

# GSP: Gossip-based Sleep Protocol for Energy Efficient Routing in Wireless Sensor Networks<sup>1</sup>

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## ABSTRACT

*In this paper, we propose a novel energy saving scheme, named Gossip-based Sleep Protocol (GSP), to achieve energy efficiency in wireless sensor networks. With GSP, each node goes to sleep for some time with some probability and the situations in which most awake nodes stay connected depend on the gossiping probability and the topology of the network. Our design does not require sensor nodes maintain any states of other nodes. It requires few operations and scales to large networks. We show the correctness and effectiveness of the protocol by both simulations and analysis.*

## I. INTRODUCTION

A sensor network is composed of a large number of sensor nodes that are densely deployed either inside the phenomenon or very close to it. The position of sensor nodes need not be predetermined, so the random deployment is allowed in inaccessible terrains or disaster relief operations and the topology may be random. Some of the application areas are health, military, and home. Since the large size and density of such network, routing protocols are necessary for end-to-end transmission. Although many routing protocols have been proposed for wireless ad hoc networks, they are not suitable to the sensor network. Sensor networks have some unique feature and application requirements [6]: larger size, higher density, more limited power supply and computational capacity, etc..

One of the reasons that the routing protocols for wireless ad-hoc networks may not be directly applicable to sensor network is the severe constraints on power. Additionally, the sensor networks can be characterized as data centric network, where data is not always requested from a specific node, but based on certain attributed. Sensor networks are also application-specific in that the network's requirements change with the applications. As an example, in some applications, the sensor nodes are fixed, but other networks are a combination of fixed and mobile nodes, thus requiring mobility support. Adjacent nodes might have similar data; therefore, sensor networks should aggregate similar data to reduce unnecessary transmissions and save energy. Assigning unique IDs may not be suitable in sensor networks because these networks are data centric—routing to and from specific node is not required. In addition, the large number of nodes will require large IDs, which might make a big overhead compared to data being transmitted. Therefore, the protocols in sensor networks need to be optimizing energy consumption, application specific, data centric, and capable of

aggregation data. Since most wireless sensor nodes are not connected to a power supply and the battery replacement is difficult to do. Optimizing energy consumption in these networks is the first priority.

In this paper, we study the problem of energy efficiency for sensor network routing by employing sleep mode. Our design has been driven by the following three goals:

*Simplicity:* Sensors have limited computing capability and memory resources. Minimized operation and information maintained are required. In particular, we do not maintain any information except a timer.

*Scalability:* Unlike conventional ad hoc networks, a sensor network can be composed of thousands of nodes, scalability is very important.

*Connectivity:* Network connectivity can keep the data transmission delay low. Although not all applications require a small data transmission delay, we aim at the non-energy-efficient routing protocols without long delay incurred.

Our protocol, Gossip-based Sleep Protocol (GSP), meet all the three goals above by employing *gossiping* – essentially, tossing a coin to decide whether or not to sleep for the next period. In the paper, we prove that with certain value of gossip probability and certain density of the topology, the network are still connected, thus work properly.

The remainder of this paper is organized as follows. In section II, we present a brief review of current sensor network routing protocols. Section III presents our Gossip-based Sleep Protocol (GSP). Theoretical analysis is presented in section IV. Our simulation is shown in section V. We conclude our work and point out some possible future works in section VI.

## II. RELATED WORK

Basically, there are two types of sensor network routing protocols in the literature, energy-based and non-energy-based. Energy-based routing schemes utilize energy as routing metric to save power and prolong the network lifetime. Non-energy-based routing schemes try to get power efficiency in an indirect way by reducing the overhead and sometime tradeoff for other performance. This section presents a brief review of these two types of routing to provide a better understanding of the current research issues in this area.

Energy efficient routing has been a very active research area in sensor networks in recent years. Due to severe constraints of power in sensor networks, cluster-based energy efficient routing protocols have been focused. In cluster-based routing

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protocols, all fixed nodes are organized into clusters with one node selected to be cluster-head for each cluster. This cluster-head will receive data packets from its members, aggregate these packets then transmit to Base-Station. In some cluster-based routing protocols, cluster-head must assign TDMA slots to its members. The examples of cluster-based energy efficient routing protocols are LEACH, TEEN, and APTEEN.

