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Short communication

Equal energy dissipation in wireless sensor network

Ashraf Hossain

Department of Electronics & Communication Engineering, National Institute of Technology (NIT), Silchar, Assam 788 010, India

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ABSTRACT

Wireless sensor network consists of a large number of energy constrained nodes. The lifetime of such a network is limited by the energy dissipated by individual nodes. The important issues are of modeling a sensor network and assessment of its lifetime. This paper gives an analytical framework to establish equal energy dissipation over a network. The equal energy dissipation profile is first obtained for a linear array of wireless sensor nodes and then it is extended for a Y-shaped array of nodes in order to cover a planar area. This approach ensures that all nodes run out of battery energy almost simultaneously. It is shown that the network lifetime almost doubles with the proposed scheme as compared to other reported schemes.

1. Introduction

A wireless sensor network consists of energy-constrained nodes that are deployed for monitoring multiple phenomena of interest [1]. There are three broad classes of sensor networks, viz. (i) data gathering (clock-driven), (ii) event-driven and (iii) demand-driven [2]. The sensor nodes are equipped with a battery with limited energy that may not be replenished once it gets exhausted. The lifetime of a sensor network is defined as the time interval from the instant when the network is deployed to the instant when the network is deemed to be non-functional [2–4].

In multi-hop linear wireless sensor network, the nodes near the sink has higher load as compared to the distant nodes. Hence the nodes near the sink are likely to get over-burdened and run out of their battery energy very soon. Bhardwaj et al. [5] have proposed upper bound on the lifetime of a linear multi-hop network. However, this analysis is not applicable where each node in the network senses and transmits its own packet, in addition to the packets received from other nodes. Shelby et al. [6] have considered a linear multi-hop sensor network. It has been found that the node farthest from the sink consumes maximum energy as compared to the nodes close to the sink. Hence the problem of non-uniform energy consumption by the nodes still exists.

Several authors have addressed the issue of minimization of total energy consumed by the network. This approach results in faster run out of nodes far away from the sink. A different approach has been reported in [7], where nodes are placed intelligently in a linear array ensuring that all nodes run out of energy at the same time. Haenggi [8] has found the inter-node distance ensuring equal energy consumption. This analysis has been carried out considering only the energy required to transmit a packet. Energy requirement for receiving a packet and idle state energy are not considered in the analysis. In [9], we have established the equal energy consumption for a linear array of wireless sensor nodes. However, planar area has not been considered.

Several authors [10–25], have studied network lifetime. It has been shown that lifetime can be improved by using multiple mobile sinks [11,12,23,24], relay nodes [13,17] mobile sensor nodes [14], controllable mobile cluster heads [15]. In [26], we have extended the idea of equal energy dissipation over a linear wireless image sensor network (WISN) to mitigate energy-hole problem. However, planar network has not been considered.

In this paper, we address the important issue of lifetime enhancement by ensuring same energy dissipation by all the nodes over a data gathering cycle. Our analysis is based on linear and Y-shaped array of nodes. We also extend the idea of equal energy dissipation condition for a planar network.

The rest of the paper is organized as follows. Section 2 gives the system description and problem formulation. In Section 3, we present regular placement of sensor nodes in linear array for equal energy dissipation. We extend the idea of equal energy dissipation for a planar (2-D) area in Section 4. Finally, we conclude the paper in Section 5.

2. System description considering linear array

A linear array of K wireless sensor nodes is considered with the sink at one end as shown in Fig. 1. It is usually the practice to

E-mail addresses: hossain_ashraf@rediffmail.com, ashrafiit@gmail.com

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consider and analyze such arrays of sensor nodes [6,8,20,21] without bringing in the numerous practical considerations. We consider that all the nodes have same initial energy of E_0 units. We also consider that sink node is not energy constrained. The distance between ith node and (i–1)th node is denoted as h_i units for $2 \leqslant i \leqslant K$. The distance between the sink and the 1st node is presented as h_1. The farthest node i.e., Kth node is at a distance of D units from the sink.

We assume a data-gathering network where each node generates one packet of B bit for a data gathering cycle of T_d second. We have assumed that a sensor node has adjustable sensing range and is equal to half of the corresponding maximum inter-node distance. We have considered nearest neighbour routing towards the sink. Nodes near the sink are expected to forward all the packets towards the sink. We assume that each node can handle with maximum P packet/s.

