An Energy Aware Routing Protocol with Sleep Scheduling for WSN

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Abstract: ***Wireless Sensor Networks (WSNs) consist of a large number of small and low cost sensor nodes powered by small batteries and equipped with various sensing devices. Usually, for many applications, once a WSN is deployed, probably in an inhospitable terrain, it is expected to gather the required data for quite some time, say for years. Since each sensor node has limited energy, these nodes are usually put to sleep to conserve energy, and this helps to prolong the net work lifetime. There are two major approaches to sleep scheduling of sensor nodes, viz. (i) random (ii) synchronized. Any sleep scheduling scheme has to ensure that data can always be routed from source to sink. In this paper, we propose a novel approach for sleep scheduling of sensor nodes using a tree and an energy aware routing protocol which is integrated with the proposed sleep scheduling scheme. The tree is rooted at the sink node. The internal nodes of the tree remain awake and the leaf nodes are made to sleep. This provides an assured path from any node to the sink node. The tree is periodically reconstructed considering the remaining energy of each node with a view to balance energy consumption of nodes, and removes any failed nodes from the tree. The proposed approach also considerably reduces average energy consumption rate of each node as we are able to put more number of nodes to sleep in comparison to other approaches. Additional fault-tolerance is provided by keeping two paths from each node towards the sink. The most important issue that must be solved in designing a data gathering algorithm for wireless sensor networks (WSNS) is how to save sensor node energy while meeting the needs of applications/users. In this paper, we propose a novel energy-aware routing protocol (EAP) for a long-lived sensor network. EAP achieves a good performance in terms of lifetime by minimizing energy consumption for in-network communications and balancing the energy load among all the nodes. EAP introduces a new clustering parameter for cluster head election, which can better handle the heterogeneous energy capacities. Furthermore, it also introduces a simple but efficient approach, namely, intra cluster coverage to cope with the area coverage problem.***

Keywords: (WSN) Wireless Sensor Networks.

1. Introduction

A Wireless Sensor Network (WSN) consists of hundreds or thousands of sensor nodes or motes equipped with various sensing devices to observe events in the real world. Sensor nodes usually communicate among themselves using wireless only. Also they are usually powered by battery, and therefore have limited energy. Besides each sensor node has limited computation power and memory again due to constraints imposed by the available supply of energy. The major function of WSNs is to observe and record events in the environment and report them to the sink if necessary. In the process, the sink node may also need to broadcast messages to each node of the WSN, and sensor nodes may need to communicate with each other as well. Wireless sensor network are usually deployed, possibly in extreme conditions such as mountainous region, and left unattended to function for long time. In order to prolong the network lifetime, it is necessary to minimize the consumption of energy by individual nodes. In addition, it is also necessary to ensure that the average rate of consumption of energy by each node is also the same. This would ensure that the connectivity needed to transmit data from a sensor node to sink can always be maintained. A third requirement of WSNs for applications such as tracking of intruders, detection of fire etc. is that the delay to transmit data from sensor node to the sink should be as less as possible. These are complex set of requirements which a routing protocol for wireless sensor networks needs to fulfill.

Moreover, the transceiver is the major unit that consumes lots of energy in each sensor node even when it is idle. Therefore, sensor nodes are usually put to sleep if they are not required to transmit data and/or sense environment, and the challenge is to integrate sleep scheduling scheme with routing protocols for WSNs so that the objective of routing protocols as given above are also met. We assume that the transceiver, processor, and sensing units can be put to sleep independently [1] and when we say that the sensor node is put to sleep, we mean that the transceiver and the processor are put to sleep. The sleep scheduling of sensing units can be done independently to ensure sensing coverage. In this paper, we propose a novel sleep scheduling scheme using a tree, and an energy aware routing protocol that is appropriately integrated with the above sleep scheduling scheme with a view to meet the objectives for routing protocols as given above. The rest of the paper is organized as follows. In section II, we give a survey of related works, and motivation for our work. The details of the proposed sleep scheduling scheme and energy aware routing protocol are described in section III. Result of the performance evaluation of the proposed routing protocol and gossip based energy efficient Procedure for Paper Submission Review Stage Submit your manuscript electronically for review. Routing protocol with sleep scheduling (GSP) [2] and their comparisons are given in section IV. Section V concludes the paper with future work.

