Sleep Scheduling Towards Geographic Routing in Duty-Cycled Sensor Networks

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***Abstract*—This paper focuses on improving the geographic routing performance of the two-phase geographic greedy forwarding (TPGF) in duty-cycled wireless sensor networks (WSNs) and proposes a geographic routing oriented sleep scheduling (GSS) algorithm. The algorithm analysis and simulation results show that GSS can shorten the length of the first explored transmission path of TPGF, compared with the connected-k neighborhood (CKN) algorithm.**

***Index Terms*—Geographic Routing; TPGF; Duty-Cycle; WSNs; CKN**

I. The research problem

Connected-k neighborhood (CKN) is a sleep scheduling algorithm proposed by Nath *et al.* in [1] for wireless sensor networks (WSNs) with duty-cycle. It aims at allowing only a portion of sensor nodes to be asleep to save energy consumption but the whole network is still connected by the awake nodes. Specially, the asleep or awake state of a node is decided locally by the number and connectivity status of the node's currently awake neighbor nodes to make the network connected, while every node is also sleep scheduled to have some certain number (k) awake neighbor nodes. Moreover, the number of asleep nodes in a CKN based WSN can be decreased by increasing the k in CKN. One example of a CKN based WSN with different k is shown in Fig. 1.

Two-phase geographic greedy forwarding (TPGF) [2] is one of the earliest geographic routing algorithms designed for facilitating stream transmission in WSNs and it focuses on exploring the maximum number of optimal node-disjoint routing paths while minimizing the length of paths. Particularly, a greedy forwarding principle and a step & mark approach are utilized in the first phase of TPGF to explore the possible delivery guaranteed routing path while bypassing holes. And a label based method is used in the second phase of TPGF for optimizing the found routing path with the least number of hops. Furthermore, TPGF has the following three unique properties. First, it is a pure geographic greedy forwarding routing algorithm, which does not include the face routing concept. Second, it does not require the computation and preservation of the planar graph [3] [4] in WSNs, making it have a natural advantage to explore more node-disjoint routing paths. Third, it does not have the well-known local minimum

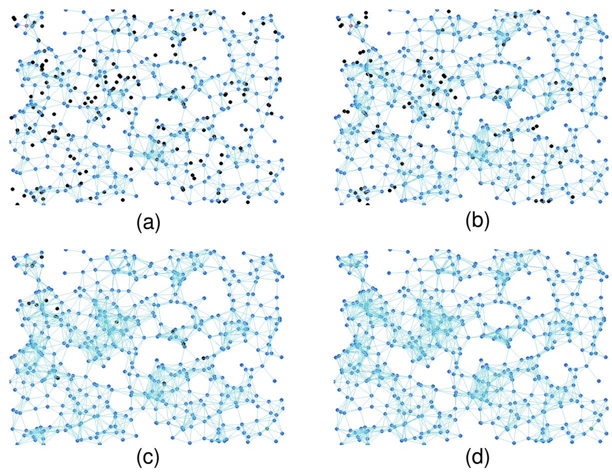

Fig. 1. One example of a CKN based WSN with different k. There are total 500 nodes and the k in CKN is 1, 2, 4, 8 in (a) (b) (c) (d), respectively. The red node is the source node and the green node is the sink node. The black nodes are asleep nodes and the blue nodes are awake nodes. The line between two nodes means they are neighbors. When the k in CKN increases, the number of asleep nodes decreases.

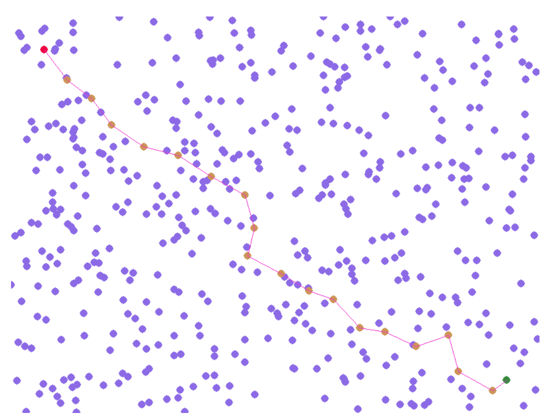

Fig. 2. One example of the first transmission path from a source node (red color) to the sink node (green color) explored by TPGF in an always-on WSN. There are total 500 sensor nodes and they are all awake.

problem [3] [4], which may make a node cannot find the next-hop node that is closer to the sink than itself. One example of the first transmission path explored by TPGF is presented in Fig. 2.

