Energy Conserving Opportunistic Routing for Self-Powered Wireless Sensor Networks

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***Abstract*—Survivability is a looming threat for Wireless Sensor Networks (WSNs) especially when they are used for monitoring and tracking applications with limited available resources. Self-powered WSNs can alleviate the problem and extend network lifetime. In this poster, we introduce an Energy Conserving Opportunistic Routing (ECOR) protocol that tries to keep a balance between the energy consumption and the packet delay. Every node is self-powered and draws energy via solar panels. Preliminary simulation results are presented that show an increase in network lifetime of up to 25% compared with simple opportunistic routing while the packet delay is similar.**

I. Introduction

Wireless Sensor Networks (WSNs) are a commonly used solution for a plethora of application such as event monitoring and tracking. Inch scale sensor devices have been designed to work unattended with limited power requirements for long periods of time. Energy consumption can threaten the successful deployment of these networks. The lifetime of any individual node, and as a consequence, of the whole network, is solely decided by how the limited amount of energy is utilized. Energy harvesting can alleviate the problem. Self-powered WSNs provide the possibility of very long sensor node lifetimes while their deployment would have the least impact on the existing infrastructure. The total network lifetime can be extended compared with traditional battery-powered WSNs. The routing protocol that will be applied in those networks should be carefully designed. Moreover, the nodes should participate in packet transmissions to achieve the best possible performance while they should have sufficient time for energy harvesting and storage.

Opportunistic routing is a dynamic routing that tries to take advantage of the broadcast nature of wireless communications [1]. It can adapt to network changes and deliver the packets through different paths according to the network conditions. The next relay node selection criterion is crucial for any opportunistic routing protocol [2]. In this poster, we extend the idea of Energy Aware Opportunistic Routing (EAOR) [3], and we introduce an *Energy Conserving Opportunistic Routing (ECOR)* protocol. *ECOR* tries to give sufficient time for energy harvesting and storage to the nodes that have participated in a number of transmissions and have low energy levels compared to their neighbors. *ECOR* has been designed for self-powered sensor nodes which draw energy via solar panels. In the following we will give a brief description of the protocol along with preliminary results on network simulator. *ECOR* has also been implemented and can be demonstrated on a prototype wireless sensor node, shown in Fig. 1. However, the current version of the prototype uses batteries instead of solar panels.

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II. ECOR: Energy Conserving Opportunistic Routing

ECOR is a dynamic routing protocol which follows opportunistic routing principles. In opportunistic routing, the next node selection process is crucial. Every sensor node in the network knows its relative location. Every message and packet transmission is subjected to Packet Error Rate (PER). When a node has a packet to transmit, it starts with a Request To Send/Clear To Send (RTS/CTS) handshake with the neighbor nodes. The source node broadcasts a RTS message. Some of the neighbor nodes will successfully receive that message, while some nodes will be at the energy harvesting mode and will not participate in any transmission. The nodes that received the request will wait for time $T_{backoff}$ and will reply with a CTS message. The node that will reply first with a CTS, will be the next relay node. In this way, the $T_{backoff}$ can be used to prioritize the neighbor nodes. As a result, $T_{backoff}$ is of high importance for the network performance.

In a simple opportunistic routing protocol [4] we proposed a scheme where $T_{backoff}$ can be inverse proportional to the distance from the destination:

$$T_{backoff} = \frac{C_1}{D_{src,cnd}} + SIFS,\ D_{src,cnd} \leq R \qquad (1)$$

where C_1 is a constant related with the transmission range, R is the transmission range of each node, SIFS is the Short Interframe Space and $D_{src,cnd}$ is the distance between the source node, *src*, and the candidate node, *cnd*, defined as:

$$D_{src,cnd} = 1 + |d_{src,cnd} - d_{cnd,dst}|,\ src \neq cnd \qquad (2)$$

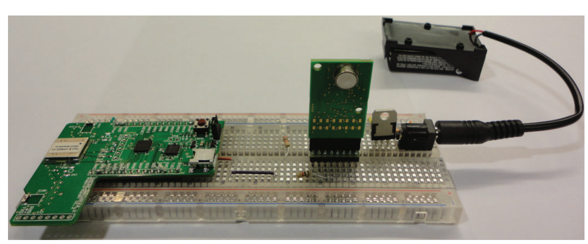

Fig. 1: Prototype of opportunistic wireless sensor node.

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where $d_{src,cnd}$ is the distance between the source and the candidate node and $d_{cnd,dst}$ is the distance between the candidate and the destination node *dst*.