2. Related Work

In general, routing in WSNs can be divided into three types, viz. flat structure based routing, hierarchical structure based routing and location-based routing [3] [4]. In flat structure based routing [5] [6], all nodes are typically assigned equal roles or functionality. In hierarchical structure based routing [7] [8] [9], however, nodes play different roles in the network depending on their position in the hierarchy.

In location-based routing [10] [11], sensor nodes' positions are exploited to route data in the network. In the recent past, many routing protocols have been proposed for sensor networks. Most of the protocols try to ensure that the consumption of energy by different nodes of WSN does not lead to situations where some nodes become dead early, and thereby disrupt the connectivity of the WSN. The descriptions of some of these protocols are as given below. Heinzelman, Kulik, and Balakrishnan have proposed a protocol, called Sensor Protocols for Information via Negotiation (SPIN) [12], that provides data-centric routing approach where the data should be named using high level descriptors or metadata. The SPIN family of protocols includes many protocols. The main two protocols are called SPIN-1 and SPIN-2. The SPIN-1 protocol is a 3-stage protocol, but does not consider any energy aware technique. However, in SPIN 2, when energy in the nodes is abundant, it communicates using the 3-stage protocol of SPIN-1. However, when the energy in a node starts approaching a low energy threshold it reduces its participation in the protocol, i.e., it participates only when it believes that it can complete all the other stages of the protocol without going below the low-energy threshold. In the energy aware routing protocol [13] proposed by Shah and Rabaey, a set of path is chosen based on probability.

The value of this probability depends on how low the energy consumption of each path is. By choosing paths at different times, the energy of any single path will not deplete quickly, and this can achieve longer network lifetime as energy is dissipated more equally among all nodes. The protocol initiates a connection through localized flooding, which is used to discover all routes between source to sink and their costs; thus building up the routing tables.

The high-cost paths are discarded and a forwarding table is built by choosing neighboring nodes in a manner that is proportional to their cost. Problems with this protocol are complex addressing method and communication overhead during the setup phase. Ye, Chen, Lu, and Zhang have proposed an algorithm, called Minimum Cost Forwarding Algorithm (MCFA) [14] that sets up a back off based cost field to find the optimal cost path from all the nodes to the sink. Once the field is established, the message, carrying dynamic cost information, flows along the minimum cost path in the cost field. This protocol consists of two phases. First phase is a setup phase for setting up the cost value in all nodes. In the second phase, the source broadcasts the data to its neighbors. To reduce the number of broadcast messages, the MCFA was modified to run a back off algorithm at the setup phase. The back off algorithm dictates that a node will not send the updated message until back off time units have elapsed from the time at which the message is updated. Problems with the algorithm are high consumption of bandwidth and it may cause duplicate copies of sensor messages to arrive at the sink.

In Power Aware Chain (PAC) [15] routing protocol proposed by Pham, Kim, Doh, and Yoo, all nodes organize themselves into the energy efficient chain with the help of MCFA protocol and depth first search. One node, elected as leader node, transmits data back to sink on behalf of all other nodes. Leader node election is based on the power available and the power needed for transmission from the node to sink. Each node aggregates received data from the previous node in the chain with its own collected data to produce an aggregated data packet.

In the recent past, Hong and Yang have proposed an energy balanced multipath routing protocol for sensor network [8] which is based on rumor routing technique. In this protocol, authors consider a probabilistic approach to find multipath from source to sink by considering the residual energy and hop count from source to sink. Chakchouk, Hamdaoui, and Frikhax also have proposed a protocol [9] that uses remaining energy and the hop count from sensor node to the sink in order to make hop-by-hop energy-aware routing. There are some energy aware routing protocol like [7], [16] which use hierarchical or cluster based approach by considering the residual energy or remaining energy to distribute the traffic over the whole network and also prolong the network lifetime.