LEACH is a proactive, adaptive, self-organizing cluster-based routing protocol [7]. It utilizes randomized rotation of cluster-heads to evenly distribute the energy load among the sensors in the network. TEEN is a reactive cluster-based protocol [8]. In TEEN, nodes sense the environment continuously, but send the sensed data to cluster-heads only when the thresholds are reached. Thus, the energy will be saved more in TEEN compared to LEACH protocol. In APTEEN protocol [9], it combines the best features from proactive and reactive networks. It provides periodic data collection as well as near real-time warning about critical events. To handle queries efficiently, it assumes that adjacent nodes can sense similar data. A pair of nodes is formed, and only one node must response to a query. As a result, it will reduce energy consumption by allowing the other node to be in sleep mode and need not even receive the query. The TDMA slots of idle nodes must be modified to have larger timeslots than the sleeping nodes' in order to send out not only data but also queries. Even though the positive point of these three cluster-based routing protocols is that they mainly focus on the energy constraints of sensor networks, the main drawbacks of these protocols—complexity and large overhead—still exist.

There are three types of non-energy-based routing, namely, flooding, forwarding and data-centric based routing. Flooding is an old routing technique that can be used in sensor networks. In flooding, every node repeats the data once by broadcasting. It doesn't require costly topology maintenance and complex route discovery algorithms. But it has several deficiencies [6]:

*Implosion*: duplicated messages are sent to the same node. A node with multiple neighbors may receive multiple copies of same message.

*Overlap*: if two sensors share the name observation region, both of them may sense the same stimuli at the same time. As a result, neighbor nodes receive duplicated messages.

*Resource blindness*: flooding doesn't take into account the available resources, e.g. remaining energy stored in the sensor node.

To overcome the problems of flooding, some forwarding schemes have been proposed to utilize certain local information to forward messages. Unlike traditional routing protocols, forwarding doesn't maintain end-to-end routing information. Instead, intermediate nodes just maintain the neighbor information. Various routing protocols employing various information have been proposed. With gossiping protocol [3], a node only forwards data to one randomly chosen neighbor, so it doesn't maintain any routing information or we can say it uses randomness to forward data. Best Effort Geographical Routing Protocol (BEGHR) [1] employs position information to forward data, and therefore requires GPS or other positioning service. Field based Optimal Forwarding employs *cost field* to forward data [2]. A cost field is the minimum cost

from a node to the sink on the optimal path. A sink node is the user of this network.

Some other routing protocols are based on data-centric approach. In data-centric based routing, an interest message is disseminated to assign the sensing tasks to the sensor nodes, so attribute-based naming [6] is required. The users are interested in querying an attribute of the phenomenon, rather than querying an individual node. So instead of using "the temperature read by a certain node", we may use "the areas where the temperature is over 70F". Also, data aggregation is used to solve the implosion and overlap problems. There are two types of data-centric based routing based on either the sink broadcasts the interest to require for data, e.g. Directed Diffusion [4], or the sensor nodes broadcast an advertisement for the available data and wait for a request, e.g. Sensor Protocols for Information via Negotiation (SPIN) [5].

In all the non-efficient-routing protocols, energy efficiency is not the most important issue and they reduce the routing overhead as much as possible to achieve scalability. As a result, they require all nodes in the network awake, which consumes significant energy. In this paper, we introduce the sleep mode concept into these protocols to achieve energy efficiency as well as low overhead.

### III. GOSSIP-BASED SLEEP PROTOCOL

#### A. Gossip-based ad hoc routing

In ad hoc networks, *gossiping* protocol [10] is proposed to reduce the flooding overhead. Almost all the ad hoc routing protocols use some kind of flooding scheme to send routing messages. With a flooding, every node needs to forward the message once, but this is not necessary since a node with more than one neighbors receives multiple copies of that message. Gossiping reduces this by making some of the nodes discard the message instead of forwarding it. Essentially, a node tosses a coin to decide whether or not to forward the message. The probability  $p$  that a node forwards a message is called gossip probability. [10] shows that, with certain value of  $p$ , almost all the nodes in the network can receive the message. For example, in a  $20 \times 50$  grid topology, a value of 0.72 with the first 4 hops from the source node forwarding the message with probability 1 can make almost all nodes get the message in almost all executions of the simulation. This can reduce 28% of the flooding overhead.