In the proposed *ECOR*, the selection criterion of the next relay node is a combination of the distance from the destination and the remaining energy at the node. The calculation of the backoff time changes in order to reflect energy level of the nodes while the complexity remains simple for the limited capabilities of the sensor nodes. Moreover, in order for a node to participate into a packet transmission, the remaining energy in the node should be higher than a threshold Th_{energy}. This threshold is related with the minimum energy required from the node to remain active and proceed to the energy harvesting mode. In *ECOR* the backoff time can be defined as:

$$T_{backoff} = \frac{1}{D_{src,cnd} + C_1 \times L_{energy}} + SIFS, \quad only\ if\ L_{energy} \geq Th_{energy} \tag{3}$$

where L_{energy} is an approximation of the percentage of the remaining energy in the node, in comparison with its initial energy, E_{init}, and C_2 is a constant related with the network density. The use of approximation L_{energy} in Eq. 3 is preferred because it is easy to be implemented in the hardware, it does not need to be the exact value of the remaining energy and if the energy source changes (from 2 batteries goes to 3 or solar panels etc.) the routing can adapt quickly to changes.

As it can be inferred from Eq.3, *ECOR* tends to use less nodes with low energy levels. For every packet transmission, it checks the energy level of the remaining nodes. When the energy level of a node is low, it will not participate in packet transmission and can switch to energy harvesting mode. The energy level in which the node will switch to harvesting mode depends on the E_{init}, and hence on the energy source requirements of the self-powered WSN.

III. Performance Evaluation

To evaluate the performance of the proposed routing protocol we used OMNeT++ simulator. Real data were used during the simulation. The data were collected with the use of 10 wireless sensor node prototypes [5], shown in Fig.1, distributed in different indoor locations in our university. Each prototype was powered up with one 9V battery and it monitors the temperature for 2 hours. The transmission power was $15mW$ and the transmission rate 250 kbps. The energy threshold was $Th_{energy} = 24\%$ and $C_1 = 10$. These data were used in OMNeT++ to form packets. However, since the current version of the prototype is powered with batteries, in order to examine the performance of *ECOR*, a self-powered energy model was built for each node in the simulator. The model follows the requirements of the solar panels.

We examine the performance of simple opportunistic routing and *ECOR* in terms of network lifetime and packet delay under different network density. Network lifetime is increased up to 25%, shown in Fig. 2, while the packet delay tends to remain the same, shown in Fig. 3, as the network density increases. The main reason is that as we increase the number of the nodes in the network, *ECOR* adapts faster to the density change and tends to use nodes with similar distance from the destination but with higher energy level. As a consequence, the sensor nodes can spend sufficient time in energy harvesting without an increase in the packet delay.

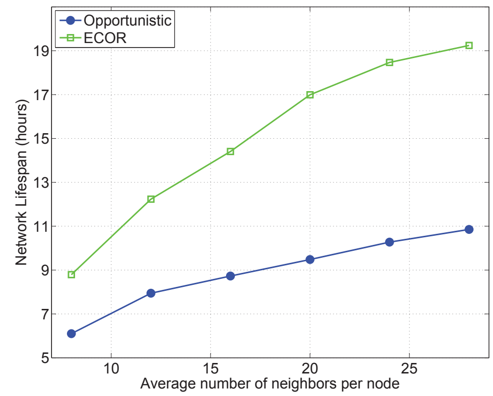

Fig. 2: Network lifetime under different network density.

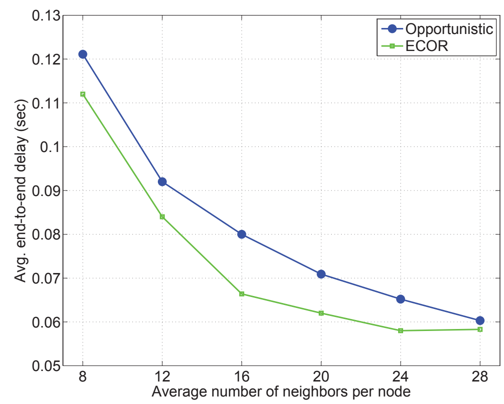

Fig. 3: Average end-to-end delay under different network density.

IV. Conclusion and Future Work

In this poster we introduce *ECOR* for self-powered WSNs. Simulations with real time temperature data show that *ECOR* can extend network lifetime. Future work will focus on the integration of the solar panels and the prototype as well as the evaluation of the simulation results with real time experiments.

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