Wireless Sensor Network: Improving the Network Energy Consumption

Ingrid Teixeira, José Ferreira de Rezende and Aloysio de Castro P. Pedroza

Abstract-- **In a remote sensor application it is desirable that the lifetime of the nodes be increased. This work proposes a modification to directed diffusion protocol, a data-centric protocol for low energy wireless sensor network. The main motivation behind is to balance the energy consumption among the sensor nodes to avoid early depletion of the network. Using a deterministic criteria our protocol selects the paths that have the higher relation of nodes energy reserves and distance to the destination. Simulation-based studies have been used to quantify the performance gains of our algorithm.**

Index Terms-- **wireless sensor networks, routing, energy-aware protocol**

I. INTRODUCTION

Recent advances in the IC technology make it possible to produce micro-sensing devices that are equipped with processing, memory and wireless communication capabilities [1]. In Wireless Sensor Networks, WSNs, nodes are untethered and unattended. They are distributed across an area of interest and communicate among themselves in multiple hops, building an ad-hoc network. Nodes have limited and non-replenish energy resources. There are special nodes named sink (or gateways) nodes, that are responsible for processing and store the information collected by the network. Such sophisticated devices allow the production of systems that introduce a new information flow: environment to person. Smart Dust, Cots Dust [2] and Berkley Mica Mote [3] are examples of WSNs.

In this paper we propose a new energy efficient packet forwarding scheme to increase the survivability of low-energy networks. Energy efficient routing, as Srivastava et al. [4] defines, performs its decisions based only on past and present data. By survivability we mean that the protocol should ensure that the connectivity in a network is maintained for as long as possible and that the energy depletion of the network should be the same. It is a reactive protocol and performs only localized interaction.

The work presented in Shah et al. [6] has inspired the approach described in this paper. An energy cost is calculated to the path and a probability inversely proportional to this cost is assigned to each neighbor. It can be classified as a multi-path scheme, since it constructs a forwarding table.

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Multi-path protocols may not scale to large size networks and table driven approach may not be able to adapt well to network or traffic dynamics at a low cost. Our protocol modifies the directed diffusion (DD) protocol so that it spreads the traffic over the network without maintaining multiple paths. Nodes locally store only one neighbor to forward data to, at each round of the protocol.

The remainder of the paper is organized as follows. In section II we present a review of related work in energy aware protocols. Section III describes the modifications we made in the directed diffusion protocol. Simulation results are presented in Section IV. Finally, the paper is concluded in Section V.

II. RELATED WORK

Energy is a factor of utmost importance in WSNs. To increase network lifetime, energy must be saved in every hardware and software solution composing the network architecture. According to the radio model proposed in [7] data communication is responsible for the greatest weight in the energy budget when compared with data sensing and processing. Therefore, it is desirable to use short-range instead of long-range communication between sensor nodes because of the transmission power required. In most WSN scenarios, events can be sensed by many source nodes near the phenomenon of interest and far away from the sink nodes. Then, the use of short-range communication leads obligatorily to data packets being forwarded through intermediate nodes in a multi-hop path.

Current research has focused on protocols that are low power, scalable with the number of nodes and fault tolerant. Chang et al. [5] proposes a flow redirection algorithm which balances the energy consumption rates among the nodes in proportion to the energy available. Their objective is maximize the lifetime of the system instead of minimizing the consumed power. The drawbacks of this approach is that it requires prior knowledge of the rate at which information is generated (data flow) and the set of origin nodes where the information is generated, and a set of destination nodes.

LEACH [7] proposed a clustering based protocol, where the cluster heads are randomly rotated to evenly distribute the energy load among the nodes in the network. Their underlying assumption is that the nodes have adjustable transmission power and the cluster heads transmission range reach the gateway node. In this present work, the nodes have fixed transmitting power.

Geographical and Energy Aware Routing (GEAR) [8] uses energy aware neighbor selection to route a packet towards the target region and restricted flooding algorithm to disseminate the packet inside the destination region. However, this solution depends that nodes have either GPS device or localization system, such as the ones based on tri-lateral principle.

We think that the metric of interest in WSN is *network survivability*, as Shah et al. [6] defines. The protocol should ensure that connectivity is maintained as long as possible, and that the energy spent by the entire network should be uniformly distributed. This proposal is in contrast with energy optimal protocols, which find optimal paths and consumes the energy of these nodes, leaving the network with a disparity in the energy levels, sometimes can form disconnected sub-graphs. The survivability of the network is to lead to a more graceful degradation of the network.

The protocol we propose tries to increase the network survivability of low energy networks. It is a reactive protocol; however it does not find a single optimal path and use it for communication. Rather, at each round of path discovery it computes the residual energy of path and chooses one based on the total energy available of the nodes.

