On Minimizing Data Delivery Delay in Duty Cycling Wireless Sensor Networks

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ABSTRACT

For maximum conservation of energy in sensor networks, one of the most effective approaches is duty cycling. *M*inimum latency data delivery in wireless sensor networks employing duty cycling is a challenging issue. .To deliver data in a timely manner for such duty-cycling sensor networks, communication needs to be carefully managed among sensor nodes. Forwarding data along a longer but faster path can be a better option to obtain faster delivery while preserving the benefit of duty cycling. In this paper, first the issue of end to end delay minimization in data forwarding through WSNs is addressed. Then the use of an energy efficient threshold based routing protocol that effectively minimizes the end to end packet delivery delay in wireless sensor networks with duty cycling is demonstrated. This protocol can be adjusted to operate with an optimum threshold value so that the delay incurred in delivering the packet to the sink node will be significantly reduced.

General Terms

Wireless sensor network, Routing

Keywords

Duty cycling, delay minimization

1. INTRODUCTION

A wireless sensor network is made up of spatially distributed autonomous sensor nodes deployed to cooperatively monitor any physical quantities or environmental conditions such as pressure, temperature, humidity, motion, pollutants etc. Each individual sensor node will be having a limited communication range and constrained energy capacity because of the small battery power. On detecting of an event, a sensor node will be generating data samples to be communicated towards the sink node. These data packets are to be routed to the sink node through the intermediate nodes along the path. The transmission of data packets must be lossless and must consume less amount of energy.

Since sensor nodes are generally battery powered, reduction in the usage of energy during data transmission could eventually increase the lifetime of the sensor nodes. Since most of the energy is consumed by the transceivers which are the most power hungry component of a sensor node, a sleep awake scheduling technique like duty cycling is an effective mechanism for reducing battery power consumption and thus prolonging the lifetime of a sensor network.

However duty cycling could cause substantial increase in end to end message delivery delays because any transmitting node has to wait until the next hope neighbor node wakes up. When the next hope neighbor node is sleeping, a node has only the option of buffering the message till the waking up of the neighbor node. This will be a critical issue in applications that require data samples to be promptly communicated to the sink.

Even though duty cycling concept can be used as an effective solution for energy efficiency maximization, the problem of increasing end to end data delivery delay must be addressed seriously by researchers. The need of a class of energy efficient minimum delay routing protocols is becoming more and more significant in the field of wireless sensor network routing protocol design.

This paper proceeds in two steps. First the issue of end to end delay minimization in data forwarding through WSNs is studied. Then the design and implementation of an energy efficient threshold waiting time based routing protocol [1] that effectively minimizes the end to end packet delivery delay in wireless sensor networks with duty cycling. This protocol can be adjusted to operate with an optimum threshold value so that the delay incurred in delivering the packet to the sink node will be significantly reduced. The implementation and analysis of the protocol has been done using MATLAB simulation tool.

2. RELATED WORK

The issue of minimum latency data delivery under duty cycling nodes has been addressed by several research papers. The existing approaches suggested so far are divided into two categories. One is coordinated sleeping mechanism and the other is random sleeping mechanism. In the first mechanism nodes communicate with each other to adjust their sleeping schedules in order to meet the requirements, for example, coverage. Geographic Adaptive Fidelity (GAF) [2] is an example which allows idle nodes to turn off their radio without affecting the level of routing fidelity. Each node uses GPS-based location information to associate itself with a point in a virtual grid. Nodes associated with the same point on the grid are considered to be equivalent in terms of the cost of routing. In SPAN [3] which is another example, the nodes that are designated as coordinator nodes stay awake to route the packets while other redundant nodes are allowed to sleep and thus energy is conserved. The coordinators election is done in a distributed way so that the role of the coordinator is rotated among different nodes. In Asynchronous Wakeup Protocol (AWP)[4] the nodes wake up based on a Wakeup Schedule Function (WSF). Any shifted version of a WSF would still have one or more active period of nodes overlapped. So the complexity involved in synchronization of all nodes is reduced and the network partition problem due to different sleep-and-wake schedules of nodes is avoided.