#### A. Gossip-based sleep protocol

As mentioned in section II, some of the current sensor network routing protocols require all sensors awake and keep listening. This wastes a lot of energy, as we will show in the next section. Inspired by gossip-based ad hoc routing, we propose the Gossip-based Sleep Protocol (GSP) to achieve energy efficiency in wireless sensor networks. Our observation is that if gossiping can make all nodes receive a message, then the nodes forwarding the message are connected at least by the paths the message passing through. So we have the following foolproof claim.

**Claim 1:** With certain probability  $p'$ , if gossiping can make almost all nodes receive the message, then if all nodes go to

sleep with probability  $p=(1-p')$ , almost all the awake nodes stay connected.

With Claim 1 in mind, we can safely make  $p$  of the nodes in sleep mode without losing network connectivity. We term  $p$  as *gossip sleep probability*. Since the sleep nodes are randomly distributed in the network, we assume that this will not affect the data collection. We describe the GSP as follows.

At the beginning of a period, each node chooses either going to sleep with probability  $p$  or staying awake with probability  $(1-p)$  for this period

All sleeping nodes wake up at the end of each period

All nodes repeat the above process for every period

The period in GSP depends on the application. If the application can tolerate longer delay, the period is longer, otherwise, it's shorter.

The major objective of GSP is to achieve energy efficiency by making some nodes go to sleep mode. But the data may go through longer paths if the sleep nodes are on the optimal paths of other nodes to the sink, resulting in more energy consumption in the network-wide data transmission. So we are concerned if the energy saved by DSP is larger than the extra energy it consumes and. Our evaluation in the next two sections focuses on this problem.

## IV. ANALYTIC MODELING

### A. Radio Model

In GSP, we assume a simple model where transmit or receive data will consume 50 nJ/bit ( $E_{elec}$ ) as in Table 1. Transmitter amplifier uses 100 nJ/bit/m<sup>2</sup> ( $\epsilon_{amp}$ ) based on  $r^2$  energy loss due to channel transmission. We also assume that a turned on receiver consumes 40 nJ in a period time ( $E_{Rx-turn-on}$ ) and each node is 10 meters apart from one another.

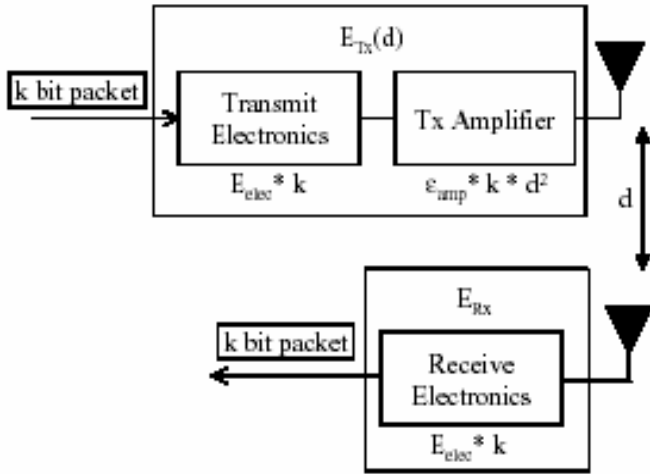


Figure 1 Radio Model [7]

Operation	Energy Dissipated
Transmitter Electronics ( $E_{Tx-elec}$ )	50 nJ/bit
Receiver Electronics ( $E_{Rx-elec}$ )	
( $E_{Tx-elec} = E_{Rx-elec} = E_{elec}$ )	
Transmit Amplifier ( $\epsilon_{amp}$ )	100 pJ/bit/m <sup>2</sup>

Table 1 Radio Characteristics [7]

