MobiCom Poster Abstract: Protocols and Model for Sink Mobility in Wireless Sensor Networks *

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This paper concerns the definition of an analytical model and of a distributed protocol, termed Greedy Maximum Residual Energy *(GMRE), for determining the routes of a mobile data collector (*sink*) traveling through the nodes of a wireless sensor network (WSN). The routes are determined with the overall aim of maximizing the network lifetime. An ns2-based simulation comparison between GMRE, optical static sink placement and random sink mobility shows that GMRE yields remarkable improvements both for network lifetime and for balancing energy consumptions throughout the network.*

I. Introduction

Wireless sensor networks (WSNs) are networks comprised of a large number of wireless nodes with sensing capabilities. Routing of the sensed data to a collection point (called *sink*) happens as in ad hoc networks, i.e., in a multi-hop fashion. Given the nodes energy constraints, particular attention has been given to the definition of data dissemination protocols that aim at minimizing energy consumption. This research concerns the design of protocols and mathematical model for controlling the mobility of the sink with the ultimate goal of prolonging network lifetime (here defined as the time till the first node “dies” because of energy depletion). The advantages that can be achieved by moving the sink have been shown, independently and with different techniques, in [1] and [2] (where further references can be found). A linear programming (LP) formulation of the problem of maximizing network lifetime is given in [1]. Values obtained for network lifetime in networks with a static sink are compared with those obtained by having the sink moving according to the LP model: The improvements are fivefold. Luo and Hubaux [2] formulate the problem of lifetime maximization as a min-max problem. By considering together sink mobility and data routing a solution for sink movement is obtained that achieves lifetimes 500% higher than when the sink stays in the center of the network.

For the sink mobility problem we here define centralized and distributed solutions that take into account practical and realistic parameters and constraints. Differently from previous schemes we consider the costs of moving the sink, constraints on the distance the sink can travel, and the impact of different sink mobility rates. Optimum sink mobility is obtained by a MILP formulation which is extremely flexible, being independent of the number and type of network nodes, the shape and size of the particular deployment area, and the data routing protocol in use. Furthermore, such model can be easily extended to take into account multi-sink networks as well as cases when the mobility of the sink is constrained to predefined routes.

II. Problem formulation

We address the following problem.
Determine the starting position (site) and the route for the mobile sink over a set of possible sink sites S together with the sojourn times t_k of the sink at each visited site $k \in S$ so that network lifetime is maximized.

We assume nodes generate packets at a constant (possibly heterogeneous) rate.

A first problem to be solved is how the sensor nodes route the packets to the current sink site. Our solution is having the sink initiating a (routing protocol-dependent) route construction/maintenance process every time it moves to a new site. Once the sink moves, it will inform the nodes about it, resulting in route release. Sensor nodes will then buffer new packets and the packets that are still in transit, until they are made aware of the new sink site and routes to it.

There is virtually no bound on how far the sink can travel between two sites. However, we note that while the sink is traveling, the sensors do not transmit. This implies the possibility of high delays for data packets. In order to contain this delay, we introduce a new parameter d_{max} which represents an upper bound on the distance that the sink can travel from a site to the following one. We observe that the mechanism for route set up and release introduces an overhead that can be demanding on nodes that are energy constrained. We take this overhead explicitly into account in the definition of our model and in the protocols evaluation. Finally, the effect of different mobility rates is modeled by imposing that the sink should sojourn at each site for at least a given time t_{min}.

III. A new MILP Analytical Model

The first contribution of this work concerns the definition of a new mixed integer linear programming (MILP) analytical model that takes into account all the realistic constraints mentioned above. Here is a high-level description of the model, whose details can be found in [3].

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Maximizing the network lifetime corresponds to maximizing the joint time the sink spends at each individual site $k \in S$, namely, the sum over k of $t_k \geq t_{min}$. A natural constraint requires that the energy consumed by each node to forward data packets to the sink sojourning at each site k for t_k time plus the energy required to build and release routes when the sink moves to those sites cannot exceed the energy available at the node. Additional constraints are needed to enforce a simple sink route throughout the network sites. More specifically, the routes are seen as a unitary flow going from a virtual source node to a virtual destination node. In order to avoid loops, sites are assigned weights, and we impose that moving from site i to site j implies that i's weight is less than j's. The model can be easily extended to the case when the sink is allowed to go through the same site up to a finite number h of times. The general solution to the problem is then obtained by progressively running the model for increasing h until the optimum stabilizes.