III. Energy Aware Protocol Proposed

In this paper, we propose an extension to an existing data-centric routing protocol that tries to perform energy balancing among nodes to avoid early depletion of some nodes, leading to network partition.

The protocol has three phases:

A. Setup phase

The sink floods interest messages to its neighbors in each round of the protocol. The interest messages describe the task as an attribute-value pair [9]. When a node receives an interest, it checks to see if the interest exists in the cache. If the message received has no match with the message entry (*MsgEntry*), the node creates an interest entry. This entry has a single gradient towards the neighbor from which the interest was received. After receiving an interest, the node re-sends the interest to a subset of its neighboring nodes. Although the interest might have come from a distant sink, to its neighbors this interest appears to be originated from the sending nodes. So, this protocol performs only *local* interactions and is similar to some Internet multicast routing protocols.

B. Route establishment phase

When the interest reaches an appropriate region one or more sensors are activated, becoming sources. Sources send data to the neighbors they have gradient. The first data is called exploratory data. In directed diffusion, nodes re-send the first received exploratory data until they reach the sink node, favoring the low-latency paths. In our protocol, every node puts its energy reserve in a message field and send the exploratory data to its neighbors. A timer is created at each node in the network upon the reception of the exploratory data. The fact is there is a trade-off between delay and network consumption. Always selecting the lowest-latency

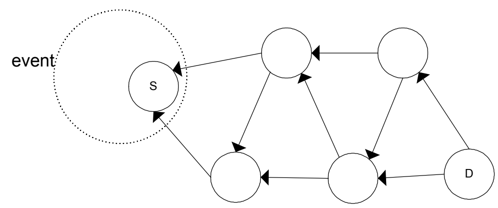


Fig. 1. Interest Propagation

path depletes the network´s energy and is not the metric of interest in many WSN applications, as Akyildiz [1] shows. For instance, in an environment sensing network, each sensor node contributes with its own data to correctly monitor the area. If the routing algorithm depletes some nodes earlier than others, the user may have an incomplete vision of the region being monitored.

The first message is assumed to be the best, that means it has the highest residual energy of the path. Afterwards, if it receives other messages, the node checks the residual energy of the path from the source to it and decides to store or discard it. When the timer expires only one message is forwarded to the selected neighbor node. The protocol routing table will store *one* single entry to each source.

1) Sending Exploratory Messages

The sources nodes send exploratory data to the neighbors they have gradient. The protocol set the message fields: *PathEnergy* and *DistToSource* to zero before sending the data. Suppose D is the destination node, then at every intermediate node N of the network :

$$N_D(PathEnergy) = 0$$

$$N_D(DistToSource) = 0$$

2) Receiving Exploratory Messages

The nodes store a copy of the message locally , in a message entry, and the protocol sets up a timer. Then every intermediate node increments the *DistToSource* field, store in the *PathEnergy* field the total available energy of the nodes along the path. If data is sent from node N_i to node N_j, then:

$$N_j(DistToSource) = N_i(DistToSource) + 1$$

$$N_j(PathEnergy) = N_j(ResidualEnergy) + N_i(PathEnergy)$$

3) Selecting the best energy path

Until the timer expires, the intermediate nodes may receive other exploratory data that comes through other path along the network. If that happens, these nodes will check if the new message is better than the message stored in the *MsgEntry*. The criteria applied is the relation of the path residual energy of the message to the distance to source. The message is compared to the ones stored in the *MsgEntry*. A message is considered better if:

$$\frac{Msg(PathEnergy)}{Msg(DistToSource)} > \frac{MsgEntry(PathEnergy)}{MsgEntry(DistToSource)}$$

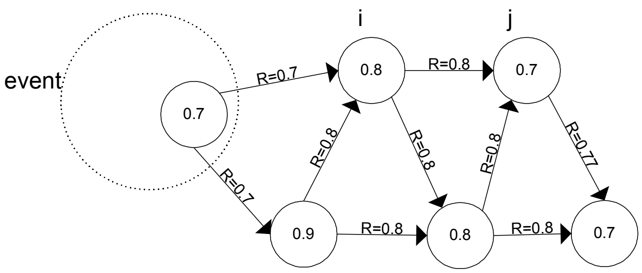


Fig. 2. Exploratory Data Propagation

4) *Expiration of Timer*

As timer expires, the exploratory data stored in the *MsgEntry* is sent to the gradient filter with updated values. In the original implementation of directed diffusion, all exploratory data were sent to the gradient filter and the protocol always selects the low-latency path. In our energy-aware scheme we may select longer paths at each round of the protocol to balance the energy consumption among nodes.

