Two-Hop Geographic Multipath Routing in Duty-cycled Wireless Sensor Networks

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Abstract. As an extension of our previous designed Two-Phase geographic Greedy Forwarding (TPGF) routing algorithm in wireless sensor networks (WSNs), this paper proposes a new 2-hop geographic greedy forwarding algorithm called TPGFPlus, which uses 2-hop neighborhood information for geographic routing. In our TPGFPlus, a forwarding node selects its next-hop node which is closest to the based station among all its 1-hop and 2-hop neighbor nodes. Moreover, to prolong network lifetime, not all the nodes are awake for working in our work since the EC-CKN algorithm is applied to make the network be duty-cycled. We evaluate the performance of our algorithm versus running existing TPGF algorithm on the same duty-cycled WSNs. Simulations show that our proposed algorithm outperforms previous work TPGF on finding more average paths and shorter average length of paths, yet without causing additional energy consumption.

Keywords: Duty-cycle, Wireless sensor networks, 2-hop neighborhood, Geographic routing.

1 Introduction

Geographic routing is considered to be an efficient and scalable data delivery scheme and is quite commonly adopted for information delivery in large scale WSNs . The basic idea for geographic routing is greedily forwarding data packets to the neighbor geographically closest to the destination. Sensors need only maintain local knowledge on the locations of their one-hop neighbors to select their next forwarders [2,8].

TPGF routing algorithm [9] is one of the earliest geographical multipath routing algorithms designed for multimedia transmission in static & always-on WSNs. In TPGF, packets are expected to proceed in such a greedy manner: they are always forwarded to a node closest to the based station among all

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1-hop neighbors. Such a greedy strategy, were it to succeed, can explore the maximum number of near shortest node-disjoint multipaths. Early studies (e.g., [1,2,3,4]) assume all sensors are always on during forwarding. However, several recent studies [5], [8], [11], [12] have stressed that such assumption of previous works is unrealistic, for sensors in practical deployment are duty-cycled to save energy. There have also been a few works addressed the problem of geographic forwarding on duty-cycled wireless sensor networks [14], [16], [17], e.g., GeRaF [17] considers geographical forwarding in a wireless mesh network in which sensors know their locations, and are sleep-wake cycling. HM Ammari [8] proposes the first design of a geographic forwarding protocol for duty-cycled k-covered WSNs with data aggregation.

Moreover, the knowledge of the 2-hop neighborhood has been assumed in many distributed algorithm and protocols such as constructing structures, improved routing, broadcasting, and channel assignment [6]. Stojmenovic and Lin [10] have previously proposed GEDIR-2 extending existing geographic routing schemes to two-hop neighbors. It has shown 2-hop GEDIR increases the success rates compared with the 1-hop variant, nevertheless, is also implemented in static & always-on WSNs. It is expected that higher performance improvement will be achieved even if taking the duty-cycle schedule into consideration. Duty-cycling, this important characteristic seems to be ignored in [9,10] and insufficiently studied in [12].

In this work, we address the research of a novel geographic routing combining both characteristics of 2-hop neighborhood and duty-cycling. Specifically, we design a geographic routing protocol using 2-hop neighborhood information on EC-CKN [13] based duty-cycled WSNs.

The rest of the paper is organized as follows: Section 2 reviews related work. Section 3 introduces the network model of our research work. Section 4 describes the design of our algorithm. Section 5 shows the simulation results. Finally, we conclude this paper in section 6.

2 Related Work

2.1 CKN and EC-CKN

The Connected K-Neighborhood sleep scheduling algorithm CKN [14] allows a portion of sensor nodes going to sleep but still keeps all awoken sensor nodes k-connected to elongate the lifetime of a WSN. Then it carries on geographic routing duty-cycled nodes. This algorithm provides the first formal analysis of the performance of geographic routing on duty-cycled WSNs, where every sensor has k awake neighbors.

A variant of this method called EC-CKN [13] prolongs network lifetime further. Different from CKN, EC-CKN takes nodes' residual energy information as the parameter to decide a node to be active or sleep, not only can achieve the k-connected neighborhoods problem, but also can assure the k awake neighbor nodes have more residual energy than other neighbor nodes at the current epoch.

