Energy-Efficient Algorithm Based on Gradient Based Routing in Wireless Sensor Networks

Lusheng Miao, Karim Djouani, Anish Kurien, Guillaume Noel
French South African Institute of Technology (F'SATI)
Tshwane University of Technology, P. O. Box X680, Pretoria South Africa
Tel: +27 12 3824809, Fax: +27 12 3825294
email: miaolusheng@hotmail.com, djouani@gmail.com , kurienam@tut.ac.za, noelg@tut.ac.za

Abstract-Energy efficiency is one of the critical parameters for the routing protocol in wireless sensor networks. In this paper, two energy efficient algorithms based on the Gradient-based routing (GBR) protocol are proposed. First, a Competing algorithm for GBR (GBR-C) is proposed. The core idea in this algorithm is to forward the message to more than one next hop nodes and hence reduce the retransmission and save the related energy. Secondly, a Refilling algorithm for GBR (GBR-R) is proposed which can prolong the lifetime of a network by 'refilling' new nodes into the network, a process in which new nodes are refreshed in the network. Simulation results show that GBR-C performs better than GBR in terms of energy efficiency when the transmission probability is less than the threshold which is *p=0.75* obtained in this paper. Furthermore, the network lifetime is prolonged up to 63% when adopting GBR-R in the scenario that the nodes which are near the sink die before others.

Index Terms—Energy Efficiency, Gradient-based Routing, Wireless Sensor Networks.

I. INTRODUCTION

Wireless Sensor Networks (WSNs) consist of intelligent sensor nodes with sensing, computation and wireless communication capabilities. Routing in WSNs is challenging since sensor nodes are strongly constrained in terms of energy, computational power, and storage capacities. The limited energy supply is critical for the development of WSNs. As a result, the core question to be answered for WSNs is: How can energy be saved in order to prolong the lifetime of the network?

Gradient-based routing (GBR) is an energy efficient routing protocol for WSNs proposed in [1]. In [2], the authors show that GBR is reliable in choosing the shortest route to a sink while balancing the energy of the whole network. However, a few shortcomings exist in the GBR scheme. Firstly, nodes deliver the message in a point to point manner and do not use the broadcast nature of wireless networks. Wireless sensors are usually equipped with Omni-directional antennas and are placed in environments with the potential of high data retransmissions. This in turn creates significant multipath transmissions so that if one node sends a message, all its neighbours have the potential of receiving this message. The retransmission can be reduced if the best node which has already received this message can be selected from its neighbours to transmit this message forward. Secondly, the nodes which are near the sink will be overused and will die before others. The failure of these nodes leads to the failure of the entire network.

In this paper, two energy-efficient algorithms based on the GBR protocol are proposed to overcome the above-mentioned shortcomings of GBR. Firstly, the use of a competing algorithm to choose the best relay node to forward the packet which reduces the retransmission probability and saves the energy of the relative nodes is proposed. Secondly, new nodes are inserted into the network to prolong the lifetime of the network which can avoid the phenomenon that network dies due to the death of some bottleneck nodes. The rest of the paper is organized as follows, Section II discusses related work. In Section III, the proposed energy-efficient algorithms are discussed. In Section IV, simulation results are presented. In Section V, conclusions and future work are given.

II. RELATED WORK

A. *Competing algorithm*

The basic idea of a competing algorithm is to exploit the spatial diversity of the wireless medium by involving a set of candidate forwarders instead of only one as in traditional routing. One forwarder which has already received the packet is then chosen as the actual relay.

In [3], the authors propose a contention-based forwarding scheme (CBF). In CBF, the source node broadcasts packets to all its neighbours and then selects one best node to forward the packet. Furthermore, the authors propose three suppression algorithms: Basic suppression scheme, Area-based suppression, and Active selection. The aim is to prevent multiple next hops and thereby reduce packet duplication. However, duplication still occurs in the Basic suppression scheme and Area-based suppression. Active selection can prevent all forms of packet duplication but with the cost of additional control messages.