In the later mechanism known as random sleeping mechanisms, sensor nodes enter the sleeping state in a random manner and independently from each other. For example, the Randomized Independent Sleeping (RIS) mechanism [5] assumes that sensors are synchronized globally. At the beginning of each time slot, a sensor independently decides whether to remain awake or enter sleeping mode with probability of p and 1-p, respectively. Random Asynchronous Wakeup (RAW) technique [6] employs random wake-up schedules and allows a node to forward the message to one of its active neighbors that belongs to a Forwarding Candidate Set, which is the set of neighbors that is closer to the sink by at least some given value than the node s itself. RAW is suited for high-density networks and it do not allow a message to increase its distance from the destination. Holes are not allowed in the network. Another technique for supporting duty cycling is based on a dedicated signaling band for waking up a node on-demand, e.g., PAMAS [7]. However, this method is more costly since it requires two-radio architecture.

This paper uses biased random walk for the performance model of the protocol. Random walk on a given network is a sequential process in which a walker moves from one node of the network to another, selected at random among its neighbors. The rest of the paper includes the design and implementation of this threshold based random walk protocol and the performance results obtained using Matlab tool shows that the protocol contributes to significantly reduce the end to end packet delivery delay in duty cycling sensor networks.

3. PROBLEM FORMULATION

3.1 End to end Delay minimization in duty cycling sensor networks

Data delivery is the first and foremost function of any applications using sensor networks. For example many applications, such as military surveillance or whether forecasting require the detected events to be reported to a base station or command center within a specified time frame. This therefore impose a real-time bound on communication delay.

Beside constraints on energy consumption by sensor nodes, these applications require real-time data delivery, which usually has delay constraints in the form of end to- end (E2E) communication deadlines. For example, a military surveillance system may require the positions of enemies or intruders to be reported to the data center within several seconds, so that timely actions can be initiated. To resolve the conflict between the limited power supply of sensor nodes and this real time data delivery deadline of applications, it is essential to design routing protocols that can achieve designated data delivery deadline with the minimum energy consumption.

On the other hand, for the maximum conservation of energy, one of the most effective approaches is duty cycling. This technique relies on how to keep sensor nodes in the Sleeping state as long as possible while satisfying application requirements. Obviously a node cannot communicate if it is not active. Therefore, to deliver data in a timely manner for such duty-cycling sensor networks, communication needs to be carefully managed among sensor nodes.

Obviously, if all nodes are always in active state, E2E delay equals to the number of hops between a source and a destination. However, if nodes in a network have certain sleep wake-up schedules, i.e. duty cycling then transmission at each hop could be delayed, waiting for the receiver to wake up. Consequently, the sleep latency between two nodes become considerable. *Sleep latency is* the time spent waiting for the receiver to wake up.

Exploring the existence of certain paths from source to destination with minimum delay, along with their statistical characteristics will eventually lead to an optimal solution to the problem of increased data delivery delay in duty cycling sensor networks. In general, a path with minimum delay is assumed to be the classical shortest path between the source and destination..

But when sensor networks use duty cycling, compared to data forwarding along a shortest path, the end to-end delay of data forwarded along a still longer but faster path may be much smaller. That is, the minimum delay is obtained when the data is routed through some other paths than the shortest path. Since energy consumption is dominated by the duty cycle, it can be concluded that forwarding data along a longer but faster path can be a better option to obtain faster delivery while preserving the benefit of duty cycling.

3.2 A Threshold based forwarding protocol for delay minimization

A simple random walk threshold based forwarding protocol which provides an effective solution for the end to end data delivery delay problem in wireless sensor networks employing duty cycling, is designed and implemented.. This protocol behaves with the characteristics of the hot potato routing as well as the traditional shortest path based routing. That is , a parameter called threshold waiting time value is defined and by appropriately varying the value of this threshold parameter the protocol routing behavior can be adjusted between that of the hot potato routing and the classical shortest path routing. When certain optimal value is set for the threshold parameter, the average end to end delay from source to sink will be minimal. That is at this value of threshold, the protocol contributes for significantly reducing the end to end packet delivery delay at the sink.

According to this protocol, the node which holds a message to be forwarded is always interested in passing the message to a neighbor quickly. However, if it knows that its next hope neighbor node which lies on the shortest possible path towards the sink will wake up within a threshold amount of time, the node will be forwarding the message to that particular node.. Otherwise, it will be forwarding the message to some neighbor node that will be becoming active at the first.