S. Lindsey *et al.* proposed an algorithm related to LEACH, called PEGASIS [4]. These authors noticed that for a node, within a range of some distance, the energy consumed for receiving or sending circuits is higher than that consumed for amplifying circuits. In order to reduce the energy consumption of sensor nodes, PEGASIS uses the GREED algorithm to form all the sensor nodes in the system into a chain. According to its simulation results, the performance of PEGASIS is better than LEACH, especially when the distance between sensor network and sink node is far large. In [5], to deal with the heterogeneous energy circumstance, the node with the higher energy should have the larger probability to become the cluster head. In this paper, each node must have an estimate of the total energy of all nodes in the network to compute the probability of its becoming a cluster head. As a result, each node will not be able to make a decision to become a cluster head if only its local information is known. In this case, the scalability of this protocol will be influenced.

Sh. Lee *et al.* proposed a new clustering algorithm CODA [6] in order to relieve the imbalance of energy depletion caused by different distances from the sink. CODA divides the whole network into a few groups based on node's distance to the base station and the routing strategy. Each group has its own number of clusters and member nodes. CODA differentiates the number of clusters in terms of the distance to the base station. The farther the distance to the base station, the more clusters are formed in case of single hop with clustering. It shows better performance in terms of the network lifetime and the dissipated energy than those protocols that apply the same probability to the whole network. However, the work of CODA relies on global information of node position, and thus it is not scalable.

All the routing protocols discussed above are based on energy-aware technique. But, to minimize energy consumption and prolong the lifetime of the network, the routing protocols have to support sleep scheduling schemes so that most of the nodes are put to sleep, and the remaining nodes are active. There are very few routing protocols that support sleep scheduling and some of them are described below. Hou and Tipper have proposed flat structure based protocol called Gossip-based Sleep Protocol (GSP) [2] that employs probabilistic based sleep modes. At the beginning of a gossip period, each node chooses either to sleep with probability *p* or to stay awake with probability 1 - *p* for the period, so that all the sleep nodes will not be able to transmit or receive any packet during the period. When an active node receives any packet, it must retransmit the same.

All sleeping nodes wake up at the end of each period. All the nodes repeat the above process for every period.

```
Procedure BTC-phase1
begin
CFj, 1 = CFj, 2 = ∞;
if (First period) then
PFj, 1 = PFj, 2 = −1;
end
is Active = is Broadcasted = false;
timer Flag = RESET;
while (node j receive ADV 1(Ni, CFi, 1, PFi, 1)
message from node i) do
if (timer Flag = RESET) then
Set back off timer to;
Timer Flag = SET;
end
if (is Broadcasted=false) then
if (Ni is sink) then
CFj, 1 = CFj, 2 = CFi, 1 + Cj;
PFj, 1 = PFj, 2 = Ni;
else if ((PFj, 1 is sink and CFj, 1 = ∞) or
(PFj, 1 is not sinking)) then
if ((CFi, 1 + Cj) < CFj, 1) then
CFj, 1 = CFj, 2 = CFi, 1 + Cj;
PFj, 1 = PFj, 2 = Ni;
end
end
else
if ((Nj = PFi, 1)) then
is Active=true;
end
end
if (Back off timer expire and
is Broadcasted=false) then
is Broadcasted=true;
Broadcast ADV 1(Nj, CFj, 1, PFj, 1)
message;
end
if (Construction phase completed) then
Break;
end
end
if (is Active) then
Nj is an internal node;
else
Nj is a leaf node;
end
end
```

```
Procedure BTC-phase2

begin
timer Flag = RESET; is Transmitted = false;
while (node j receives ADV 2(Ni, CFi, 1) message
from node i) do
if (timer Flag = RESET) then
Set back off timer to;
Timer Flag = SET;
end
if ((PFj, 1 = Ni) or (PFj, 1 is sink)) then
Discard ADV 2 message;
else
if (Ni is sink) then
CFj, 1 = CFj, 2 = CFi, 1 + Cj;
PFj, 1 = PFj, 2 = Ni;
else if ((PFj, 1 = PFj, 2) or
((PFj, 1 6= PFj, 2) and
((CFi, 1 + Cj) < CFj, 2))) then
CFj, 2 = CFi, 1 + Cj;
PFj, 2 = Ni;
end
end
if ((is Transmitted = false) and (Nj is an
internal node)) then
is Transmitted=true;
Broadcast ADV 2(Nj, CFj, 1) message;
end
if (Back off timer expire) then
Break;
end
end
if (Nj is a leaf node) then
Nj goes to sleep mode;
end
end
```

