BESM: A Balancing Energy-aware Sensor Management Protocol for Wireless Sensor Network

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Abstract

How to efficiently use energy is always one of most important issues in wireless sensor network(WSN) since the limited energy of sensor nodes. This paper presented a balancing energy-aware sensor management protocol for WSN, namely BESM, based on PEAS(Probing Environment and Adaptive Sleeping). BESM allots more sleep time to those nodes that have less energy by two key means, i.e. negotiation strategy based on energy and energy saving method of nodes on the edge, therefore assigns system overall energy consumption to all nodes as balancing as possible and increases system lifetime. Simulation results exhibit longer system lifetime with almost same sensing coverage after introducing our scheme than before.

Keywords: Wireless Sensor Network, Sensor Management, Energy Saving, Protocol.

I. Introduction

Wireless Sensor Network(WSN) is a kind of measuring and controlling network system consisting of a mass of ubiquitous tiny sensor nodes that have communication and computing capabilities, and a typical autonomous and intelligent system which can independently accomplish specific duties depending on the changing environment(Lan, et al., 2002; Yu Haibin, et. al., 2004). Compared with traditional network systems, WSNs are featured with large-scale, random-deployment, multi-hop communication, self-organization, collaborative working, etc. These features ensure that WSN find a wild range of applications in sectors of military, industry, health care, home life, environment protection, etc. WSN is involved with many research fields such as sensor, micro-electro-mechanical systems (MEMS), communication, automation, artificial intelligence and so on. However, the benefits that WSN will bring to our society are immeasurable. To be sure, WSN gives us a new set of challenges, including limited resources, complicated dynamic topology, and scalability, etc, all of which need to be addressed before we can get real benefits from it. Currently, WSN has won more and more attentions from researchers and governments of various countries, becoming a new R&D focus.

The most important resource in wireless sensor network is the energy. At present most of researches in wireless sensor network are about how to save energy so as to extend the network lifetime. Sensor management is one important means of saving energy in WSN, whose main goals are to save energy and guarantee sensing coverage by putting unnecessary sensor nodes into sleeping mode for wireless sensor network. To preserve the limited battery power, various approaches of energy management have been explored. PEAS(Probing Environment and Adaptive Sleeping, Ye, F. et al, 2003) is a protocol that was developed to provide consistent environmental coverage and robustness to unexpected node failures through avoiding redundant nodes and adjusting sleeping time of nodes adaptively. In NSSS(Node Self-Scheduling Scheme, Tian D. and Nicolas D. Georganas, 2002), a node measures its neighborhood redundancy as the union of the sectors/central angles covered by neighboring sensors within the node's sensing range. Also, the problem of optimal sensor selection for a given resolution was modeled as a Gur game by Iyer R. and Kleinrock L. in 2003. And a reference time-based scheduling scheme was presented by Yan T. et al in 2003. CCP(Coverage Configuration Protocol, Wang X. et al, 2003) is an eligibility rule to maintain a certain degree of coverage(coverage at every location by a given number of sensors). Among above sensor management protocols, PEAS is a simple, but efficient. However PEAS is not ideal. Therefore, a balancing energy-aware sensor management protocol based on PEAS is proposed. And simulation results show that designed sensor management protocol is better.

The paper is organized as followings. In section II PEAS protocol is introduced and its shortcomings are analyzed. BESM, a balancing energy-aware sensor management protocol is presented in section III. Simulation experiments and results are described in section IV. And conclusions are in the last section.

II. PEAS

PEAS is an energy saving protocol that build long-lived, resilient sensor networks using a very large number of sensors with short battery lifetime. PEAS consists of two simple algorithms: Probing Environment and Adaptive Sleeping.

PEAS uses a simple probing environment mechanism to solve the problem of node failures. Initially all nodes are sleeping and they sleep for a random time. When a node wakes up, it sends a PROBE message. Any working nodes within a certain probing range should send back a REPLY message. A sleeping node starts working continuously only if it does not hear any REPLY message. Otherwise, it goes back to sleep again for another random time.

The goal of Adaptive Sleeping is to keep the number of wakeups. The desired frequency of wakeups is decided by the application. Adaptive Sleeping adjusts the wakeups of sleeping neighbors for each working node at appropriate levels. The basic idea is to let each working node measure the aggregate probing rate. The working node then includes the measured rate when sending a REPLY message to a probing neighbor. Each probing node then adjusts its sleeping times accordingly.

