# A Route-Oriented Sleep Scheme in Wireless Sensor Network

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**Summary**

In resource-limited wireless sensor network, significant energy savings and longer life time of sensors can be achieved by having an effective energy management forcing sensors to sleep as long as they can. In this paper, we propose a Route-Oriented Sleep (ROS) approach which allows sensors to sleep based on routing information and the level of network's activities. The scheme lets sensors switch their roles in the network according to the critical probability of the percolate theory without losing their sensing and communication connection coverage. This technique takes advantages of routing decisions and implements an effective sleep scheme at the network level, which allows some of sensors along the route path to sleep and wake up when they are a part of specific route. This produces balanced and low energy consumption for each node. ROS does not only achieve significant energy savings, but also reduces the communication interferences in the data transmissions, thus reduces the latency of data transmissions.

The simulation results show that the proposed ROS approach significantly saves the sensor energy consumption more than 50%.

***Key words:***

*Percolation Theory, Wireless Sensor Network, Rate-Oriented Sleep.*

## 1. Introduction

In wireless sensor network, most sensors are battery powered and deployed in the locations where it may be difficult to replace or recharge it. This limits the sensor's network life time. Thus innovative methods are needed to extend the network life time and reduce the batter drain. Network methods such as protocol topology control, media access and routing have been considered in many research works. Among them, significant energy savings could be achieved by allowing sensors to enter into a sleep mode when no network action is performed.

Sleep patterns in published works have two typical methods: asynchronous independent sleep pattern [1][2] and synchronous sleep cycles in a local neighborhood [3]. Independent sleep patterns allow sensors go to sleep without consideration of the local network environment, and the node goes to sleep based on a critical probability under which the network still maintains connectivity. In paper [3], the energy consumption is reduced by synchronizing all nodes in neighborhood to wake up in the same slot within multi-slot frame. However, the network operations such as routing decisions could be done to benefit the sensor sleep pattern. This is not addressed by either independent sleep scheme or synchronous sleep in neighborhood.

In this paper, we design a Route-Oriented Sleep (ROS) approach to achieve energy savings by fully utilizing routing decisions. The basic idea is that sensor nodes don't need to wake up when they are not a part of a routing path. However, once a route path is determined (the node on the route path is called RN node), if we force all the neighbors of RN nodes to sleep, it might make the network lose their sensing and communication connection coverage in the local area. When the neighbors of RN nodes in a route path are forced to sleep, if there are other routes trying to pass through those neighbors, the route may be inactive since some routing nodes may be sleep. This refers to as the communication connection coverage loss problem due to sleep. Also, when some events happen in this area along the route path, it is possible that not enough active sensors could detect it. This is the sensing coverage loss problem due to sleep, we propose to solve it in using a novel ROS approach that allows sensors sleep as long as they can.

## 2. Sensor Coverage analysis

In this section, we describe the relationships between sensing and communication radio coverage, which determines what mode of ROS we could choose. In Wireless Sensor Network, both sensing coverage and communication radio coverage are critical for the network and applications. The sensor network can not bear the sensing coverage loss, which could lead to missing events. This should be prohibited especially in some sensitive sensor applications such as military target tracking and surveillance. On the other hand, the loss of radio communication coverage could cause the network communication hole, which impacts the network connectivity and make data undeliverable. Thus, it is necessary to propose a solution to achieve the goal in these two prospective. For different sensors applications, sensing coverage and communication radio coverage might be different for sensors. In Figure 1, we describe three scenarios:

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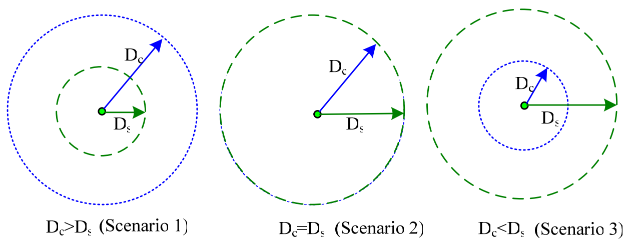



Fig. 1 Communication Radio and Sensing Coverage

In Figure 1, $D_s$ is the diameter of sensing coverage, and $D_c$ is the diameter of communication radio coverage.