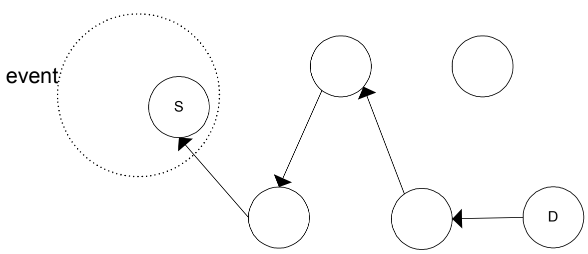


Fig. 3. Best Energy Path

C. *Data communication phase*

Data is sent from sources to the neighbor node selected in the earliest phase. Each of the intermediate nodes forwards the data packet until it reaches the sink node.

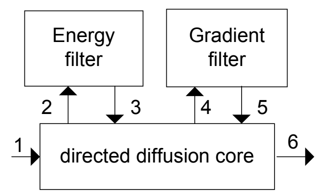
IV. SIMULATION RESULTS

In this section we report on some performance evaluation of our energy-aware protocol. This section describes our methodology and compares the performance of the protocol against the original directed diffusion protocol.

A. Methodology

We added a module to the current implementation of directed diffusion in the *ns-2* simulator, named Energy filter, as shown in Figure 3. This filter is instantiated in every node of the network and is set to act on the exploratory data used to discover routing paths. The routing module of directed diffusion, Gradient filter, receives the message selected by the Energy filter. Instead of immediately forwarding the first received message to the gradient, Energy filter sets up a timer to wait for other messages to arrive and makes comparison among them until the timer expires.

Below is a simple data flow to illustrate the message processing at the nodes.



1 - Reception of Exploratory data

2 - Energy filter stores the Exploratory data locally and sets up a timer

3 e 4 - Energy filter selects one message in the message entry and sends it to the Gradient filter

5 - Gradient filter forwards the message to the neighbors that have interest on the message

6 - Directed diffusion core sends the message to the network. This will set up the reinforced paths to deliver the message to its destination

Fig. 3. Data Flow

In order to more closely mimic realistic sensor network radios, we altered the *ns*-2 radio energy nodel such that the antenna transmission range is 20m and 40m of carrier sense. The transmission power dissipation is 660mW. All nodes initial energy were set to 1J.

Regardless of which type of medium access scheme is used for sensor networks, it certainly must support the operation of power saving modes for the sensor node. One means of power conservation is to turn the transceiver off when it is not required. In our simulations, we set the energy spent to receive a packet to zero, that implies the node is in the *sleep* operation mode.

The scenario simulated was constructed to allow a didactical understanding of the algorithm proposed. The topology is similar to a regular grid. In a regular grid topology, each node may communicate up to 4 neighbors. In the cenario created each node may have up to 8 neighbors. There are 64 nodes, in a 8 x 8 grid topology. There are three data flows consisting of three sources (S_0, S_1, S_2) and one sink, or destination (*D*). The source nodes generates one event each second and are located at the corner of the grid. The total time of simulation was 1000 seconds and we repeated the simulation three times. Events were modeled as 64 byte packets, interests as 36 byte packets, the interest duration was 15 seconds.

We choose two metrics to evaluate the performance of directed diffusion and the Energy filter: network energy map and energy consumption. The network energy map shows the remaining energy at each sensor node. The energy consumption measures the ratio of the total available energy of all nodes to the number of nodes.

B. Comparative Evaluation

In directed diffusion the reinforced paths are the ones with the lowest latency. This was confirmed through our simulations, figure 4 shows the preferred reinforced paths in many rounds of the protocol. We observed that these paths were not used in all rounds of the simulation. The reason is that directed diffusion stores the first message received and discards all the others. However, a link between two nodes may cause a message loss or have different propagation delay. Then, the first message received may come from a different neighbor in each round of the protocol. Using the Energy filter with directed diffusion, the protocol was able to reinforce different paths deterministically.

