Random Backoff Sleep Protocol for Energy Efficient Coverage in Wireless Sensor Networks

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Abstract. A Wireless Sensor Network is a collection of many small sensor nodes. Every sensor node has a sensing range and a communication range. Coverage of a sensor node means the sensing region within which an event can be observed or detected. Most protocol designs for energy efficient coverage optimization maintain an adequate working node density. However, they ignore the residual energy level of the nodes. In this paper, we propose Random Backoff Sleep Protocol(RBSP) which ensures that the probability of neighbor nodes becoming active is inversely related to the residual energy level of the current active node. This will help in increasing the network lifetime by balancing energy consumption among the nodes. RBSP uses dynamic sleeping window, for the neighbor nodes, based on the amount of residual energy at an *active* node. Simulation results show that our scheme achieves more power saving and longer lifetime compared to Probing Environment and Adaptive Sleeping protocol(PEAS).

Keywords: Coverage, Random Backoff, Sleeping window, Wireless Sensor Networks.

1 Introduction

A typical Wireless Sensor Network (WSN)[1],[2] is an adhoc network composed of small sensor nodes which cooperatively monitor some physical environment. Each sensor node has a sensing range or sensing coverage range[3],[4],[5] which is the region or area that a node can observe or monitor. Sensing coverage for a WSN could be interpreted as the collective coverage of all the sensors in the WSN. Sensing coverage ensures proper monitoring and radio coverage ensures proper data transmission within the WSN. Sensing coverage and radio coverage both are important for ensuring that the coverage of the region is adequate and the sensors are able to transmit data to the sink. It is important to minimize the number of active nodes, while still achieving maximum possible sensing and radio coverage. The aim here is to ensure that sufficient number of nodes are available for the longest possible time while ensuring proper functioning of the WSN.

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Sensor nodes have limited energy, usually supplied by a battery. In view of the limited battery life, it is essential to make these nodes energy efficient. Energy saving is important for applications that need to operate for a longer time on battery power. Most of the existing work[6],[7],[8],[9],[10],[11], for coverage optimization, obtained by node scheduling, does not consider the residual energy of the nodes. For example, in Probing Environment and Adaptive Sleeping(PEAS)[6], a sleeping node occasionally enters probing mode and broadcasts messages(probes) within its local probing range and checks whether an active (working) node exists within its probing range. The probing node enters the active state only when it receives no replies from its working neighbors, else it goes back to sleep mode. The probing node calculates a random sleeping time before the next round of probing, based on the reply message received from the active node.

The aim of PEAS is to maximize network coverage and connectivity by waking up minimum number of nodes. The authors show that the network lifetime increases linearly with the number of nodes. In PEAS, the wakeup rate is randomized and spread over time based on an *exponential function*. This causes unnecessary waking up of nodes, due to which energy consumption increases and network lifetime decreases. PEAS is useful for a network where the node density is high. If the node density is not high enough then some of the probing nodes may enter the active state which would lead to a reduction in the network and node lifetime. To avoid these shortcomings we propose *Random Backoff Sleep Protocol* (RBSP).

Random Backoff Sleep Protocol(RBSP) is a probe based protocol which utilizes the information about residual energy level in the active node. This is in contrast to PEAS, which ignores this information. Further, RBSP does not use any exponential function for the wakeup time. PEAS uses an *exponential function* to compute the random backoff time[6]. This exponential function causes the intervals between successive wakeups of the sleeping nodes to increase. A *sensing void* (uncovered area) could get created if an active node dies, and the sleeping node has not woken up in time. RBSP protocol employs a novel backoff algorithm for calculation of sleeping time period. The proposed protocol uniformly chooses a random value of sleeping window based on residual energy of the active node. Using this mechanism, when an active node has high residual energy, the probability of a neighbor node turning *on* is low. Similarly, when an active node has low residual energy, the probability of a neighbor node turning *on* is high. This will help in balancing the energy consumption among the nodes. Due to this, we expect the network lifetime to increase substantially.

The rest of paper is organized as follows: in Section 2, we review some coverage optimization protocols used in wireless sensor networks. In Section 3, we present the details of our protocol – RBSP. Section 4 contains performance evaluation using simulations. Finally, we present our concluding remarks in Section 5.

2 Related Work

Many research efforts have been made to exploit the inherent coverage redundancy to extend the lifetime of wireless sensor networks. Ye *et al.* [6] present Probing Environment and Adaptive Sleeping(PEAS) which is a distributed protocol, based on probing to extend network lifetime by turning on minimum number of active nodes. PEAS is a location independent protocol. Gui *et al.* [7] propose Probing Environment and Collaborating Adaptive Sleeping(PECAS) which is an extension to PEAS [6]. PECAS does not allow active nodes to operate continuously until energy depletion. Occurrence of sensing void is reduced in PECAS because a active node schedules itself to enter into sleep mode after some specified time.

