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A Study on Energy-Balanced Transmission policies for Maximize Network Lifetime in Wireless Sensor Networks

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Abstracts

Unbalanced energy consumption is an inherent problem in wireless sensor networks characterized by multihop routing and many-to-one traffic pattern, and this uneven energy dissipation can significantly reduce network lifetime. Existing transmission policies, however, cause an extremely unbalanced energy usage that contributes to early demise of some sensors reducing overall network's lifetime drastically. In this paper, we study the problem of maximizing network lifetime through balancing energy consumption for uniformly deployed data-gathering sensor networks. Considering cocentric rings around the sink, we decompose the transmission distance of traditional multihop scheme into two parts: ring thickness and hop size, analyze the traffic and energy usage distribution among sensors and determine how energy usage varies and critical ring shifts with hop size. we use three transmission policies, namely, fixed hop size (FHS), synchronous variable hop size (SVHS), and asynchronous variable hop size (AVHS) transmissions. These transmission policies differ in terms of their degree of flexibility in using variable transmission ranges and their associated duty cycles among sensor nodes. Moreover, we presented distributed heuristics for SVHS and AVHS transmissions, namely, heuristic-SVHS (H-SVHS) and heuristic-AVHS (H-AVHS), respectively, by exploiting the inherent energy usage distribution pattern among sensors for varying hop sizes. Performance analysis shows substantial improvement of network lifetime over the existing SH, MH, and their hybrid transmission policies irrespective of network parameters. Energy usage is more uniformly distributed over the rings and critical energy per data cycle is reduced significantly in our policies.

Keywords: Wireless sensor networks, energy efficiency, energy balancing, network lifetime, Optimal transmission range.

Introduction

A wireless sensor network (WSN) is a large number of sensor nodes scattered throughout large geographical area of interest. These sensors monitor various conditions by measuring different parameters like temperature, pressure, sound, light intensity, heat, movement, etc. The sensed data is routed to the sink node via intermediate sensor nodes.

Sensor-to-sink direct transmission is the easiest way for reporting sensed data to the data sink(s) [1] [4] if the transmission range of each sensor node is large enough to reach a data sink. However, if each node uses power-adjusted sensor-to-sink direct transmission to report the sensed data, the nodes farther away from the sink run out of energy quickly due to the long transmission distance. Moreover, sensor-to-sink long-range transmission [2] is not energy efficient since the transmission power is proportional to the square or quadruple of the transmission distance.

Energy consumption is a primary concern in Wireless Sensor [3] [4] Network. This is because in many practical scenarios, sensor node batteries cannot be (easily) replenished, and nodes have a finite lifetime. To save [6] energy, multihop routing is more preferable than sensor-to-sink direct transmission for long-distance transmissions. However, multihop routing schemes tend to overuse the nodes close to the sink and make them run out of energy quickly, leading to the existence of energy holes around the sink(s).

Unbalanced energy consumption is an inherent problem for both direct transmission and multihop routing schemes, and this unbalanced energy consumption can make the network collapse early due to the death of some critical nodes, resulting in significant network lifetime reduction.

Literature review

Three main [1] [7] reasons that can cause an imbalance in energy distribution:

1. **Topology**. The topology of the initial deployment limits the number of paths along which the data packets can flow. For example, if there is only a single path to the sink, nodes along this path would deplete

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their energy rather quickly. In this extreme case, there are no ways to reach an overall energy balance.

2. **Application.** The applications themselves will determine the location and the rate at which the nodes generate data. The area generating more data and the path forwarding more packets may suffer a faster energy depletion.

3. **Routing.** Most energy-efficient routing protocols always [3] choose a static optimal path to minimize energy consumption, which readily results in energy imbalance since the energy at the nodes on the optimal path is quickly depleted.

To improve [1] [4] overall network lifetime, a transmission policy should have following features:

1. **Multihop**: Transmission power increases exponentially by the power of distance, where $2 \leq \gamma \leq 4$ is the path loss factor. Single-hop transmission of data to the sink causes rapid depletion of energy for long range applications. Thus, an energy efficient transmission policy is necessarily multihoping.

2. **Variable transmission range**: Multihop transmission with fixed transmission range creates hot spots since a small number of nodes near the sink need to relay all the incoming traffic from the outer nodes, hence die out quickly reducing the network's lifetime drastically even though many nodes still have considerable amount of residual energy. Varying transmission range over time attains more uniform traffic and energy usage distribution among sensors.

3. **Energy balanced duty cycles**: The number of cycles nodes use a particular transmission range is crucial to achieve balanced energy usage among sensors. Thus, a transmission policy should optimally determine duty cycles for each transmission range with the objective to maximize overall network lifetime.

4. **Regularity**: Scheduling sensors avoiding interference needs a great deal of effort. The transmission ranges and associated dutt a set of noninterfering nodes can be scheduled together.

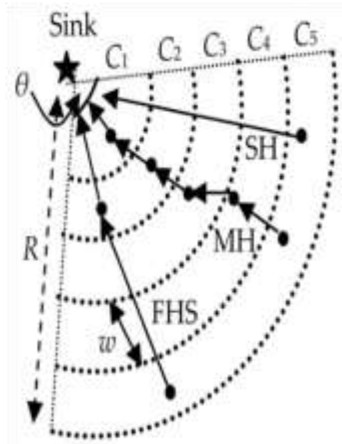

Fig. 1. Single hop, multihop, and fixed hop size.

