Proc. 2nd Annual Conference of the International Technology Alliance, ACITA 2008, London, UK, September 2008

Analysis of Cost-Quality Tradeoff in Cooperative Ad Hoc Sensor Networks

Eyuphan Bulut, Jin Zheng, Zijian Wang and Boleslaw K. Szymanski
Department of Computer Science, Rensselaer Polytechnic Institute, 110 8th Street, Troy, NY, 12180, USA
{bulute, wangz, szymansk}@cs.rpi.edu and zhengj3@rpi.edu

Abstract—**In wireless ad hoc sensor networks, cooperation of nodes provides sensors with a broader range of information, often leading to an improvement in network's ability to meet its global objectives. However, increased communication caused by cooperation leads to a cost-quality tradeoff in the network operation. We model the cooperation based on the range of its information sharing. In h-cooperation, each node shares its information with those nodes that are at most h hops away. We analyze the tradeoff in three different applications and show that significant performance improvements arise when the optimal cooperation level is chosen.**

I. INTRODUCTION

An emerging trend in wireless sensor networks is to use cooperative communication and networking to achieve higher quality of service. A sensor network employing such cooperation has many advantages over conventional networks including (i) better decision making thanks to sharing information, (ii) increased reliability of sensed data, and (iii) improved efficiency of operation that is achieved via careful coordination of activities. However, such cooperation creates a complex network structure with increased energy cost and messaging overhead. Consequently, a cost-quality tradeoff arises during the design of a sensor network and its applications when deciding the level of cooperative networking.

In [1], authors discuss energy-quality tradeoff for target tracking in wireless sensor networks. Furthermore, in [2] authors explore the effects of node cooperation for routing algorithms proposed for delay tolerant networks. In our previous work [3], we also discussed this tradeoff in traffic light adjustment problem.

II. COOPERATIVE SENSOR NETWORKING

In an ad hoc sensor network, cooperation between nodes causes tradeoff between the improvement in network's functionality and the communication cost of the network. Therefore a careful design of the cooperation is needed to obtain overall optimal performance of the network. In our cooperation model, the average cost of h-cooperation for a single node is approximately:

$$\delta(h) = \sum_{m=1}^{N} \sum_{i=0}^{h-1} \left(\frac{E_r}{N} \sum_{j \in S_i(m)} |S_1(j)| + \frac{E_t}{N} |S_i(m)| \right) \tag{1}$$

where N denotes the total number of nodes in the network, $S_i(m)$ stands for the set of neighbors of node m that are exactly i-hops away, and $|...|$ returns cardinality of its set argument. Finally, E_r and E_t denote the power needed to receive or transmit one message, respectively.

A. Coverage Redundancy Based Sleep Scheduling

The objective of this application is to find the set of sensors necessary to cover the monitored domain and put the other nodes into sleep mode. Some examples of sleep scheduling algorithms are presented in [4], [5]. The challenging part of this problem is to decide which nodes should be active. A well known method applicable here is to check whether each node's sensing area is covered by other nodes not yet asleep. If each node in the network knows the global network topology with current status of nodes, then the problem is easy and the only remaining challenge is to prevent message collisions while each node is performing the test. However, in sensor networks, the nodes know directly only the status of their one-hop neighbors. Hence, to minimize the number of active nodes, each node needs to collaborate with others to assess the current coverage of its sensing region.

Let $u_{h,s}$ denote the average percentage of the nodes sleeping under the sleep schedule with h-hop neighbor definition. $u_{h,s}\delta(h)$ simply gives a pretty realistic approximation of the energy cost per node of using the different numbers of hops. Let t_{duty} be the period of running coverage redundancy algorithm in a network and E_{active} be the energy cost of sensing per node per time unit. Remember that, $\delta(h)$ denotes the energy cost of selecting new duties (sleep or active) in this application. Then, the total energy used per node per time unit, $E_{h,total}$, can be computed as:

$$E_{h,total} = (1 - u_{h,s})E_{active} + u_{h,s}\frac{\delta(h)}{t_{duty}}$$

When the hop distance of neighbors increases, the number of sleeping nodes increases. We can compute how large t_{duty} should be for $h+1$ solution to be more efficient than h solution from the inequality:

$$t_{duty} > \frac{u_{h+1,s}\delta(h+1) - u_{h,s}\delta(h)}{E_{active}(u_{h+1,s} - u_{h,s})} \tag{2}$$

Consequently, when sensing, communication costs and duty periods for a network are given, E_{active} can be found and the optimal value of h can be calculated.

