A System for Distributed Event Detection in Wireless Sensor Networks

CSCI 780 Wireless Sensor Networks

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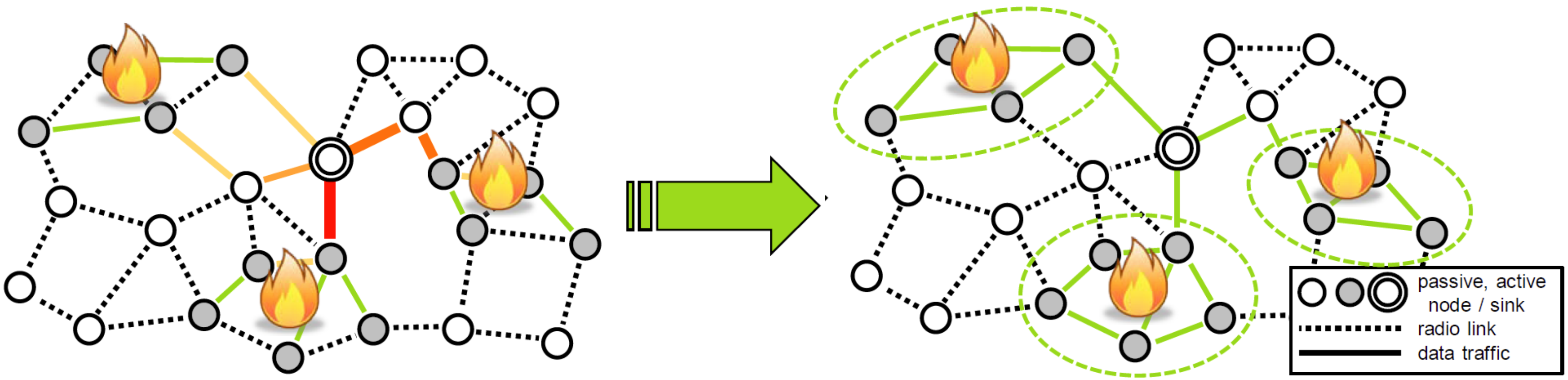
Based on slides from Georg Wittenburg etc.

Motivation



- General-purpose event detection
  - Decide locally whether an application-specific event occurred (e.g., "There is a fire!")
  - Only transmit confirmed events to the base station
  - Reduce communication between nodes and base station and extend network lifetime