In [5], where the TPGF is implemented in the CKN based WSNs, we found that sleeping nodes can seriously decrease the number of transmission paths as well as increase the average length of transmission paths. In this paper, we are extremely interested in improving the geographic routing performance when executing TPGF in duty-cycled WSNs. Specially, our interest falls into the following aspect:

- How to revise the CKN algorithm to shorten the length of the first transmission path explored by TPGF while keeping the major features of original CKN algorithm unchanged?

II. Proposed Method

We incorporate both the connectivity and geographic routing requirement while designing the sleep scheduling algorithm. Specially, considering that the network should be connected by the awake nodes after sleep scheduling so that data can be transmitted unrestrictedly and sensor nodes will choose the neighbor node which is closest to the sink among all neighbor nodes to transmit data during geographic routing, we strategically take account of the geographic information of sensor nodes and make the potential nearest neighbor nodes from sink continue to be awake, although the original CKN already decides the node to be asleep without impairing the network connectivity.

We define our new method as geographic routing oriented sleep scheduling algorithm (GSS) and the pseudocode of GSS is shown below. During the first part of GSS, the geographic location (e.g., g_u) of each node u is obtained (Step 1 of first part) and the potential nearest neighbor to the sink for each node is identified (Step 3 of first part). In the second part of GSS, a random rank $rank_u$ of each node u is picked (Step 1 of second part) and the subset C_u of u's currently awake neighbors having rank $< rank_u$ is computed (Step 5 of second part). Before u can go to sleep, it needs to ensure that (1) all nodes in C_u are connected by nodes with rank $< rank_u$ (2) each of its neighbors has at least k neighbors from C_u and (3) it is not the potential nearest neighbor node for other nodes (Step 6 of second part). The pseudocode without the underline are the original CKN algorithm.

Pseudocode of GSS algorithm

First: Run the following at each node u.

1. Get its geographic location g_u.
2. Broadcast g_u and receive the geographic locations of its all neighbors A_u. Let G_u be the set of these geographic locations.
3. Unicast a flag to w, $w \in A_u$ and g_w is the closest to sink in G_u.

Second: Run the following at each node u.

1. Pick a random rank $rank_u$.
2. Broadcast $rank_u$ and receive the ranks of its currently awake neighbors N_u. Let R_u be the set of these ranks.
3. Broadcast R_u and receive R_v from each $v \in N_u$.
4. If $|N_u| < k$ or $|N_v| < k$ for any $v \in N_u$, remain awake. Return.
5. Compute $C_u = \{v | v \in N_u \text{ and } rank_v < rank_u\}$.
6. Go to sleep if both the following conditions hold. Remain awake otherwise.
    - Any two nodes in C_u are connected either directly themselves or indirectly through nodes within u's 2-hop neighborhood that have $rank$ less than $rank_u$.
    - Any node in N_u has at least k neighbors from C_u.
    - It does not receive a flag.
7. Return.

III. Evaluation

To further demonstrate the effectiveness of our GSS compared with CKN, we conduct extensive simulations in NetTopo[1] [6]. The network size is 800×600 m^2. The number of deployed sensor nodes ranges from 100 to 1000 (each time increased by 100). The value of k in CKN is changed from 1 to 10 (each time increased by 1). For every number of deployed sensor nodes, 100 different network topologies are generated using 100 different seeds and the transmission radius of each node is 60 m. A source node is deployed at the location (50, 50) and a sink node is deployed at the location (750, 550). One example of the first transmission path from source node to sink node explored by TPGF in GSS based WSNs is shown in Fig. 3. The performance with respect to the length of the first transmission path explored by TPGF in GSS and CKN based WSNs as well as the asleep rate of sensor nodes in GSS and CKN based WSNs are presented in Fig. 4.