Yun-Sheng *et al.* [8] propose Controlled Layer Deployment(CLD) which uses deterministic node deployment and is based on PEAS. CLD [8] helps to achieve a longer network lifetime as compared to PEAS[6].

Xing *et al.*[9] present Coverage Configuration Protocol(CCP) which is a decentralized protocol. CCP requires lesser number of active nodes. CCP is a location dependent protocol. Zhang *et al.*[10] introduce Enhanced Configuration Control Protocol(ECCP) which provides a mechanism to avoid sensing voids in the network. However, it requires more number of active sensor nodes as compared to CCP. Honghai *et al.* [11] present an Optimal Geographical Density Control algorithm that determines the minimum number of active nodes for full coverage. When OGDC is compared with PEAS, it requires 50% lesser active nodes for full coverage.

Chen *et al.* [12] present *Span* which is a distributed, randomized algorithm where nodes make local decisions whether to sleep, or become active as a *coordinator*. Network lifetime increases due to *Span*. Kijun *et al.* [13] propose MAC protocol which is based on a backoff algorithm for wireless sensor networks which used dynamic contention period based on residual energy at each node. In case of all the above protocols, the residual energy of the active node is not considered for determining the sleep schedules. In case of reference [13] the residual energy is considered for medium access and not for planning the coverage. In the section below we discuss RBSP's random backoff sleep cycle, state transition diagram and finally details of the working of the protocol.

3 Random Backoff Sleep Protocol

We propose Random Backoff Sleep Protocol(RBSP) for node scheduling. The wakeup rate of RBSP is based on residual energy of an *active* node. At each active node a *sleeping window* is dynamically computed based on the amount of residual energy of the active node. The probability of neighbor nodes becoming active is inversely related to the residual energy level of the current active node. Neighbor nodes use the sleeping window information from the active node to determine its sleep time.

Fig. 1 gives a simple example for illustration. We have considered three cases for RBSP, in case-I we assume that, for time interval T0 to T1, node A is active and its residual energy is only 10%. Hence the sleeping window of active node A is very small due to which, wakeup rate of neighboring sleep nodes is also very high. In case-II for the time interval T to T', node B is active and its residual energy is 40%. As a result, the sleeping window of active node B is slightly larger as compared to that of node A. This causes the wakeup rate of neighboring sleep nodes to be moderate. Therefore, the probability of sleeping nodes turning *on* is also moderate. Similarly, for case-III, the time interval t to t', node C is active, and its residual energy is -90%. This causes the sleeping window of active node C to be very large. Therefore, the wakeup rate of neighboring sleeping nodes is very low. Due to this the probability of sleeping nodes turning *on* is very less.

While in PEAS (case-IV), node A is active at T0, a sleeping node B wakes up at T1 and a sleeping node C wakes up at T2. In PEAS wakeup rate of sleeping nodes is not based on residual energy of active node. PEAS uses an *exponential function* to compute the sleep interval[6]. Due to this, initially the sleeping nodes would wakeup frequently and later at a slower pace. This could create a sensing void if the active node dies when the sleep intervals are wide. Also the frequent wakeups could cause energy loss.