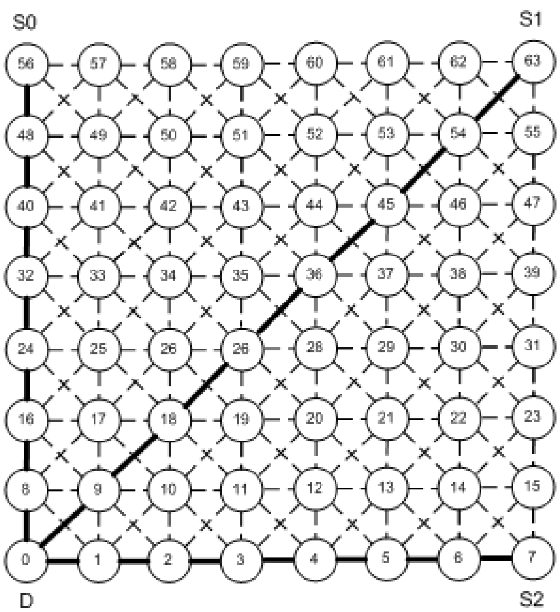


Fig. 4. Most preferred paths chosed by directed diffusion protocol

The energy consumption map is shown in figures 5 and 6 after 500 seconds of simulation. Analyzing the surface we observe two interesting results. First, the nodes in the borders of the surface using directed diffusion alone have lower energy reserves than using Energy filter. Second, the graph plotted with directed diffusion has a depression that represents an extreme energy consumption of the nodes that are in the diagonal line of the topology.

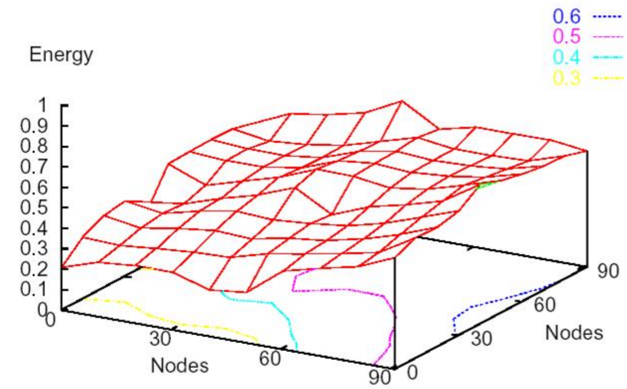


Fig.5 Energy map distribution (directed diffusion + Energy filter)

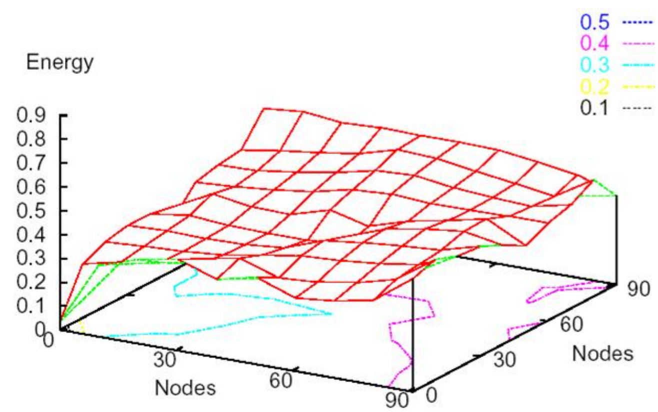


Fig.6 Energy map distribution (directed diffusion)

Figure 7 shows that energy consumption of the entire network is increased with Energy filter. This result is expected since Energy filter algorithm selects longer paths, then it increases the number of hops to the destination. Energy filter exploits new paths in the network, which may increase the energy spent in the communication.

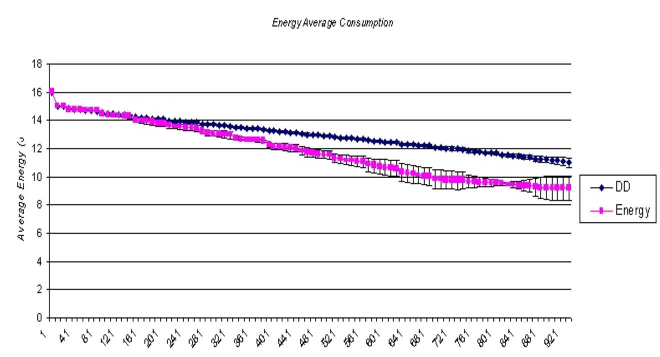


Fig.7. Energy consumption

V. CONCLUSIONS

Sensor networks create many new and exciting application areas for remote sensing. However, realization of sensor networks needs to satisfy the constraints introduced by factors such as fault tolerance, cost, hardware, topology change and power consumption. Since these constraints are highly stringent and specific for sensor networks, new wireless ad hoc networking protocols are required.

In this paper we describe a routing algorithm to extend the lifetime of the network. Extending the lifetime is required since all nodes contribute to collect the environment data. The early death of a node may lead to an incomplete monitoring. We added a software module to the directed diffusion protocol implementation to balance the energy consumption of the paths. Our preliminary evaluation of the energy filter shows that it caused a more equally distribution of energy even with relatively unoptimized path selection. This allows a greater network lifetime, avoiding early human action and reducing expenses on maintenances of the service.

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