### B. GSP Theoretical Performance

In GSP, we study how much the energy will be saved if we let some random nodes go to sleep mode. By applying sleep mode to some random nodes, the minimum cost paths between any source nodes and a sink node may not be established. Therefore, the average energy consumption of entire network will be increased because some data packets will be transmitted via non-minimum cost paths. This required energy is estimated by using simulation to find an average extra path cost ( $\alpha$ ). Finally, we try to prove that the amount of energy saved by using probability of sleep nodes ( $E_{GSP-saved}$ ) is bigger than the amount of extra energy needed for source nodes to transmit data packets via non-minimum cost paths ( $E_{GSP-extra}$ ). We assume that all calculations are within a period of time to transmit one bit of data (bit time). The saved energy ( $E_{GSP-saved}$ ) can be shown as follow equation.

$$\begin{aligned} E_{GSP-saved} &= (E_{Rx-turn-on}) * p * N \\ &= (40 \text{ nJ}) * p * N \end{aligned} \quad (1)$$

where  $p$  is a probability of sleep nodes in network.  
 $N$  is number of sensor nodes in the network.

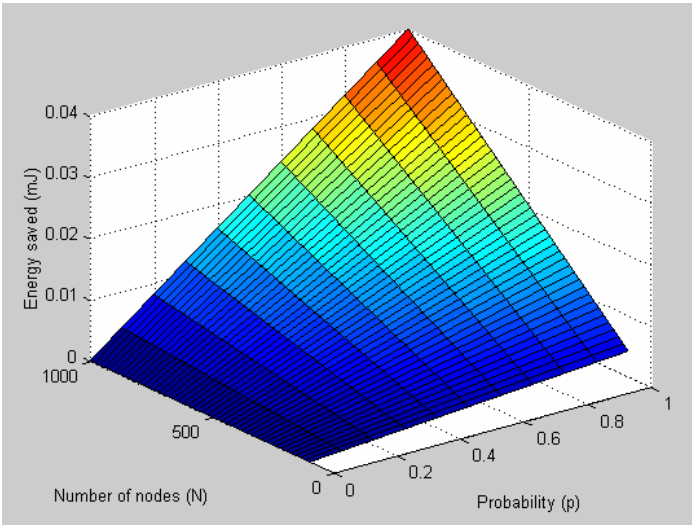
For example, if network has 100 sensor nodes and probability of sleep nodes in network is 0.25. Then energy is saved 1 J. The extra energy consumption ( $E_{GSP-extra}$ ) due to some data packets are sent via non-minimum cost paths is set as equation below.

$$\begin{aligned} E_{GSP-extra} &= \{ \{ E_{Tx-elec} + [d^2 * (\epsilon_{amp})] \} - [E_{Rx-turn-on}] \} * B * \alpha \\ &= (50 \text{ nJ/bit} + 10 \text{ nJ/bit} - 40 \text{ nJ/bit}) * B * \alpha \\ &= (20 \text{ nJ/bit}) * B * \alpha \end{aligned} \quad (2)$$

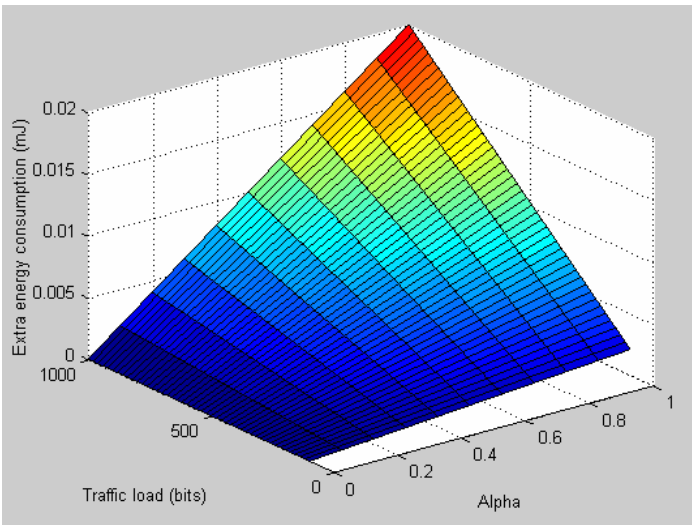
where  $B$  is traffic load (bits).  
 $d$  is a distance between nodes (10 m).  
 $\alpha$  is an average extra path cost in GSP

$$E_{diff} = E_{GSP-saved} - E_{GSP-extra} \quad (3)$$

Figure 2 represents the relationship among energy saved in GSP, number of nodes in network, and probability of sleep nodes in the network. We can say that energy saved will be increased when network has larger number of nodes and higher probability of sleep nodes. However, it should be considered that high probability of sleep nodes ( $p$ ) would lead to network partition. The relationship among extra energy consumption in GSP, alpha and traffic load is shown in figure 3. It can be said that extra energy consumption will be increased when network has higher traffic load and alpha value.



