A Review of Routing Protocols in Energy Harvesting Wireless Sensor Networks

Genxiong Zhang(✉)

Inner Mongolia Electronic Information Vocational Technical College, Hohhot, China
33384146@qq.com

Abstract. With the development of wireless networks in recent years, battery-powered wireless sensor networks are gradually moving towards energy harvesting wireless sensor networks. Energy harvesting technology overcomes the problems of limited energy and difficulty in replacing batteries in traditional wireless sensor networks, and is therefore widely used in various fields. In an energy harvesting wireless sensor network, due to time, space, location, placement angle, energy source, technology, etc., the energy that each sensor node can collect is also different. And nodes with different energy will affect the network life, or data loss occurs on some nodes. Therefore, for this type of network, it is very important to improve and optimize energy usage across the entire network. This article mainly introduces the existing routing protocol optimization algorithms in this type of network. It summarizes studies, analyzes, finds the advantages and disadvantages, and further optimizes ideas for this type of research.

Keywords: Wireless sensor network · Energy harvesting · Routing protocol

1 Introduction

The development of energy harvesting technology has promoted the development of EH-WSN [1]. In our living environment, there are many scattered energy, such as solar energy, wind energy, vibration energy, thermal energy and radio frequency energy [2], etc. A lot of research has been done on how to collect and use the environmental energy. The node in EH-WSN is an energy harvesting system added to the node of traditional WSN. EH-WSN can collect energy from the environment and convert it into electrical energy and store it in the energy storage device of the node. At present, the research on energy harvesting nodes mainly focuses on the environmental energy collection technology and energy storage technology. Literature [3] used hot-spot generator technology to convert the temperature difference into usable electrical energy. Literature [4] uses wind energy sensors to collect wind energy in the surrounding environment to power its own nodes. Literature [5] proposed a method of optimizing solar collectors to maximize the energy transferred from solar panels to energy storage devices. Literature [6] designed a new type of energy harvesting device to enable nodes to collect RF energy in the environment (Fig. 1).

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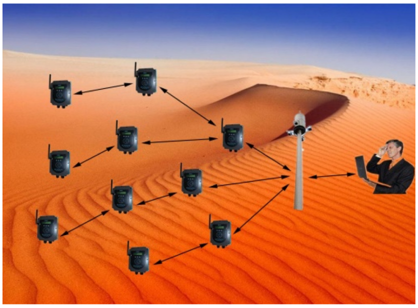

Fig. 1. Energy harvesting wireless sensor networks

The sensor node collects energy from the environment and converts it into electrical energy and stores it in a capacitor to provide energy to the sensor node. The research and development of energy harvesting technology has avoided the process of manually replacing the battery of the node. Theoretically, when the harvesting energy is sufficient, the permanent operation of EH-WSN can be realized. However, in practical applications, it is still challenging to use energy harvesting technology for sensor nodes, because of 1) the size of the sensor nodes and related technologies, energy harvesting equipment still cannot provide enough energy to maintain the node's continuous work. Energy harvesting technical issues also need to consider how to collect, store and effectively use this natural energy in a small scale, and power small wireless sensor nodes. 2) Due to the ever-changing nature of nature, the energy collected from nature is also unstable. 3) Due to the gap between the development of supercapacitors and lithium batteries and theoretical research, there are many problems in the process of energy harvesting, conversion and storage, such as low conversion rates and energy loss. In view of the above problems, EH-WSN needs further research and optimization (Fig. 2).