IV. GMRE

The investigation on the performance of several routing protocols has shown a clear dependence of a node energy consumption on its vicinity to the sink. This observation suggests a general strategy for the selection of the next site the sink should be moving to: The next location of the sink will be in the area with the highest current minimum residual energy. In time, this should most likely result into a balanced energy consumption throughout the network, and hence into a longer network lifetime.

Based on this intuition we describe here the *GMRE* heuristic (GMRE stands for Greedy Maximum Residual Energy). After spending a time t_{min} at a site, a sink evaluates whether to move toward one of the adjacent sites (two sites are adjacent if their distance is $\leq d_{max}$) or to stay where it is. In order to make this decision it gathers information about the minimum residual energy at the nodes around each of the potential future sites (we call this energy value the residual energy at the site), and compare it with the residual energy at the current site. This is implemented by inquiring selected sensor nodes close to the adjacent sites (sentinels). Each sentinel gathers information about the minimum residual energy around the site and reports it to the sink. If there are adjacent sites with residual energy higher than that at the current site, the sink moves to the site with the highest residual energy (random choice breaks the ties). Otherwise the sink stays at the current location. (Protocol implementation details can be found in [3].)

V. Simulation Results

The GMRE protocol has been evaluated by means of extensive, ns2-based simulations. Its performance has been compared to the performance of data dissemination in case of WSNs with static sink (optimally placed at the center of the deployment area: We call this scheme STATIC) and in case the sink moves according to the following simple heuristic. Every t_{min} the sink selects randomly and uniformly the new location among all the sites within distance d_{max} from the current. In case a new site is selected it moves to that site. This heuristic, termed the Random Movement heuristic (*RM*), is here introduced mainly as a benchmark for assessing the effectiveness of GMRE in prolonging network lifetime. We choose this simple scheme because it well captures the type of uncontrolled/random mobility which has been often described in previous literature (e.g., [4]).

The simulations refer to scenarios in which $n = 400$ static wireless nodes with a maximum transmission radius of 25 meters and a fixed data rate of 0.5bit/s are placed on a grid in a geographic square area of side $L = 400$m. We make the assumption that two nodes are neighbors if and only if their Euclidean distance is ≤ 25m. Each device has an initial (residual) energy of 50J. The power consumed while transmitting and receiving are equal to 14.8mW and 12.5mW, respectively (as from the data sheet of the TR1000 radio transceiver from RF Monolithics). The GeRaF geographic routing protocol [5] is adopted. An ideal awake/asleep schedule for the sensor nodes has been considered, i.e., the nodes consume energy only when they either receive or transmit. The sink sites are distributed on a 8×8 grid. The parameter d_{max} has been set to 190m, while t_{min} ranges between $50,000$s and $1,000,000$s. All our results achieve a 95% statistical confidence with 5% precision.

We have considered several metrics of interest to sensor networking, which include (all averages): network lifetime, data packet latency, and the node residual energy over time.

We have observed that, in the case of GMRE and RM, the network lifetime decreases with increasing values of t_{min}, reflecting the fact that at high t_{min} the sink cannot freely move to all possible sites. Furthermore, the higher t_{min}, the coarser the granularity of sojourn times and hence the less balanced is the energy depletion throughout the nodes.

Optimum sink movements (termed OPT in the following) achieves a fourfold increase in network lifetime with respect to STATIC, as depicted in Figure 1. The GMRE solution only falls short by a mere 22%. Finally, RM also improves over STATIC. However, the improvement is never higher than 160%.

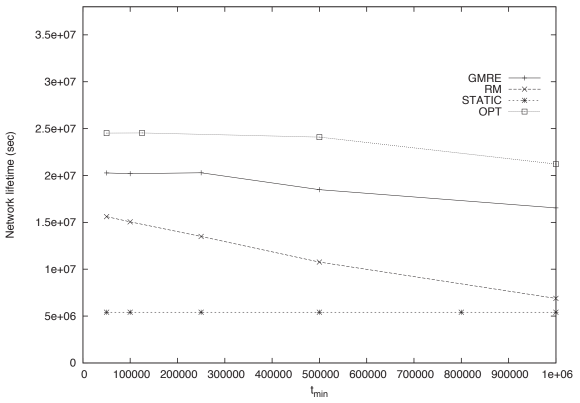

Figure 1: Network lifetime

In order to understand these improvements we have investigated the sojourn times of the sink at the different sink sites and the node residual energy over time according to the four different schemes. Figure 2 shows the nodes residual energy at network lifetime for STATIC. Nodes in the way from the corner to the sink experience high energy consumption. The closer to the sink, the higher the power required to relay data. At network lifetime, only the sink neighbors have little (or none) residual energy left. As clear from the figure, most of the network nodes still have almost full batteries.