However, PEAS is not ideal and has its own shortcomings. On the one hand, PEAS has not considered the problem that nodes on the edge will have less chance to sleep and consumes all the energy more quickly than other nodes. On the other hand, PEAS does not regard remaining energy of nodes as one of basis selecting wakeup or sleep status for nodes so that energy consumption is not balanced. Therefore, some nodes consume their energy earlier, which are important for coverage preserving and data delivery, and network lifetime is shortened. Aiming at shortcoming of PEAS, a new sensor management protocol was designed in Section III.

III. BESM

This paper presented a balancing energy-aware sensor management protocol for WSN, namely BESM, based on PEAS, which can assign system overall energy consumption to all nodes as balancing as possible, therefore increase system lifetime, by allotting more sleep time to those nodes that have less energy.

The finite state machine model of BESM is shown in Fig.1. Each node on BESM has following five operation states: Initializing, Sleeping, Probing, Active and Dead. The state transition diagram among these states is shown in Fig.1.

- **Initializing state:** Initializing State is necessary to wireless sensor network. In this period, each node fulfills infrastructure setups, such as time synchronization, node localization and topology formation.
- **Sleeping state:** Node in the Sleeping state waits for a random time, and then goes to Probing state.
- **Probing state:** Node in this state broadcasts PROBE message in its probing range and determines whether to go to Active state or Sleep state.
- **Active state:** Node in this state can do work including sensing, processing and communication.
- **Dead state:** This is the final state. Node enters this state if it fails or consumes all its energy.

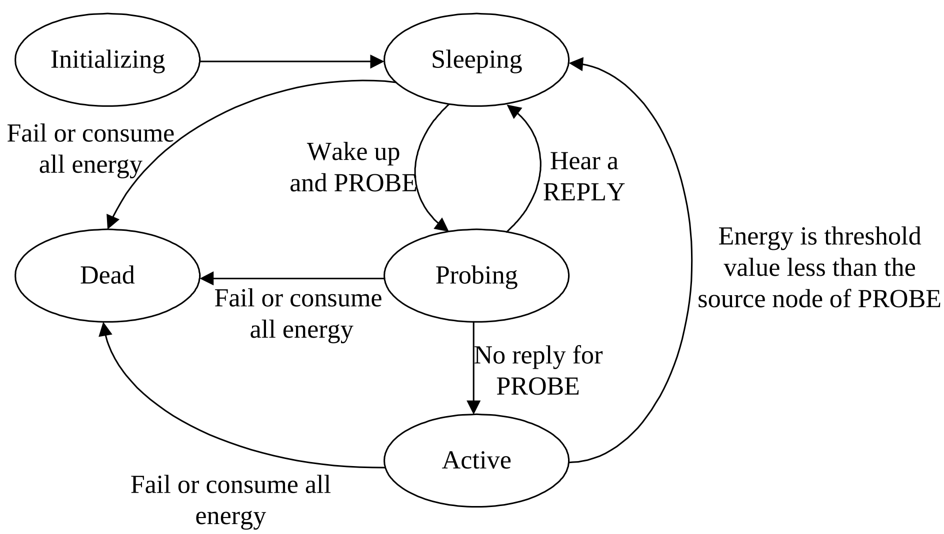


Fig.1 The finite state machine model of BESM

The work in BESM differs from existing sensor management protocols, especially PEAS in two key ways as follows.

A. *Energy Saving Method of Nodes on the Edge*

To save energy of nodes on the edge of region covered by WSN, the mean of random sleep time for each node is modeled in inverse proportion to their own neighbor count. Consequently, nodes on the edge can have more time to sleep so that their energy is not exhausted quickly. And this idea is of benefit to balance energy consumption of other nodes. In addition, each node computes their neighbor count according to the probing range during the initializing period, making use of infrastructure setups, such as time synchronization, node localization and topology formation. Accordingly, no extra energy consumption for communication is introduced.

