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EECP: A new cross-layer protocol for routing in Wireless Sensor Networks

Fouzi Semchedine[a,c] *, Wahiba Oukachbi[b], Naima Zaichi[b], Louiza Bouallouche-Medjkoune[b,c]

[a]*Institute of Optics and Precision Mechanics (IOMP), University of Sétif, Algeria*
[b]*Computer Science Department, University of Béjaïa, Algeria*
[c]*Research Unit LAMOS, University of Béjaïa, Algeria*

Abstract

Maximizing the lifetime of a Wireless Sensor Network (WSN) is a very important challenge of network design. Therefore, the design of effective techniques that conserve scarce energy resources is a critical problem in a WSN. In this regard, a detailed study of the cross-layer protocols allowed us to draw their major drawbacks and that concerns the routing of messages and the synchronization at the sleep mode. Taking advantage of this study, we proposed a variant of the CLEEP protocol to improve and optimize the network performance. Our basic idea is to consider the network, the MAC and the physical layers when routing the sensed data. In fact, the new protocol, and by using the physical layer information, routes the data to the node that has the maximum of energy and closest to the sink. On the other hand, the protocol considers the MAC layer to determine the duty-cycle of the node and extend the sleep mode time. A comparative analysis with CLEEP shows that our protocol can improve the network performance.

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Keywords: Wireless sensor networks; cross-layer protocols; routing; MAC layer.

* Corresponding author. Tel.: +213550493611; fax: +213 34 21 51 88.
E-mail address: fouzi.jams@gmail.com

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1. Introduction

The technological advances in telecommunications have created a new generation of networks, called: Wireless Sensor Networks (WSN), that allows providing economically attractive solutions for remote monitoring and processing of data in complex and distributed environments. These networks are at the heart of numerous applications covering diverse areas like: the health, the home automation, the agronomy and the environment.

In order to monitor and to take action in target fields, the sensor network must be equipped with a large number of sensor nodes to better cover a given surface. Each node is powered by a limited amount of energy (battery) and communicates by using a radio signal. Indeed, the sensor energy consumption plays an important role in the life of the network which has become a predominant performance criterion. To address this problem, many researches are developed to maintain energy efficiency at every layer of the protocol stack by offering new algorithms and protocols. However, the separation of layers has become an obstacle to improve these networks. Thus, a combination of the different network layers are proposed [2,3].

In this mode of interaction, we propose an energy efficient protocol called: Energy Efficient Cross-layer Protocol (EECP), which exploits the data generated by the adjacent layers: physical, MAC and network. The main objective of the EECP protocol is to ensure the efficient transmission of data by minimizing the energy consumption. The sources of energy dissipation covered by our solution are: the energy cost of the routing path, the collisions, the overhearing and the idle listening. In fact, the EECP protocol, and by using the physical layer information, routes the data to the node that has the maximum of energy and closest to the sink. On the other hand, the protocol considers the MAC layer to determine the duty-cycle of the node and extend the sleep mode time. A comparative analysis shows that our protocol can improve the network performance compared to the CLEEP protocol8.

The rest of the paper is organized as follows: Section 2 presents the different Cross-layer protocols proposed in the literature. Section 3 consists in the design of the new routing protocol, which ensures the energy conservation of sensors and avoids the collisions, the overhearing and the idle listening. In Section 4, we show a comparative analysis of the new protocol compared to the CLEEP protocol and we conclude the paper in Section 5.