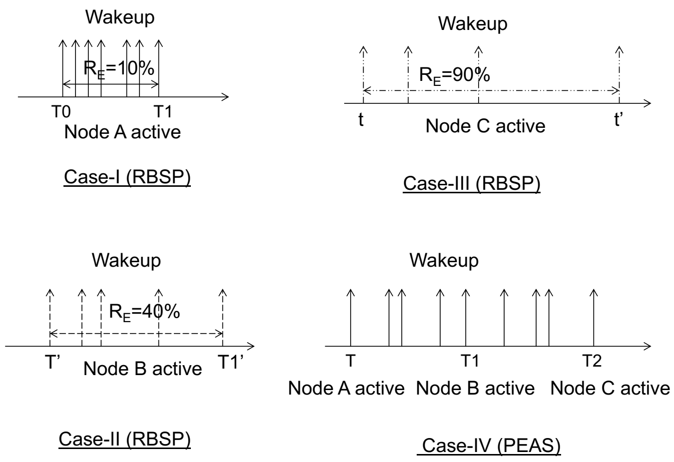

Fig. 1. RBSP and PEAS wakeup cycle

3.1 State Transition of RBSP

Each node in RBSP has three operating states which are similar to PEAS [6]: *SLEEP*, *FLOAT* and *ACTIVE*. The state transition diagram for all three modes is shown in Fig. 2. In the SLEEP state, a node turns its radio off to conserve energy. Each node in FLOATING state broadcasts HELLO message within its sensing range *Rs*, where *Rs* is the maximum sensing range within which an event can be observed or detected. The ACTIVE node continuously senses the physical environment and communicates with other sensor nodes. Each node in RBSP has three operating states which are similar to PEAS [6]: *SLEEP*, *FLOAT* and *ACTIVE*. The state transition diagram for all three modes is shown in Fig. 2. In the SLEEP state, a node turns its radio off to conserve energy. Each node in FLOATING state broadcasts HELLO message within its sensing range *Rs*, where *Rs* is the maximum sensing range within which an event can be observed or detected. The ACTIVE node continuously senses the physical environment and communicates with other sensor nodes.

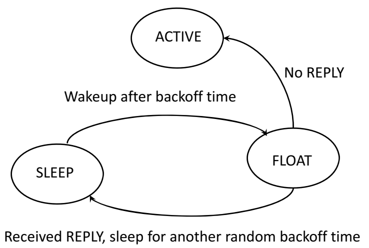

Fig. 2. State Transition Diagram of RBSP

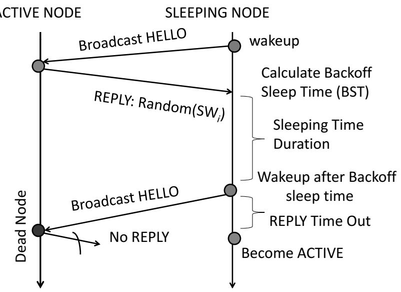

Fig. 3. Flow diagram of RBSP

The flow diagram of RBSP is shown in Fig. 3. Nodes are initially in sleeping state. Each node sleeps for a random backoff time based on *sleeping window* of active node. After the node wakes up, it enters into a floating state. The Floating node broadcasts HELLO message within its sensing range *Rs*. Any active node(s) within that sensing range responds with a REPLY message, which includes a unique random number from the *sleeping window* based on its residual energy. If the floating node hears a REPLY, it goes back to sleep mode for another random period of time, generated according to equations 1 and 2. If floating node does not hear any REPLY, it enters into active state. The floating node computes the *Reply Time (RT)* based on the time interval from sending the HELLO packet to the receipt of the REPLY message. The floating node maintains a timer with the value *Reply Time Out (RO) = 2 * RT*. If a reply is not received within the reply time out period, then the floating node enters into active state. Thus using RBSP, each sleeping node determines whether any active node is present within its sensing range or not. Any node once enters into active state, it remains active until it consumes all of its energy. RBSP's working mechanism and the computations at the nodes is explained below.

3.2 Working Mechanism of Random Backoff Sleep Protocol

In our protocol, each node has 10 energy levels depending on its residual energy. The energy level i and the sleeping window SW_i, corresponding to the energy level of a node, are shown in the equation below.

$$i = ceil(\frac{b\%}{10})$$
$$SW_i = 2^i to 2^{i-1} \quad (1)$$

where, b is the battery level of node in percentage. Each node initially starts from energy level $i = 10$ where its sleeping window is $SW_{i=10} = 2^{10} to 2^{10-1}$, i.e. (1024-512). When active node consumes more than 10% of its initial energy, its energy level changes to $i = 9$ and its sleeping window size decreases to $SW_{i=9} = 2^9 to 2^{9-1}$, i.e. (512-256). Similarly, if the active node consumes 20% of its initial energy, its energy level changes to $i = 8$ and its sleeping window size decreases to $SW_{i=8} = 2^8 to 2^{8-1}$ i.e. (256-128). In this way, the sleeping window size becomes smaller as the node consumes more power. The Backoff Sleep Time (BST) used by a node based on energy level i is given by

$$BST = Random(SW_i) * \frac{R_E}{I_E} * \eta \quad (2)$$

where, R_E is the residual energy and I_E is the initial energy of active node. η is a tunable parameter having unit of time and depends on the application of the sensor network. In the next section, we evaluate the performance of RBSP and compare it with PEAS.