The value for threshold can be set according to the delivery requirements and the preference of data. If an event contains data that has to be urgently communicated to the sink, then the threshold value can be set to zero or sum minimum value so as to forward the data with minimum required delay. On the other hand , if the event generates data that are to be normally communicated to the sink, with no delay constraints the threshold parameter can be set to the optimum value so as to reduce the end to end delay without significantly increasing the number of transmissions.

The protocol works as follows. If the forwarding node is denoted as F, and any generic neighbor of this forwarding node as G, then let P be the neighbor of F which is on the shortest path from F to the sink. Moreover, let DF be the forwarding delay through P, which is the time elapsed from when F received the message until P will wake up. The key step of the protocol is that F forwards the message to P only if DF is not larger than the threshold amount of time." Otherwise, F sends the message to the first neighbor that becomes active. The rule based on what the forwarding of the message from the current node to a neighbor node is performed is as follows:

• If DF< T, then F sends the message to P.
• Otherwise, F sends the message to the first node G that becomes active (ties are broken at random).

4. IMPLEMENTATION

4.1 Network simulation model

In our simulation experiments, a random deployment model in which nodes are located at random positions on a square field and all nodes have the same normalized transmission range r is considered. Links are established between any two nodes at distance less than the constant value r from each other. It is assumed that the clocks of the sensors are synchronized. The protocol works according to a time slot model, where slots are synchronized. Moreover, it requires that a sensor knows the identity of its next hop nodes. Also it is assumed that the packet transmission requires one time slot, i.e., medium access protocol, collisions, etc., are all such that they can be managed within a time slot.

Here the implementation of the algorithm based on which the routing process carried out is done. .This implementation has been done using Matlab simulation tool for which Windows XP or Windows 7 is the working platform.

4.2 Algorithm

The outline of the algorithm is as follows

F: The node which has the message to be forwarded

G: A neighbor of F

P: The shortest path neighbor node of F

DF: Forwarding delay, i.e., the time elapsed from when F received the message until P will wake up.

TH: Threshold time amount

```
If (DF<TH)
        {
                Forward the message to P
        }
Else
        {
                Forward the packet to G which is the
                first to become awake
        }
```

5. RESULTS

The results are obtained by simulating the algorithm using Matlab simulation Tool.. The Deployment of the network, Event Generation and Routing process are all simulated. The user can generate multiple events on the same run of the simulation and for each event; the routing process will be shown .The routing destination is always a single sing node. Simulations are carried out for different number of nodes and different sensing and transmission ranges. Figure 1 shows the routing of packets from source node to sink node.

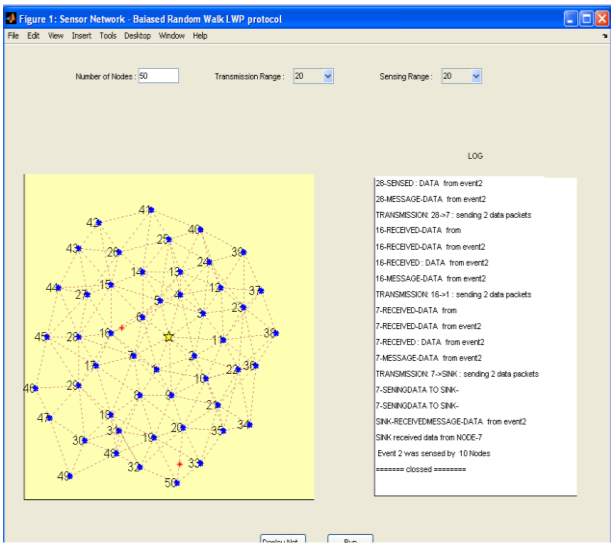

Figure1 Routing of packets to the sink node

6. PERFORMANCE ANALYSIS

The graph in Figure 2 shows the average delay as a function of the threshold T.

