Solar-aware Routing in Wireless Sensor Networks

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Abstract. In wireless sensor networks energy is a valuable but not necessary scarce resource. While it is often assumed that nodes in sensor networks are powered by batteries, other energy sources such as solar power may provide unlimited energy resources to a changing subset of the nodes. Since these nodes can receive and transmit packets without consuming battery power, routing via these nodes is appealing. In this paper, we present solar-aware routing, a routing protocol for wireless sensor networks that preferably routes traffic via nodes powered by solar energy. Simulations show that solar-aware routing can provide significant energy savings in many scenarios.

1 Introduction

Routing in wireless sensor networks has to take into account the very limited resources of the nodes. While many researchers assume that all nodes in a sensor network are battery-driven [1], [5], [6], nodes can also be powered by other energy sources such as gravitation or solar power. Nodes powered by such a source can receive and transmit packets without consuming battery energy. Therefore, routing packets via such nodes is appealing. It is, however, complicated by the fact, that the energy source is not permanent. In our lab, we have developed sensor boards which we will soon equip with solar cells. This motivated us to investigate if preferably routing via solar-powered nodes is feasible and can provide energy savings. We present simulation results using a protocol we call solar-aware routing. As other routing protocols for sensor networks this protocol is mainly based on local interactions between adjacent nodes. Our results indicate that solar-aware routing can provide significant energy savings in certain scenarios.

Our routing protocol has similarities to directed diffusion [2] and reactive protocols for ad-hoc routing such as AODV. Willig et al. have developed a routing protocol that considers nodes with permanent power supply [4] while our protocols assumes that the set of nodes having “unlimited” solar energy resources changes over time.

This paper presents our hardware (Section 2), the routing protocol (Section 3) as well as simulation results (Section 4) and concludes with conclusions and future work.

2 Sensor Board Hardware

The hardware used in our labs consists of a Texas Instruments MSP430 controller as core and a set of associated sensor hardware. These sensors are:

- A light sensor for the detection of visible light
- A passive infrared sensor for detection of movement
- A temperature sensor
- A gravitation sensor for the detection of movement of the sensor board
- A microphone for determination of the ambient noise level

The sensors communicate via an RF module in the 868 MHz band. The sensor board can be operated in three different power modes. The energy needed even in the most power-intensive mode (ca. 40 mA) can be provided by a solar cell. Fig. 1 shows the sensor board and an attached solar cell. Note that much smaller solar cells could be used as long as they provide enough power. The first generation of the sensor board has the size of three AAA batteries.

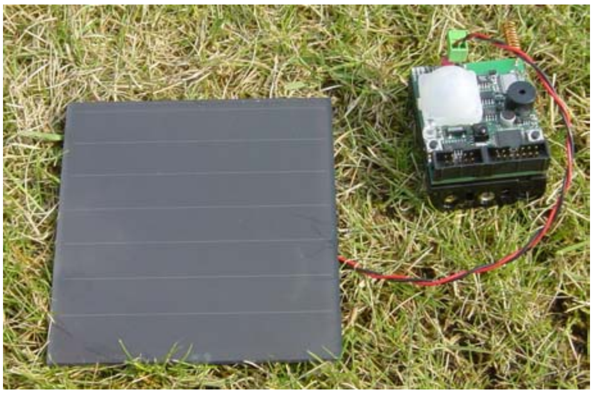

Fig. 1. Sensor board with attached solar cell.

Thus the hardware demonstrates that an operation mode we further call *solar-powered* is possible. We are currently building large quantities of the sensor boards (see `www.scatterweb.net`).

3 Protocol Description.

As in directed diffusion, data propagation in this version of our protocol is based on localized interactions, i.e. interactions with neighbouring nodes. In the protocol description, we use terminology known from directed diffusion. A *sink* is a node that is interested in some information a sensor in the network might be able to deliver, i.e. the node has a certain *interest*. A sensor node being able to deliver the desired information is called a *source*. Sinks express their interest by sending an *Interest* mation is called a *source*. Sinks express their interest by sending an *Interest message* into the network. The requested data is named as an attribute-value pair. While interest messages are propagated towards a potential source, nodes set up *gradients*. A gradient denotes state information about the sensor data the sink desires and about the neighbours, which we call other nodes in transmission range. The gradient also contains information about the *solar state* of the neighbours that denotes if a node is battery-driven or if it is running on solar power. A source delivers its information back to the sink using *Data messages*.