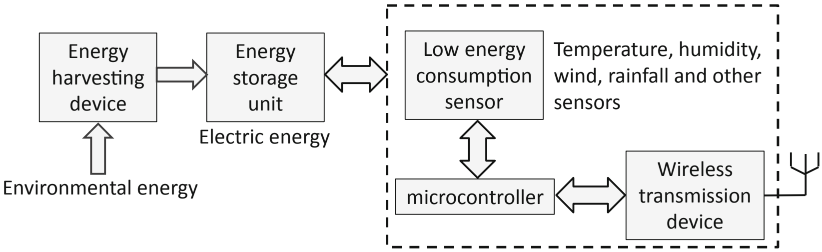

Fig. 2. The structure of energy harvesting wireless sensor

2 Related Work

EH-WSNs technology was proposed by Raghunathan [7] and others as early as 2005, using MicaZ wireless sensor nodes and Solar Inc's solar panels to realize self-powered wireless sensor networks. In 2011, Alippi [8] et al. proposed an energy-based TDMA protocol based on the MicaZ wireless sensor node, and implemented an underwater illumination environment monitoring system for near- and long-range wireless communication [8, 9]. In recent years, in addition to solar-powered WSNs, vibration energy WSNs, wind energy WSNs, etc. have also received extensive attention and active research. EH-WSNs can be divided into battery-operated Energy Harvesting Wireless Sensor Networks (B-EHWSNs) and pure energy harvesting (without batteries) wireless sensor networks (Energy Harvesting Wireless Sensor Networks) from the power supply mode., EH-WSNs). Earlier studies were conducted on the first model. A typical example is the Heliomote Energy Harvesting System designed by a Srivastava team led by UCLA (UCLA) in 2005. Through the prediction of the energy collected by the sensor nodes within a certain period of time [10–12], they achieved the optimal work cycle and the optimal task scheduling [13, 14] to optimize the system performance.

Because the collectible energy in the environment changes in real time, the node energy collection rate also changes over time. Therefore, an effective energy prediction algorithm is very useful for EH-WSN's task scheduling, MAC protocol and routing protocol, etc. [15]. For a variety of collectible energy sources, solar energy is diurnal and periodic to a certain degree [16], so most of the existing energy prediction algorithms are designed for solar energy. Weather Conditioned Moving Average (WCMA) [17] considers the effect of weather conditions on harvestable energy. In energy-efficient Routing Protocol [18], the author first divides each node between the source node and the destination node into multiple levels. Then use the method of Dynamic programming to get the path with the smallest number of hops in the network. Among multiple paths with the smallest number, select the optimal path.

In Adaptive Energy-Harvesting Aware Clustering routing protocol (AEHAC) [19], at first, they takes node energy state into cluster head election algorithm. and can adjust its parameter according to the network deploying environment. We analyze and evaluate the routing performance in terms of two metrics available node number and network throughput.

This article mainly introduces the existing routing protocols in EH-WSN, and summarizes and analyzes the advantages and disadvantages and possible challenges of each routing protocol. The structure of this paper is as follows: Sect. 2 introduces several groups of existing routing protocols. The third chapter analyzes and summarizes current routing protocols and points out future challenges. The fourth chapter is the summary of this work.

3 Typical Routing Protocols

In this section we introduce several typical routing protocols of EP-LEACH, AODV-EHA, Opportunistic routing protocol of EH-WSN and an Energy Neutral Routing (ENR) Protocol.

3.1 An Effective Routing Protocol for Energy Harvesting Wireless Sensor Networks

Meng [20] et al. introduces Energy Potential Function which is utilized to measure the node's capability of energy harvesting and extend the traditional LEACH to Energy Potential LEACH (EP-LEACH). EP-LEACH uses a new energy potential function to measure the node's energy acquisition capability. In LEACH, the original cluster head selecting function was extended to an energy potential function to measure the ability of a node to collect energy, as well as the ability of a node to run continuously. The algorithm works as follows: at first, the LEACH protocol is carried out according to a "round" cycle, and each round is divided into two phases. In each round, each cluster remains the same. However, the cluster head is re-selected each round. At the beginning of each round, the LEACH protocol randomly selects sensor nodes as cluster heads. Then an energy potential function (EP-Function) is introduced to measure node capability of energy harvesting. Therefore, each round of cluster head selection, nodes with potential energy should have a greater chance of being elected as cluster heads. There is no limit to the number of times each node can be elected as the cluster head. Compared with LEACH, it improves the throughput, reduces the data error rate, and reduces the possibility of node death. The evaluation results show that the proposed EP-LEACH exhibits a better performance than previous work in terms of lifetimes and throughput.