4 Performance Evaluation

We have implemented RBSP and PEAS in ns-2[14]. The energy model in this protocol is similar to PEAS[6], where Sleep:Idle:Tx:Rx as 0.03mW:12mW:60mW: 12mW. We assume that the maximum sensing range is 5 meters and is equal to the transmission range. The initial energy of each node is set at 1 Joule. We run the simulation for 150 sec. The packet size of HELLO and REPLY messages are 20 bytes each. We have deployed 100 sensor nodes over $50 \times 50m^2$ network field. We vary node density fraction from 0.02 to 0.1 in order to calculate number of active nodes, where the node density fraction is the ratio of number of deployed nodes to the total area of the network field. Nodes are randomly deployed in the field and remain stationary after deployment.

Fig. 4 shows the number of active nodes with respect to time. Number of active nodes in case of RBSP is comparable to PEAS.

Fig. 5 shows the number of active nodes with varying fraction of node density. The RBSP and PEAS maintain adequate active nodes in order to monitor the intended network field. As we increase the node density fraction, active nodes vary in linear proportion to the number of deployed nodes. Again the number of active nodes in case of RBSP is comparable to PEAS.

Fig. 6 shows the average energy consumption of the network with respect to time. The average energy consumption is the ratio of the total energy consumption to the total number of nodes in the network. We can see that the average energy consumption of RBSP is less as compared to that of PEAS. The energy

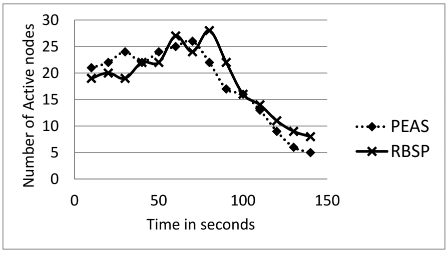

Fig. 4. Number of active nodes

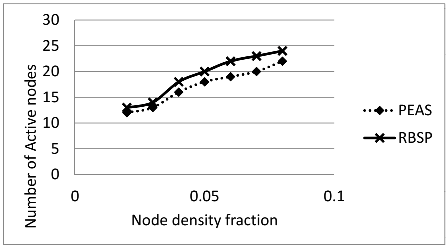

Fig. 5. Number of active nodes

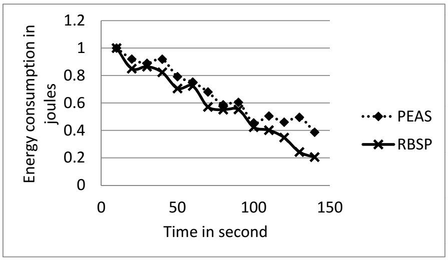

Fig. 6. Average energy consumption

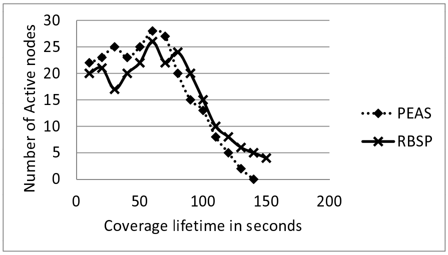

Fig. 7. Coverage lifetime

consumption of RBSP is less, due to changeable sleeping window determined on the basis of residual energy of active nodes. If the node has more residual energy, it requires fewer wakeups of sleeping nodes, due to which average energy consumption is less and network lifetime is more.

In Fig. 7, we can see the coverage lifetime for RBSP and PEAS. We assume that the presence of at least one active node in the network is sufficient to maintain minimum coverage in the region. For the case of a well-planned deployment, it is worth noting that the ratio of the entire sensing area to the maximum sensing area per node is about $\frac{50*50}{\pi*(5)^2} \approx 31$, which implies that at least 31 nodes are required to cover the entire area. At the time instant of 150 seconds, PEAS does not have any active node to monitor the field but in case of RBSP, four nodes are in active state to monitor the area. Hence, RBSP maintains adequate number of nodes active for a longer period of time, approximately 12.5% longer than that of PEAS. Therefore, RBSP has 12.5% more coverage lifetime as compared to PEAS.

5 Conclusion

We have proposed a Random Backoff Sleep Protocol(RBSP) which is a location free protocol that depends on the residual energy of ACTIVE nodes. Moreover, by simply varying the tunable parameter η, different sleeping time intervals based on application requirement can be provided. In RBSP each node adaptively determines its *sleeping window* based on the amount of residual energy. The size of *sleeping window* varies, which in turn increases or decreases the probability of turning *on* of the neighbor nodes. This balances the energy consumption among nodes due to which network lifetime can be prolonged.

The simulation results show that RBSP and PEAS maintained sufficient active nodes in order to maintain sensing coverage. Average energy consumption of RBSP is less compared to that of PEAS. RBSP maintains 12.5% longer coverage and network lifetime. In our future work we will extend our protocol to handle node failure probability which could creates sensing void.

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