As in directed diffusion, our protocol assumes that at least adjacent nodes can be distinguished by identifiers.

3.1 Interest Propagation

Interest messages are generated by a sink and are simply flooded through the network. Note that other methods such as directional flooding based on location or previously cached data are more efficient and could be used as well [2]. Interest messages contain the attribute value pair, source and destination identifier, an interval that states the rate at which the sink wants to receive sensor data as well as a hop counter and the solar state of the sender. Nodes establish gradients to all other nodes from which they receive interest messages. A gradient to a neighbour is updated when an interest message for the same interest is received with a smaller hop count.

For every interest, nodes rebroadcast the first interest message they receive as well as following interests with a lower hop count. In most of the cases, however, the first interest message should have the lowest hop count.

3.2 Data Propagation

When a source receives an interest, it senses the environment at the specified rate and sends a data message towards the sink. A data message contains the attribute-value pair that allows the intermediate nodes to identify the gradients and the next hop towards the sink. When choosing the next hop, care must be taken to avoid loops. Propagating data along the shortest path is one method to avoid a loop. However, if there is exactly one shortest path we will not be able to preferably route via solar-powered nodes. Therefore, we allow the source and exactly one intermediate node to choose a next hop different from the one closest to the sink. The latter nodes are those neighbours from which a node has received the smallest hop counter in the interest message. A flag in the data message indicates if a node already has utilized the option to route via an intermediate node not on the shortest path to the sink. If this is not the case, an intermediate node may choose to forward the data to another node, that is solar-powered rather than a node on the shortest path. Once the flag is set an intermediate nodes must forward the message to a neighbour that is on the shortest path. If one of its neighbours is both on the shortest path and solar-powered, intermediate nodes forward the message to such a node.

3.3 Status Updates

When nodes change their solar status, they should inform the nodes closer to the source about their new status to make them route via them if they are solar-powered or to give them the possibility to route via a solar-powered node instead.

There are two design options here. One is that a node simply broadcasts its new status; the other option is that it waits until it hears some communication going on or itself receives a data packet. The advantage of the first option is that a more energy-efficient route can be found at once while using the second option some data messages might still be routed via a less energy efficient route. The advantage of the second option is that it avoids unnecessary broadcasts, meaning broadcasts that do not lead to more energy-efficient routes.

4 Experiments

We have conducted simulation studies using the OMNet++ discrete event simulator [3]. The aim of the study was to investigate if solar-aware routing provides energy savings by preferably routing via solar-powered nodes.

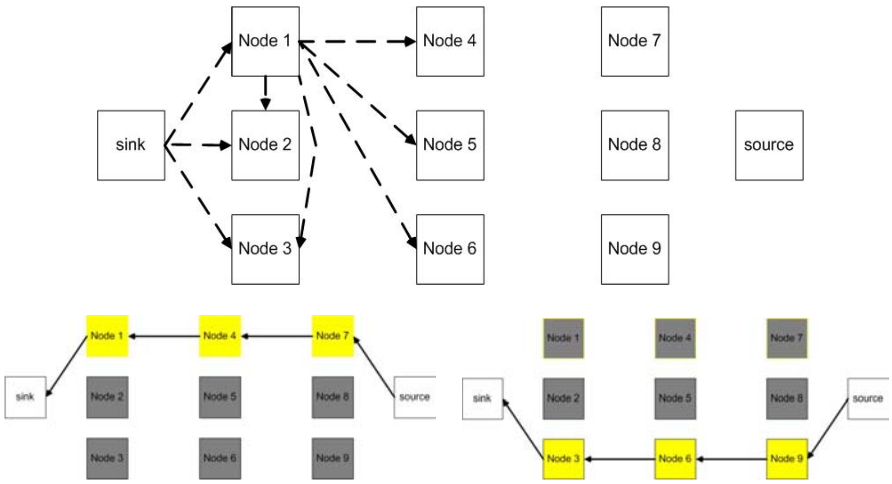

Fig. 2. Experiment with simple topology

4.1 Experiment with a Simple Topology

The setup for the first experiment is shown in Figure 2. In this experiment, each node is in the transmission range of the nodes in the same column and the neighbouring columns. For example, the sink is in the transmission range of the nodes 1 to 3 and vice versa. Node 7 is in the transmission range of the nodes 4-6, 8-9 and the source.