In [4], the authors propose a novel forwarding technique based on geographical location of the nodes involved and random selection of the relaying node via contention among receivers. The receivers which are closer to the destination have the higher priority to forward the packet which also means that the nodes closer to the destination are always selected and overused. As a result, these nodes will die before others.

In [5], the authors propose ExOR, an integrated routing and MAC protocol that increases the throughput of large unicast transfers in multi-hop wireless networks. ExOR operates on batches of packets. The source nodes include a list of candidate forwarders in each packet prioritized by closeness to the destination. The receivers with highest priority pass on packets. The remaining forwarder nodes then pass on packets which have not been forwarded by the higher priority forwarders.

In [6], the authors propose an algorithm to set the forwarder priorities depending on the expected advancement (EPA) rate in order to achieve the maximum end-to-end throughput.

All of these works are based on the basic idea of a competing algorithm. However, none of them consider the energy efficiency of the network. The source node broadcasts packets to all its neighbours which wastes the energy of the related nodes.

B. *Mixed strategy algorithm*

GBR has a limitation that bottleneck nodes (or bottleneck regions) in the routing graph tend to be overused and run out of energy before others [7]-[10]. The authors in [11] improve the GBR protocol by using a mixed strategy. The core of the proposed algorithm in [11] is to transmit the message directly to the base station to save energy of the nodes which are near the sink (bottleneck regions). The authors in [11] prove that the proposed algorithm can improve the lifetime of the WSNs. However, for the whole network, it does not save energy; it uses more energy from other nodes to save the energy of the nodes which are close to the sink. This paper proposes two algorithms aimed at reducing the energy used by the network as a whole.

III. Proposed Algorithms

In this section, two energy-efficient algorithms based on GBR are presented:

1. GBR-C: In this algorithm, a competing algorithm for GBR is designed.
2. GBR-R: This algorithm is designed for managing new nodes added to the network which refills the network when the nodes close to the sink die.

A. *GBR-C*

In this paper, the basic idea of the competing algorithm based on GBR is to reduce the retransmission in order to save the energy of the network. There are two questions that need to be answered in this algorithm. First of all, how many candidate forwarders should be involved for each hop transmission? Because receiving packets also consume energy, hence, broadcasting packets to all neighbours may waste energy. Secondly, the decision on how to choose the best nodes to forward the packet without duplication needs to be answered.

In order to answer the first question, the energy consumption for GBR is analyzed in order to determine the number of candidate forwarders. Assume that the power consumption of sending is p_{TX} while the energy overhead of receiving is p_{RX}. Assume that the data message size is M and the bit rate is *Bitrate*. The candidate forwarders number is n. The transmission probability p is referred to as the probability for one link that the receiver receives the message successfully. Then the one hop transmission energy consumption can be determined as

$$E = \frac{(p_{TX} + n*p_{RX})}{\text{Bitrate}}\left(\frac{M}{1-(1-p)^n}\right) \quad n = 1,2,3,4,5. \quad (1)$$

Assuming the small, low-power sensors node Mica2's power consumption model presented in [13] is used and p is set as $0.4 \leq p \leq 1$, then the energy consumption for n from 1 to 5 can be determined. The results obtained are shown in Figure1.

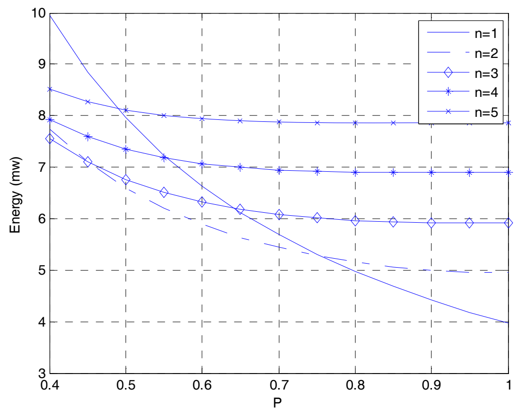


Figure 1: The energy consumptions ($p_{TX} = 65mw/sec$, $p_{RX} = 21mw/sec$, *M=800 bits*, *Bitrate=19200 bits/sec*.)