2. Related work

Recently, a new generation of cross-layer protocols [4,5,6,7,8,9,10] which operates several layers to optimize the energy consumption has emerged. In fact, these protocols use different layers to route the sensed data to the sink by considering the characteristics that can offer each layer. In [4], the authors use a distribution of the information to reduce the control packets. The paths are created using the on-demand mode. All the nodes of the path between the source and the destination exchange messages to ensure an optimal node that must route the data. This increases the collision risks and consumes the energy since each intermediate node must be waked up and the optimal nodes must remain active during the path research process. In [5], the authors consider that only the farthest node has the right to retransmit the packet at the flooding process. So, they classify the nodes in N classes based on the received signal power. In fact, this process does not avoid collisions of packets in the same class, mainly if the network is dense. In [6], and based on the NAV (Network Allocation Vector) parameter, the authors consider the nodes with an expired NAV and that belong to the routing path to be waked up at the difference with the S-MAC protocol that wakes up all the nodes when their NAV expires [1]. Although the protocol routes the data by choosing the closest node to the sink, the source can always choose the same path which exhausts quickly the energy of the participating nodes. In [7], the authors try to improve the protocol proposed in [6] by waking up just the nodes belonging to the routing path and maintaining the other at the sleep mode. The protocol uses a routing table and tries to find the shortest path by using the Djikstra-Moore algorithm. Like [6], the protocol suffers from the large number of awakened nodes. In [8], the authors propose a cross-layer protocol that considers a static routing table and that contains the shortest paths from each node of the network toward the sink. This table is used to choose the duty-cycle nodes. In [9], the authors try to construct a tree based on the energy of nodes and by using the synchronization packets (used in the synchronization process of [6]). When routing the data, the protocol considers a cost function in terms of energy and link costs. Although, the cost function may improve the routing process, the protocol exchanges the energy and the link information between nodes which may increases the collision risks and consumes the energy. On the other hand, and by using the synchronization process, the nodes may be waked up before or after the ideal moment of transmission. Like [4], the protocol of [10] exchanges messages between the source and the next hop by using a Route-Request (RR). If the next hop is not in the sensing range of the source, this last sends RR message at the maximum distance in its sensing range. In fact, this process increases the collision risks and consumes the energy since the source must retransmit the RR messages when there is no node belonging to its sensing range.

3. Energy Efficient Cross-layer Protocol

Although the protocol CLEEP [8] shown an energy efficiency by using a wake up mechanism that wakes up just the node selected to route the data (at the difference with the recalled protocols which use the synchronization to wake up the nodes), it suffers from different drawbacks. In fact, the protocol, when selecting the node, wakes up this last before the ideal moment. Further, the parameter used to construct the routing table seems to be very costly in energy; mostly, in dense networks. Finally, the protocol does not ensure the load balancing of the energy since it can use the same path to route the data due to the static routing table.

Based on these analyses, we propose a new protocol that we call: Energy Efficient Cross-layer Protocol (EECP), and which interacts between the different layers: physical, MAC and network, at the aim of:

- Maximizing the sleep time of the nodes that do not participate in the routing process;
- Avoiding the energy exhaustion caused by the idle listening and the overhearing;
- Avoiding using the same path to route packets;
- Avoiding waking up a node before the perfect time of its participation in the communication;
- Reducing the collisions.

3.1. Hypothesis

In our conception of EECP, we based on the following assumptions:

- EECP is designed for flat network architectures;
- EECP is suitable for wireless sensor networks with a single sink;
- In EECP, each node has a unique identifier (the sequence number or the MAC address);
- EECP is a reactive routing protocol. It creates dynamically a route at each packet transmission;
- EECP is a protocol in which the communication is initiated by a source node (the sink does not broadcast requests);
- Each node maintain a neighboring table;
- As for CLEEP, each node has two radios: one with a low flow and a low consumption for signaling (wake up), and another with a high flow but a high consumption for data communication.

3.2. Protocol conception

In EECP, the data packets are transmitted through a path established dynamically. If a node must send a data, it selects one of its neighbors based on its energy level and its distance from the sink. Then, to calculate the distance, EECP uses the RSSI signal (Received Signal Strength indicator) [11]. So, in the first step of the EECP protocol, we initialize the RSSI of all the nodes in the network relative to the sink (Local_RSSI), the distance of each node with respect to its neighbors and we construct the neighbor table of all the nodes. After this first step, all the nodes of the network transit to the sleep mode. When a node senses an event, the protocol performs a simple calculation to select the next node in its neighboring table by using the following cost function:

$$\cos t = \frac{Local\_RSSI_{neighbor}}{RE_{neighbor}} \quad (1)$$

Where:
$RE_{neighbor}$: is the residual energy of the neighbor.

When the source node sends the packet, all its neighbors receive the signal. Then, each neighbor updates the residual energy of such node for further communications. So, the neighbor estimates the consumed energy as follows:

$$E_{estimate} = E_{send} + E_{reception} + E_{cp} + E_{trans} \quad (2)$$

Where:
E_{send} : is the emission energy. This energy is calculated using the average distance of the node with respect to its neighbors.
$E_{reception}$: is the reception energy.
E_{cp} : is the energy of receiving a control packet.
E_{trans} : is the energy of transition sleep/active mode.

The choice is done by selecting the neighbor whose cost is the minimal. Once the next node is known, the source wakes up it and sends the data. Once this last is acknowledged, the source goes into the sleep mode. Each node that receives the data does the same until the packet reaches the sink (see Fig. 1.).