Node declares itself as an internal node. If a node does not receive any *ADV1* message where its own *ID* is equal to the parent node *ID* stored in the broadcast message, then the node declares itself as a leaf node. The algorithm to add second parent to each node of the tree constructed in phase 1 is given in the procedure *BTCphase2* which performs its task as follows. At the beginning of this phase, sink node broadcasts an *ADV2* message to all its neighbors. When a node receives the first *ADV2* message, it sets back off timer. When a node receives an *ADV2* message, and the node has already stored the sink node *ID* in its parent node fields or the node *ID* stored in the received *ADV2* message is equal to the node *ID* stored in its first parent node field, it will discard the *ADV2* message. Otherwise, the node executes the following steps.

1) If the node receives the *ADV2* message from the sink node, then it computes the new cost by adding reciprocal of its remaining energy to the received cost, and sets its two cost fields to new cost and stores the sink node *ID* in its both parent node fields.
2) If both the parent node fields of the receiving node are equal, then it stores the new cost value as computed in *step* 1 in the second cost field and stores the received node *ID* in the second parent node field.
3) If both the parent node fields of the receiving node are not equal, then it compares the new cost with the cost stored in the second cost field, and if the new cost is less than the value stored in the second cost field, then it stores the new cost value in the second cost field and stores the received node *ID* in the second parent node field. After receiving

the first *ADV2* message, if a node has declared itself as an internal node in the first phase of the algorithm, the node broadcast its own *ADV2* message that contains its own *ID* and the value stored in the first cost field. Upon receipt of further *ADV2* message from any other node, it will not broadcast any more advertisement message.

Once the back off timer expires, if a node has declared itself as a leaf node in the first phase of the algorithm, then the node goes to sleep mode. After completion of BTC phase, each node is classified either as an internal node or as a leaf node. Since a leaf node will not receive any data packets from any other node for onward transmission, it can go to sleep till the beginning of next period or till it detects an event. The leaf nodes will again participate in the BTC phase at the beginning of next period.

When an event occurs at an internal node, data will be transmitted to a parent node in the tree. If an event occurs at a leaf node, the node will wake up and transmit data and again go to sleep till next event or next period whichever is earlier. Each data packet consists of *ID* of node which would receive the data, *ID* of node which generated the data, and the data itself. Data will be transmitted from source to sink via minimum cost paths computed in the BTC phase. The first packet received by any internal node is forwarded to its parent that is in the first parent node field, and the next packet is forwarded to the parent that is in the second parent node field.

Similarly, for subsequent data packets, it chooses one of the parents from parent node fields alternately. A periodic check is also made using hello packet to find out if any of the parent is dead. If any parent is dead, packets are forwarded to active parent only.

3. Proposed Routing Protocol with Sleep Scheduling

The routing protocol proposed in this section is intended for WSNs in which sensor nodes are static. Beside the applications running in the WSN require that the information gathered by the sensor nodes have to be transmitted immediately to the sink. Furthermore, it is also assumed that each node has a unique *ID*, and the communication between neighboring nodes is symmetric and bidirectional. It is also assumed that the clocks of the sensor nodes in the WSN are synchronized so that nodes can be woken up nearly at the same time, and they can execute the proposed protocol.

