Applied Soft Computing 41 (2016) 135–147

Contents lists available at ScienceDirect

Applied Soft Computing

journal homepage: www.elsevier.com/locate/asoc

An improved harmony search based energy-efficient routing algorithm for wireless sensor networks

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ARTICLE INFO

Article history:
Received 9 May 2015
Received in revised form
25 November 2015
Accepted 16 December 2015
Available online 25 December 2015

Keywords:
Wireless sensor networks
Routing algorithms
Energy-efficient
Meta-heuristic
Harmony search algorithm

ABSTRACT

Wireless sensor networks (WSNs) is one of the most important technologies in this century. As sensor nodes have limited energy resources, designing energy-efficient routing algorithms for WSNs has become the research focus. And because WSNs routing for maximizing the network lifetime is a NP-hard problem, many researchers try to optimize it with meta-heuristics. However, due to the uncertain variable number and strong constraints of WSNs routing problem, most meta-heuristics are inappropriate in designing routing algorithms for WSNs. This paper proposes an Improved Harmony Search Based Energy Efficient Routing Algorithm (IHSBEER) for WSNs, which is based on harmony search (HS) algorithm (a meta-heuristic). To address the WSNs routing problem with HS algorithm, several key improvements have been put forward: First of all, the encoding of harmony memory has been improved based on the characteristics of routing in WSNs. Secondly, the improvisation of a new harmony has also been improved. We have introduced dynamic adaptation for the parameter HMCR to avoid the prematurity in early generations and strengthen its local search ability in late generations. Meanwhile, the adjustment process of HS algorithm has been discarded to make the proposed routing algorithm containing less parameters. Thirdly, an effective local search strategy is proposed to enhance the local search ability, so as to improve the convergence speed and the accuracy of routing algorithm. In addition, an objective function model that considers both the energy consumption and the length of path is developed. The detailed descriptions and performance test results of the proposed approach are included. The experimental results clearly show the advantages of the proposed routing algorithm for WSNs.

1. Introduction

In recent years, due to the rapid progress of micro-electro-mechanical-system (MEMS) and wireless communication technology, wireless sensor networks have obtained dramatic development. As one of the most important technologies in the 21st century and the core technology of the Internet of things (IoT) [1], WSNs are profoundly changing the human life, and its application scopes become wider and wider, especially, the application of Small-scale Wireless Sensor Networks (SWSNs) which contains dozens to several hundreds of sensor nodes. Large-scale Wireless Sensor Networks can be hierarchical sensor networks comprised of some SWSNs [2,3]. The wide applications are involved with both civilian and military scenarios, including environmental monitoring, surveillance for safety and security, automated health care, intelligent building control, traffic control, object tracking, smart homes and smart grid, etc. [4–12].

A WSN comprises of numerous small devices, i.e., sensor nodes, which contain sensing (measuring), computing, and communication component that ensure an administrator to observe and react to events and phenomena in a specific area called a sensor field [1]. These sensor nodes scattered in the sensor field can collect local environmental information, process them into useful data packets, and send the packets to the sink node by multi-hop. The sink node transmits the packets to administrator via internet or GPRS. Most of these sensor nodes suffer from the same constraint: limited battery life, limited transmission power, low memory and limited processing capabilities [1]. With the dramatic development of hardware technology, the CPU and flash memory are becoming smaller, more powerful and cheaper. As a result, the memory and processing capabilities of sensor nodes will not be the most important obstacle for the application of WSNs. However, the battery technology has failed to obtain a breakthrough yet. Obviously, the energy capacity of sensor nodes will be the key bottlenecks for the development of WSNs in a very long time. So the research on improving energy efficiency of WSNs, so as to prolong the network lifetime, is still the focus at present and in the future. The technical ways and methods of improving energy efficiency of WSNs mainly involve the energy efficient routing algorithms and clustering algorithms. This paper is devoting to develop an energy efficient routing algorithm for WSNs.

For the wide applicability range of WSNs, WSNs routing protocols must be application-based [13], which means that designing a WSNs routing algorithm that meets the requirements of all application is impossible. Instead it is of importance that designing general routing algorithms which somehow can be applied to some application and meanwhile balance the energy consumption to increase the network lifetime as far as possible, which is an important and challenging issue, as well as the focus of developing the routing protocols for WSNs. As routing in WSNs

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http://dx.doi.org/10.1016/j.asoc.2015.12.028
1568-4946/

for maximum lifetime has proven to be a NP-hard problem [14], more and more researchers try to develop heuristic and meta-heuristic based routing algorithms to address it. However, there is enormous scope for improvements in energy efficiency for some WSNs applications. And on account of the uncertain variable number and strong constraints of the routing problem in WSNs, most meta-heuristics are inappropriate to design routing algorithms for WSNs. This paper tries to develop an energy efficient routing algorithm for WSNs based on an improved Harmony Search (HS) algorithm, a meta-heuristic.

The energy-saving mechanisms based on the management of the node status [15], allowing turning nodes from sleep mode to transmitting/receiving mode, has not been taken into account in this paper. Because these mechanisms are normally implemented in Physical and MAC layer.

The rest of this paper is organized as follows. Section 2 describes the state-of-the-art of routing protocols for WSNs, mainly discusses the routing algorithms based on heuristic and meta-heuristic approaches. In Section 3, the IHSBEER algorithm is described in detail, in conjunction with another approach, which is the core of this paper. Section 4 presents the experimental results performed to evaluate the proposed routing algorithm. Related discussion about the proposed routing algorithm is presented in Section 5. The last section is the conclusions and topics for further work.