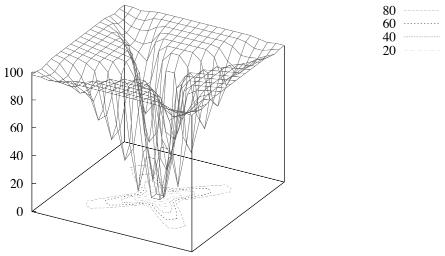

Figure 2: STATIC: Node residual energy

This widely contrasts with nodes residual energy in the case of OPT. As depicted in Figure 3 a large number of nodes (those enclosed by the inner circle at the bottom of the figure) have almost no energy left, showing a remarkable energy load balancing.

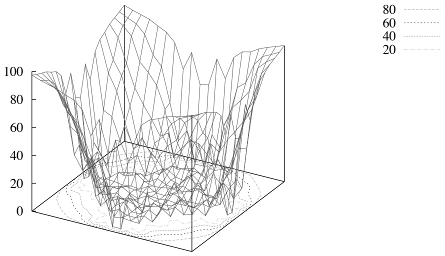

Figure 3: OPT: Node residual energy

This is achieved by OPT being able to select a subset of the sink sites that impose the higher energy consumption on different sets of nodes. Figure 4 shows that OPT sends the sink for longer times along the perimeter of the deployment area, and also in the central area, although for a shorter time. We notice that the corner areas are totally avoided by the sink, since visiting them would stress on the same nodes already drained when the sink stays at the other sites.

The uniform balance of residual energy, and hence the highest improvement in lifetime, is obtained by OPT because of the global knowledge of network topology and data relay costs which enables the optimal choice of sink sites and sojourn times. The GMRE heuristic, being distributed and localized, is able to perform only a coarser "tuning" of the sojourn times. By greedily choosing the best possible next site GMRE can avoid visiting sites whose surrounding nodes have already been drained. Figure 4 shows clearly that GMRE recognizes that staying at the corners is alternative to visiting sites on the sides and at the center. However, lack of global knowledge of key network parameters does not allow to find the best load balancing solution. This justifies the observed reduced network lifetime with respect to OPT.

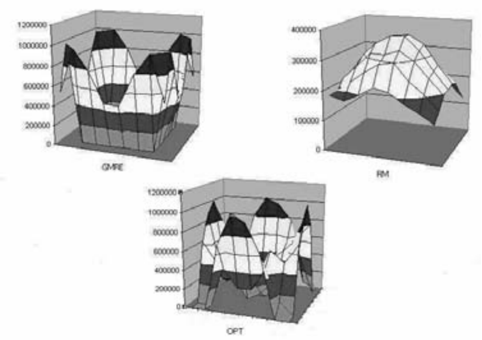

Figure 4: Sojourn times for 64 sink sites

The RM heuristic blindly sojourns at the center of the deployment area, stressing the same central nodes. This is why it experiences much worse performance than GMRE and OPT.

The price to pay for increased network lifetime is increased data packet latency. This is due to both the delays associated to sink movements and to increases in the average route length when the sink is far from the center of the deployment area. RM and OPT have similar performances, given that in both schemes the sink avoids the most external areas. The end-to-end latency increase with respect to STATIC in these cases is never higher than 40%. GMRE pays a further 18% increase (with respect to OPT) due to the sink spending the most time at the corners, which imposes longer routes.

References

[1] Z. M. Wang, S. Basagni, E. Melachrinoudis, and C. Petrioli, "Exploiting sink mobility for maximizing sensor networks lifetime," in *Proceedings of the* $38th$ *HICSS*, Big Island, Hawaii, January 3–6 2005.

[2] J. Luo and J.-P. Hubaux, "Joint mobility and routing for lifetime elongation in wireless sensor networks," in *Proceedings of IEEE Infocom 2005*, Miami, FL, March 13–17 2005.

[3] S. Basagni, A. Carosi, E. Melachrinoudis, C. Petrioli, and Z. M. Wang, "Exploiting sink mobility to improve the performance of wireless sensor networks," Università di Roma, "La Sapienza", Roma, Italy, Research Report I-05/06, December 2005.

[4] S. Jain at al., "Exploiting mobility for energy-efficient data collection in sensor networks," in *Proceedings of IEEE WiOpt 2004*, Cambridge, UK, March 24–26 2004.

[5] M. Zorzi and R. R. Rao, "Geographic random forwarding (GeRaF) for ad hoc and sensor networks: Multihop performance," *IEEE Transactions on Mobile Computing*, vol. 2, no. 4, pp. 337–348, October-December 2003.