The objectives of the proposed routing protocol with sleep Scheduling are as follows.

i. Most sensor nodes should be asleep most of the time so that the energy consumption by each node is reduced.
ii. Consumption of energy by all the sensor nodes remains balanced, i.e., at any time, every node should have consumed nearly the same amount of energy.
iii. Time required to transmit data from a sensor node to the sink is as minimum as possible subject to the constraints given in (ii) above.

A. Informal Description of the Algorithm

We first construct a broadcast tree using the approach similar to the one given in [14]. During the construction of the tree, the following needs to be ensured in order to minimize energy consumption during the tree construction phase and provide support for fault-tolerance.

(i) Number of broadcasts is as less as possible.
(ii) There are two branches from each node of the tree towards the sink to ensure fault-tolerance.

After the construction of the tree is complete, each node can identify itself either as internal node of the tree or as leaf node of the tree. The leaf nodes are put to sleep and internal nodes remain awake. A node wishing to send data to the sink can send it along the edges of the tree towards the sink. The tree is constructed in such a way that the internal nodes have higher remaining energy compared to the other nodes. This is required to ensure that the consumption of energy by all nodes remains balanced. The tree is reconstructed periodically to ensure balanced consumption of energy by all the nodes. As outlined above, the proposed routing protocol with sleep scheduling consists of the following.

(i) Construction of the broadcast tree at the beginning of the every period.
(ii) Transmission of the data from source to sink whenever required.

B. Construction of the Broadcast Tree (BTC)

Each node in the WSN stores the *ID*s of two parent nodes along with the associated least cost of the paths to the sink through them. The nodes which are directly reachable from the sink have both the parent nodes set to sink node. Besides, each node also stores its node *ID*, its remaining energy, the cost to be added to a path to sink that passes through this node. These variables at each node *j* are represented as follows.

CFj, 1 = Value of first cost field of node *j*
CFj, 2 = Value of second cost field of node *j*
PFj, 1 = Value of first parent node field of node *j*
PFj, 2 = Value of second parent node field of node *j*
Nj = jth node
REj = Remaining energy of Nj
Cj =1REj
= Each node's cost to be added to a path.

4. Simulation Experiments and Results

We have carried out extensive simulation studies of the proposed protocol to evaluate its performance, and compared its performance with that of GSP [2]. In the following, we describe the simulation model, and the results obtained using Castalia simulator 1.3 [18].

Table 1: Radio Characteristics

Radio Mode	*Energy Consumption (mW)*
Transmit	57.42
Receive	62
Listen	62
Sleep	1.4

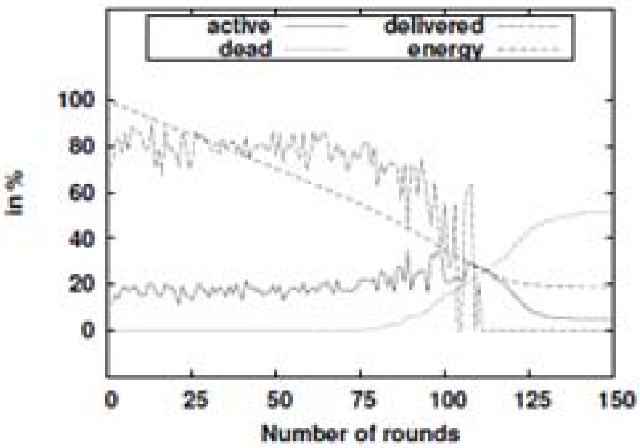

Figure 1: Percentage of active nodes, dead nodes, packets delivered and average remaining energy in unipath approach