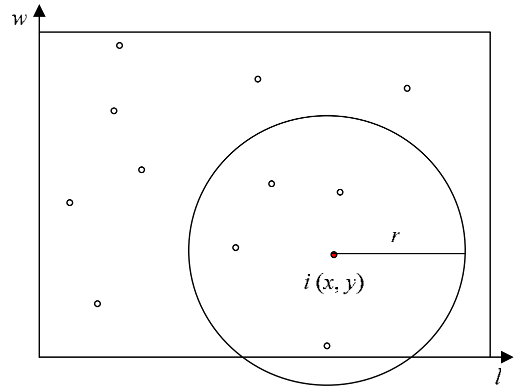


Fig.2 Communication Model Between nodes

As Fig.2 shown, suppose covering area of the wireless sensor network is a rectangle whose length and width is respectively *l* and *w*., then we have *n*+1 nodes in the rectangle. The nodes are distributed uniformly. Sensing radius of nodes is *r*. Apparently, solution to node count within the sensing radius for Node *i* (*x*, *y*) is a classic binomial distribution problem. According to the nature of binomial distribution, the average neighbor count N_{agv}^{i} of Node *i* is depicted in Eqs.(1).

$$N_{agv}^{i} = n \times p \tag{1}$$

where *p* is the distributing probability of nodes in the sensing radius of certain Node *i*, i.e.

$$p = \frac{S}{l \times w} \tag{2}$$

where *S* is the mean value of the effective regional areas covered by all sensor nodes, then *S* follows

$$S = E(s) \tag{3}$$

where *s* presents the intersection of $l \times w$ rectangle and the circle whose centre and radius is respectively Node *i* and *r*.

Therefore,

$$S = \frac{1}{l \times w} \int_0^w \int_0^l s \, dxdy \tag{5}$$

Assume that the maximum average sleeping time is $T_{\max,}$ the minimum sleeping time is $T_{\min}$ and the sleeping time T_s^i of node *i* meets exponential distribution with mathematical expectation $E(T_s^i)$, where

$$E(T_s^i) = T_{\min} + (T_{\max} - T_{\min}) \cdot \frac{N_{agv}^{i} - \min_{j=1}^{n+1}(N_{agv}^{j})}{\max_{j=1}^{n+1}(N_{agv}^{j}) - \min_{j=1}^{n+1}(N_{agv}^{j})} \tag{6}$$

B. *Negotiation Strategy Based on Energy*

Like PEAS, all nodes in BESM are in the Sleeping state and they sleep for an exponentially distributed random time after Initializing state. When a node wakes up and enters Probe state, it sends a PROBE message to its neighbors within a certain probing range. To balance energy consumption of nodes, a negotiation strategy based on remaining energy of nodes is adopted in BESM. Energy value of probing node is carried by PROBE message. Any working neighbor nodes within the probing range compare their own energy value to the energy value in PROBE packet after receiving the PROBE packet. If its energy is threshold value more than its neighbor node, it polls a negative vote by sending a REPLY message and keeps working, whereas it polls a positive vote via not sending REPLY message and goes to Sleeping state again. And it enters Probe state after a random time sleeping. If the probing node does not hear any REPLY message or receives positive vote, it starts working. Otherwise, it goes back to sleep again for another random time. Node enters the Dead state if it fails or consumes all its energy.

IV. CASE STUDY

Some simulation examples were studied in this section to show the performance and characteristics of BESM protocol. In our simulation experiments, BESM protocol was compared with PEAS roundly.

A. Energy Consumption Model

To analyze the energy consumption of sensor node, the “first order radio model” shown in Eqs.(7) and Eqs.(8) was used as our energy consumption model, which was originally proposed in reference [7].

$$E_t = E_{t\text{-}elec} + E_{t\text{-}amp} = \alpha_t b + \alpha_{amp} d^k b \tag{7}$$

$$E_r = E_{r\text{-}elec} = \alpha_r b \tag{8}$$

where

E_t : the transmitting energy consumption of transmitter.

E_r : the receiving energy consumption of receiver.

$E_{t\text{-}elec}$: the energy consumption used for transmitter to run transmitter circuitry first. It spends α_t per bit for transmitter.

$E_{t\text{-}amp}$: the energy consumption used for transmitter to amplify the signal so that signal is strong enough to reach the location of receiver. It spends α_{amp} per bit per m^k for transmitter.

$E_{r\text{-}elec}$: the energy consumption used by receiver to receive packet from transmitter. It spends α_r per bit for receiver.

b : the size of packet, its unit is bit.

d : the distance between a receiver and the transmitter.

α_{amp} : the energy dissipated per bit per m^k.