Scenario 1: Communication radio coverage is larger than the sensing coverage. In this scenario, communication radio has more redundancies.

Scenario 2: Communication radio coverage is equal to the sensing coverage. In this communication radio and sensing coverage have same extent redundancies.

Scenario 3: communication radio coverage is less than the sensing coverage. In this scenario, sensing coverage has more redundancies.

Generally in WSN the communication radio coverage ( $\pi D_s^2/4$ ) should be more than the sensing coverage ( $\pi D_c^2/4$ ) thus, there are usually higher requirement of sensing quality and resolution. In those applications, sensing accuracy and redundancy are critical. We will address this difference in our ROS approach. Note that our scheme will still work after a straightforward extension of the approach if the communication coverage is less than sensing coverage.

In the ROS scheme, we switch different roles of the sensors in the network according to the critical probability of percolate theory, which guarantees that the sensor network does not lose their sensing and communication connection coverage. The role-switch method based on the probability helps sensors to take advantages of the routing decision and executes an effective sleep schedule at the network level.

## 3. ROS approach based on role Switching

Sensors in the WSN have two functionality roles: one is sensing functionality (called S node), the other is forwarding and sensing function (called SF node). Thus, in the dense sensor network, since sensor nodes are usually deployed redundantly, it is possible that some nodes will play the sensing role, some nodes will play the sensing and forwarding roles, the role can be switched according to the probability of percolate while both sensing and communication radio coverage are still maintained effectively.

The role switch is based on a percolate model [4][5][6], which was introduced by Broadbent and Hamersley as a mathematical model (or a collection of mathematical models) of random media. Consider the square grid in Figure 2.

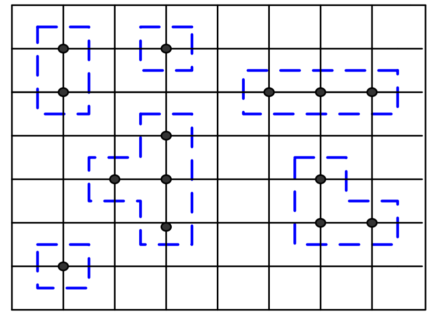


Fig. 2: Percolation Lattice [4]

Each site is “occupied” with probability $p$ or “vacant” with probability $(1-p)$, independently of all the other sites on the lattice. A “percolation cluster” on this grid is a collection of nearest-neighbor occupied sites. As the occupation probability $p$ is increased from zero, the average or typical clusters become larger in terms of both the number of sites and geometric size. We define $P(p)$, “the percolation probability”, as the probability for the origin to be the part of an infinite cluster. When $p$ is below certain value $p = p_c$, called the critical probability, we can find that $P(p)$ is always zero. As $p$ is increased above $p_c$, the percolation probability becomes non-zero. This change in behavior is an example of a phase transition. Therefore, the percolation theory can be applied in a static infinite network (infinite nodes in an infinite space), if every node or link is open/active with probability $p$, the network will be grouped into clusters. The result from percolation theory shows that there exists a critical value $p_c > 0$ such that in the sub critical phase (when $p < p_c$), nodes form finite clusters almost surely; in the supercritical phase (when $p > p_c$), however, it exists a unique infinite cluster almost surely.

Furthermore, we define an operating node that switches from S to SF as “site occupied”, and from SF to S as “site empty”. According to the percolation model, it must exist a critical probability $p_c$ that can satisfy the following description: when the probability $p$ for each node to switch from SF to S is greater than $p_c$, the transition characteristics can guarantee that the network has good SF functionality.

The graph in Figure 3 shows the distribution of S and SF node. From it, we could understand that it is feasible for the SF coverage to be effective if nodes switch between S and SF roles with probability $p$ . In Figure 3, there are route paths between source and sink, which are drawn by the solid line.

