Moving Multiple Sinks Through Wireless Sensor Networks for Lifetime Maximization *

Stefano Basagni† Alessio Carosi‡ Chiaro Petrioli‡ **Cynthia Phillips**§

Unattended sensor networks typically watch for some phenomena such as volcanic events, forest fires, pollution, or movements in animal populations. Sensors report to a collection point periodically or when they observe reportable events. When sensors are too far from the collection point to communicate directly, other sensors relay messages for them. If the collection point location is static, sensor nodes that are closer to the collection point relay far more messages than those on the periphery. Assuming all sensor nodes have roughly the same capabilities, those with high relay burden experience battery failure much faster than the rest of the network. However, since their death disconnects the live nodes from the collection point, the whole network is then dead.

We consider the problem of moving a set of collectors (sinks) through a wireless sensor network to balance the energy used for relaying messages, maximizing the lifetime of the network. We show how to compute an upper bound on the lifetime for any instance using linear and integer programming. We present a centralized heuristic that produces sink movement schedules that produce network lifetimes within 1.4% of the upper bound for realistic settings. We also present a distributed heuristic that produces lifetimes at most 25.3% below the upper bound.

More specifically, we formulate a linear program (LP) that is a relaxation of the scheduling problem. The variables are naturally continuous, but the LP relaxes some constraints. The LP has an exponential number of constraints, but we can satisfy them all by enforcing only a polynomial number using a separation algorithm. This separation algorithm is a p-median facility location problem, which we can solve efficiently in practice for huge instances using integer programming technology. This LP selects a set of good sensor configurations. Given the solution to the LP, we can find a feasible schedule by selecting a subset of these configurations, ordering them via a traveling salesman heuristic, and computing feasible transitions using matching algorithms. This algorithm assumes sinks can get a schedule from a central server or a leader sink. If the network owner prefers the sinks make independent decisions, they can use our distributed heuristic. In this heuristic, sinks maintain estimates of the energy distribution in the network and move greedily (with some coordination) based on local search.

This application uses the new SUCASA (Solver Utility for Customization with Automatic Symbol Access) facility within the PICO (Parallel Integer and Combinatorial Optimizer) integer programming solver system. SUCASA allows rapid development of customized math programming (search-based) solvers using a problem's natural multidimensional respresentation. In this case, SUCASA also significantly improves runtime compared to implementations in the ampl math programming language or in perl.

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†ECE Department, Northeastern University, Boston, MA.

‡Dip. di Informatica, Univ. di Roma "La Sapienza", Rome, Italy.

§Discrete Mathematics and Complex Systems Dept, Sandia National Laboratories, Albuquerque, NM 87185-1318.