**Figure 2** Equation 1 Plot, Energy saved ( $E_{\text{GSP-saved}}$ ) in mJ vs. probability of sleep nodes ( $p$ ) and number of nodes ( $N$ ).

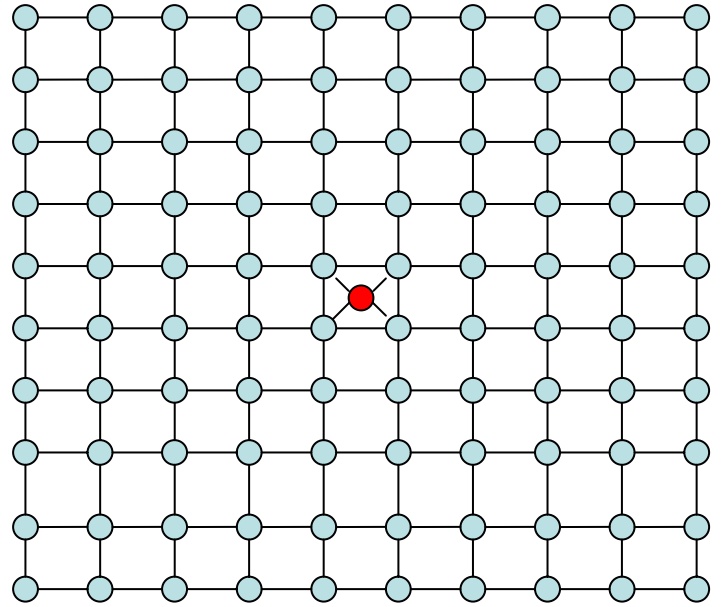


**Figure 3** Equation 2 plot, Extra energy consumption ( $E_{\text{GSP-extra}}$ ) in mJ vs. alpha ( $\alpha$ ) and traffic load ( $B$ ) in bits.

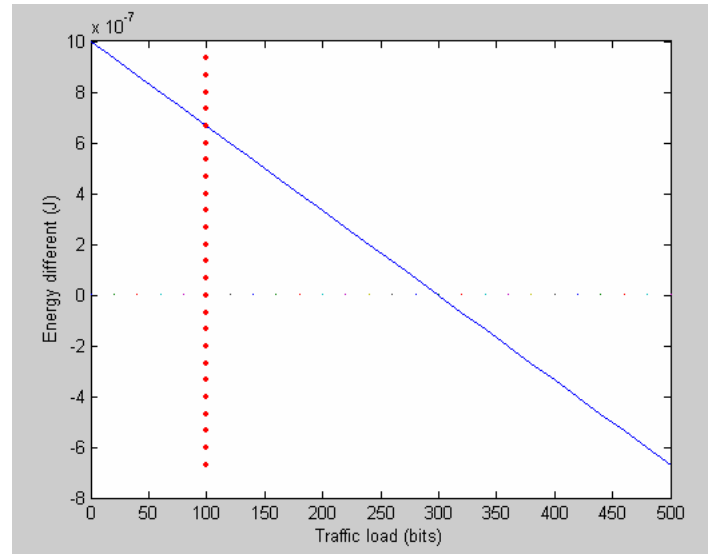
## V. SIMULATION RESULTS

### A. Simulation model

We utilized ns-2 network simulator [11], with CMU Monarch Project wireless and mobile ns-2 extensions, to study the characteristics of topology change by employing GSP. A  $10 \times 10$  grid topology with a single sink node in the center is used. The topology is shown in Figure 4, and there are total 101 nodes, i.e. 100 sensors and a sink. We assume the sink has external power supply, so we just need to study the property of the sensor nodes with GSP. We use DSDV [12], an ad hoc routing protocol, to find the shortest path from every sensor to the sink protocol. The gossip sleep probability in the simulation is 0.25, i.e.  $p=0.25$ .