In the experiment the sun is moving from North to Source, i.e. in the beginning node 1, 4 and 7 are solar-powered. When the interest messages are flooded from the sink to the source as depicted in the top part of the figure, each node learns which adjacent nodes are solar-powered. The same is true for the source that therefore transmits the first data message to node 7. Since node 8 and 9 are also in the transmission range, they receive this data message as well, but do not forward it. We have not yet designed a sleeping protocol which would enable nodes 8 and 9 to sleep. It is obvious that assuming there is at least one solar-powered node in each column, solar-aware routing is able to find a path using solar-powered nodes only. The bottom left of Figure 2 shows the data flow when nodes 1, 4 and 7 are solar-powered, the bottom right of the figure shows the data flow when nodes 3, 6 and 9 are solar-powered.

4.2 Experiments with Random Topologies

We generated random topologies with the nodes distributed randomly across a certain area *a* for a given number of nodes. The sink and source are placed in the middle of the eastern and western boundary of this area *a*. The transmission range of the nodes is fixed. In our scenarios we let the sun move across the area from North to South, covering an area which is about a third to a fifth of the area *a.* We compare solar-aware routing with shortest-path routing, i.e. a route that would be found by directed diffusion. For comparison we use a simple metric, namely the number of data messages that must be transmitted using battery power. We do not include the interest messages in our comparison since they do not differ between solar-routing and shortest path routing. However, we include the extra status messages generated by solar-aware routing in our comparison. The sensor networks contain 20 and 50 intermediate nodes.

Table 1. Improvement with solar-aware routing

Number of nodes	20	50
Improvement (%)	26,8	6,9

As shown in Table 1, with 20 nodes, the average improvement of solar-aware routing over shortest-path routing is 26.8 %. For several scenarios, the improvement was more than 40%, while for other scenarios the improvements were only marginal. The latter scenarios often contained one bottleneck “link” each packet had to pass and thus solar-aware routing was not able to deviate from the shortest path for more than a few hops.

With 50 nodes, solar-aware routing was only 6.9 % better than shortest-path routing. Also here, the improvement depended on the random scenario. We saw improvements of 15 % to 20% but also only marginal improvements. However, solar-aware routing was only in very rare cases (and in these negligibly) worse than shortest path routing. The improvement with 50 nodes is less than with 20 nodes, because solar-aware routing based on localized interactions cannot take advantage of paths containing solar-driven nodes in the northern or southern areas.

5 Conclusions and Future Work

We have presented solar-aware routing, a routing protocol for wireless sensor networks that preferably routes traffic via nodes powered by solar energy. Our simulations show that this can provide significant energy savings in many scenarios.

Localized interactions are an important feature that enables the energy-efficiency of directed diffusion [5]. While for solar-aware routing this is true for small networks, for larger networks other methods need to be explored. Routing based solely on local interactions in a large sensor network makes it, for example, almost impossible to route via the nodes in the North if only these are solar powered and the shortest path is more towards the South. We are currently designing and exploring protocols with more global knowledge suitable for larger sensor networks. Among other tasks of future work, we are considering multiple sinks and sources as well as the definition of a suitable protocol that enables nodes to decide when to go into sleep mode.

References

1. Akyildiz, I., Su, W., Sankarasubramaniam, Y., Cayirci, E.: Wireless Sensor Networks: a survey. Computer Networks, 38 (2002) 393-422
2. Intanagonwiwat, C., Govindan, R., Estrin, D., Heidemann, J., Silva, F.: Directed Diffusion for Wireless Sensor Networking. Transactions on Networking, Feb. 2003
3. Varga, A.: The OMNeT++ Discrete Event Simulation System. European Simulation Multiconference, Prague, Czech Republic, June 2001
4. Willig A., Shah R., Rabaey, J., Wolisz, A.: Altruists in the PicoRadio Sensor Network. Factory Communication Systems, Västerås, Sweden, August 2002
5. Zhao, Y., Govidan R., Estrin, D.: Residual Energy Scan for Monitoring Sensor Networks. Wireless Communications and Networking Conference, Orlando, FL, USA, March, 2002
6. Heinzelman, W., Chandrakasan, A., Balakrishnan, H.: Energy-Efficient Communication Protocol for Wireless Microsensor Networks, International Conference on System Sciences, Hawaii, January 2000