It can be seen that energy can be saved if we set *n*=2 for *P*<0.75. This can save up to 23% energy for one hop transmission. Furthermore, it can also be seen that it is enough to set at most two candidate forwarders when $0.45 \leq p \leq 1$. In this work, the setting up of at most two candidate forwarders according to the transmission probability *P* as shown in Table1 is considered. Hence two candidate forwarder rather than one will be considered when *P*<0.75.

Table 1: Candidate Forwarder Number.

Transmission Probability	Candidate Forwarders Number
$P \geq 0.75$	n=1
$P < 0.75$	n=2

The second question can be answered by the details of the competing algorithm. Before this algorithm is discussed, the three kinds of messages used are defined.

DATA: This refers to the data packet which needs to be transmitted through the network.
ACK&DACK: These are the transmission control characters used to indicate that a transmitted message was received uncorrupted or without errors. The receiver sends an ACK or DACK to the sender depending on the destination nodes number of the received message. If the message only has one destination node, then the receiver sends an ACK. Otherwise, it sends a DACK.
TOGO: This is a signal that asks a node to transmit the data message forward.

The operation of the competing algorithm is as follows:

1. The source node sends a data message to receivers (candidate forwarders).
2. The receiver receives the message. If the message is received successfully, then it will check the destination address list of this message.
3. If the destination address number is one, then the receiver transmits this message to the sink immediately. In addition, for a reliable communication network, the receiver also needs to send an ACK message to the sender.
4. If the destination address number is two, then the receiver sends a DACK message to the source. Then, a waiting time T (for example 1s) is set.
5. The source receives the message and then checks the message type. If it is an ACK message, it then deletes it. If it is a DACK message, then the source node checks if it is the first DACK message for the data message which it sent before. If it is the first, then the source node sends a TOGO message to the sender of the DACK message. Otherwise, it deletes it.
6. If the receiver receives a TOGO message in the waiting time T, then it transmits the message to the sink; otherwise, the message is deleted.

The above algorithm which adopts a competing algorithm for the GBR protocol is referred to as GBR-C.

B. *GBR-R*

In the GBR scheme, bottleneck nodes (or bottleneck regions) in the routing graph tend to be overused and run out of energy before others. The nodes near the sink are bottleneck nodes because all the data need to pass through them to reach the sink. The failure of these nodes leads to the failure of the entire network. In this section, an algorithm is designed for managing new nodes added to the network which makes the network to be refilled when the nodes closer to the sink are dead.

The basic idea of this algorithm is that the sink node keeps monitoring its neighbours. Then an alarm message is sent out to remind the network that it needs to fill the network with new nodes when the sink node has only one neighbour left.

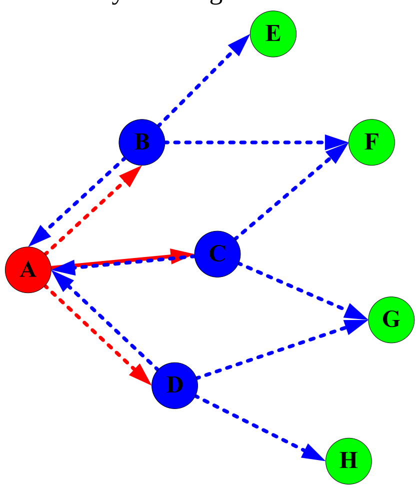


Figure 2: A simple wireless sensor network

Considering a simple wireless sensor network as shown in Figure 2, the sink node A has three neighbours node B, C and D. In the GBR framework, the sink needs to broadcast an interest message through the entire network and then each node needs to rebroadcast this message again. Then, it can be observed that node A also can receive interest messages that are rebroadcasted from node B, C and D. Hence, the sink node A can record the neighbours ID into a neighbour table as shown in Table 2.

Table 2: The Neighbours Table.

