Energy Adaptation Techniques to Optimize Data Delivery in Store-and-Forward Sensor Networks

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Abstract

Wireless sensor networks are severely-energy constrained devices. Energy-related issues are one of the common failure modes in sensor deployments. One challenge in system-wide energy management is that individual nodes in a sensor network often have widely varying energy profiles due to the amount of data transmitted, hardware construction, and other environmental effects. These differences result in unpredictable node and system lifetimes. As a result, sensor network bit-rate and reliability may degrade prematurely. Our research explores and evaluates an easily implemented dynamic scheduling policy supported by a battery gauge aimed to solve this problem.

The dynamic scheduling policy presented here operates in a slotted manner. The decision for each node to communicate is based on the available energy of that node. Our policy guarantees a minimum communication bandwidth, while allowing nodes with more energy to increase their available bandwidth by a factor related to the amount of "extra" energy they have. We present real-system results measured on test nodes in several different network scenarios. The results show our scheduling, when compared to a fixed schedule, guarantees a longer usable system lifetime by preventing premature degradation of connections. In addition to improving connectivity, it reduces data delay by as much as 50% for intermittently connected nodes, with no added communication overhead.

Categories and Subject Descriptors

D.4.4 [**Software**]: Operating Systems—*Communications Management*[Network Communication]; C.4 [**Computer Systems Organization**]: Performance of Systems—*Reliability, availability, and serviceability*

General Terms

Management, Reliability, Experimentation

Keywords

Energy, Adaptive, Scheduling, System Lifetime

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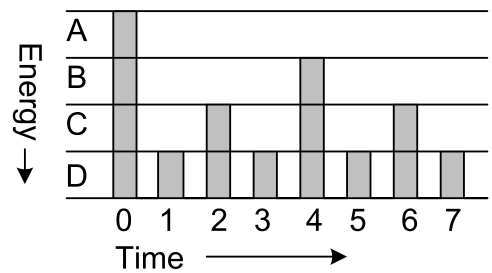

Figure 1. Adaptive scheduling implementation with 4 energy levels.

1 Energy Aware Adaptive Scheduling

As sensor network deployments and real applications are realized, usable system lifetime has become an issue of great importance [1][2]. However, efforts aimed at improving these lifetimes are complicated by the fact that nodes will have different energy profiles. Due to variations in the hardware, manufacturing processes, node placement, and node data requirements, the energy profile of two nodes can vary drastically. This leads to networks where component nodes have vastly different lifetimes, which in turn reduces the system's usable lifetime as connections in the network degrade [3].

A store-and-forward network is delay tolerant and is more flexible, being able to withstand network disconnections and subsequent data backlog. We propose an adaptive scheduling technique for these networks to reduce node variability. Our adaptive scheduling implements a set of energy levels. Each level corresponds to an amount of deviation of a node's energy from the expected energy profile. The node will attempt to communicate more when it is in a higher energy level. The more frequent communication allows more information to pass though the high energy nodes, and allow nodes disconnected from other nodes to search for neighbors more aggressively.

2 Experimentation

For our experiments, we chose 4 energy levels, with Level D being the most-capable. Figure 1 shows the schedule for each energy level with communication slots shown in gray. Communication schedules for each energy level are generated at compile time and energy level is recalculated after each communication. In these schedules, the greater the energy reserve, the more slots they attempt to communicate. The schedule ensures, however, that even low-energy nodes

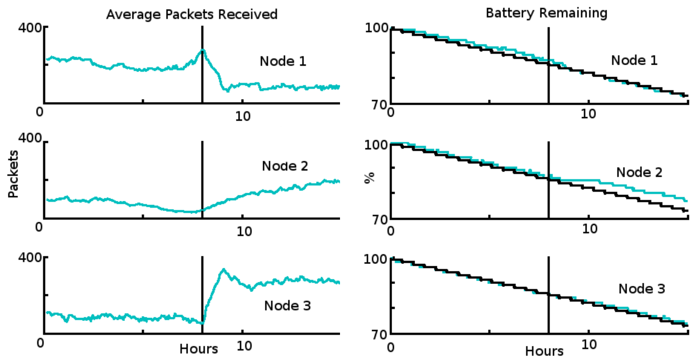

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Figure 2. Data from the variable charge experiment. a) shows number of packets received averaged over 16 communication cycles. b) Shows the energy of the node compared to the expected energy profile.