α_t : the energy spent in transmission circuitry per bit

α_r : the energy spent in reception circuitry per bit

k : the environment factor influencing the amplify power, $k \geq 2$. The radio propagation model of $k = 2$ which energy dissipation is directly proportional to d^2 is called “free space model”. The free space propagation model assumes the ideal propagation condition that there is only one clear line-of-sight path between the transmitter and receiver. Another radio propagation model which energy dissipation is directly proportional to d^4 is called “two-ray ground model”. A single line-of-sight path between two mobile nodes is seldom propagation. The two-ray ground reflection model considers both the direct path and a ground reflection path. The k is 4 for the “two-ray ground model”.

B. Simulation Setting

Before analyzing the results of simulation result, the setting of our simulation must be described first. The energy consumption using the two-ray round model described and the values of parameters are illustrated as the Table 1[8, 9]. The idle power is the energy cost while the working sensor node dose not proceeds transmitting or receiving, which is fixed at 2mW. Sleep power is the energy cost for sleeping sensor nodes. The sleeping time for every node is a random interval with mean 20 second. And Sensor nodes randomly generate data every random time at [0, 5] second and transmit to the sink node. A part of simulation Scenario is shown in Fig.3.

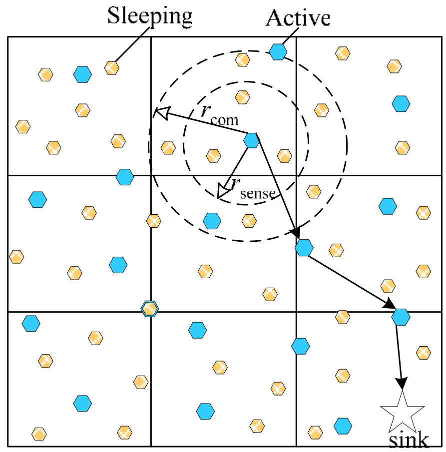


Fig.3 Simulation Scenario

In each of our experiments, we study three different sensor fields with 100, 200 400 nodes. Our node field generated by randomly placing the nodes is in a 300m by 300m square. The radius of sensing and radio communication is respectively 50m and 80m. Other simulation environment was set up as follows: propagation delay of radio being $3*10^8$m/s, speed of radio communication, 1Mbps, and this test network assumes no losses and no queuing delay, having data packet size of 64 byte, message packet size of 16 byte.

Table 1. Energy Consumption Parameters

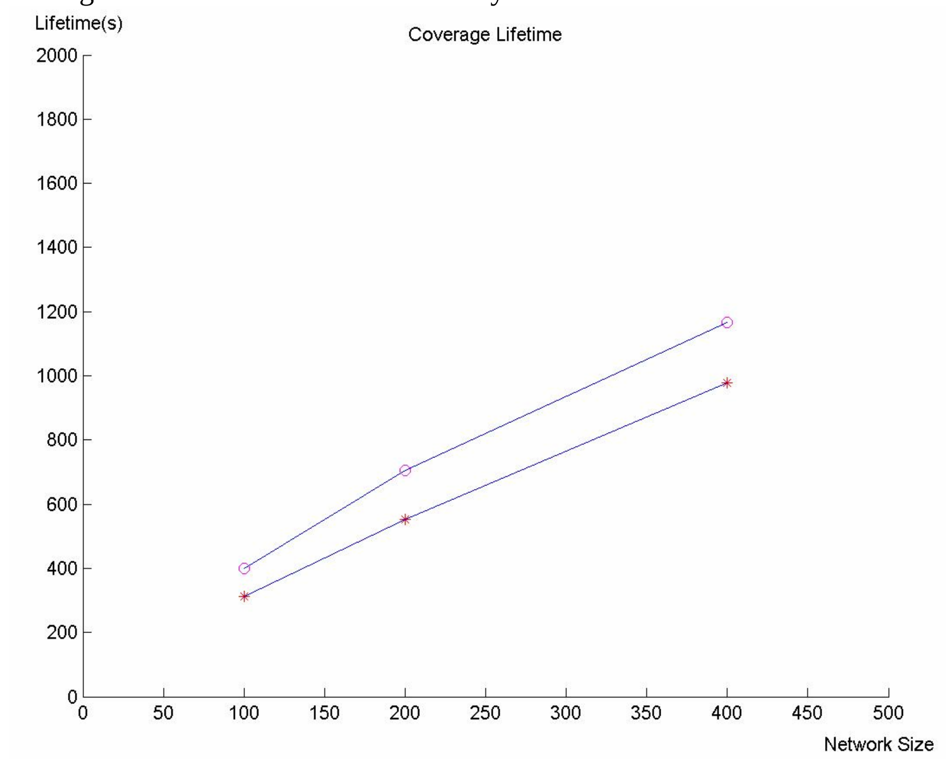
Parameters	Value
$\alpha_{amp-friss}$	100pJ/bit/m^2
$\alpha_{amp-two-ray}$	0.013pJ/bit/m^4
$\alpha_t = \alpha_r$	50nJ/bit
Initial energy	0.2Jules
Idle power	2mW
Sleep power	0.02mW
Threshold value of energy comparison	0.03Jules