2. Related work

WSNs and mobile ad hoc networks (MANETs) have a lot in common, such as they both involve the multi-hop communications. However, the two systems have several significant differences. The typical and most important difference is that WSNs is subject to energy constraint, which is not always the case in MANETs, where the communication devices handled by humans can often be replaced or recharged. Due to the unattended operation of several weeks or months for most applications of WSNs, it is very important to manage energy resources of sensor nodes efficiently. Therefore, many routing schemes of MANETs [16] are inappropriate to WSNs. And the design of energy-efficient routing algorithm for WSNs has become the research focus.

At present there is a great amount of research about the design and development of routing protocols in WSNs [17–20]. These protocols are designed for different applications and different architecture of networks. However, they all have one thing in common: they have considered the energy efficiency of sensor nodes, which directly affects the extension of the network lifetime. In this section, a brief overview on applying heuristic and meta-heuristic algorithms to design routing protocols for WSNs is presented. A detailed and complete reference on the motif can be seen from [21–23].

Camilo et al. proposed an Energy Efficient Ant Based Routing (EEABR) Algorithm, which is based on Ant Colony Optimization (ACO), to improve the energy efficiency of WSNs and maximize the network lifetime [24]. In this routing algorithm, the paths between the source nodes and the sink node are found by forward ants, which select next hop according to the amount of pheromone trail stored in current nodes routing table and residual energy of neighbors. When computing the number of pheromone trail that a backward ant will left during its journey, both the energy levels of all nodes in path and the path length are taken into consideration, which have a great contribution to balancing the energy consumption of nodes and reducing the time delay. Meanwhile, a parameter called travelled distance, i.e., the number of visited nodes, is introduced in this phase, which makes those nodes closer to sink node have more pheromone trail, so that forward ants could reach the sink node more efficiently. However, during the early period of transmitting packets, the forward ants cannot find the optimal or near optimal paths due to the little difference of the amount of pheromone trail in routing table.

Multipath Routing Protocol (MRP) is proposed by Jing et al. to reduce energy consumption and maximize the network lifetime [25], which is based on dynamic clustering and ant colony optimization. MRP contains three phases: cluster formation, multipath construction and data transmission. In the first phase, the cluster head is selected from those nodes located in the event area according to their residual energy. Furthermore, with dynamic clustering, the efficiency of data aggregation has been improved dramatically, so that the energy consumption of network has been decreased effectively. In the phase of constructing multipath, an improved ACO algorithm is used to calculate the multiple paths between the cluster head and the sink node, which has balanced the energy consumption of nodes. In the last phase, the cluster head dynamically select one path to transmit data to the sink node according to a load balancing function.

Adaptive energy-efficient and lifetime-aware routing protocol (QELAR), based on Q-learning technique, is proposed by Hu et al. [26]. It has introduced Q-learning technique to the routing protocol to balance nodes workload for prolonging network lifetime. Whats more, QELAR can improve energy efficiency of network by decreasing networking overhead, and better adapt to dynamic networks by efficiently learning the environment.

Routing using ant colony optimization router chip (ACORC), proposed by Okdem and Karaboga, is a multi-path routing protocol, which can provides reliable communications in the case of node faults [27]. Whats more, the packets to be transmitted do not need to retain those nodes that have ever been visited, so that the size of data has been decreased and nodes energy has been saved. However, in the phase of calculating the amount of pheromone trail that a backward ant will deposit during its journey, it only considers the length of path not the energy levels of nodes in path, so that the distribution of pheromone is not so reasonable, which will have a negative effect on maximizing network lifetime.

Marcelo et al. have proposed a Cognitive LF-Ant protocol for emergency reporting in healthcare wireless sensor networks [28], which is inspired by the natural behavior of the ants and a cognitive component providing the capabilities to dynamically allocate resources, in accordance with the emergency degree of each patient. The inter-cluster routing is inspired by the behavior of foraging Saharan desert ants, which is based on the criterion of shortest path between the cognitive sensor node and the sink node. Simulations results show the decrease in the average delay time to report emergency situations. And the packet loss rate was also reduced.

Liu et al. have proposed an agent-assisted QoS-based routing algorithm (QoS-PSO) for WSNs, which is based on Particle Swarm Optimization [29]. In QoS-PSO, the objective function of PSO is the synthetic QoS composed of delay, bandwidth and packet loss, which contributes to obtain the optimal path and improve the network performance. The changes of network communication flow, each nodes routing state and network topology can be monitored by intelligent software agents, which can also participate in network routing and maintaining. It can be seen from the experimental results that QoS-PSO provides better quality of service than other algorithms. However, the global information needs to be stored in each sensor node for QoS-PSO, which is not suitable for large-scale WSNs.

BeeSensor protocol, proposed by Saleem et al., is an event driven, reactive and on-demand multipath routing protocol, which is inspired by the foraging principles of honey-bees [30]. There are four phases in this protocol: scouting, foraging, swarming and routing loops and path maintenance. Hence, BeeSensor works with four types of agents: packer, scouts, foragers and swarms. The major responsibility of packer is to receive packets coming from the upper layer and locate an appropriate forager for them. Scouts are of two sorts: forward scouts and backward scouts, whose task is to build a path between the source nodes and the sink node and report the quality of the discovered path. In BeeSensor protocol, foragers are the main workers, whose major task is to carry packets to the sink node through a predetermined path that is selected stochastically at the source node. And a swarm encapsulates all foragers belonging