Information Quality Aware Sensor Network Services

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Abstract: *Wireless sensor networks have proven useful for applications in diverse domains. The challenges of scale and resource constraints posed by these systems have led to development of novel network protocols and services, but their focus has been on traditional metrics of quality of service of network data transport. Rather, sensor networks require combining networking quality of service concerns with metrics of quality and integrity of sensor data sources and performance of sensor fusion algorithms. We describe how network protocols, data integrity management, and sensor fusion algorithms can be design to cooperatively optimize the "Quality of Information" returned by a sensor network.*

Extended Summary

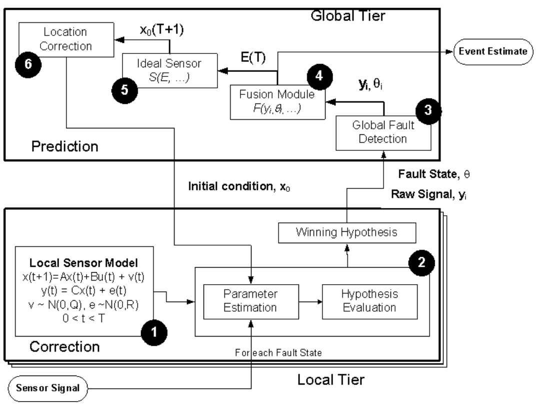
High-fidelity and real-time observations of the physical world are critical for many applications in military, scientific, medical, industrial, urban, social, and personal settings. With their ability to sample physical world processes in spatially and temporally dense fashion, wireless sensor networks are able to make these observations with unprecedented details and perspectives. In a typical wireless sensor network, measurements from distributed sensors are aggregated to reconstruct spatiotemporal behavior of desired physical variables or to detect, identify, and localize sources and events of interest. The system is designed under constraints on cost, bandwidth and energy resources while optimizing performance metrics such as reconstruction fidelity, detection performance, latency etc.

Researchers have sought to capture the multi-dimensional performance metrics under the unifying notion of "Quality of Information (QoI)" [Zahedi07] returned by a sensor network. Consider a sensor network deployed to monitor acoustic activity in a region of space. Multiple distributed sensors observe the space and send measurements to a sink node where they are fused to detect occurrence of unusual events that are reported to the end-user. The QoI of the system can be characterized in terms of characteristics of the event reports delivered to the end-user, such as probability of detection, probability of false positives and negatives, latency etc. In addition to being dependent on properties of the sensor fusion algorithm, the QoI is also dependent on the quality of data received from the various sensor nodes. The latter in turn depends not only on packet loss, delay, and jitter introduced by the network as it transports packets from a source sensor node to the sink, but also on the quality and integrity of data produced by the sensor to begin with due to factors such as node location relative to event, sampling rate and resolution, and most existence of various faults due to failures and environmental conditions.

With bandwidth and energy resources usually being scarce in sensor networks, clearly network resource allocation at various layers must take into account the utility of data to the overall QoI. However, traditional sensor network protocols for medium access control, routing, and congestion control by and large ignore the fact that not all sensor nodes are equal and not all sensor measurements at those nodes are created equal. They focus solely on the quantity of data transported and fairness across nodes, as opposed to the quality of the data and the nodes producing them. A recent exception is [Gelenbe08] which explores routing mechanisms that provides differential service to the low-priority high-volume routine sensor measurements and high-priority low-volume unusual event reports by adaptively dispersing the routine traffic to secondary paths so that the event reports can be sent through faster paths with better delay characteristics.

In this work we explore data dissemination in sensor networks that is aware of the quality and integrity of the sensor nodes that are the data sources. The example application context is an acoustic sensing network that monitors a space and provides the user with reports of unusual acoustic events. In addition to the quality of data from a sensor node being affected by its location, we also consider sensor faults that corrupt the measurements, thus reducing its utility to the fusion algorithm. Faults include misbehaviors such as stuck sensor, miscalibrated sensors, noise, offset bias etc. Furthermore, a faulty sensor node may need to be replaced and thus network also provides the user with reports of fault occurrences. Such a system requires the data dissemination mechanism to be closely coupled with the sensor fault detection, particularly since reliable identification of a faulty sensor in general requires global knowledge about observations at other sensors.

Our architecture has several key components. The first is a *two-tiered fault detection* mechanism [Zahedi08] shown in the figure below. The local tier consists of independent model-based fault detectors embedded at each sensor node that have access to high-frequency sensor samples. The model assumes that the sensor responds to changes in the measurand as a linear dynamical model within a small time window $0 \leq t \leq T$ which is smaller than the time constant of the "event" being tracked by the network. The normal and various faulty behaviors (noisy, frozen, saturation, bias) are described as labeled regions in the multi-dimensional model parameter space, and the fault detection is done via a two-step process of parameter estimation and hypothesis evaluation. The sensor nodes send at a low-rate measurements, augmented with their normal or faulty status, to a global tier. The global fault detection algorithm exploits analytic and physical redundancy to augment local fault detection, and works in concert with the second key component of our architecture, a *fault-aware fusion module* that estimates the occurrence of event of interest. In addition to being reported to the user, this estimate is also fed to an ideal sensor model to predict what the response of each sensor should be to this event. This value is then fed back to local tier at each sensor for use in the next round of fault detection. Thus these two components of our system form a predictor-corrector scheme wherein a faulty sensor is progressively isolated, a fault-aware fusion progressively discounts information provided by a fault sensor, and contributes positively towards system QoI. Based on the results of the fusion module, the global tier also feeds back to the sensor nodes an indication of their relative importance to the QoI so that a set of nearby sensors with highly correlated measurements each have less importance than a relatively isolated sensor. The third key component of our architecture is the *quality-aware data dissemination* mechanism that uses at its core the Random Re-Routing algorithm of [Gelenbe08] and augments it with marking the priority bit of packets and controlling their rates according to the decision from the local tier (indicating whether the packet represents a normal measurement, an unusual event, or on-set of a fault), and the relative importance of the node to the QoI.



The full paper will detail this system architecture and underlying mathematical formulation, and present results from simulations showing that co-designing sensor network data dissemination, fault detection and data fusion mechanisms in tight integration yields significant QoI improvements in resource constrained settings.

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References

[Gelenbe08] Erol Gelenbe and Edith C.-H. Ngai, "Adaptive Random Re-Routing for Differentiated QoS in Sensor Networks," Technical Report, Imperial College, London, April 2008.

[Zahedi07] Sadaf Zahedi and Chatschik Bisdikian, "A framework for QoI-inspired analysis for sensor network deployment planning," Proceedings of International Workshop on Performance Control in Wireless Sensor Networks (PWSN), October 2007.

[Zahedi08] S. Zahedi, M. Szczodrak, P. Ji, D. Mylaraswamy, M. Srivastava, and R. Young, "Two-Tier Framework for Sensor Fault Characterization in Sensor Networks," Technical Report, Networked and Embedded Systems Laboratory, UCLA, April 2008.