2.2 Geographic Routing with 2-Hop Neighbors

Geographic routing uses position information to forward a message to its destination. Sensor nodes are not required to maintain global and detailed information on the entire network topology. They only need to maintain local knowledge on their one-hop neighborhood information with respect to their final destination. Although most geographic routing protocols use one-hop information, generalization to two-hop neighborhood is also possible [10]. Extending geographic routing schemes to two-hop neighborhood increases success delivery rate, referring to 2-hop GEDIR. Another algorithm called NADV [17] also considers a geographic routing scheme that uses two-hop neighborhood information. Not surprisingly, utilizing two-hop neighborhood information leads to higher-quality paths than the one-hop case.

However, these schemes still cannot guarantee that packets are delivered in an energy-efficient manner. In real networks, nodes commonly employ low duty-cycling and are asleep at most time to get a long battery life [15]. This important feature is ignored in previous work.

2.3 Geographic Multipath Routing in Duty-Cycled WSNs

Although many multipath routing protocols have been studied [18], most of them focus on reducing delay, providing reliability, reducing overhead, maximizing network lifetime or supporting hybrid routing, and are extended versions of DSR [19] and AODV [20]. These routing protocols cannot provide a powerful searching mechanism for the maximum number of shortest paths, as well as bypassing holes [21], not to mention in duty-cycled WSNs. For such drawbacks, we propose TPGFPlus, which is a geographic node-disjoint multipath routing algorithm in duty-cycled WSNs.

To the best of our knowledge, there is no existing multipath routing researching on exploring geographic multipath routing in duty-cycled WSNs.

2.4 TPGF Geographic Multipath Routing

TPGF [9] does not require the computation and preservation of the planar graph in WSNs. This point allows more links to be available for TPGF to explore more node-disjoint routing paths, since using the planarization algorithms actually limits the useable links for exploring possible routing paths. GDSTR [1] is another geographic routing approach that does not apply the planar graph, but maintains two or more hull trees. However, GDSTR does not support multipath routing, since the number of available links in the hull trees topology is limited.

Our TPGF algorithm includes two phases:

- Phase 1 is responsible for exploring a delivery guaranteed routing path while bypassing holes.
- Phase 2 is responsible for optimizing the found routing path with the least number of hops.

TPGF algorithm finds one path per execution and can be executed repeatedly to find more node-disjoint routing paths with the guarantee that any node will not be used twice. At the same time, TPGF algorithm has been well implemented on duty-cycled WSNs based on CKN algorithm through our previous research work [12].

2.5 Our Novelty in TPGFPlus

In conclusion, existing researches either are concerned with duty-cycling or 2-hop forwarding. In this paper, TPGFPlus first tries to consider both duty-cycling and 2-hop geographic forwarding for shortest node-disjoint muli-path routing.

3 Network Model

We model a network with N sensors randomly deployed. The locations of sensor nodes and the base station are fixed and can be obtained by using GPS. Each node knows its own location and the locations of its 1-hop and 2-hop neighbors. r is the communication range of each node.

Definition 1. 2-hop neighbors. Let $N(v_i)$ and $N(v_i)'$ be respectively the sets of node v_i's 1-hop and 2-hop neighbor nodes, that is, v_i's 2-hop neighbors are the neighbors of v_i's 1-hop neighbors after removing the duplicated ones.

We assume all nodes are operated with EC-CKN based wake/sleep duty-cycling. 2-hop neighbors are gathered when executing EC-CKN for sleep scheduling in WSNs. Each sensor dynamically turns on and off the radio in turn based on the 2-hop neighbors' remaining energy information. Time is divided into epochs, and each epoch is T. In each epoch, the node will first transmit packets, and then run the EC-CKN sleep/awake scheduling algorithm to decide the state of the next epoch: sleep or awake. Sensor nodes depend on their current energy levels to adjust power consumption accordingly. Each wireless sensor node is only equipped with a single radio interface, and has the same initial energy E_{init}.

Note that, the impact of MAC layer is ignored in our model. In other words, if the network is collision-free and connected, then each message is delivered.

4 The TPGFPlus Algorithm

We combine 2-hop geographic forwarding and the characteristic of duty-cycled WSNs for a novel multipath routing. *The gathering of 2-hop neighbors is not an additional overhead for TPGFPlus algorithm, since the 2-hop neighborhood information is obligatorily gathered when executing EC-CKN.* But extending to 3-hop or even more will incur extra broadcasting, which is not included in EC-CKN any more. In summary, TPGFPlus algorithm consists of two phases: A) 2-hop geographic forwarding; B) Path optimization.