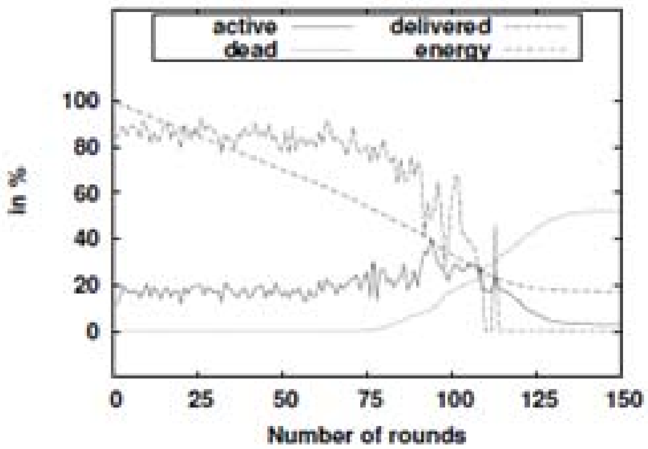

Figure 2: Percentage of active nodes, dead nodes, packets delivered and average remaining energy in multi path approach

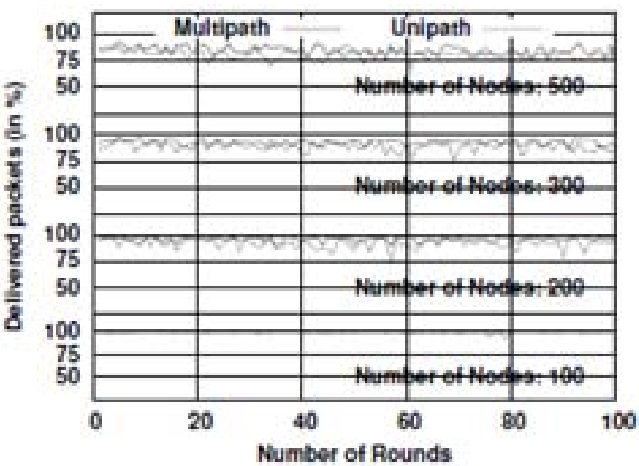

Figure 3: Percentage of Packets Delivered in Multi Path and Unipath approach

A. Simulation Model

In our simulation, we have varied the number of nodes from 100 to 500, which are randomly deployed using uniform distribution in different parts of deployment area with a fixed density. For this simulation, the network parameters, such as transmission range, transmission rate, sensitivity, transmission power etc., are similar to the parameters specified in CC2420 data sheet [19] and TelosB data sheet [20]. Energy consumption for different radio modes used in this simulator is given in Table I. By experiment, we find that the suitable value of to be 10ms and we have set the duration of each round to 1000 seconds. The input data is generated randomly every 1 second at each node. We have taken the initial energy of each node to be 29160 joules for 2 AA batteries as given in the Castalia simulator.

B. Simulation Results

An active node is one which remains awake after the broadcast tree construction phase is over. A dead node is one which has lost all its energy. Nodes which are asleep are neither dead nor active. Due to collisions, some of the packets may not be delivered. Also energy of each node gets depleted continuously. Figure 1 and 2 give percentage of active and dead nodes in a 500 node WSN in each round for unipath and multipath approach respectively. For these two figures, it is assumed that initial energy of each node is 2000 joules. It is to be noted that nodes start dying nearly at the same time (at around 75th round) in both unipath and multipath approach. Also the percentage of active nodes for both unipath and multipath approach is nearly the same.

Figure 1 and 2 also give percentage of packets delivered in each round in a 500 node WSN. It is to be noted that percentage of packets delivered in multipath approach is slightly more than that in unipath approach. In both unipath and multipath approach, after some of the nodes are dead, i.e., after 110th round, the percentage of packet delivered sometimes increases. This is due to the fact that only few nodes are alive, and they have an assured path to rich the sink. Figure 1 and 2 also give average remaining energy per node after each round. The average reaches very close to zero after 110th round, which shows that all the nodes lose energy nearly at the same time.