SN	ID
1	B
2	C
3	D

In GBR, the node broadcasts a DEATH message when it is going to die. Then, each node that received the death message deletes the related node ID from its neighbour table. Suppose that node C and D are dead. Then, node A deletes C and D from its neighbour table. It is easy to see that the sink will be disconnected from the other nodes if node D is dead which means that the whole network will be dead too. Then, the sink sends an alarm message once it finds that there is only one node left in its neighbour table.

The operation of this algorithm is as follows:

1. The sink broadcasts an interest message.
2. The sink's neighbors receive the interest message and rebroadcast it again.
3. The sink receives the interest message from its neighbors and records the neighbors ID into a neighbor table.
4. The sink maintains the neighbor table. A neighbor ID will be deleted if the sink receives a DEATH message from this neighbor.
5. When there is only one neighbor left in a sink's neighbor table, an alarm message is sent out to remind nodes to refill new nodes into the network.
6. Sinks rebroadcast interest message after the network is refilled.

The new GBR protocol which adopts the above algorithm is referred to as GBR-R.

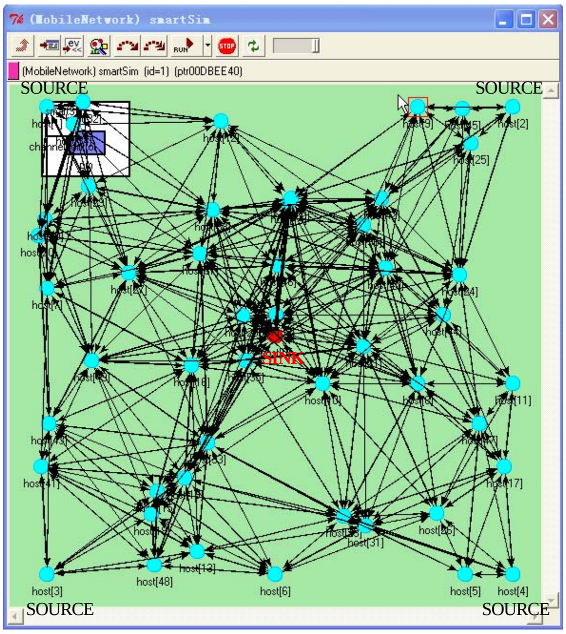
IV. SIMULATIONS &RESULTS

The protocols GBR-C and GBR-R were implemented in the OMNeT++ network simulator. The results obtained were compared with the GBR protocol.

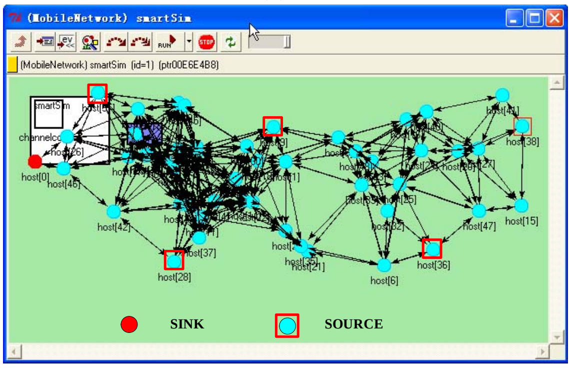
A. Simulation Configurations

In our simulations, two wireless sensor networks with 50 static sensor nodes were deployed inside a rectangle field and were considered to be randomly distributed. Two scenarios are depicted in Figure 3, Figure 3(a) with one sink and four sources, Figure 3(b) with one sink and five sources.

The EnergyFramework-2.0 provided in the OMNeT++ is used. The energy consumption is further set for sending time and receiving time as 65mw/sec and 21mw/sec respectively (the same parameters as Mica2's power consumption model). In addition, it has been shown in paper [12] that compared to sending and receiving, the sleeping time consumption is very small. As a result, the sleeping time energy consumption is ignored and set to 0. The B-MAC layer presented in [14] is used. The MAC bit rate and the message length are set as discussed in Section III.



