement Learning (RL) framework scenario is shown in figure 5.

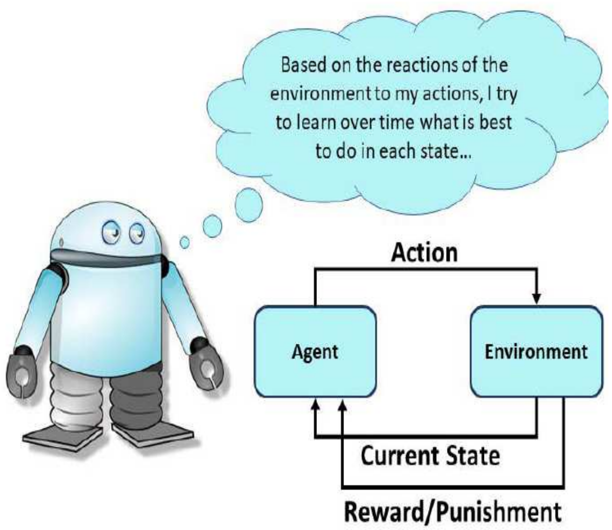

Fig. 5: A typical Reinforcement Learning (RL) scenario

IX SWARM INTELLIGENCE BASED ROUTING IN WSNs

Swarm Intelligence (SI) is a kind of meta-heuristic method used by the researchers to find the optimal solutions for various real-world optimization problems successfully. SI techniques are inspired by the adaptation of collective behavior exhibit by the societies in nature such as birds, fish, honeybees and ants. SI systems are composed of population of agents and decentralized and self-configuration in nature. These agents interact with each other and with the environment to solve the complex problem efficiently. The popular SI techniques that have been applied for routing optimization in WSN include Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), Bacterial Foraging Optimization (BFO), and Artificial Bee Colony (ABC) [13].

Swarm Intelligence (SI) is a collective behavior observed in social insects such as ants, bees, and termites, where individuals coordinate their actions to achieve a common goal. This concept has been applied to various fields, including computer science and wireless sensor networks (WSNs).

Routing in WSNs refers to the process of establishing paths for data to be transmitted from source nodes to destination nodes. Traditional routing protocols in WSNs, such as the Ad-hoc On-demand Distance Vector (AODV) or the Dynamic Source Routing (DSR), may suffer from limitations like high energy consumption, inefficient path selection, and poor adaptability to dynamic network conditions.

To address these issues, researchers have explored the use of swarm intelligence-based routing algorithms in WSNs. These algorithms mimic the behavior of social insects to achieve efficient and robust routing. Some popular SI-based routing algorithms in WSNs include Ant Colony Optimization (ACO), Particle Swarm Optimization (PSO), and Bee-inspired algorithms.
Ant Colony Optimization (ACO): ACO algorithms are inspired by the foraging behavior of ants. Ants deposit pheromone trails as they explore their environment, and other ants use these trails to guide their movement. In the context of WSNs, ACO algorithms can be used to discover and reinforce optimal paths between sensor nodes. The pheromone trails can represent the quality of a route, and the nodes can update and follow these trails to find efficient paths.
Particle Swarm Optimization (PSO): PSO algorithms are inspired by the collective movement of bird flocks or fish schools. Each particle in the swarm represents a potential solution, and the particles iteratively adjust their positions based on their own best position and the best position found by the swarm. In the context of WSNs, PSO algorithms can be used to optimize the selection of routes based on various metrics, such as energy efficiency or end-to-end delay.
Bee-inspired algorithms: Bee-inspired algorithms are based on the behavior of honeybees in searching for nectar sources. Honeybees communicate with each other through "waggle dances" to convey information about the location and quality of food sources. In the context of WSNs, bee-inspired algorithms can be used to establish and update routes by exchanging information between nodes, similar to the waggle dances of honeybees.
These SI-based routing algorithms offer advantages in terms of adaptability, robustness, and energy efficiency in WSNs. By leveraging the collective intelligence of the swarm, these algorithms can dynamically adjust routing paths based on the changing network conditions, optimize resource usage, and extend the network's lifetime.
However, it is important to note that the performance of SI-based routing algorithms in WSNs can be affected by various factors, such as the size and density of the network, the type of application, and the specific routing requirements. Therefore, it is essential to carefully design and tune these algorithms to suit the characteristics of the WSN and the specific application domain.

X Conclusions

It is a proven fact that Wireless Sensor Networks are different from traditional networks in various aspects that demand the development of suitable communication protocols, localization techniques, data aggregation methods, scheduling mechanisms, security, fault detection, and data integrity. Machine Learning techniques help to enhance the ability of WSNs to adopt the dynamics of the environment. In conclusion, this research paper conducted a comprehensive survey of routing protocols in wireless sensor networks (WSNs). Through the analysis of various routing protocols, their design principles, and underlying mechanisms, we have gained valuable insights into the challenges and advancements in WSN routing. The survey revealed that routing protocols in WSNs are designed to address the specific constraints and requirements of these networks, such as limited resources, energy efficiency, scalability, and fault tolerance. Different categories of routing protocols, including data-centric, hierarchical, and location-based approaches, were explored, showcasing a wide range of techniques used for efficient data transmission.

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