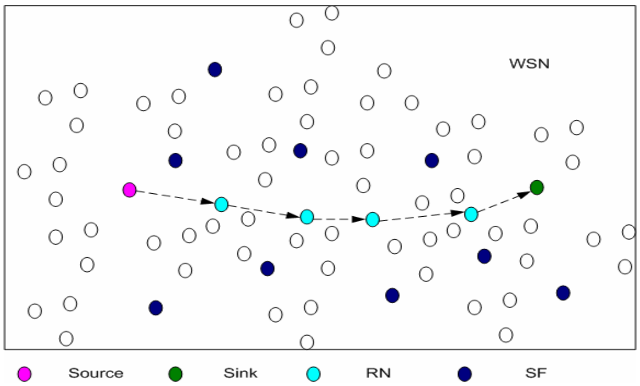


Fig.3 Role Switch between F and SF

The nodes switch their roles independently according to the probability $p$ ( $p > p_c$ ), which can be adaptive to the network density and the residual energy of each node.

When a route path has been determined, any S node (i.e., the node at Sensing status) among the neighbors of RN nodes will be forced to sleep for the remaining period switching time. Once the sleeping time expires, the node will automatically switch to the SF status. Then, if a node is not RN node and its neighbors keep in SF status for a period of time, it will automatically switch to S status with the probability $1-p$ at time $T > T_{threshold}$ . This sensor node automatically switches from S status to the sleep status for a fixed time interval with the probability $P_{adaptive}$ , depending on the network density in that local area and the node's neighbor status. Thus $P_{adaptive}$ is determined by the following equation (1):

$$P_{adaptive} = f(N, N1, \sum_{i=0}^{N} P_i) \quad (1)$$

$N$ is the number of neighbors of this node, $N_1$ is the number of neighbor nodes in the sleep status. $P_i$ is the current $P_{adaptive}$ for the $i_{th}$ neighbor nodes. The finite state transition graph in Figure 4 shows how the S-mode scheme works: In Figure 4, the node switches from S to SF status with the probability $p$ ( $p > p_c$ ), and switches back from SF to S status with probability $1-p$ in every period of switching time. The node switches from S to sleep status only if it is the neighbor of the route node. If it is not the route node and also has any sleep time left for $T$ ( $T > T_{threshold}$ ), it will also switch to sleep with the probability $P_{adaptive}$ .

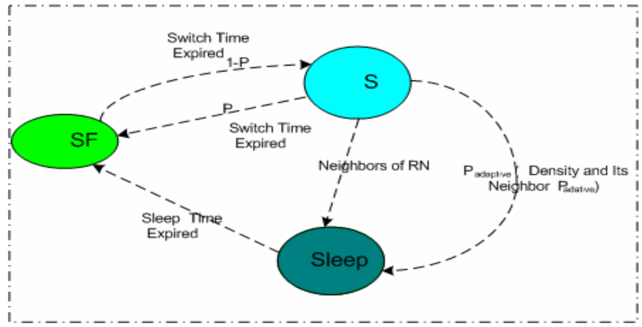


Fig. 4 Role Switch in ROS scheme (S-mode)

For the RN nodes, they will switch to the SF status when transmitting packets. This scheme allows some sensors along the route path to sleep, but still keeps good sensing coverage and communication radio coverage. This is based on the reasonable assumption that sensor coverage is one of most significant requirements for the sensor network. The reliable sensor network can not lose its sensing coverage. In Scenario 1, the S-mode finite state transition would be applied because the radio coverage is larger than the sensing coverage of each sensor. On the other hand, in Scenario 2, 3, the F-mode finite state transition (Figure 5) will be applied, where the sensing coverage is more than or equal to the communication radio coverage of each sensor. In Figure 5, we design the sensor nodes with two roles: Forwarding functionality, called F mode, and forwarding and sensing functionality, called SF mode.

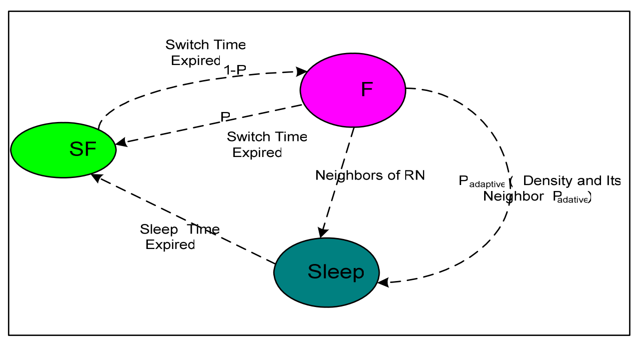


Fig. 5 Role Switch in ROS scheme (F-mode)

The only difference between Figure 4 and Figure5 is that S status is replaced by F status. This guarantees that the network still keep good communication connection coverage after probabilistic switch on the sensor modes.