(a)



(b)

Figure 3: The simulation networks: (a) One sink with four sources; (b) One sink with five sources.

B. Results and Discussion

Figure4 shows the remaining energy for the network (a) after the simulation.

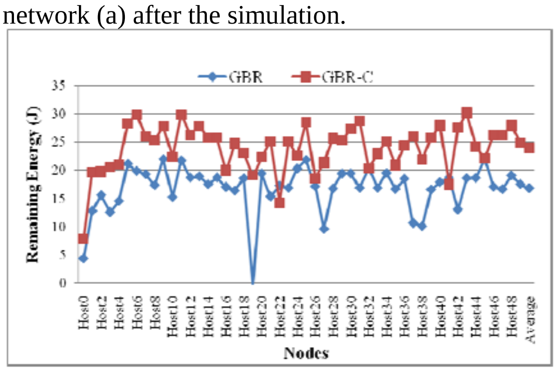


Figure4: The remaining energy for random network (The initial energy capacity for each node is 40 J).

In this network, the transmission probability for each node is $0.1 \leq p \leq 1$, the average transmission probability for the whole network is p=0.63 which is less than the threshold 0.75. It can be observed that GBR-C uses less energy than GBR to deliver the same number of messages when the probability P is less than the threshold. Compared to GBR, GBR-C can save up to 30% energy for this random network.

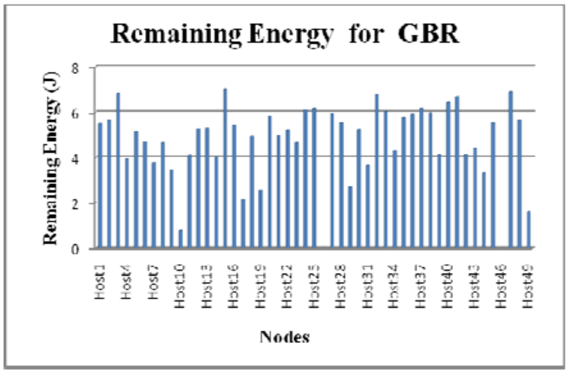


Figure5: The remaining energy for GBR when the network is dead due to the death of the sink's neighbours (Host(26) and Host(46)).

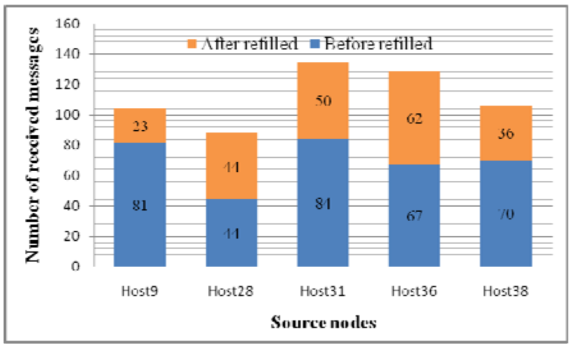


Figure6: The number of received messages from different sources.

Figure 5 shows the remaining energy of the network for GBR when the network is dead where the initial energy capacity is 30J for the sink and 10J for the other nodes. It can be observed that there is nearly 47% energy remaining for the whole network when the network is dead because of the death of the sink's neighbours. Figure 6 shows the number of messages received by the sink from different sources before and after the network is refilled. It can be observed that network lifetime was prolonged with the GBR-R algorithm. Compared to GBR, the lifetime of the whole network was prolonged up to 63%.

V. CONCLUSIONS

In this paper, two energy-efficient algorithms based on the GBR protocol were proposed to overcome the shortcomings of GBR and conserve energy in the network. The competing algorithm (GBR-C) aims to reduce the retransmission attempts and save energy by considering two next hop nodes rather than one. Simulation results show the proposed scheme has higher energy efficiency than the GBR when the transmission probability is less than the threshold which is $p=0.75$ obtained in this work. The refilling algorithm (GBR-R) aims to solve the bottleneck problem in GBR and prolong the network lifetime. Simulation results show the network lifetime is prolonged up to 63% by adopting GBR-R in the scenario that the nodes which are near the sink die before others. In this paper most of the work is focused on energy efficiency. Future studies will be carried out to do comprehensive evaluation and to find the transmission probability threshold more accurately.

