A Multipath Routing for Lifetime Maximization Based on Heterogeneous Wireless Sensor Networks

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Abstract- In wireless sensor networks, sensor nodes are typically power-constrained with limited lifetime, and thus it is necessary to know how long the network sustains its networking operations. Heterogeneous WSNs consists of different sensor devices with different capabilities. For monitoring burst events in a kind of reactive wireless sensor networks (WSNs), a multipath routing protocol (MRP) based on dynamic clustering and ant colony optimization (ACO) is proposed. Such an approach can maximize the network lifetime and reduce the energy consumption. An important attribute of WSNs is their limited power supply, and therefore some metrics (such as energy consumption of communication among nodes, residual energy, path length) were considered as very important criteria while designing routing in the MRP. Firstly, a cluster head (CH) is selected among nodes located in the event area according to some parameters, such as residual energy. Secondly, an improved ACO algorithm is applied in the search for multiple paths between the CH and sink node. Finally, the CH dynamically chooses a route to transmit data with a probability that depends on many path metrics, such as energy consumption. The simulation results show that MRP can prolong the network lifetime, as well as balance of energy consumption among nodes and reduce the average energy consumption effectively.

I. Introduction

WSNs consists a large number of sensor nodes in a target area for performing surveillance tasks such as environmental monitoring, military surveillance, animal tracking, industry, agriculture and home applications [1]–[2]. Each sensor node collects data by sensing its surrounding region and transfers the data to a sink (also called a base station). In the WSNs, a lot of sensor nodes operate on limited batteries, making energy resources the major bottleneck. Therefore, an economical and frugal management for improving the lifetime of wireless sensor is important. WSNs are much more demanding on energy conservation than the other kinds of networks. How to maximize the network’s lifetime is a critical research topic in WSNs. The wireless sensor networks (WSNs) technology have been widely applied in military, industry, agriculture and many other areas [1,2]. In the WSNs, a lot of nodes operate on limited batteries, making energy resources the major bottleneck. Therefore, an economical and frugal management of energy is essential for improving energy efficiency. Because energy consumption due to communication is the major part of the energy consumption in WSNs [3], a high performance routing protocol is often a key requirement in WSNs systems. The design of routing protocols in WSNs is very challenging due to their inherent characteristics of large scale, no global identification, dynamic topology, and very limited power, memory, and computational capacities for each sensor. Currently, many energy-efficient routing algorithms have been studied with the aim of saving energy [4-6]. The existing routing protocols in WSNs can be categorized into flat routing protocols and hierarchical routing protocols, or single-path routing protocols and multipath routing protocols [7]. Recent research on WSNs routing protocols has proven that clustering and multipath are needed to improve energy efficiency and load balancing. When designing multipath routing algorithms, many parameters (e.g., path length and energy consumption of communication) also need be considered. The optimization of network parameters for WSNs routing processes might be considered as a combinatorial optimization problem. Our proposed approach benefits from the success of ant colony optimization (ACO) [8] in solving the problem. The ACO algorithm is a heuristic algorithm introduced by Dorigo and his collaborators for solving some combinatorial optimization problems [9], such as traveling...
salesman problem (TSP) [10]. The ACO algorithm has some characteristics, such as distributed computing, self organization and positive feedback, suited for searching routing in modern communication networks. However, few of the existing works have considered the integration of clustering, multipath and ACO to maximize the network lifetime and achieve load balancing in WSNs. Motivated by the advantages of clustering, multipath and ACO, this paper proposes a multipath routing protocol (MRP) based on dynamic clustering and ACO for reactive WSNs.

II. Related Work

Currently, lots of work is going on congestion control for WSNs. Scenarios with multipath routing are not considered. It is not clear whether they can be directly applied to WSNs with multipath routing enabled. WSNs are a kind of decentralized network of autonomous nodes that collect and process information, and send the information to a sink node over wireless links. Limited energy nodes are not taken into account in the traditional routing protocols, which has significant impact on the overall energy dissipation. Therefore, new routing protocols need be designed for WSNs.

Hierarchical Routing: Hierarchical (clustering) technology is particularly promising and has received much attention in the research community. In a hierarchical network, the data gathered by sensor nodes is transmitted to CHs. The sensed data from nodes within one cluster usually exhibit high correlation, and therefore, a CH can aggregate data to remove redundancy and only send one packet to the sink. In the last few years, many hierarchical routing algorithms are proposed for WSNs. One pioneering work in the literature is LEACH (Low-Energy Adaptive Clustering Hierarchy) [11]. LEACH is an application-specific data dissemination protocol that uses clustering to prolong the network lifetime. However, the assumption that all nodes are capable of communicating with any node in the field does not allow the network to be scalable, and LEACH does not guarantee good distribution of CHs. To improve LEACH performance, Lindsey et al. introduced chain into clustering (power-efficient gathering in sensor information systems, PEGASIS) [12]. In this work, all nodes are connected in a chain and communicate only with the nearest neighbor. Nodes take turns to be the CH and send aggregation data to the sink. Although PEGASIS outperforms LEACH in network lifetime, it assumes that all nodes have a global knowledge of the network. Thus, PEGASIS may not be efficient with closely deployed nodes in a specific area. In [13], the authors designed an ant-based algorithm (T-ANT) to cluster and achieved a uniform distribution of CHs in the network.

