A Wireless Sensor Network based Closed-loop System for Subsurface Contaminant Plume Monitoring

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Motivation:
monitoring and predicting groundwater contamination

[Diagram showing groundwater flow and contamination source]
Goal 1: Virtual Sensor Networks

- Formed by a subset of nodes dedicated to a certain task or application at a given time

Benefits

- Enable collaboration among sensor networks deployed within the same geographical area
- Enable coherence among dynamically varying subset of sensors
- Enhance performance, resource sharing, scalability, simplified application deployment, security, etc.
- Applicable to a broad class of problems
Goal 2: A Closed-loop System Architecture

- Wireless Sensor Network
  - Model Feedback
  - Sensor data
  - Inverse Model (System Identification)
  - Calibrated Model Parameters
  - Forward Model (Prediction)
  - Decision/optimization Model
  - State variables
  - Goals Match
    - No
      - New design/Strategy
Sensor noise, calibration drift, and network faults are important concerns which require a robust solution.
Issue 1:
REDFLAG: A REal-time, Distributed, Flexible, Lightweight, and Generous Fault Detection Service

- Sensor Reading Validity subservice for detecting abnormal sensor readings
- Network Status Report subservice
Sensor Reading Validity Subservice

- (in)validate sensor readings using a set of rules:
  - Noisy reading: standard deviation exceeds an expected noise threshold
  - NLDR reading: sensor value falls outside the range of calibration
  - Out of range reading: sensor value falls outside the total detection range
  - Stuck reading: an unusually steady set of readings
  - Abruptly changed reading: the rate of value changes exceeds a threshold
Network Status Report Subservice

- **Local Detection Phase**
  - each node monitors neighboring nodes and identifies suspicious ones

- **Neighbor Consensus Phase**
  - each node corroborates previous findings with neighbors before reporting any alarms
Performance of Sensing Reading Validity Subservice

![Bar chart showing % Faults Detected with various parameters: $\sigma_{min}=0.01$, $\sigma_{min}=0.007$, $\Delta_{max}=0.02$, $\Delta_{max}=0.1$, $\sigma_{max}=5.2$]
Performance of Network Status Report Subservice

[Graphs showing network performance metrics for different node counts and accuracy levels.]
Issue 2:
Real-time Automatic Calibration Transport Model

Relative Concentration Plot of Conservative I
Prediction Error after Each Model Calibration

Error Between Predicted and True Observation

SSE
Time for Transport Model Calibration

Transport Model Calibration Time

![Graph showing transport model calibration time](image-url)
Findings from Completed Studies

- Available transport modeling codes and inverse techniques may be employed to perform RAC in the context of a WSN under the following provisions:
  - Available observations contain no noise or faults
  - There is sufficient resources available to complete the inversions
  - Initial, boundary, and source conditions are known
  - The contaminant behaves conservatively

- Next step
  - Integrate REDFLAG
Current Status

http://alamode.mines.edu/~qhan

- **Completed Work**
  - preliminary proof-of-concept study in an intermediate tank test bed
  - fault detection service
  - real-time automatic calibration of an existing transport model

- **Ongoing Work**
  - phenomena-aware clustering
  - detection and tracking of amorphous events with dynamic signatures
  - set up of a larger tank test bed

- **Future Work**
Project Team

- **Faculty**
  - Computer Science: Qi Han
  - Electrical and Computer Engineering: Anura
  - Environmental Science and Engineering: Tissa Illangaskare, Toshihiro Sakaki

- **Students**
  - Computer Science: Nick Hubbell, Inigo Urteaga