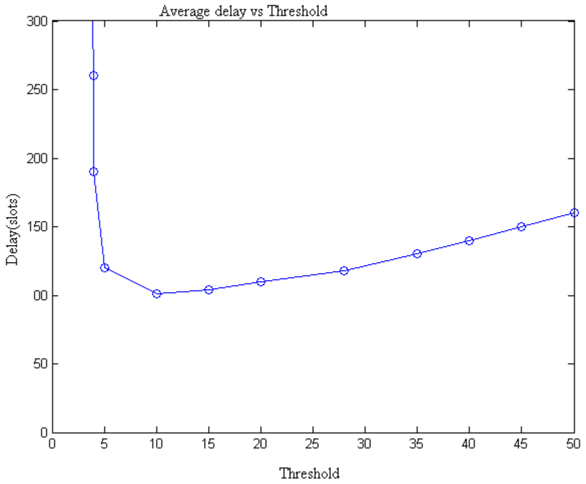

Figure 2. Average delay versus threshold

For the analysis of the performance of the algorithm, the total energy consumption and the energy consumption per node are taken as the two parameters. Simulation results shown in the Figures 3 and 4 shows that, even though the total energy consumed is higher as compared to the classical shortest path routing,(as the number of event detections in the network increases), the energy consumed per node is lesser than that in shortest path routing. So if the energy consumption per node is minimized it can lead to prolonging of lifetime of a sensor node.

The comparison of the implemented algorithm with the classical shortest path algorithm is obtained in the following figures. The red line represents classical shortest path routing and the blue line represents the minimum delay threshold based protocol.

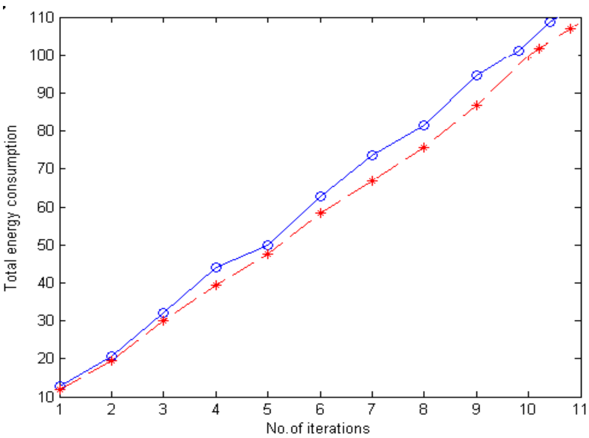

Figure 3 Total energy consumption Vs Number of events

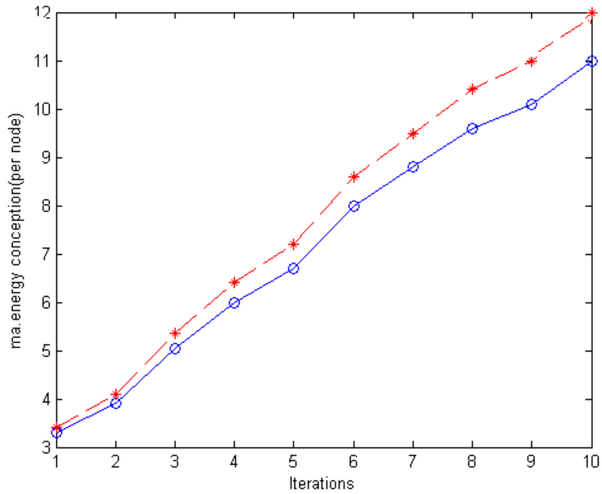

Figure 4 Energy consumption per node Vs number of events

7. CONCLUSION

Duty cycling is a widely used approach to reduce energy consumption and prolong the life of a sensor network. However duty cycling could cause substantial increase in end to end message delivery delays. Forwarding data along a longer but faster path can be a better option to obtain faster delivery while preserving the benefit of duty cycling. In this paper, a study on the issue of end to end delay minimization in data forwarding through WSNs is presented. Then an energy efficient threshold based routing protocol that effectively minimizes the end to end packet delivery delay in wireless sensor networks with duty cycling is used. The simulation results shows a comparison of the this protocol with the classical shortest path routing. It is found that as the number of event detections increase the energy consumption per node is lesser when compared to shortest path routing. But the protocol requires more number of data transmissions while achieving minimum end to end data delivery delay. This issue can be addressed by researchers in order to improve the protocol.

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