3.2 Energy Harvesting Aware AODV (AODV-EHA)

The Energy Harvesting Aware AODV (AODV-EHA) [21] protocol combines the traditional AODV protocol with energy harvesting, which is not only suitable for changing network topology structures, but also achieves energy efficiency for a longer network life cycle. All these functions utilize the existing mechanisms of the AODV protocol without additional complexity and routing overhead. The AODV-EHA protocol tries to find the least transmission cost on the route instead of the minimum number of hops. In actual operation, the AODV-EHA protocol is similar to the traditional AODV protocol, and there are some changes in the composition of communication messages: routing requests, routing responses. Relative to the traditional AODV protocol's routing request and routing response message format, in the AODV-EHA protocol, the "hop count" is replaced by the "energy count". The energy count here means the predicted average transmission cost of a data packet was successfully provided from the initiator node to the destination node. The experimental results show that with the increase of nodes, the average point-to-point transmission cost of AODV-EHA is decreasing, and the cost of AODV-EHA is always lower than the AODV protocol. Compared with the AODV protocol, AODV-EHA can usually find the path with the lowest transmission cost, but it is the longest path.

3.3 Opportunistic Routing in Wireless Sensor Networks Powered by Ambient Energy Harvesting

In literature [22], for accurate evaluation, the authors define and present a realistic outdoor solar energy harvesting model. On the basis of the real model, they proposed an opportunistic routing protocol EHOR. The main idea is as follows: 1) EHOR divides the possible set of forwarding neighbors into several regions for determining the best forwarding candidates and gives different IDs to the regions according to the distance of a sender and the sink node. For a transmission, the further a region from the sender, the lower probability of receiving the data packet it has, nodes further away from the sender; on the contrary, the nearer a region from the sender, the lower probability of sending the data packet it has. 2) After deciding the forwarding region, the EHOR considers the priority of a forwarding node according to the remaining energy of the node and quality of the link in the selected forward region. Here, they refers the weight of the forwarding priority in terms of β and the simulation results show that proposed EHOR achieves high goodput, efficiency, data delivery ratio and fairness.

3.4 Energy Neutral Routing (ENR) Protocol

The Energy Neutral Routing [23] protocol can keep sensor network in a state which energy consumption of the sensor is smaller than to the energy or equal to the energy that could be collected within a certain amount of time. The ENR protocol is implemented in three phases. In the first phase, the network sets the minimum hop count from all nodes to the sink node named gradients to 0 to initialize the network. Sink generates data packets to obtain data information, after that, nodes updates their gradients according to ENR algorithm and select nodes that have smaller gradients to form network. After receiving the data packet, the receiver will generate a reinforcement interest (RI) packet to extract the data. In the second phase, The node that received the reinforcement interest from the sink node hopes to look for the next-hop neighbor and transmit on the RI to the data source. The node will forward the RI message to the optative neighbor node, if the RI message will destroy the neutrality of the optative neighbor node, the optative neighbor node will broadcast refusion information. The node will successively send the RI message to the optative neighbor nodes among the remaining nodes until all neighbor nodes send RM messages, and the node will broadcast the RM message related to the RI message. In the third phase, The node receiving the RI will enter the data transmission stage by forwarding a packet about data in the light of the higher data rate designated in the reinforcement interest. After entering the data transmission phase, relay node checks interest cache. If the relay node does not find a matching entry in the data packet in the data cache, then the data packet is sent to the next hop node. Empirical research shows that ENR can usefully supply energy-neutral operations within the network, and can significantly increase the rate of packet distribution.

3.5 Open Problems and Challenges

Although the proposed routing protocol improves the performance of energy harvesting wireless sensor networks, there are still some problems not considered and solved.

In EH-WSN, the ability of node acquisition is asymmetric, which is ignored by most routing protocols, which limits the performance of practical application networks. At the same time, due to the different energy states of nodes, it is difficult for each node to keep the energy neutral state for routing data transmission and keep the network running continuously in theory. In addition, due to the unbalanced energy consumption of network nodes, multi hop transmission produces energy hole problem, which greatly reduces the throughput and energy consumption efficiency of the network. The existing routing protocol research on this problem needs to be further explored.

4 Conclusions

Wireless sensor networks are widely used in various fields, such as environmental monitoring, security monitoring, industrial control, and military. The biggest challenge of traditional wireless sensor networks is to use non-rechargeable batteries as the energy supply. The sensor network will die. Energy harvesting wireless sensors successfully solve this problem. This paper introduces seven routing protocols for energy harvesting wireless sensor networks. When choosing an energy harvesting sensor network routing protocol, according to the different deployment environments and requirements of the sensors, the energy harvesting wireless sensor network has the following characteristics: The performance of different performances, such as rates, is different, so choosing the right routing protocol can make the network show better performance and achieve the expected goal.

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