C. ***Performance Criteria***

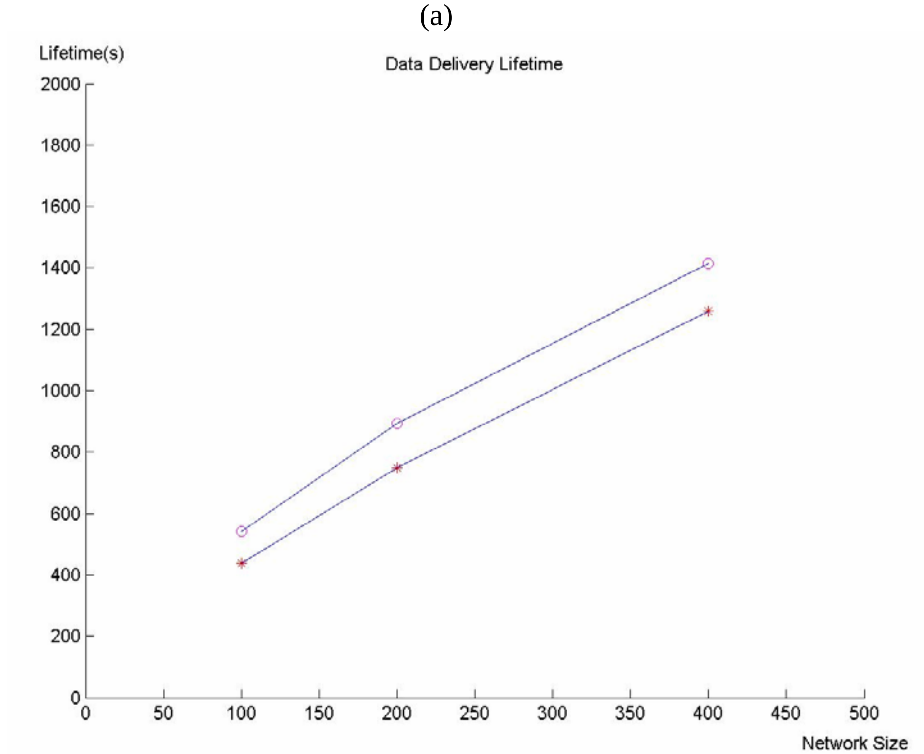
We implemented BESM and evaluated its performance by two main metrics: coverage lifetime and data delivery lifetime. Coverage lifetime denotes the period during which the network has enough working nodes to ensure every place is being monitored by working nodes. Data delivery lifetime represents the time during which the network can deliver data reports successfully.

D. ***Simulation Results***

Simulation results are shown in Fig.4 where coverage lifetime and data delivery lifetime comes from experiments performed 10 times. And “*” stands for performance of PEAS protocol, “o” shows BESM performance. Fig.4(a) and (b) respectively is the coverage lifetime and data delivery lifetime. In terms of simulation results, the BESM protocol is better than PEAS not only in coverage lifetime but also in data delivery lifetime.



(a)



(b)

Fig.4 Simulation Results (a) denotes the compared results of coverage lifetime
(b) represents the compared results of data delivery lifetime

In addition, simulation shows that BESM has a potential advantage that can also save a little energy. Some nodes in one region can wakeup simultaneously because of failed or collision communication in PEAS and BESM can effectively overcome this shortcoming of PEAS through shift work according to remaining energy.

V. Conclusions

Existing sensor management protocols have not paid adequate attention to balancing node energy consumption and guaranteeing sensing coverage and data delivery in WSN. In this paper we presented the design of BESM based on PEAS, which achieves energy balance and longer lifetime. We conducted simulations and analysis which confirmed the robustness and efficiency of BESM.
While BESM has demonstrated its effectiveness in controlling working node density and saving network energy, we believe that its performance can be further improved through more examinations of its interaction with the route protocol. In addition to comparing BESM' performance with related work, we also plan to develop formal analysis to estimate its performance bounds.

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