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An endocrine cooperative particle swarm optimization algorithm for routing recovery problem of wireless sensor networks with multiple mobile sinks

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ABSTRACT

In the wireless sensor networks with multiple mobile sinks, the movement of sinks or failure of sensor nodes may lead to the breakage of the existing routes. In most routing protocols, the query packets are broadcasted to repair a broken path from source node to sink, which cause significant communication overhead in terms of both energy and delay. In order to repair broken path with lower communication overhead, we propose an efficient routing recovery protocol with endocrine cooperative particle swarm optimization algorithm (ECPSOA) to establish and optimize the alternative path. In the ECPSOA, mutation direction of the particle is determined by multi-swarm evolution equation, and its diversity is enriched by the endocrine mechanism, which can enhance the capacity of global search and improve the speed of convergence and accuracy of the algorithm. By using this method, the alternative path from source nodes to the sink with the optimal QoS parameters can be selected. Simulation results show that our routing protocol significantly improves the robustness and adapts to rapid topological changes with multiple mobile sinks, while efficiently reducing the communication overhead and the energy consumption.

1. Introduction

The Internet-of-Things (IoTs) are regarded as the extension of current Internet to the real world of physical objects [5]. The basic idea of IoT is pervasively providing us with a variety of things or objects, such as radio frequency identification (RFID) tags, sensors, wireless sensor networks (WSNs), and mobile phones, which are able to interact and cooperate with each other to realize the tasks of communication, computation, and service. An important direction of the IoTs is to facilitate suitable WSNs technologies based on an efficient standard protocol to support the network of things [10,6].

Several data dissemination protocols have been proposed for the WSNs with a static sink [21,26,29]. For example, the directed diffusion approach [11] assumes that each sink needs to periodically flood its location information through the

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sensor field. The procedure sets up a gradient from the sensor nodes to the sink, so that each sensor is aware of the sink location for sending future events and measurements. However, the static sink may limit the network lifetime as the 1-hop neighbors of the sink, which is the bottleneck of the network. The WSNs with mobile sink is a powerful solution to take advantage of short-range transmission. When the energy of the sensors around one sink is exhausted, the sink can move to a new location in an area with richer sensors' energy [20]. This approach can balance the energy consumption and prolong the network lifetime.

The method of adding mobile sinks to the WSNs infrastructure has attracted much attention recently, such as the methods in [12,27]. Scalable Energy-efficient Asynchronous Dissemination (SEAD) [28], is a mechanism for routing sensing data to mobile sinks. The idea is to construct a minimum Steiner tree for the mobile sink and designate some nodes on the tree as access points. The mobile sink registers itself with the closest access node. When the sink moves out of range of the access node, the route is extended through the inclusion of new access node. Such partial path extension is allowed only for a limited number of hops and then the branch of the Steiner tree for that sink is modified by finding the least cost path to the sink.

In the ALURP [31], a sink only floods its location to the nodes within an adaptive area if the sink only moves in the adaptive area. The ALURP can significantly reduce unnecessary transmissions overhead by local flooding, but the mobile sink still needs to flood its location information throughout the entire network to announce a new adaptive area.

The Two-Tier Data Dissemination (TTDD) [18] represents the early work on data dissemination of the WSNs with mobile sinks. The protocol initially builds a grid structure which divides the network into cells with several dissemination nodes. When the sink requests data, the query packets are flooded locally within the cell until it reaches a dissemination node. A data path from the source to the dissemination node is then established. But the TTDD is not suitable for applications where the flooding area expands as the cell size grows, while a small sized grid structure incurs high overhead for the grid construction.

The Intelligent Agent-Based Routing Protocol (IAR) [13] provides efficient data delivery to mobile sinks. The IAR algorithm reduces signal overhead and improves degraded route called triangular routing problem. The sink periodically examines its distance from the current immediate relay, initiates a new relay path establishment, and reduces the packet loss as the experiment results and signaling overhead.

However, the routing recovery mechanism for the movement of multiple mobile sinks and sensor node failure has rarely been considered. As the fault-tolerant optimization problem to find the optimal routing is a NP-hard one, the heuristic deterministic methods always fall into local optimum, and obtain the approximate optimal routing result. Moreover, in these routing protocols, packets are broadcasted to repair a broken route from source node to sink, which causes significant communication overhead in terms of both energy and delay.

We design an efficient swarm intelligent algorithm to optimize the alternative path from the sources to the sinks in this paper. Our proposed method is developed based on IAR and differs from the above works. We address the routing problem of the WSNs consisting of a large number of sensor nodes and multiple mobile sinks for data gathering. The multiple mobile sinks form a virtual backbone and are concerned with maintaining the backbone connectivity as a result of sinks' movements. When the energy of the nodes around these sinks is exhausted, these sinks can move to a new location with richer sensor energy to gather information. This approach can balance energy consumption and prolong network lifetime.

The main contributions of this paper are as follows: (1) We build the WSNs model with multiple mobile sinks, address to its routing recovery problem with both the movement of multiple sinks and sensor node failure. (2) We propose an endocrine cooperative particle swarm optimization algorithm (ECPSOA), which offers faster global convergence and higher solution quality, and provides fast bio-heuristic routing recovery for the path from source node to the mobile sink. (3) The ECPSOA based routing recovery protocol is designed and proposed for efficiently solving the path breakage problem of the WSNs with multiple mobile sinks, which can decrease the control overhead and minimize energy consumption.

The rest of this paper is organized as follows. Section 2 formulates the routing recovery problem and states our network model. Section 3 describes the proposed algorithm in details, and the routing recovery protocol is presented and analyzed. Section 4 reports the experiment results of the propose approach. Finally, Section 5 concludes the paper.

2. Definition and analysis of network model

The WSNs with multiple mobile sinks is modeled as a connected graph $G(V,E)$ [7,2], where V is a finite set of sensor nodes and E is the set of edges representing connection between these nodes. Suppose there exist n source nodes and m mobile sinks, several source nodes can route the packets through multi-hops to one mobile sink. As such, there would be$n$paths from n given source nodes to m given mobile sinks, which are denoted by p_j $(j \in 1,2,\ldots,n)$. Each source v_s^j connects a sink $v_{\sin k}^i$ $(i \in 1,2,\ldots,m)$ with one path p_j. The k-th relay node on the path p_j is denoted by $v_j^k,\ k \in 1,2,\ldots,h_j$, where h_j is the hop count on path p_j. e_j^m represents the m-th direct edge between two neighbor nodes on p_j. Let $N(p_j) = \left\{v_j^1, v_j^2, \ldots, v_j^k, \ldots, v_j^n\right\} \subset N(v)$ be the set of the sensor nodes existing along the path p_j, where k represents the distance from the sink to the node on a hop scale. We introduce an agent to directly connect the mobile sink with 1-hop. This similar concept is adopted with different terminologies by several protocols in [20,19,23].

An example of the network model is shown in Fig. 1. There exist 4 source nodes $\{v_s^1, v_s^2, v_s^3, v_s^4\}$ and 2 mobile sinks $\{v_{\sin k}^1, v_{\sin k}^2\}$ in the network. Four paths $\{p_1, p_2, p_3, p_4\}$ connect the corresponding sources with the sinks, in which p_1 contains