This ROS reduces both sensing redundancies and radio redundancies in the network, which allows sensor to get more chance to sleep based on the routing information. The probability methods guarantee that the energy consumption of each sensor will be almost balanced in the network, leading to the sensor network's longer life time due to this residual energy balance. The proposed ROS scheme does not restrict itself to work with the specified routing scheme; in fact it can work independently with any existing routing scheme. The proposed ROS layer residence in the whole protocol layer stack. ROS scheme works between the network layer and MAC layer, which takes advantages of network layer information about routing decisions and lets sensors get more chance to sleep for energy savings. At the MAC protocol stacks, we utilize the ZMAC [7] to evaluate the ROS scheme, which is discussed in the next section. We use a simplified example to be used to evaluate ROS scheme. There are totally 10 deployed nodes. Node0-Node1-Node2 is a route path, where all these three nodes are at SF status; other nodes are their neighbors. At a certain time, suppose nodes 7, 8, 9, and 10 are at the sleep status, and nodes 3, 4, 5, and 6 are at the SF status. At the MAC layer, we utilize the modified ZMAC to evaluate the ROS scheme. Since ZMAC is a mixing CSMA and TDMA protocol, it becomes more robust to timing failures, time-varying channel conditions, slot assignment failures and topology changes than a stand alone TDMA. We use the following algorithm in Figure 6 to let the node take advantages of routing information.

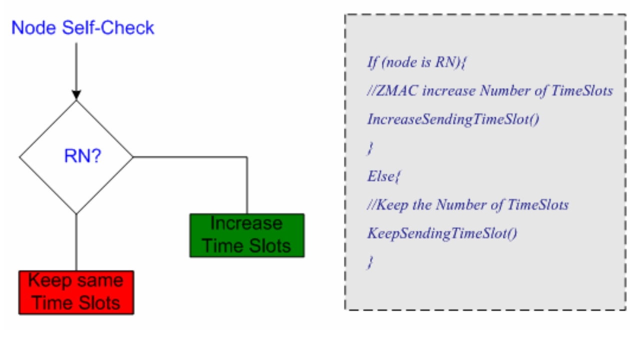



Fig. 6 Algorithm for Changing ZMAC Time Slots

The algorithm is based on the following idea: Once we increase the transmission time slots for the routing nodes, the data can be transmitted with less latency; it will save the total transmission time, so the RN nodes and other neighbor nodes could get more chance to sleep in the future.

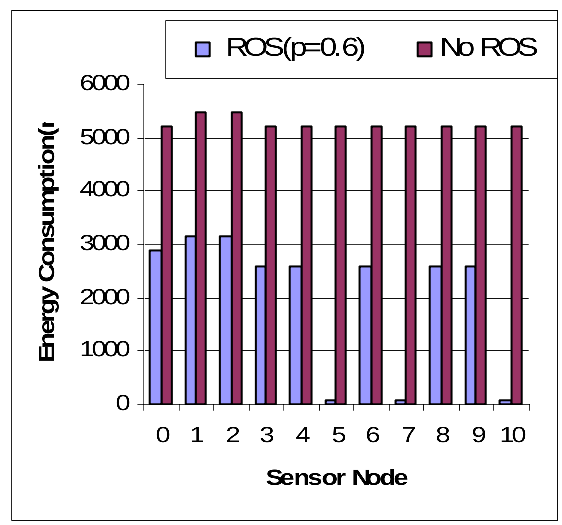
## 4. Simulation and evaluation

To evaluate the energy savings of the proposed ROS scheme, we executed computer simulation (S-Mode) and compared it with the same scenario and topology without ROS. In this situation, Node 0 sends data to Node 2 via Node 1. Data sent by these nodes has 46200 bytes length. The switch probability from S to SF is 0.6. The experimental parameters are shown in Table 1. For RN node 0, 1, and 2, we apply the algorithm in Figure 6, and double the number of sending slot when they are RN nodes.