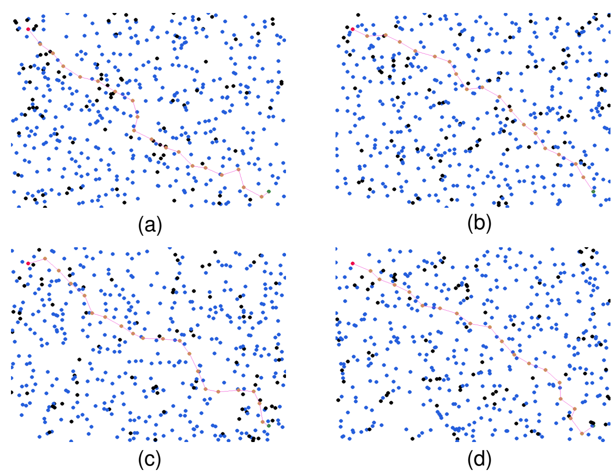

Fig. 3. One example of the first transmission path from a source node (red color) to the sink node (green color) explored by TPGF in GSS based WSNs. There are total 500 sensor nodes and the k in CKN is 1. The black nodes are asleep nodes and the rest nodes are awake nodes.

From Fig. 4(a) and Fig. 4(b), we can clearly see that the average length of the first explored transmission path of TPGF in GSS based WSNs is nearly always shorter than that in CKN based WSNs. It is because there are more awake nodes (especially the potential nodes closest to sink) in GSS based WSNs than that in CKN based WSNs, as shown in Fig. 4(c) and Fig. 4(d), respectively. In addition, in terms of the same number of nodes, the length of the first explored transmission path of TPGF in Fig. 4(a) and Fig. 4(b) decreases when the

[1] NetTopo (available online at http://sourceforge.net/projects/nettopo/) is an open source software on SourceForge for simulating and visualizing WSNs.