VI. ACKNOWLEDGEMENTS

The authors would like to thank F'SATI at Tshwane University of Technology and the Telkom Centre of Excellence program for making this research possible.

Lusheng Miao is presently studying towards his Master of Technology degree at F'SATI at Tshwane University of Technology. His research interests include network routing and coding in wireless sensor networks

REFERENCES

[1] C. Schurgers and M.B. Srivastava, "Energy efficient routing in wireless sensor networks," in the MILCOM Proceedings on Communications for Network-Centric Operations: Creating the Information Force, McLean, VA, 2001.

[2] Al-Karaki, J.N and Kamal, A.E, "Routing techniques in wireless sensor networks: a survey," in the Wireless Communications, IEEE: 2004, page(s): 6- 28.

[3] H. Fussler, J. Widmer, M. Kasemann, M. Mauve, and H. Hartenstein. "Contention-based forwarding for mobile ad-hoc networks," Elsevier's Ad Hoc Networks, vol. 1, no. 4, pp. 351–369, 2003.

[4] M. Zorzi and R. R. Rao. "Geographic random forwarding (geraf) for ad hoc and sensor networks: energy and latency performance," IEEE, 2003.

[5] S. Biswas and R. Morris, 2005. "Exor: Opportunistic multi-hop routing for wireless networks," in SIGCOMM'05, Philadelphia, Pennsylvania.

[6] K. Zeng, W. Lou, and H. Zhai, 2008. "On end-to-end throughput of opportunistic routing in multirate and multihop wireless networks," in Proceedings of the Annual Joint Conference of the IEEE Computer and Communications Societies (INFOCOM '08), pp. 1490-1498, Phoenix, Ariz, USA.

[7] C. Efthymiou, S. Nikoletseas, and J. Rolim, "Energy balanced data propagation in wireless sensor networks," invited paper in the Wireless Networks Journal, Special Issue on "Best papers of the 4th Workshop on Algorithms for Wireless, Mobile, Ad Hoc and Sensor Networks (WMAN2004)" to appear in 2005.

[8] P. Leone, S. Nikoletseas, and J. Rolim, "An adaptive blind algorithm for energy balanced data propagation in wireless sensor networks," presented at First International Conference on Distributed Computing in Sensor Systems (DCOSS), number 3560 in Lecture Notes in Computer Science. Springer Verlag, June/July 2005.

[9] O. Powell, P. Leone, and J. Rolim. "Energy optimal data propagation in wireless sensor networks," arXiv.org automated e-print archives, 2005.

[10] M. Singhand and V. Prasanna. "Energy-optimal and energy-balanced sorting in a single-hop wireless sensor network," presented at First International Conference on Pervasive Computing and Communications (PERCOM). IEEE, 2003.

[11] Powell, Olivier; Jarry, Aubin; Leone, Pierre and Rolim, José D.P., "Gradient based routing in wireless sensor networks: a mixed strategy," Comput. Res. Repos. 2005.

[12] Wei Ye, John Heidemann, and Deborah Estrin. "An Energy-Efficient MAC protocol for Wireless Sensor Networks," in Proceedings of the IEEE Infocom, pp. 1567-1576. New York, NY, USA, USC/Information Sciences Institute, IEEE. June, 2002.

[13] Shnayder, V., Hempstead, M., Chen, B., Allen, G. W., and Welsh, M. "Simulating the power consumption of large-scale sensor network applications," in Proceedings of the 2nd international Conference on Embedded Networked Sensor Systems (Baltimore, MD, USA, November 03 - 05, 2004).

[14] Joseph Polastre, Jason` Hill, David Culler. "Versatile Low Power Media Access for Wireless Sensor Networks," ACM Sensys, 2004.