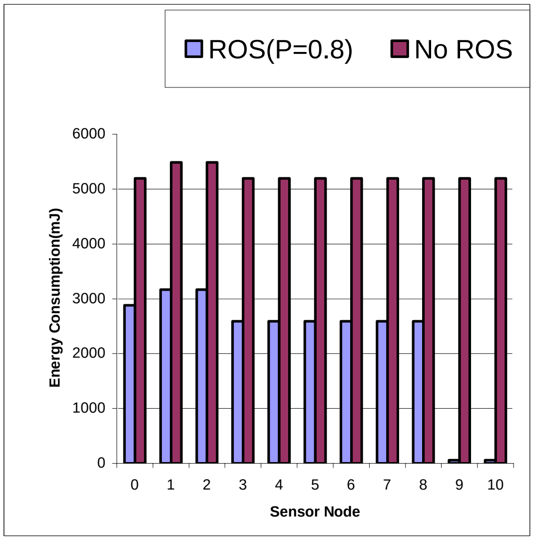
Table 1: Experimental parameters in simulation

| Parameter | Value |
|---|---|
| Sleep Current (mA) | 0.03 |
| Initialize Radio (mA) | 6 |
| Receive Current (mA) | 15 |
| Transmit Current (mA) | 20 |
| Voltage (V) | 3 |
| Preamble Length (bytes) | 271 |
| Packet Length (bytes) | 46200 |
| Link Level Data Rate (kbps) | 19.2 |
| TDMA Slot Size (ms) | 50 |
| LPL Check Interval (ms) | 10 |
| Radio Initialize Time (ms) | 0.5 |
| Crystal Startup Time (ms) | 1.5 |
| LPL Sample Duration (ms) | 0.5 |

The simulation runs with the ROS scheme and is finished within 192 time units (8 time slot per unit). But, without ROS scheme, it takes up to 385 time units. The energy consumption for each node is shown in Figure 7(a).




**(a)**




**(b)**

Fig.7 Energy Consumption of each sensor node

From Figure7 (a), it can be seen that nodes 5,7,10 have significant energy savings, because the S nodes (5, 7, and 10) get more chance to sleep as the neighbors of the RN nodes within the communication task interval. Other neighbor nodes (3, 4, 6, 8, and 9) along the RN nodes have achieved energy consumption as half as in the scheme without ROS, This is true because of the reduced duration of complete transmission task with ROS scheme. For the RN nodes(0, 1, and 2), almost the same amount of nodes energy savings as nodes 3, 4, 6, 8, and 9 has been achieved because of their more sending slots in one round, which not only reduce the whole task transmission time, but also reduce the check interval time(idle listening) in the ZMAC. Even for other nodes, since the RN nodes have more sending time slots, it reduces the time duration of the task, and helps them to get more sleep time while the transmission task is guaranteed, so other nodes also achieve more energy saving compared to the scheme without ROS. In Figure 7 (b), the value of P (0.8) is more than P (0.6) in the Figure 7 (a), less energy is saved in Figure (b). This is because that more sensors get chances to transit to SF status from S status in Figure 7 (b) , which guarantees the better communication connectivity coverage than in Figure 7 (a), but the energy consumption would be trade off. Therefore, P is the value of trade off between the energy consumption and Sensing and communication radio coverage. Overall, the simulation results show that the significant energy saving can be achieved by the ROS approach.

## 5. Conclusions

The proposed ROS scheme achieves significant energy savings by taking advantage of routing information and also utilizing it at the MAC layer. The energy savings result from the scheme in which the sensor nodes go to sleep as long as possible once there are no network routing activities. ROS scheme utilizes the graph theory model and the probability concepts to schedule sensor nodes to sleep with the routing information. A novel role switch method effectively allows some of sensors along the route path to sleep in probability based on the percolation theory while guaranteeing both sensing coverage and communication radio coverage. It effectively addresses the coverage loss problem. Since ROS scheme is based on the probability, it balances the energy consumption of nodes in the network, which leads to the longer sensor network life time. The ROS approach also works with ZMAC to achieve energy savings by reducing the duration of transmission task, which allows the sensors to get more chances to sleep in future and to reduce the idle listening time. Other advantages include the less communication interference with the RN nodes on the routing path, which causes the neighbor nodes sleeping with ROS scheme. Thus it reduces the collision of nodes at MAC layer so that the latency of transmission at the MAC layer will also be reduced.

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