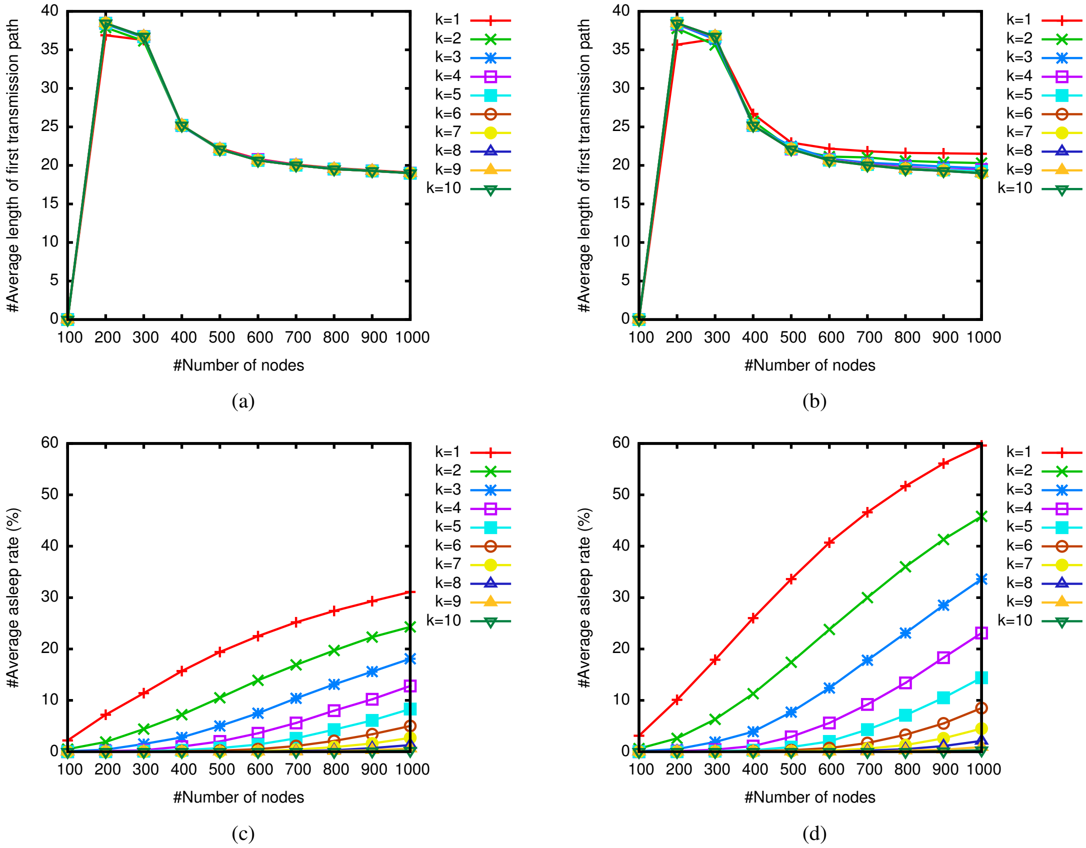

Fig. 4. Performance of GSS (a) (c) and CKN (b) (d). Fig. 4 (a) and (b) are the comparison for the first transmission length of running TPGF in GSS and CKN based WSNs. Fig. 4 (c) and (d) are the comparison for the asleep rate of sensor nodes in GSS and CKN based WSNs.

value of k in both algorithms increases, as growing k in both algorithms can make more nodes be awake shown in Fig. 4(c) and Fig. 4(d).

IV. Conclusion

Aiming at improving geographic routing performance in duty-cycled wireless sensor networks (WSNs), this paper puts forward a geographic routing oriented connected-k neighborhood sleep scheduling (GSS) algorithm for the two-phase geographic greedy forwarding (TPGF). By making less potential nodes closest to sink go to sleep, the above algorithm analysis and simulation results reveal that: the proposed GSS algorithm can own a better first transmission path when transmitting data in duty-cycled WSNs with TPGF, in contrast with the original connected-k neighborhood (CKN) algorithm.

V. Future work

The efficiency of our proposed GSS algorithm is closely related with the exactness of the positioning information. As for our future work, we plan to employ some position approaches (e.g., [7]) to further enhance the robustness and reliability of our method.

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References

[1] S. Nath and P. B. Gibbons, "Communicating via fireflies: Geographic routing on duty-cycled sensors," in *Information Processing in Sensor Networks (IPSN)*, Cambridge, Massachusetts, USA, April 2007, pp. 440–449.

[2] L. Shu, Y. Zhang, L. T. Yang, Y. Wang, M. Hauswirth, and N. Xiong, "Tpgf: Geographic routing in wireless multimedia sensor networks," *Telecommunication Systems*, vol. 44, no. 1–2, pp. 79–95, 2010.

[3] B. Karp and H. T. Kung, "Gpsr: greedy perimeter stateless routing for wireless networks," in *The Annual International Conference on Mobile Computing and Networking (MobiCom)*, Boston, Massachusetts, USA, August 2000, pp. 243–254.

[4] H. Frey and I. Stojmenovic, "On delivery guarantees of face and combined greedy-face routing in ad hoc and sensor networks," in *The Annual International Conference on Mobile Computing and Networking (MobiCom)*, Los Angeles, CA, USA, Spetember 2006, pp. 390–401.

[5] L. Shu, Z. Yuan, T. Hara, L. Wang, and Y. Zhang, "Impacts of duty-cycle on tpgf geographical multipath routing in wireless sensor networks," in *IEEE International Workshop on Quality of Service (IWQoS)*, Beijing, China, June 2010, pp. 1–2.

[6] L. Shu, M. Hauswirth, H.-C. Chao, M. Chen, and Y. Zhang, "Nettopo: A framework of simulation and visualization for wireless sensor networks," *Elservier, Ad Hoc Networks*, 2010.

[7] T. Watteyne, D. Barthel, M. Dohler, and I. Augé-Blum, "Sense and sensitivity: a large-scale experimental study of reactive gradient routing," *Journal of Measurement Science and Technology*, vol. 11, no. 12, 2010.