**Figure 4** A  $10 \times 10$  grid topology used by the simulation. The red node is the sink



**Figure 5** Energy different ( $E_{\text{diff}}$ ) between  $E_{\text{GSP-saved}}$  and  $E_{\text{GSP-extra}}$  vs. traffic load ( $B$ ) in bits when  $p = 0.25$ ,  $N = 100$ , and  $\alpha = 0.166$ .

### B. Simulation results

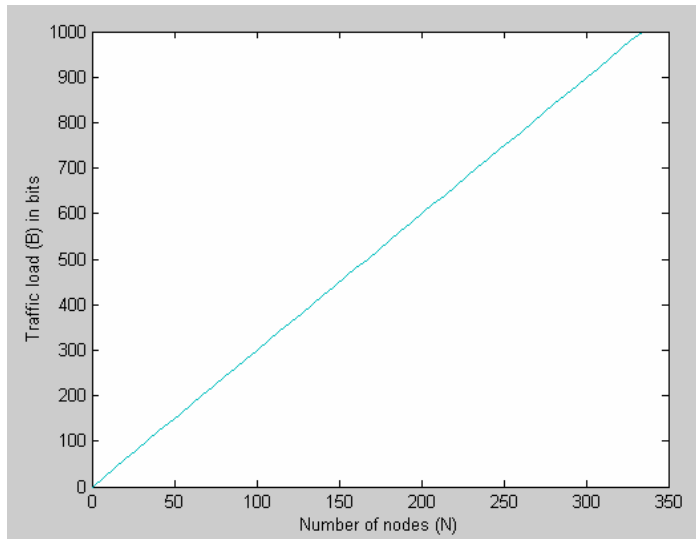
As we could expect from the theoretical analysis, the average path length becomes longer. Without GSP, the average path length is 5. With GSP, the value of this variable is 5.83, with a 90% confidence interval (5.54, 6.14). The result shows that the average path length increases by 16.6%, i.e.  $(5.83 - 5)/5 = 0.166$ .

In addition, we found 3.11 sensors on average are separated from the sink with a 90% confidence interval (1.68, 4.53). These nodes waste energy since they stay awake but

cannot attend network operation. Also as we could expect, this value is small and will not affect the GSP performance.

### C. Continued theoretical analysis

In figure 5, it can be observed that when the traffic load in network is greater than 301 bits, the energy different which defined by Equation 3 will be negative which means the amount of energy saved ( $E_{\text{GSP-saved}}$ ) is smaller than the amount of extra energy consumption ( $E_{\text{GSP-extra}}$ ). However, the simulation shows that the highest traffic load for 100 nodes in a bit time is 100 bits. At this point, energy different is positive.



**Figure 6** Number of nodes vs. traffic load (bits) when  $p = 0.25$ ,  $\lambda = 0.166$ . (Back-up figure)

Figure 6 is a plot of number of nodes vs. traffic load when probability of sleep nodes in network is 0.25 and the average extra path cost ( $\lambda$ ) is 0.166. The area above this line represents positive energy different that leads to energy efficiency of GSP.

## VI. CONCLUSIONS AND FUTURE WORK

This paper has proposed a novel sleep management approach for sensor network routing, i.e. GSP. We achieved simplicity by adding a timer only to each sensor. Once the time is up, every sensor just needs to decide whether go to sleep in the next period with the gossip sleep probability  $p$ . The property of gossiping makes it apply to large networks, theoretically, even an infinite network. Network connectivity is based on the gossip sleep probability  $p$ . Through Claim 1, we can see certain value of  $p$  makes almost the network connected. Our simulation results also prove that.

The correctness and effectiveness of GSP have been confirmed by both theoretical analysis and numeric results. Further work is required to address various properties of GSP, e.g. the value of the gossip sleep value to avoid network partition in different random topologies and the network delay in case of network partition.

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