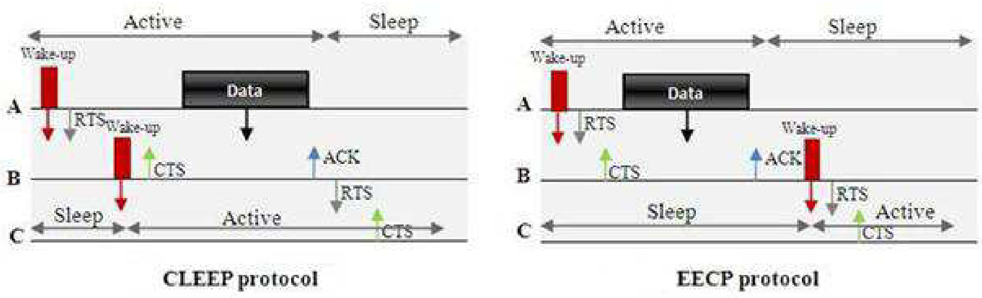

Fig. 1. Medium access and communication process.

The EECP protocol uses at the MAC layer a wake up mechanism to prevent the overhearing. The wake up is sent to the selected node of the neighboring table. The principle is only to wake up the next node that will participate in the routing process and put it in the sleep mode at the end of the communication.

4. Comparative analysis

We give in this section a comparative analysis in order to show the effectiveness of EECP protocol compared to CLEEP. These two protocols allow the interaction between the physical, the MAC and the network layers for energy conservation in wireless sensor networks.

4.1. Initialization phase

In this phase, the aim of both protocols is to maintain the neighbors table for each node of the network. Regarding CLEEP, it calculates first the minimum transmission power necessary for establishing a link with its neighbors. So that, each node finds the minimum transmission power to communicate successfully with its neighbor node. For this, each node broadcasts a small packet with different levels of power to all its neighbors and at the same time, it maintains a neighboring table to save this minimum transmission power and the neighbor node number.

However, the EECP protocol broadcasts less packets than the CLEEP protocol. In fact, EECP broadcasts just the RSSI to calculate the distances. We note that CLEEP does not take into consideration the energy constraint due to the diffusion of the packet by each node multiple times with different power levels. Therefore, it is clear that in this phase, our protocol conserves energy more than CLEEP.

4.2. Routing phase

At the routing process, the CLEEP protocol uses the construction of a routing table which is based on the ISTH algorithm (Incremental Shortest-path Tree Heuristic) [12] and a table of neighboring nodes. To route packets, CLEEP uses a fixed path. However, EECP selects paths dynamically by taking into account the energy of the neighbor nodes and their distance relative to the sink.

It is clearly obvious that the CLEEP protocol does not provide a load balancing in terms of energy of sensors. In other words, there is a risk that a node leaves the network sooner than expected, and this decreases the network lifetime. Since the routing process is dynamic, EECP provides a load balancing for all the network nodes that could participate in the routing.

4.3. Medium access phase

For CLEEP, we find that the MAC layer phase remains not optimal because each time a node receives a wake up, it wakes up the next neighboring node before the ideal time. Therefore, the node consumes the energy by an idle listening for a certain duration. EECP remedies this problem by waking up one neighboring node that participates in the routing process at the perfect time (see Fig. 2.).

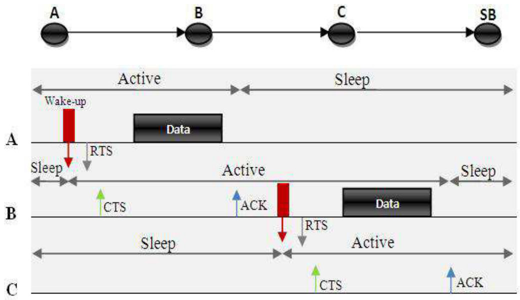

Fig. 2. CLEEP vs. EECP at the MAC layer.

5. Conclusion

In this paper, we proposed a new protocol called Energy Efficient Cross-layer Protocol (EECP) for wireless sensor networks. EECP takes into account the constraints imposed by these networks, in particular the energy consumption. With EECP, we aimed to minimize the energy consumption at three layers: physical, MAC and network to achieve our goals. EECP addresses many sources of wasted energy: the energy cost of the routing path, the collisions, the idle listening and the overhearing. In addition, EECP balances the lifetime of all the nodes, and consequently, increases the network lifetime. This is shown in the comparative analysis of our protocol with the CLEEP protocol.

As a future work, we plan to extend the work by improving the protocol in terms of next hop selection and by considering the case of equal costs and avoiding the loops. On the other hand, we introduce the simulation results of the comparison between our EECP protocol and the CLEEP protocol in order to affirm the comparative analysis.

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