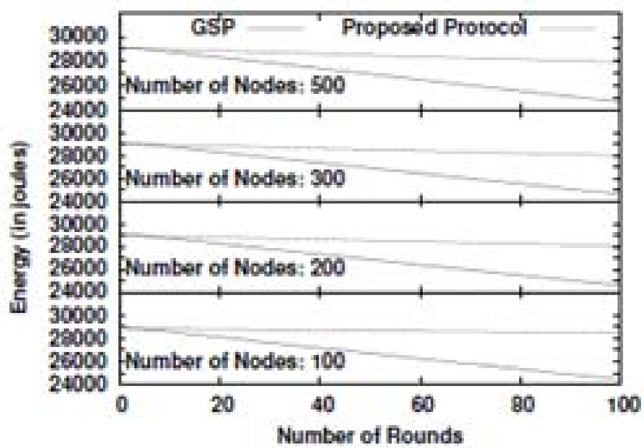

Figure 4: Average remaining energy in the proposed protocol with multi path approach and GSP

Comparison with GSP*:* We also evaluated the performance of gossip-based sleep protocol for energy efficient routing in wireless sensor networks (GSP) [2] and compared its performance with that of the proposed protocol. For this comparison, we have considered 0.25 sleep probability for the GSP protocol as specified in [2].

For this simulation, we have initialized the residual energy of each node to 2000 joules. Figure 5 shows that the proposed protocol has only 5-20% active nodes during the interval when the nodes have not yet started dying, while in case of GSP, this percentage is about 75% in all cases. As a result, in GSP, the nodes start dying earlier in comparison to that in the proposed protocol. Also, it is to be seen that in the proposed protocol, the percentage of active nodes increases with the total number of nodes. This is due to the nature of the tree structure. From Figure 6, it is to be noted that, with 500 nodes, the first node to become dead in the proposed protocol occurs much later as compared to that in GSP (i.e., 50th rounds) with an initial energy of 2000 joules for each node. If we consider initial energy to be 29160 joules, then the first node in the proposed protocol will become dead after a long period of time in comparison to that in GSP. With higher remaining energy at each internal node of the tree, the tree is reconstructed at the beginning of each period so that none of these nodes die before other nodes, which means that all nodes will die at around the same time. Consecutive packets are routed through alternative path to reduce traffic in individual paths. Leaf node sleep mechanism is highly energy efficient as more number of nodes is able to sleep, and this helps to prolong the network lifetime. We have evaluated the performance of our protocol through simulation studies for different number of nodes and rounds. Simulation results show that data packet delivery in our multipath protocol is more than that using unipath, and energy consumption of nodes is also balanced. Comparison with GSP shows that our protocol has more number of sleep nodes, and therefore provides longer network lifetime. We have used very high data rate in our simulation studies. Future work includes adaptively adjusting the period of tree reconstruction depending on the input data rate with a view to further increase the network lifetime.

5. Conclusions and Future Work

In this paper, we have presented an energy aware routing protocol with sleep scheduling for WSNs. The core of the routing protocol is the efficient construction of the broadcast tree with two paths from each node towards the sink with higher remaining energy at each internal node of the tree. The tree is reconstructed at the beginning of each period so that none of these nodes die before other nodes, which means that all nodes will die at around the same time. Consecutive packets are routed through alternative path to reduce traffic in individual paths. Leaf node sleep mechanism is highly energy efficient as more number of nodes is able to sleep, and this helps to prolong the network lifetime. We have evaluated the performance of our protocol through simulation studies for different number of nodes and rounds. Simulation results show that data packet delivery in our multipath protocol is more than that using unipath, and energy consumption of nodes is also balanced. Comparison with GSP shows that our protocol has more number of sleep nodes, and therefore provides longer network lifetime. We have used very high data rate in our simulation studies. Future work includes adaptively adjusting the period of tree reconstruction depending on the input data rate with a view to further increase the network lifetime.

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