4.1 2-Hop Geographic Forwarding

This phase consists of two courses: *greedy forwarding* and *step back & mark*.

The *greedy forwarding* policy is: Suppose a current forwarding node always chooses its next-hop node which is closest to the based station among all its 1-hop and 2-hop neighbor nodes and the next-hop node can be further to the base station than itself. Once the forwarding node chooses its next-hop node among its 2-hop neighbor nodes that have not been labeled, it will have to find an intermediate 1-hop direct neighbor that has not been labeled according to some selecting policy. A digressive number-based label is given to the chosen sensor node along with a path number. This greedy forwarding principle is different from the greedy forwarding principle in [2]: a forwarding node always chooses the 1-hop neighbor node that is closer to the base station than itself. And, the Local Minimum Problem does not exist.

Supposing candidate nodes with similar progress to the destination, the one with higher residual energy will first be chosen. In this point, our work is significantly different from the previous TPGF [9] of which the strategy is forwarding the packets to the direct 1-hop neighbor which is nearest to the sink. Fig. 2 and Fig. 1 briefly describe the geographic forwarding process of TPGF and TPGF-Plus respectively.

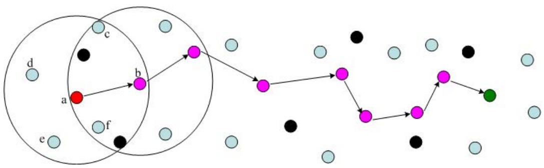


Fig. 1. 1-hop geographic forwarding example: Node *a* always forwards packets to node *b* since it has the shortest distance to the sink

Though such a method does not have well-known Local Maximum Problem, there may be *block situations* [9]. During the discovering of a path, if any forwarding node has no 1-hop neighbors except its previous-hop node, we will mark this node as a *block node* and this situation as a *block situation*. In this situation, the *step back & mark* course will start. The *block node* will step back to its previous-hop node, which will attempt to find another available neighbor as next-hop node. This course will be repeatedly executed until a node successfully finds a next-hop node to convert back to the *greedy forwarding* course.

4.2 Path Optimization

Though our work use 2-hop neighborhood, path circles also appears. To eliminate the path circles and optimize the found routing path with the least number of hops, we introduce the *label based optimization*. The principle of the *label based*

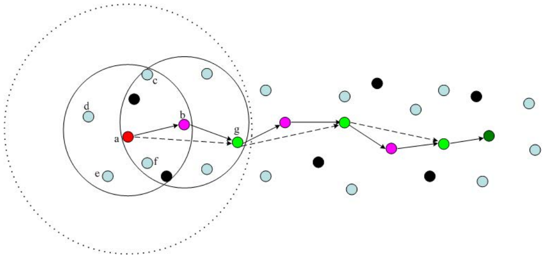


Fig. 2. 2-hop geographic forwarding example: Node a choose 2-hop neighbor g as its next-hop which is closest to the sink among all a's 1-hop and 2-hop neighbors. Once choose g, we have to select b as an intermediate 1-hop direct neighbor.

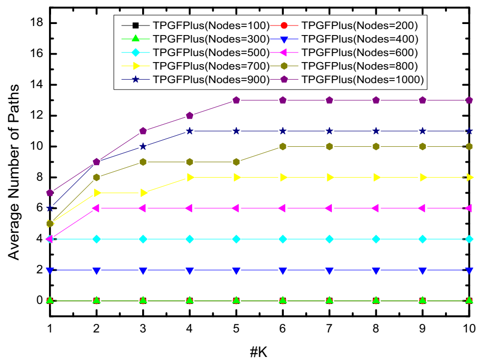
optimization is: Any node in a path only relays the acknowledgement to its one-hop neighbor node that has the same path number and the largest node number. A release command is sent to all other nodes in the path that are not used for transmission. These released nodes can be reused for exploring additional paths. After receiving the successful acknowledgement, the source node then starts to send out data to the successful path with the pre-assigned path number.

