Efficient Sensor Web Communication Strategies: Jointly Optimized Compression and Routing

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Motivation and key concepts

Many sensor web applications aim at providing users with high quality data captured at the sensors, while operating during long stretches of time with minimal cost and maintenance needs. To reach this goal it is important to devise strategies such that power consumption is kept low in order to maximize battery life. Note that here we specifically focus on low-power embedded processor-based wireless sensor networks, where power constraints are key, instead of other scenarios where power is not a limiting factor.

From current and past work our team has undertaken, we propose that the following two ideas should be taken into consideration when proposing practical, power-efficient data gathering sensor webs based on embedded processors:

1. Joint design of data compression and routing has the potential to lead to significant increases in overall data acquisition quality. This is in fact well known and has been established through a number of primarily theoretical results, under somewhat simplistic assumptions about both input data (e.g., spatially stationary is considered) and compression techniques (e.g., entropy bounds, rather than actual encoding).

2. These joint design tools can be applied to practical systems, that is, it is possible to design network initialization, data capture, compression and routing algorithms, that can be implemented in existing embedded platforms (such as Motes), and that lead to gains in overall system performance (e.g., same data representation accuracy with lower power consumption).

Prior work

In our AIST funded work we set out to develop a variety of algorithms for acquisition, compression, routing and interpolation, with the final goal of achieving minimal energy consumption while providing a satisfactory representation of the data captured by the sensor web.
This work is a continuation of research work conducted at USC that has explored i) a distributed wavelet transform where each node can carry out part of the wavelet transform operation on the data it captured, as well as data from other nodes, ii) quantization and bit allocation algorithms to provide a compressed representation of both wavelet coefficients and intermediate data generated by the nodes, and iii) the performance of different routing strategies in terms of overall power consumption for a given fidelity in data representation.

Our results, based on relatively small examples, with real or simulated datasets indicate that:

1. Significant gains can be achieved when using wavelet transforms, as these are able to exploit correlations in the captured data. In one of the cases we considered, applying the distributed wavelet transform leads to 85% lower overall power consumption (and better reconstruction quality) than sending raw data back to the network sink.

2. Practical compression algorithms can be designed, that is, our results can be achieved with algorithms suitable for embedded devices and do not rely on idealized models for data and/or encoding algorithms. It is also possible, based on training data, if available to select optimally various characteristics of the wavelet transform (e.g., number of levels of decomposition) in terms of their quality vs. power trade-off.

3. Different routing strategies, in combination with the proposed wavelet transform, exhibit very different performance. Occasionally, shortest path routing may not be optimal and routing that follows paths with maximum data correlation can lead to better overall performance.

Challenges

We are approaching this project by addressing multiple key components of a data gathering and communication system. Our goal is to develop the basic tools and then identify concrete use scenarios for which these tools can be adapted.

- *Entropy coding* and optimization based on statistical properties of data to be encoded.

- *Path merging* techniques to combine information captured by two sensor paths, so that after merging less information needs to be transmitted to the sink.

- *Filter optimization* to use as alternatives to path-wise wavelet transforms, including techniques based on compressed sensing.

- Transforms that allow nodes to broadcast information to surrounding sensors, so that more general transforms can now be used (i.e., no longer 1D wavelet transforms).

- *Node selection/sampling* techniques based on signal processing theory for irregular sampling and interpolation. An additional objective in this activity is to link the interpolation method to compression decisions, i.e., represent with higher fidelity information that contributes most the quality of the interpolated signal.

- *Robustness* of the system to changes in the status of the nodes or in the link quality.

- *Network initialization* techniques that would enable a sensor web to self-configured given the type of information that is needed for our sampling, representation and compression techniques.

- *Routing optimization* techniques leading to different trade-offs between distortion in the information estimate and overall power consumption.

Proof of concept demonstrations

Our team has access to the experimental resources to demonstrate the technology we develop in a ~100 node wireless network in the lab, this will be done based on Motes and will lead to a complete implementation of the processing algorithms in these embedded processors.

In addition, our team is actively seeking feedback as to the suitability of our proposed techniques for a variety of science environments. In particular, we are in the process of starting a collaboration with reseachers from AIMS in Australia to implement our proof-of-concept in a real application testbed to monitor temperature and water quality in the Great Barrier Reef. The JPL investigators have started to develop a plan to select specific NASA applications that could be suitable to demonstrate our techniques.