Monitoring Energy Consumption In Wireless Sensor Networks

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Abstract. This note introduces an approach to monitor the consumption of energy in wireless sensor networks based on video streams composed from sequences of temperature maps. It is used to compare and evaluate beacon-less geographic routing algorithms.

1 Introduction

Wireless sensor networks are increasingly becoming an important part of the next-generation network infrastructure. One of the chief limitations of these wireless networks is the limited battery power of the network nodes. The lifetime of a wireless sensor network is determined by the duration over which the network can perform its assigned tasks. If a sufficient number of nodes run out of energy, it may impair the ability of the sensor network to function. Therefore, minimizing energy consumption is an important challenge in mobile networking [1]. Capable architectures and circuit techniques to address energy consumption in both standby and active modes is the basis of wireless networks. Energy preserving procedures can be leveraged at different layers of a sensor network architecture:

- *MAC layer*: S-MAC [2] is a protocol developed to address energy issues in sensor networks. It uses a simple scheduling scheme to allow neighbors to sleep for long periods and synchronize wakeups.
- *Adaptive Topology Schemes*: STEM [3] is a two-radio architecture that achieves energy savings by letting the data radio sleep until communication is desired while the wakeup radio periodically listens using a low duty cycle. In GAF [4] nodes use location information to divide the network into fixed square grids and nodes in each grid alternate between sleeping and listening.
- *Energy aware routing*: With power-aware broadcasting based on connected dominating sets [5] only nodes in a dominating set need to relay broadcast packets. Activity scheduling rotates the role of nodes between dominating and dominated.
- *Transmission power control*: The transmission power of the nodes is reduced as long as the topology has desired properties such as k-connectivity [6].
- *In-network aggregation*: Network traffic is reduced by aggregating sensor data inside the network and thus saving energy [7].

2 Energy Management

The goal of energy management is twofold: Minimizing the total energy consumption of all nodes in the network and secondly, achieving a homogeneous consumption of energy throughout the network. The second criteria is aimed at maximizing the network lifetime. It is well known that these are two conflicting criteria. Network lifetime is defined as the time until the network no longer is able to fulfill the tasks it was designed for. Depending on the task this might be when

- the first node fails,
- the network becomes disconnected and packets can no longer be routed between any pair of locations,
- the number of serviceable nodes falls below a critical level, or
- a specific region is no longer covered by any active node.

A theoretical analysis of the lifetime of a wireless network requires a model of energy consumption. Since communication is the dominant factor in power consumption, most models are based on communication only. Due to the complicated interactions between the different layers, these models consider only application related data packets. But such an analysis excludes the energy consumption of the idle mode and caused by lower level protocols such as the MAC layer or the routing protocol. Nevertheless, such models can be helpful in the preliminary analysis of network routing algorithms. A better tool for this purpose are simulation environments that consider MAC layer issues and that support sophisticated energy models. Unfortunately, realistic experiments are in most cases too sumptuous.

To evaluate and compare the energy consumption of different routing protocols we utilize temperature maps. Contour lines on the temperature maps are similar to contour lines on a topographic map; they show areas of higher or lower amounts of remaining energy. To this end, we simulate a sensor network with its nodes randomly distributed in a 2-dimensional plane with the tool ns-2. While running a series of routing tasks the energy levels of all nodes (related to sending packets) are read periodically over a fixed span of time and transformed into temperature maps. Finally, sequences of these maps are combined into video streams. Combined with a visual representation of other characteristic quantities such as error rate and average path length, this approach brings about a simple mechanism for analyzing and comparing the energy consumption of routing algorithms and the resulting network lifetimes.

The discussed visualization technique is used to analyze and compare different beacon-less routing algorithms. In particular, we investigate a novel algorithm called *BGR (Blind Geographic Routing)* [8]. This algorithm is reliable in fields with high node density and sends significantly fewer packets than other algorithms. Redundancy in the network topology is exploited to achieve a uniform energy consumption and thus, to extend the network lifetime.

We consider different application patterns such as all nodes send sensor readings periodically or sporadically to a fixed sink (with and without in-network aggregation) or randomly selected pairs of nodes exchange packets. At the beginning, a fixed amount of energy is assigned to every node. When this energy is consumed by a node, it is no longer available for the application. Furthermore, we consider cases, in which selected nodes (either randomly determined or computed via a backbone algorithm such as those based on connected dominating sets) get assigned a significantly higher amount of energy at the start of the simulation.

Figure 1 shows an example of a temperature map with 150 nodes; the dark nodes already ran out of energy. The left bar shows the number of hops divided by the optimal number of hops; the right bar depicts the packet delivery rate throughout the last measurement interval.

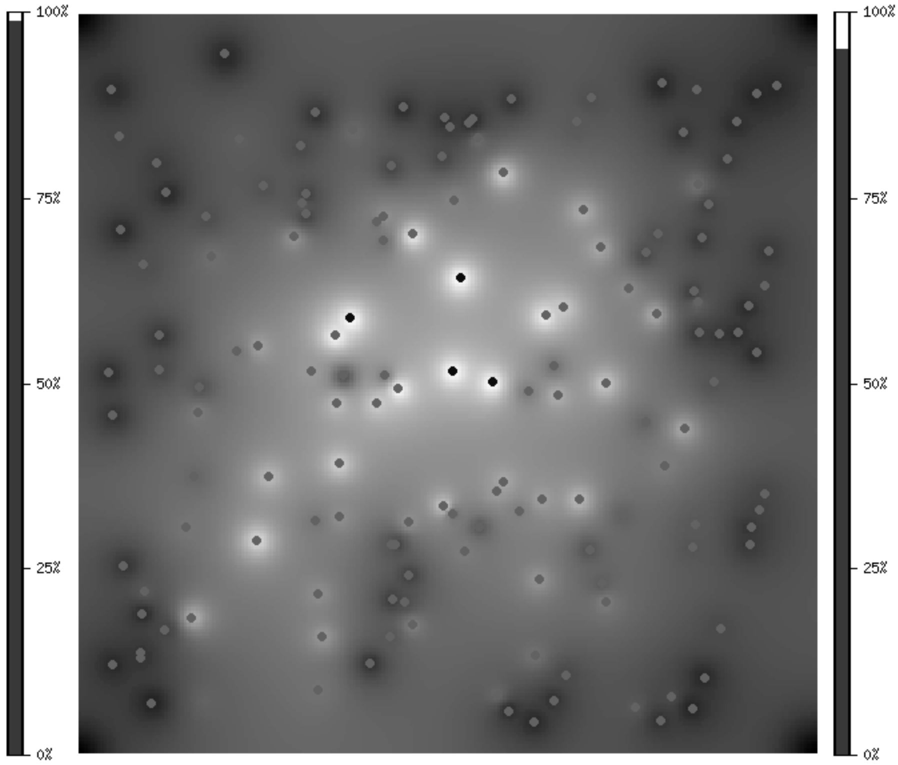

Fig. 1. Typical temperature mapping

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