5 Simulation Results

To evaluate the performance of TPGFPlus algorithm, we conduct extensive simulations in NetTopo [22]. The studied WSN has the network size: 800 m * 600 m. The number of deployed sensor nodes are increased from 100 to 1000 (each time increased by 100). The value of k in EC-CKN algorithm is changed from 1 to 10 (each time increased by 1), letting more nodes awake. For every number of deployed sensor nodes, we use 100 different seeds to generate 100 different network deployments, in which ordinary nodes are random distributed. A source node is deployed at the location of (50, 50), and a sink node is deployed at the location of (750, 550). The transmission radius for each node is 60 m. Each node is initialized with a certain amount of energy (100 Units) before deployment. The energy consumption is simulated to be 1 Unit for executing EC-CKN one time in each node. The following performance metrics are evaluated during the simulations:

5.1 The Average Number of Paths of TPGFPlus Algorithm

Fig. 3 shows the comparison of explored average number of paths by TPGF-Plus and TPGF algorithms when the value of k changes for different number of deployed nodes. We can see that TPGFPlus algorithm finds more transmission paths than TPGF. In addition, as shown in Fig. 3, when k exceeds 6, waking up more sensor nodes cannot always increase the number of found paths.



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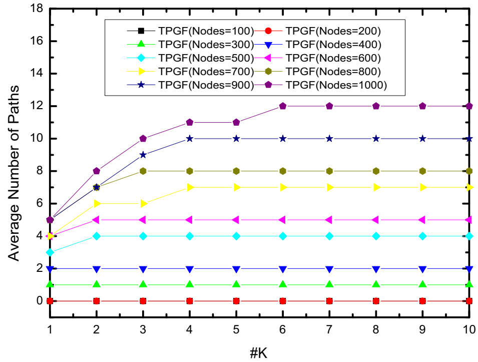


(b)

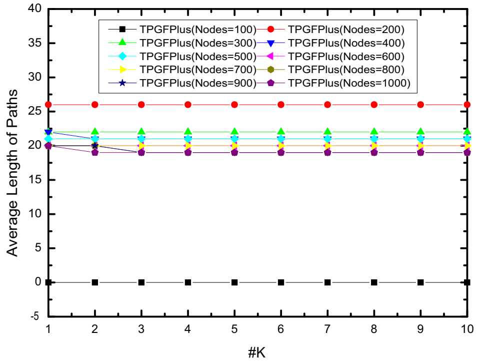
Fig. 3. Average number of paths found by TPGFPlus and TPGF vs. the value of k

5.2 The Optimized Average Hops of Paths of TPGFPlus Algorithm

Fig. 4 shows the optimized average hops of paths obtained by TPGFPlus and TPGF algorithms. Both algorithms are not dramatically affected by the changing value of k. But our TPGFPlus utilizes 2-hop neighborhood information and performs better.

5.3 The Comparison of Network Lifetime of TPGFPlus and TPGF Under EC-CKN and CKN Algorithms

The network lifetime in both EC-CKN and CKN based WSNs are represented by the number of epochs. By executing TPGFPlus and TPGF under the same



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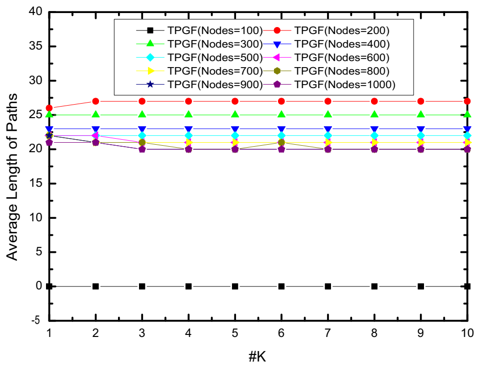
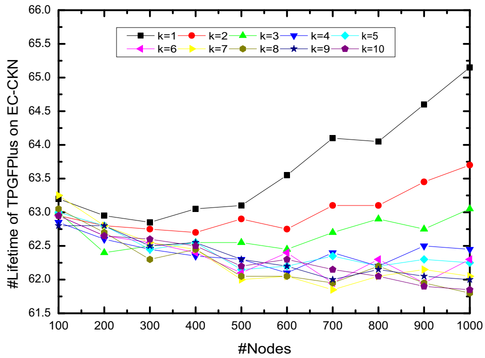


(b)

Fig. 4. Average hops of paths found by TPGFPlus and TPGF vs. the value of k

situation, simulation results in Fig. 5 reveals that our algorithm incurs no additional energy consumption, while achieving better routing performance in terms of both average number and average hops of paths, but somewhat prolong network lifetime. In addition, Fig. 5 and Fig. 6 reflect that implementing EC-CKN sleep scheduling algorithm prolongs network lifetime over CKN algorithm. Furthermore, it confirms that decreasing the value of k, letting more nodes sleep can definitely prolong the network lifetime, particularly when network nodes are densely deployed.