Transmission policies

1. Characteristics distance for transmission

To find the optimal transmission distance at each hop that minimizes the total energy usage along the path, in, a data link between a radio transmitter and [1] a receiver separated by D meters are divided into K subpaths by introducing (K - 1) intervening relay nodes. The authors have shown that, for given D and the number of hops K, the overall energy dissipation along the path is minimum when length of all the subpaths are made equal to D/K and the optimal number of hops is given by

$$K_{opt} = \lfloor D/d_{char} \rfloor \text{ or } \lceil D/d_{char} \rceil$$

Where the distance d_{char}, called the characteristic distance, is independent of D and is given by

$$d_{char} = \left[\frac{2\alpha}{\beta(\gamma - 1)}\right]^{\frac{1}{\gamma}}$$

The above study assumes uniform relay traffic on the intermediate nodes along the multihop path which is not valid in WSN. The study focuses on one source-destination pair at a time without taking into account the many-to-one communication paradigm of WSNs where relay traffic is much higher on the nodes closer to the sink than that of the nodes near the network boundary.

2. **Energy Balanced Data Propagation**

Energy balanced data propagation in wireless sensor networks has been studied in where the average per sensor energy dissipation during [5] [2] the entire lifetime is the same for all the sensors in the network. Once generated, a sensor sends data either one hop closer to the sink or directly to the sink.

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We assume the network area as a cycle sector with the sink at the center. The cycle sector is divided into ring sectors or "slices" with each slice having thickness r. For balancing load and spreading energy dissipation evenly among sensors, a sensor in ring sector T_i forwards data to T_{i1} (i.e., the next sector toward the sink) with probability p_i, while with probability 1 p_i it transmits data directly to the sink. There is a trade-off for choosing p_i:

1) if p_i increases then transmissions tend to happen locally, thus energy consumption per transmission is low; however, sensors close to the sink tend to be overused since more data pass through them, and

2) On the other hand, if p_i decreases, distant transmission by a sensor increases resulting in higher energy drainage by a sensor per transmission.

Although the scheme attains balanced energy usage among sensors, use of either direct transmission to the sink or only one ring forward toward the sink results in overall energy inefficiency. Instead, better energy efficiency is expected when a combination of various hop sizes is used.

3. **Singlehop, multihop, and hybrid transmissions**

Analyzed the SH, MH, and their hybrid transmission policies. A heterogeneous WSN divided into clusters and each cluster region is circular [1] [3] with the cluster head (sink) at the center. The whole cluster is divided into concentric rings around the sink and sensors send their data toward the sink using single hop or multihop or combination of them.

In SH transmission, a sensor sends data directly to the sink. It is found that, in SH transmission, a significant amount of energy remains unused in sensors residing in rings C_1 to C_{l1} while sensors in the farthest ring C_l is out of energy. A sensor in ring C_i needs to send data to a distance of iw on average to reach the sink directly, hence energy usages in each data cycle are

$$\Omega_s(i, SH) = \{\alpha + \beta(iw)^{\gamma}\}\lambda_s$$

In MH communication in, data are relayed by a number of intermediate nodes on the way from the source node to the sink with one ring forward toward the sink at each hop. Here, nodes close to the sink (in C_1) need to relay all data coming from the sensors in the outer rings (C_2 to C_l) and thus consume energy faster than sensors of any other rings, hence are the critical nodes. Using energy model, energy consumed by a sensor in ring C_i in each data cycle is

$$\Omega_s(i, MH) = (\alpha + \beta w^{\gamma})\lambda_s + (2\alpha + \beta w^{\gamma})\frac{\tilde{N}(i,w)}{N(i,w)}\lambda_s$$

Find an optimal transmission distance $w^{\wedge}_{MH}$ (equal to the ring thickness) that minimizes the critical energy per data cycle, hence maximizes the network lifetime for MH transmission and is given by

$$\hat{w}_{MH} = \left[\frac{4\alpha}{\beta(\gamma - 2)}\right]^{\frac{1}{\gamma}}, \quad \gamma > 2$$

Single hop is the better choice over multihop transmission for path loss factor ϒ = 2 and vice versa for ϒ = 4. Observing the two opposite energy decay characteristics a hybrid of single and multihop transmission policies was proposed in , and a unique ratio of the number of single hop, n_{SH} and multihop, n_{MH} data cycles as in was obtained that would be followed by sensors in all rings.

$$n_{SH} : n_{MH} = \Delta\Omega_{MH} \; : \; \Delta\Omega_{SH},$$

$$\text{where } \Delta\Omega_{MH} = \Omega_s(1, MH) - \Omega_s(l, MH) \text{ and}$$

$$\Delta\Omega_{SH} = \Omega_s(l, SH) - \Omega_s(1, SH).$$

Although hybrid transmission policy makes energy drainage in both ring C_1 and C_l equal to the critical energy, energy usage by sensors still falls exponentially from ring C_2 (and from C_{l1}) to the middle ring. This leaves substantial residual energy in l - 2 number of rings out of total l rings and thus the policy fails to achieve good energy usage distribution. Moreover, the network lifetime improvement is very insignificant.

Conclusion

The FHS scheme uses an optimally determined ring thickness and hop size pair while SVHS and AVHS schemes vary hop size and its associated duty cycles over the entire lifetime. In SVHS, all sensors use same hop size concomitantly but it is ring-wise different in AVHS scheme.

Performance analysis shows substantial improvement of network lifetime over the existing single hop, multihop or their hybrid transmission policies irrespective of network size and path loss factor.

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