2.1. Energy dissipation model of sensor node

The energy dissipation model for radio communication is similar to [9,21] and [27], following which the energy consumed by the ith node for transmitting a packet to the (i–1)th node over a distance h_i is $E_{t,i} = e_t + e_d h_i^n$. The terms e_t and e_d are radio parameters. The path loss exponent is n ($2.0 \leqslant n \leqslant 4.0$) [28]. On the receiving end, the energy spent to capture an incoming packet of B bits is e_r units. The radio is assumed to dissipate energy during idle state, i.e., when the radio neither receives nor transmits. The idle state energy dissipation is equal to $e_{id}T_{id}P$, where T_{id} is the idle time and $e_{id} = c.e_r$ is the idle state energy spent per packet duration, where $0 < c \leqslant 1.0$ [21]. Let R_r be the maximum radio range of a sensor node. Power control is employed. We consider an idealistic channel where the channel can be represented by radio disc model. We have also considered that $h_i \leqslant R_r$, for $1 \leqslant i \leqslant K$.

In Section 3, we determine the distance h_i between neighbouring sensor nodes ($1 \leqslant i \leqslant K$) such that each node dissipates same energy over a data gathering cycle.

3. Regular placement of sensor nodes in linear array for equal energy dissipation

In this section, we present an analysis on regular node placement over a linear array for equal energy dissipation by all the nodes.

3.1. Analysis for node placement

According to the system model, the number of packets $A_r(i)$ received by the ith node per data gathering cycle is

$$A_r(i) = K - i, \quad \text{for} \quad 1 \leqslant i \leqslant K \tag{1}$$

The number of packets $A_t(i)$ transmitted by the ith node including its own packet per data gathering cycle is

$$A_t(i) = (K - i) + 1 = A_r(i) + 1, \quad \text{for} \quad 1 \leqslant i \leqslant K \tag{2}$$

The idle time, $T_{id}(i)$ over which the radio of the ith sensor node neither transmits nor receives any packets may be expressed as

$$T_{id}(i) = \left(T_d - \frac{2(K-i)+1}{P}\right), \quad \text{for} \quad 1 \leqslant i \leqslant K \tag{3}$$

where, P is the packet dealing rate of a node.

Following the energy consumption model, the total amount of energy $E(i)$ spent by the ith node per data gathering cycle is,

$$E(i) = e_t(K+1) + e_rK + e_{id}(PT_d - 2K - 1) - i(e_t + e_r - 2e_{id}) + e_d(K - i + 1)h_i^n, \quad \text{for} \quad 1 \leqslant i \leqslant K \tag{4}$$

Now, imposing the condition that all the nodes consume same energy E joule per data gathering cycle i.e., $E(i) = E$, for $1 \leqslant i \leqslant K$, the inter-node distance h_i can be expressed as

$$h_i = \left[\frac{1}{(K-i+1)e_d}[E + (K-i)(2e_{id} - e_r) - (PT_d - 1)e_{id} - e_t(K-i+1)]\right]^{\frac{1}{n}}, \quad 1 \leqslant i \leqslant K \tag{5}$$

3.2. Results and discussions for regular placement of nodes in linear array

In this sub-section we present some numerical examples to study the issue of node placement and its effects on network lifetime.

Let E_{th} be the threshold value of residual energy below which a sensor node becomes non-functional. Also, let E_{max} be the maximum energy consumed by a node over a data gathering cycle in a sensor network. Since the duration of each data gathering cycle is T_d units, the network lifetime (T_{life}) is

$$T_{life} = T_d\left(\frac{E_0 - E_{th}}{E_{\max}}\right) \tag{6}$$

Energy utilization ratio (η) is defined as

$$\eta = \frac{E_{used}}{E_T} \times 100\% \tag{7}$$

where E_{used} is the total energy utilized by the network during its lifetime and E_T *is* the total deployed energy. For K nodes E_T equals to KE_0. For all the studies we consider a typical set of parameters as shown in Table 1.

Three schemes have been used for performance comparison. *Scheme a*– All nodes have equal inter-node spacing i.e., $h_i = D/K$ [6]. *Scheme b*– Nodes are placed for minimizing the overall energy dissipation in a data gathering cycle [6]. *Scheme c*– This is our proposed scheme. Here, the nodes are placed so that each node dissipates equal amount of energy in a data gathering cycle. Typical values of other relevant parameters in Table 1 have been chosen following [27] closely. Table 2 summarizes the result for regular node placement. It is clear from Table 2 that by ensuring equal energy consumption one can gain two things: (a) effectively no residual energy when network dies and (b) the consequence of that is gaining maximum network lifetime.

So far we have discussed regular node placement. It is interesting to study the random node placement of nodes over a linear array. The analysis and results for random node placements are presented in [9].

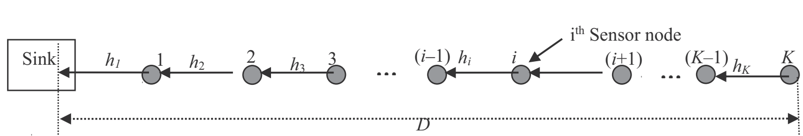

Fig. 1. Linear array of wireless sensor nodes.