Ad Hoc Networks 000 (2016) 1–17

Contents lists available at ScienceDirect

Ad Hoc Networks

journal homepage: www.elsevier.com/locate/adhoc

An adaptive energy balanced and energy efficient approach for data gathering in wireless sensor networks

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ARTICLE INFO

Article history:
Received 19 July 2015
Revised 25 October 2016
Accepted 31 October 2016
Available online xxx

Keywords:
Wireless sensor network
Routing
Energy-efficiency
Energy balanced data transmission
Mixed hop transmission schemes

ABSTRACT

Energy efficiency and energy balancing are the most stringent needs of wireless sensor network for prolonging its lifetime. As direct transmissions are costly, multi-hop approach is often used to collect the data of the nodes at the sink. However, many-to-one communication pattern in multi-hop communication may result in an unbalanced energy consumption in the network. Nodes closer to the sink deplete their energy at a faster rate than nodes that are further away. Mixed transmission approach, where each node trades-off between the cheaper hop-by-hop transmission and costlier direct transmission, is a good solution for balancing energy consumption. This paper proposes a receiver contention based mixed transmission scheme for energy balancing. In addition to distance and residual energy of the receivers, it also considers the link reliability and the number of neighboring nodes, in setting of the timer that will determine the relay node selection. The proposed approach gives more efficient and effective energy balanced data transmission as compared with the other works proposed in the literature. Its performance is evaluated and presented both analytically and through simulations, and the analytical estimations are validated by the simulation results. The simulation results show a significant improvement over the other closely related approaches. Moreover, the proposed approach can be easily used with both uniform as well as non-uniform node deployment.

1. Introduction

Wireless Sensor Networks (WSN) consist of very small, low-cost and low-power nodes. These nodes are capable of sensing various types of physical or environmental phenomenon like temperature, pressure, humidity, light, radiation, vibration, seismic waves, presence of some biological organism(s), etc. These nodes also have processing and communication capabilities.

Due to their characteristic features, sensor networks have a broad range of applications like environment monitoring, battlefield surveillance, patient/elderly people monitoring, monitoring and control of production process in industries, condition monitoring, creating smart homes, vehicle tracking and detection, etc [1].

The sensor nodes have limited memory and processing capacity. Therefore, these nodes collect the data and send it to some base station or sink for processing. The nodes also possess a constrained battery power. Apart from this, a lot of applications of WSN require sensor nodes to be deployed in hostile environments, where it is difficult to replace or recharge the batteries. For example, in case of environment/habitat monitoring, the sensor nodes are deployed in forests; in case of battlefield surveillance, they are deployed in battlefields; in case of process surveillance/monitoring, sensor nodes can be deployed inside boilers, radioactive tanks, etc. In all these hostile environments it is not possible to replace or recharge the batteries of the sensor nodes. Hence, the available energy needs to be conserved so that the network remains operational for a long time. Further, the energy consumed in communication is more significant than the energy consumed in computations [2,3]. Hence, energy efficient routing approaches are needed to minimize communication cost.

Energy efficiency and energy balancing are two major factors for prolonging the network lifetime. Energy efficiency aims at minimizing the energy consumption of the nodes or of the network as a whole. Energy balancing ensures that the average energy consumption is uniform among all the nodes. Approaches targeting energy efficiency might use the nodes on energy efficient path repeatedly and thus, those nodes will be exhausted early. In addition, due to many-to-one communication pattern, nodes near the sink are prone to die faster, even if the individual path is energy efficient. This is due to the fact that these nodes have additional relay burden of forwarding the data from the nodes further away on the

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http://dx.doi.org/10.1016/j.adhoc.2016.10.013
1570-8705/

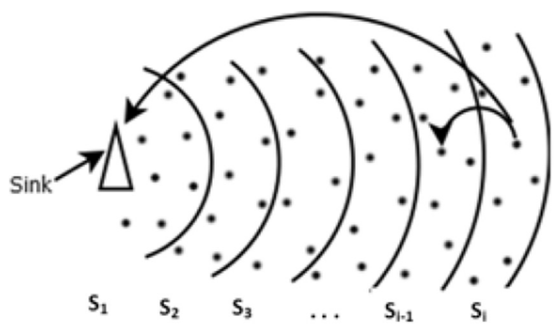

Fig. 1. General approach followed in mixed hop transmission schemes.

path to the sink. Contrary to this, in case of direct transmission, the nodes located farther away from the sink have higher energy consumption rate because of the larger transmission distance, and hence, these nodes will die out much faster. Mixed-hop transmission [4–18], where each node alternates between direct transmission mode (sending data directly to the sink without using any relay node) and hop-by-hop transmission mode (forwarding data to the next-hop neighbors), is a simple solution that effectively balances the energy consumption of the nodes. Authors in [6] present the relationship between energy consumption in direct transmission and in hop-by-hop transmission.