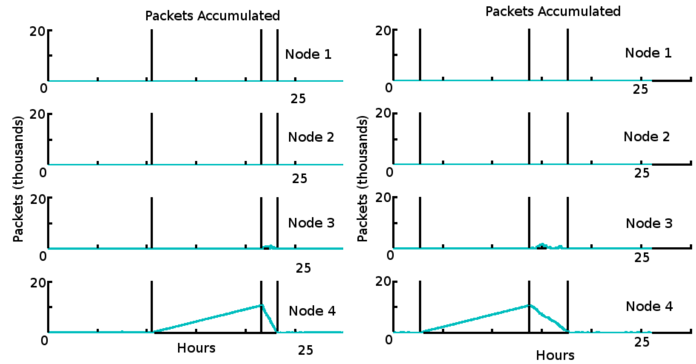

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Figure 3. Data from the varying connectivity experiment. a) shows the amount of data accumulated for a given node with the adaptive schedule. b) Shows the amount of data accumulated for a given node with fixed schedule.

have a chance to communicate with high-energy nodes once per cycle. This method is beneficial in a variety of scenarios. We preset two scenarios here.

2.1 Varying Charge

The varying charge experiment is designed to test the system response to changing energy profiles. Three nodes were placed so that nodes are always within communication range of each other. Each node always has data to send, creating a congested network. At the start of the test, a charge of 15mA was given to nodes 1 and 2. At around the 8th hour the charge was removed from node 1 and given to node 3. The results of the test, as shown in Figure 2a shows that the energy-adaptive scheduling was able to keep all three nodes roughly around the desired discharge without significant deviation from the expected energy profile, while the bandwidth of the nodes shifted according to the available energy. Figure 2b also shows that node 1 and node 3 after the switch both settled into their respective steady state quickly. Node 2 stored its unused energy because both of the other two nodes were at a lower energy level during the switchover, so it had no high energy neighbors for the duration of the switchover. Due to its stored energy, node 2 operated at the state with the most frequent transmission attempts, making itself available for additional data coming through the network.

In contrast, under the same conditions fixed scheduling is unable to respond to the change. This then results in premature network disconnections as low energy nodes drop out.

2.2 Varying Connectivity

The varying connectivity experiment is configured with two data sources and two data forwarders. The data from the source must pass through a data forwarder to be received by the receiver. One source, node 2, is in range of both forwarders nodes 1 and 3. The other source, node 4, is only in range of one forwarder node 3. Some time after the start of the experiment, the forwarder node 3 is moved away and the path to the receiver is broken for node 4. This forwarder is returned after node 4 has backlogged around 10,000 packets of data and the data is then forwarded to the receiver.

After node 3 moves away, it can not meet its energy profile due to the lack of radio activity, so it makes itself more available to forward data. After node 3 returns, we see from Figure 3a, the backlogged data flows from node 4 to the receiver at the fastest possible rate until the energy profile returned to the expected level, greatly speeding up backlogged data forwarding.

In contrast, Figure 3b shows the same situation for the non-adaptive baseline. Once node 3 moved back in range, the bandwidth did not adjust accordingly. The network operated in the congested state caused the backlogged data to be received at a rate more than 2 times slower when compared to the adaptive method.

3 Conclusion

Our work improves the efficiency of the network through energy-adaptive communication scheduling. This extends the overall system lifetime and reduces accumulated data backlog, without changing the median delay of the data. The worst case delay of the system is also limited. Our experiments show that our adaptive scheduling technique has the following characteristics:

- It offers up to 30% improvement in system lifetime.
- Mobile disconnected nodes, when reconnected, upload accumulated data more than 2 times faster, while maintaining lifetime improvements. This is an important property for mobile nodes, where connection times are short and opportunistic.
- Our approach does not change the median data delay, and limits worst case delay to one scheduling cycle.
- It has a simple implementation with no additional communication overhead.

4 References

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