Exponentially Aggressive Preservation of Nearly Depleted Nodes for Wireless Sensor Networks

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Abstract

In this paper, exponentially aggressive preservation of nearly depleted nodes is employed to discourage a node with considerably low residual energy from being selected as a routing node in wireless sensor networks (WSNs). Simulation model shows that geographical and energy aware routing (*GEAR) with dynamically adaptive transmission power (DATP) and exponentially aggressive preservation of nearly depleted nodes can send over 65% more packets than the GEAR for both uniform and non-uniform traffic regardless of network size. The exponentially aggressive preservation of nearly depleted node can be applied to various existing energy aware routing protocols to potentially extend the life-spans of WSNs.*

1. Introduction

The prolongation of the energy resource is very important research within WSNs. Energy savings can be achieved in routing protocol, and several approaches to energy aware routing algorithms in wireless networks have been proposed in the literatures [2, 3, 4, 5]. In [4], both the distance to the destination and the consumed energy of a node were considered in the route selection; however, it did not address routing with the presence of a communication hole. Geographical and energy aware routing (GEAR), proposed in [5], considered both the residual energy and the distance to the destination. It also addressed the routing with the presence of a communication hole. Existing energy aware routing algorithm could further extend the life-spans of WSNs if the energy of almost depleted nodes is used more conservatively.

The rest of this paper is organized as follows. An exponentially aggressive preservation of nearly depleted nodes is proposed and evaluated in Section 2 and 3, respectively. Section 4 summarizes our research and discusses some possible future works.

2. Exponentially Aggressive Preservation of Nearly Depleted Nodes

Energy-aware-routing schemes typically use the knowledge of depleted energy level and transmission cost per hop to preserve the life-span of the WSNs. If the residual energy of a node is considerably low, the node should receive extra care to prevent it from being selected as a part of the routing path so as to keep the connectivity of the WSNs. Motivated by this observation we propose a dynamically changing weighting factor of the residual energy to enhance the preservation of nearly depleted nodes. The proposed algorithm exponentially increases weighting factor of residual energy as the residual energy of each node falls below a pre-defined threshold value which can be set near a complete depletion of node energy. In this paper, we will use GEAR to illustrate the improvement of deploying our proposed scheme; however, the exponentially aggressive preservation of nearly depleted node can be applied to various existing energy aware routing protocols to potentially extend the life-spans of WSNs.

In GEAR, the next hop is determined by the smallest learned cost:

$$h(N,R) = \mathrm{c}(N,N_i) + h(N_i,R) \quad (1)$$

across all its neighbors. Learned cost is the combination of distance from sender to its neighbor N_i and residual energy of node N, $\mathrm{c}(N,N_i)$, and learned cost of N_i to the target region R, $h(N_i,R)$. If a node does not have $h(N_i, R)$ for N_i, it computes the estimated cost $c(N_i, R)$ of N_i as a default value for $h(N_i, R)$ as follows:

$$\alpha d(N_i, R) + (1\text{-}\alpha)e(N_i) \quad (2)$$

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where $d(N_i, R)$ is the normalized distance from N_i to the centroid C of region R and expressed as

$$d(N_i, R) = \frac{Distance \quad (N_i, R)}{Max_{\ N_j \in Nei\ (N)}(Distance \quad (N_j, R))} \quad (3),$$

and $e(N_i)$ is the normalized consumed energy at node N_i, and expressed as

$$e(N_i) = \frac{CE(N_i)}{Max_{N_j \in Nei(N)}(CE(N_j))} \quad (4)$$

where $CE(N_i)$ is the consumed energy at N_i, $Nei(N_j)$ is a set of neighbors of N, and α is a tunable weight from 0 to 1. If α is 1, learned cost is purely determined by the distance from the neighbors to the target region R.

GEAR calculates a learned cost with fixed weight for the distance between two nodes and a residual energy of node. With our scheme, GEAR algorithm will exponentially increases weighting factor of the residual energy at each node as the residual energy falls below a pre-defined threshold value. We refer the employment of our scheme to GEAR as GEAR+ throughout this paper. The threshold value can be set near a complete depletion of node energy. In particular, if a consumed energy of N_i, $CE(N_i)$ > threshold,

$$e(N_i) = \frac{CE\ (N_i) e^{(C(N_i) - threshold\ )\cdot 100 + 1}}{Max_{\ N_j \in Nei\ (N)}(CE\ (N_j))} \quad (5)$$

else

$$e(N_i) = \frac{CE(N_i)}{Max_{\ N_j \in Nei(N)}(CE(N_j))}.$$

3. Evaluation of Exponentially Aggressive Preservation of Nearly Depleted Nodes

Performance of power management in WSNs could be measured by total energy consumed in system or the number of packet being sent and/or received before network partition. We choose to measure the latter metric over the former one because it better depicts the life-span of the WSN.

3.1. Simulation Models

The number of nodes in the network ranges from 400 to 4800 nodes while its density is kept constant. For instance, the geometric area of a 600 node network is 1200 units by 1200 units square. This means one node exists per 2400 $units^2$ of area. We used this node density for all network configurations to investigate the performance of the fixed and dynamically adjustable transmission power (DATP) control. Energy level of each node is initialized to 1 joule. For the GEAR with a fixed transmission power, 0.001 joule is consumed for either transmitting or receiving a packet. For the GEAR with DATP, the energy required for sending a packet can range from 0 to 0.001 joule while the receiving energy is always fixed as 0.001 joule.