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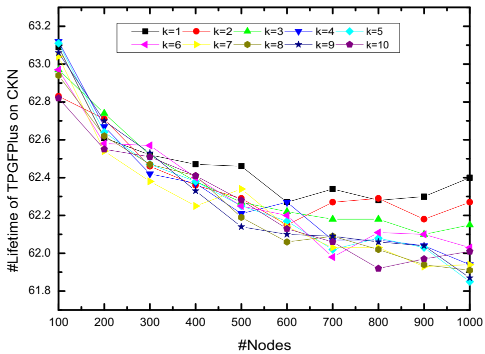


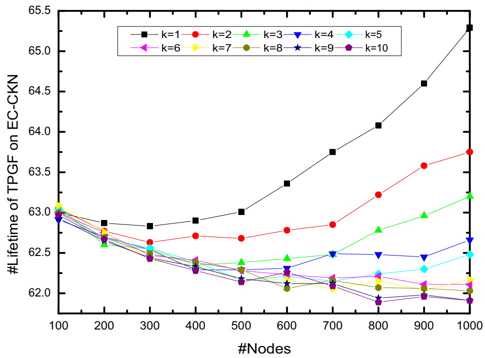
(b)

Fig. 5. Lifetime of WSNs while TPGFPlus based on EC-CKN and CKN algorithms are executed

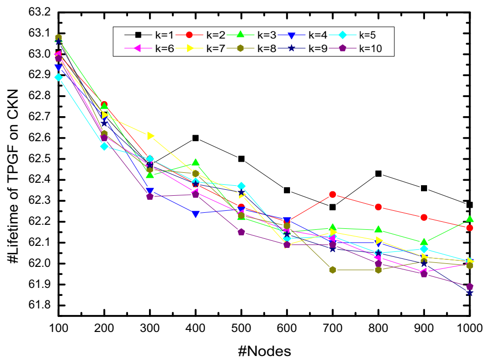
6 Conclusions

In this paper, TPGFPlus researches on 2-hop neighborhood information for geographic routing in EC-CKN applied duty-cycled WSNs. In summary, the major contributions of our work can be summarized as follows:

– To the best of our knowledge, few previous works consider utilizing 2-hop neighborhood information for geographic routing and solve the problem of dynamically finding or updating multipath in duty-cycled WSNs,
– Through extensive simulations we evaluate the performance of TPGFPlus and show that it achieves better routing performance in terms of both



(a)



(b)

Fig. 6. Lifetime of WSNs while TPGF based on EC-CKN and CKN algorithms are executed

average number and average hops of paths. Moreover, in EC-CKN based WSNs, 2-hop based geographic routing can prolong network, allowing more nodes to sleep while achieving the same desired average number of paths, compared with that of 1-hop based algorithm,

– Geographic routing in duty-cycled WSNs should be 2-hop based, but not 1-hop based, and it is mandatory for gathering 2-hop neighborhood information in most existing sleep-scheduling algorithms.

7 Future Work

As mentioned in previous subsection 4.1, there are several different policies for selecting the intermediate node in TPGFPlus. Particularly, our interests fall into the following three policies:

– Finding an intermediate 1-hop direct neighbor node which is closest to the 2-hop neighbor node. For the first forwarding policy, it will find a neighbor closest to the 2-hop neighbor node and make the maximum progress to the destination.
– Finding an intermediate 1-hop direct neighbor node which forwards packet from current node to its 2-hop neighbor node with the shortest distance. The second forwarding policy attempts to minimize total geographical distance between the source node and the sink.
– Finding an intermediate 1-hop direct neighbor node with the most remaining energy, or the best link quality (interference-minimized), or even the optimal multi-factor weighted cost function value, and so on.

In this paper, due to space limitation, we research on the first policy and provide its simulation results. For future works, we will study other policies and provide comparison among the different policies.

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