Multipath Routing: Multipath routing uses multiple paths to transmit data, which can achieve both load balancing and fault tolerance. There are two different multipath routings between the source node and the sink node. One is disjoint multipath routing [14], where the alternative paths do not intersect with each other. The other is braided multipath routing, where there are typically no completely disjoint paths [15-16]. In [14], Ganesan et al. presented a disjoint multipath routing based on local information, which is a distributed algorithm and can achieve load balancing. This algorithm uses a primary route to transmit data. Only when the primary route fails, the alternative route can be used. However, this algorithm is not attractive for the network lifetime. In [15], a meshed multipath routing with efficient strategy has been described. Such an algorithm can achieve a better throughput than the traditional multipath algorithms. However, this approach requires nodes to be equipped with GPS (Global Positioning System), which increases the cost of the node. In [16], Okdem et al. introduced a multipath routing algorithm based on Ant Colony Optimization (ACO), which uses a class of agent-like ants to develop multiple reliable routes between the source and sink. It is very effective in dealing with the failure of links and searching for the routes. Due to the Ant Routing. As an effective distributed approach, the ACO algorithms have been introduced to the design of routing protocol and have received many achievements [17-25]. The ACO algorithm was first used in traditional networks [17]. ARA [18] was the first algorithm used in mobile ad hoc networks (MANETs), which exploits the pheromone laying behavior of ants to search for routing. The above two algorithms are however not suitable for WSNs. In [19], Liu et al. used an improved ACO algorithm (PACO) to search for multipaths between source nodes and the sink node in MANETs. Although the PACO improves the efficiency of data transmission, the number
of ants required to search for routing is great, resulting in great energy consumption at the start-up stage. Moreover, the PACO only uses the length of path as metric without considering the current energy of nodes: these discovered paths may contain the low energy nodes, which will shorten the working time of the paths. Recently, routing protocols based on ACO for WSNs have been the focus of many studies [20-25]. In [20], Zhang et al. studied three distinct Ant-based algorithms for WSNs. However, the algorithms only focus on the building of an initial pheromone distribution, and thus, the algorithms are only good at system start-up phase. In [21], Camilo et al. presented a new WSNs routing algorithm based on ACO, which can minimize communication load and save energy. Nevertheless, the algorithm does not consider the feature of data correlation, the energy consumption of communication is huge when a lot of sources exist in the network. In [22], Liu et al. introduced a routing strategy on the basis of ant algorithm for WSNs, using deflection angle, energy and distance as routing factors to help the ant to search for routing. The convergence rate of the algorithm is good. However, the algorithm did not utilize the redundancy of data, and thus the algorithm has the same disadvantage as [21]. A reinforcement learning scheme is proposed in [23], which reduces the energy consumption and shortens the time delay. The algorithm, however, only uses the distance as metric, so it cannot protect the minimum energy node, and therefore, it may shorten the network lifetime. In [24], Tu et al. constructed a chain by means of an ant colony algorithm that connects all the nodes in the networks. Although the algorithm can find suboptimal routing for mobile agents, the time delay of the algorithm is long, and the cost of reconstructing routing is also high. In [25], Ren et al. proposed a multipath routing based on ant colony system, which extends the network lifetime. Although the algorithm balances the energy consumption among nodes by multipath, it does not take into consideration the influence of the minimum energy node on multiple paths. In [26], Okdem et al. presented an ACO-based multipath routing, which provides good energy efficiency.