It is well known that the transmission power $Pt = PrD^{\alpha}$ is required to transmit a signal to the receiver where Pr is the receiving power and D is the distance from sender to receiver and the value of α depends on the transmission media and antenna characteristics [1]. Node's transmission range is fixed at a 100 unit distance across all simulations for the GEAR. For GEAR/GEAR+ with DATP, transmission range was changed based on the distance to the next node located within the maximum transmission range. In this experiment, an interference-free environment is assumed, and link error rate was ignored. Our intention is to measure the optimal performance gain of the proposed schemes over GEAR. The value α is set to 2, and *threshold* is set to 0.9 for GEAR+.

In this experiment, we conducted a high level simulation of GEAR, GEAR with DATP, and GEAR+ with DATP. We were only interested in how packet can be routed to a target region, and the packet dissemination of GEAR was not considered for our evaluation. Experiments were conducted to measure the number of packets successfully delivered before network is partitioned in both uniform and non-uniform traffic environments. The network is partitioned if all the given sources are partitioned from their respective destinations.

Uniform traffic experiment: Pairs of source nodes and target regions are uniformly distributed throughout the entire network. This experiment measures the performance of the network with applications requiring relatively uniformly distributed communication patterns.

Non-uniform traffic experiment: Source nodes are clustered so as to concentrate part of the traffic. This experiment measures the performance of the network where nodes near sources will relay high volume of packets originated from several sources. Such conditions exit in many circumstances in the real WSNs.

3.2. Experimental results

Figure 1 shows the result of the number of packets delivered successfully before network partitioning for the uniform traffic experiment. This figure shows the relation between the node density and the total number of packet to be sent from 10 randomly chosen source and target region pairs. Our implementation of GEAR has a slightly different result from the result in [5] because we did not implement the packet dissemination at the target region. GEAR with transmission power control can send over 55% more packets than the GEAR without transmission power control throughout all sizes of networks measured. Furthermore, the GEAR+ with transmission power control can send over 75% more packets than the GEAR without transmission power control throughout all size of networks measured.

Figure 2 shows the result of the number of packets successfully delivered before network partitioning for the non-uniform traffic experiment. The relative performance gain of GEAR/GEAR+ with DATP over GEAR was similar to uniform traffic experiment. In summary, GEAR/GEAR+ with DATP can send an average of 50% and 62% more packets, respectively, than GEAR. Our experiments demonstrate that aggressively preserving almost depleted nodes is effective for extending the life-spans of WSNs regardless of network size.

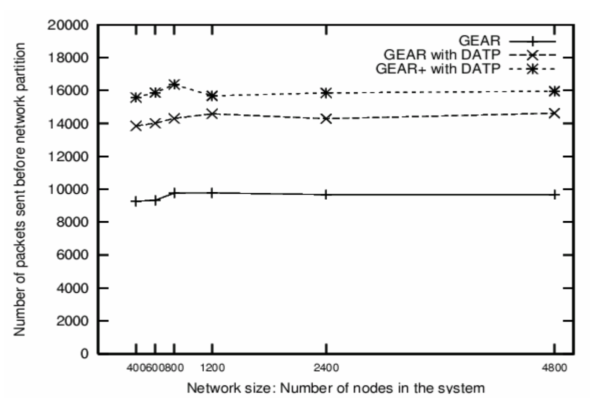

Figure 1. Total number of packets sent before network partition (uniform traffic)

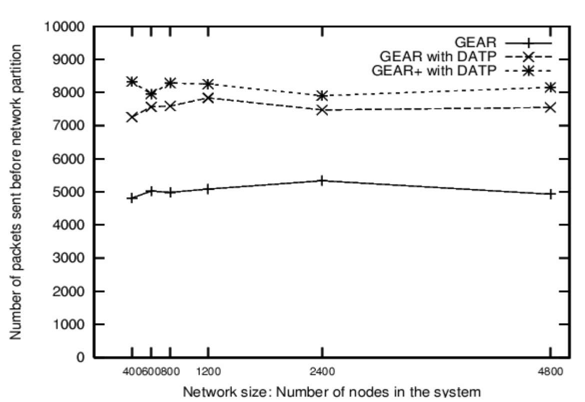

Figure 2. Total number of packets sent before network partition (non-uniform traffic)

4. Summary and Future Work

Exponentially aggressive preservation of nearly depleted nodes to extend the life-spans of WSNs was proposed and evaluated in this paper. Simulation model for GEAR with the proposed method (GEAR+) was developed to evaluate its performance. Simulation results demonstrate that the GEAR with DATP can send about 50% more packets for both uniform and non-uniform traffic for all network size examined. GEAR+ with DATP further improves the performance over GEAR with DATP for all experiments conducted.

Our simulation evaluations demonstrate that GEAR+ with DATP can significantly extend the life-spans of WSNs. Further evaluation is needed to obtain more accurate performance gain of the proposed mechanism. We intend to further investigate the performance of the proposed transmission power control and the routing protocol in a more dynamic environment including interference and the energy consumptions incurred by the exchange of information among neighboring nodes. Though an exponentially aggressive preservation of nearly depleted nodes is adapted only to GEAR in this paper, the same approach can be applied to various energy aware routing protocols to potentially extend the life-spans of WSNs. We are currently investigating the effect of employing our approach on other existing energy aware routing protocols.

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