B. Routing in a network with failure-prone nodes

In this part, we study the routing of packets in a network with failure-prone nodes. More precisely, when a time interval

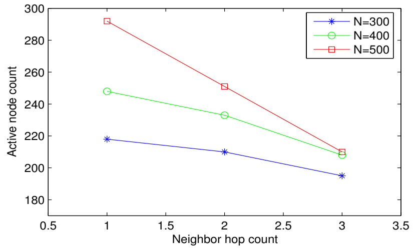

Fig. 1. The numbers of active nodes after running the sleep scheduling algorithm for different neighbor hop counts and node counts (Application A).

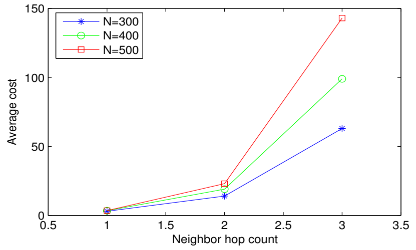

Fig. 2. The average energy costs of running the sleep scheduling algorithm with different neighbor hop counts and node counts (Application A).

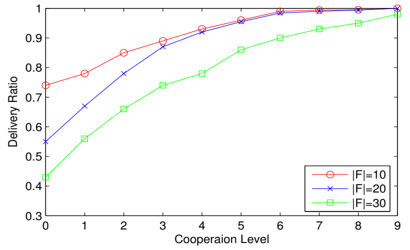

Fig. 3. The average delivery ratio obtained with different number of failure-prone nodes at different levels of cooperation (Application B).

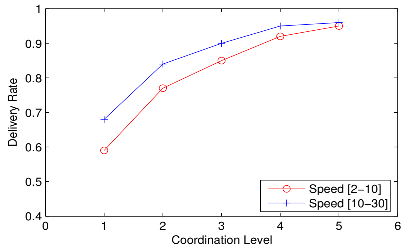

Fig. 4. The average delivery rate obtained with different speed ranges of the sink with different levels of cooperation (Application C).

Δt tends to zero, the probability of a node failing in such time interval tends to a failure rate that is characteristic parameter of the network. We assume that each node knows the whole topology at the beginning. When a node senses data, it calculates the shortest path routing to the sink using its current knowledge of other nodes status. Then, it forwards the data to next hop on this path. However, if any node on the path to sink fails, the packet is dropped. For a node to keep the status of other nodes in its local data updated, it needs to collaborate with others and as cooperation level increases, each node learns the status of more nodes so that the shortest path to the sink node is calculated more accurately.

C. Routing in a network with mobile sink node

In the last application, we again study routing but this time we assume that nodes are stable but the sink is mobile. We assume that each node knows the next hop towards which it will forward the packets on their way to the destination. However, in a network with a mobile sink node, this information needs to be kept updated, so that packets are forwarded quickly towards the current position of the mobile sink node. When the cooperation level increases, the node can learn the updated knowledge of sink node more quickly because other nodes may have the most updated location of sink node. As a result, the delivery rate of all packets increases. But, as in the two previous applications, there exists a tradeoff between the delivery rate and the energy consumption of the network.

III. CONCLUSIONS

We simulated three different sensor network applications with different levels of cooperation and observed that the proper level of cooperation leads to a significant increase in the application's performance. On the other hand, we also noticed that the cost of network operation increases with the increase in the level of cooperation. Therefore, we conclude that the cooperation among sensor nodes in a sensor network should be carefully designed considering the cost-quality tradeoff.

ACKNOWLEDGMENT

Research was sponsored by US Army Research Laboratory and the UK Ministry of Defence and was accomplished under Agreement Number W911NF-06-3-0001. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the official policies, either expressed or implied, of the US Army Research Laboratory, the U.S. Government, the UK Ministry of Defence, or the UK Government. The US and UK Governments are authorized to reproduce and distribute reprints for Government purposes notwithstanding any copyright notation hereon.

REFERENCES

[1] J. Fuemmeler and V. V. Veeravalli. *Smart Sleeping Policies for Energy Efficient Tracking in Sensor Networks*, IEEE Transactions on Signal Processing, 2007.

[2] A. Panagakis, A. Vaios, and I. Stavrakakis, *On the Effects of Cooperation in DTNs*, Proc. COMSWARE, 2007.

[3] E. Bulut, Z. Wang, and B. K. Szymanski, *A Cost-Quality Tradeoff in Cooperative Sensor Networking*, Proc. IEEE ICC Workshops, Beijing, China, 2008, pp. 112-117.

[4] E. Bulut and I. Korpeoglu, *DSSP: A Dynamic Sleep Scheduling Protocol for Prolonging the Lifetime of Wireless Sensor Networks*, Proc. IEEE AINA, Canada, 2007.

[5] J. Branch, G. Chen and B. Szymanski, *ESCORT: Energy-efficient Sensor Network Communal Routing Topology Using Signal Quality Metrics*, Proc. ICN, LNCS, vol. 3420, Springer, France, 2007. pp. 438-448.