III. ACO based routing algorithms in WSN

Three ant-routing algorithms for sensor networks. The SC algorithm is energy efficient but suffers from a low success rate. The FF algorithm has shorter time delays; however, the algorithm creates a significant amount of traffic. Despite high success rate shown by the FF algorithm that it is not energy efficient. An Adaptive ant-based Dynamic Routing (ADR) algorithm using a novel variation of reinforcement learning was proposed by Lu et al. [8]. The authors used a delay parameter in the queues to estimate reinforcement learning factor. In [15] proposed a novel approach for WSN routing operations. Through this approach the network lifetime is maintained in maximum, for discovering the shortest paths from the source nodes to the base node using an evolutionary optimization technique. The research has also been implemented on microchip PIC® series hardware, called PIC12F683. In [9] propose two adaptive routing algorithms based on ant colony algorithm, the Adaptive Routing (AR) algorithm and the Improved Adaptive Routing (IAR) algorithm. To check the suitability of ADR algorithm in the case of sensor networks, they modified the ADR algorithm (removing the queue parameters) and used their reinforcement learning concept and named it the AR algorithm. The AR algorithm did not result in optimum solution. In IAR algorithm by adding a coefficient, the cost between the neighbor node and the destination node, they further improve the AR algorithm. [10] proposed a dynamic adaptive ant algorithm (E&D ANTS) based on Energy and Delay metrics for routing operations. Their main goal is to maintain network lifetime in maximum and propagation delay in minimum by using a novel variation of reinforcement learning (RL). E&D ANTS results was evaluated with AntNet and AntChain schemes. C. Routing Techniques with Multipath Feature Currently, lots of work is going on congestion control for WSNs. Scenarios with multipath routing are not considered. It is not clear whether they can be directly applied to WSNs with multipath routing enabled. Moreover, most of the protocols deal with homogeneous traffic [12]. Earlier routing schemes for sensor networks involve direct communication protocols which facilitate direct communication between the source node and the base station [16]. Therefore, for scenarios where the base station is quite a distance away from the source node, there is excessive usage of energy resources, ultimately resulting in a complete drainage of power on a certain path. Recently, in [12] have presented an efficient scheme to perform multipath congestion control for heterogeneous traffic which avoids packet loss and thus
enhances the probability of achieving the desired throughput of heterogeneous traffic. The congestion detection mechanism is chosen based on packet service ratio and congestion notification. In the proposed protocol they have assumed three points: 1. Every sensor node in the network has equal number and same types of sensors, 2: Multiple routes have been established by any multipath routing protocol, 3: While establishing the route the sink dynamically assigns individual priority for the heterogeneous application data. Each sensor node can transmit route data of its children nodes as well as its originating data. They have calculated the average packet service time at MAC layer by using Exponential Weighted Moving Average (EWMA) formula. [13] proposed a node priority based control mechanism PCCP for WSN. It introduces an efficient congestion detection technique addressing both node and link level for detecting congestion. Algorithm SANT for Proposed MRP

```plaintext
if TTL<>0 then
    if a SANT arrives at sink then
        create and release a new BANT;
    else
        if RAND(x)<0.001 then
            create a AANT;
            the AANT randomly chooses a node at the next hop node;
        else
            choose the next hop node j according to (26)-(29);
            refresh the residual energy of i and j;
            if selected node visited then
                back to the previous hop node;
            re-elect another node as the next hop node;
        end-if
        using (30), (31) to refresh pheromone value of link (i,j);
    end-if
end-if
```

MRP is different to these algorithms in [14] because the CH in MRP dynamically chooses one path to transmit data.

### IV. Performance Evolution

An isolated ant moves essentially guided by a heuristic function and an ant encountering a previously laid pheromone will detect and decide to follow it with high probability thus taking more informed actions based on the experience of previous Artificial 'ants' - simulation agents - locate optimal solutions by moving through a parameter space representing all possible solutions. Real ants lay down pheromones directing each other to resources while exploring their environment. The simulated 'ants' similarly record their positions and the quality of their solutions, so that in later simulation iterations more ants locate better solutions. Various performance metrics are used for comparing different routing strategies in WSNs. We have used the following:

- **Average Energy**: The metric gives the average of energy of all nodes at the end of simulation.
- **Energy consumption**: The metric gives the energy consumption of nodes in the event area for transmitting a data packet to sink.
- **Standard deviation of energy**: The metric gives the average variance between energy levels on all nodes.
- **Network lifetime**: This metric gives the time of the first node running out of its energy.

By using a simulator developed by MATLAB, the proposed scheme was compared with the TEEN [29] dynamic clustering algorithm and the other two kinds of multipath algorithms in [14] (MP) and [25] (MACS), respectively. We evaluated these four algorithms over a set of sensor networks with the number of nodes ranging from 100 to 500. For the same number of nodes, we randomly generated ten network topologies and ran these algorithms over them to obtain the average results. Since the cluster-heads consume more energy, our protocol assigns this role to sensor nodes with high remaining energy. After each round, these cluster-heads will be replaced with other sensor nodes with more remaining energy. LEACH does not take into account the remaining energy of sensor nodes during the selection of cluster-heads. The choice is made randomly and all sensor nodes in the network play that role periodically. Moreover, the cluster-heads communicate directly with the base station using the highest transmission power, which requires a high energy. Our protocol uses short distance transmissions to reduce energy consumption.

### V. Conclusion

Maximizing the network lifetime, this paper considers the problem of finding the maximum
number of connected covers in a heterogeneous WSN. For monitoring the burst events in WSNs, we have proposed a novel multipath routing protocol based on clustering and ACO. By introducing an objective function to carry out dynamic clustering, MRP improves the efficiency of data aggregation, thus, reducing the energy consumption. We also use an improved ACO algorithm to search for the optimal and suboptimal paths based on many metrics, which can balance the energy consumption among nodes. Furthermore, a load balancing function is presented for dynamically choosing one path to transmit data. Performance evaluation shows that MRP achieves better load balancing and lower energy consumption, and then, maximizes the network lifetime. As explained before, MRP has some parameters that need be set. The values of these parameters have a great impact on the performance of the algorithm. For future research, we plan on making the algorithm compatible with different networks by adaptively adjusting the value of these parameters.

References