The general approach followed in mixed-hop transmission is that the network is divided into slices/rings/coronas. The nodes in a slice transmit the data to the nodes in the previous slice (closer to the sink) at some instance, and at the other, the nodes transmit the data directly to the sink (as shown in Fig. 1). When the residual energy of the nodes is not sufficient to transmit the data directly to the sink, the node is considered to be dead.

Our contribution: To the best of our knowledge, this is the first time, energy balancing using mixed-hop transmission has been studied in the context of receiver contention and to consider link reliability of the path in the selection of the forwarder. Major contributions of the paper are:

- This paper proposes an adaptive and distributed energy balanced and energy efficient approach that avoids the complex probability calculations as in [4–11,14–18]. The decision in the proposed approach depends on the current actual status of the network.
- We propose to use a receiver contention scheme using RTS/CTS, as in [19,20]. However, works in [19,20] are not targeted towards energy balancing. The criteria for selecting the forwarder is also different in the proposed approach that improves energy efficiency and energy balance.
- We propose a different method of dividing the network into slices (the slice width is taken to be two third of the transmission range). This contributes in balancing the energy of the nodes within a slice (intra-slice energy balancing).
- The scalability and lifetime of the network are increased. When the nodes are not able to transmit directly to the sink, they can transmit to slice $(i-2)$, $(i-3)$, $(i-4)$ and so on.
- In the proposed approach, routing is integrated with the energy balanced data transmission and hence, it does not incur the additional overhead of an underlying routing protocol.
- The proposed scheme can work with both uniform as well as non uniform node deployments and networks with nodes having power heterogeneity.

The rest of the paper is organized as follows: Section 2 covers the related work and mentions some of the limitations from which most of the existing schemes still suffer. Section 3 covers the proposed approach along with the assumptions made. The different parameters used in the proposed approach are formulated and presented in Section 4. In the proposed approach the slice width is taken to be two-third of the transmission range of the nodes. Section 5 shows that the probability of finding at least one node in this region is close to 1. Section 6 gives the performance analysis which includes propagation delay analysis (due to the use of timer in the proposed approach) in (6.1), and energy consumption analysis in (6.2). In Section 7, the simulation results are given which clearly shows the effectiveness of the proposed scheme. Finally, Section 8 concludes the paper and provides directions for further work.

2. Related work

A general framework is proposed in [21] to define the data flow that can maximize the lifetime of a wireless sensor network. In [22], the authors define the energy balance property and propose an energy optimal and energy balanced algorithm for sorting in single-hop wireless sensor networks. Works in [4,10–12] extend that approach to the case of multi-hop networks [18]. In [23,24], the authors propose an energy balanced approach in which the data is forwarded in one periodic epoc to the previous slice (closer to the sink) and in the next periodic epoc, data is transmitted directly to the sink. Works in [4,5,13,14] present a non-adaptive, distributed approach for energy balancing in which the data is forwarded with some probability (say p_i) to the previous slice $(i-1)$, and with probability $(1-p_i)$ it is transmitted directly to the sink. Works in [6–10,15] present a non-adaptive and centralized probabilistic approach for balancing energy of the network. In [11], the authors present two stochastic probabilistic approaches - one is non adaptive and centralized and the other is adaptive and centralized which can infer the network parameters from the observation of the data packets received at the sink. Works in [16,25] present an adaptive distributed probabilistic approach for energy balancing. However, work in [25] is not a mixed transmission approach. It only uses transmission to next hop forwarders with different probability values so as to balance energy among the sensors of the previous slice. Whether the approach achieves inter slice energy balancing or not is a lack of study. Work in [12] is different from the works mentioned above in the sense that it is not probabilistic mixed hop energy balancing approach. In this approach, the sender node checks if there is a higher energy neighbor in the previous slice, if yes, then the sender node sends the data to it otherwise, it sends the data directly to the sink. This approach is simple, distributed and adaptive. The major advantage is that the approach does not require any global information of the entire network like the message generation rate of each sensor/slice, number of sensors in each slice, the energy consumption in transmission and reception, etc. Works in [5,9,10,15,16] also achieve intra-slice energy balancing (balancing energy among the sensors of the same slice) in addition to inter-slice energy balancing. Authors in [17] present their works of [4,10–12] in an incremental related form. In [18] a survey of the work in [4,10–12] is presented.

All the approaches discussed above, have some common issues which need to be addressed if these approaches are to be made practically effective and efficient. Some of them are following:

- Assumption of constant energy consumption among the nodes of a slice in hop-by-hop transmission.
  Almost all the existing approaches assume that all the nodes of a slice consume same amount of energy in transmitting to the previous slice (hop-by-hop transmission) and same amount of energy in direct transmission. This assumption is made to simplify the calculation of probability. This assumption may work if the slice width is relatively small. However, if the slice width is significant, then varying the energy consumption with the dis-