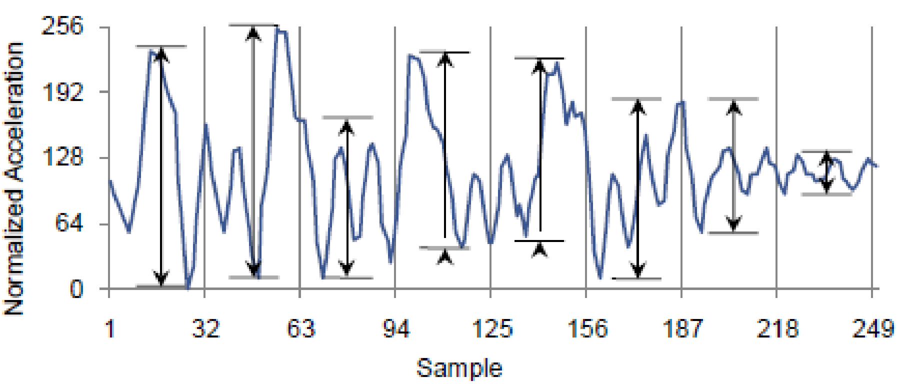
Use Case: Fence Monitoring

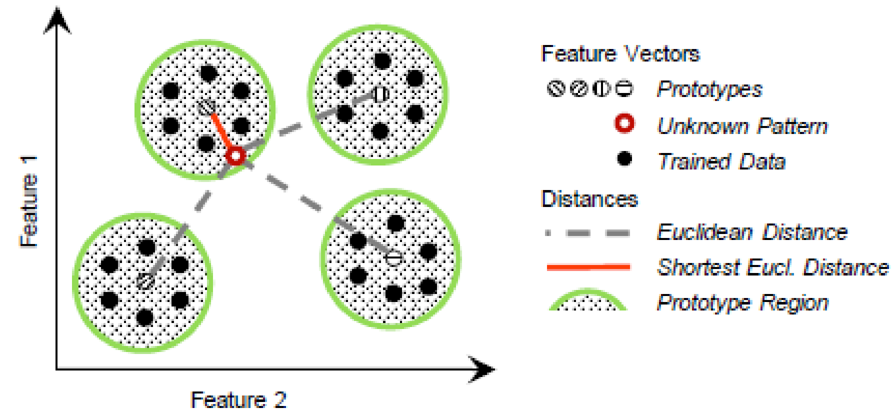

- Sensor nodes attached to fence measure acceleration to detect security-relevant events (e.g., intruder over fence)
- Use cases: access control, perimeter security, more??
- Suitable properties:
  - No mobility
  - Can be large deployment, i.e., long route to base station

Outline

- Motivation
- Basic Approach: Pattern Matching
- System Design
- Performance evaluation
- Conclusion
- Discussion

Background: Pattern Mattching

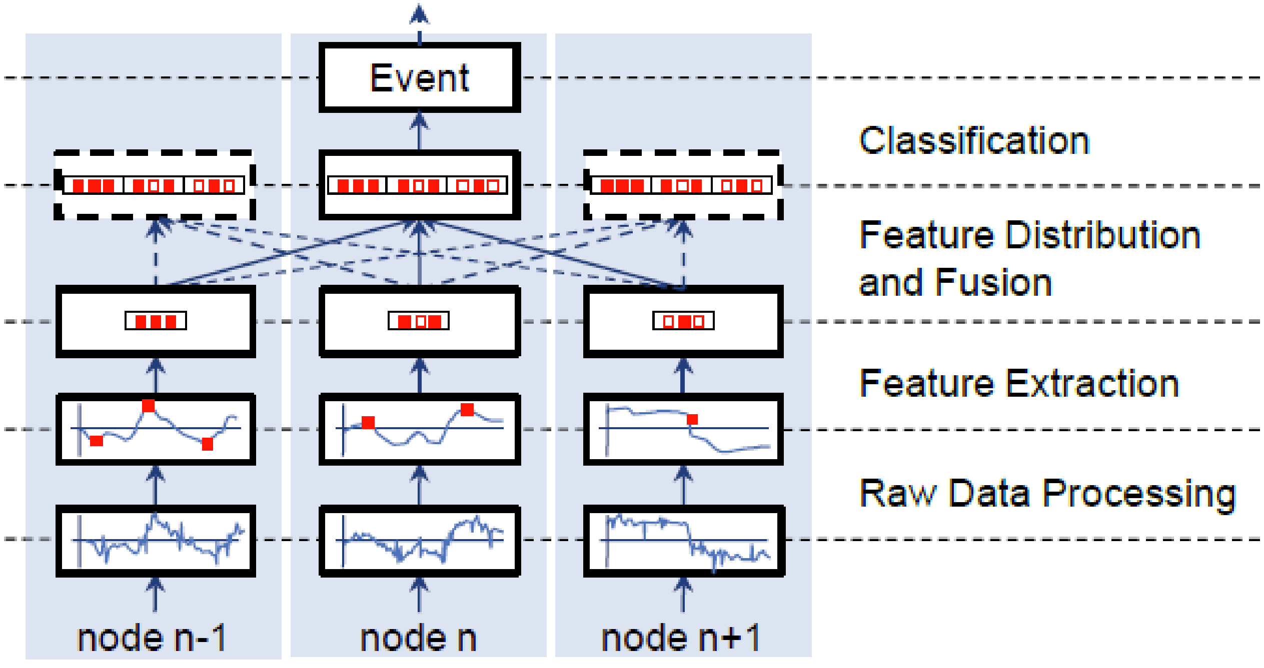




- Feature extraction
  - Extract set of descriptive features from sampled raw data
  - Example: for each time interval, the difference between the minimal and maximal acceleration value is computed
- Classification
  - Use extracted features to deduce previously trained event
  - Example: four prototype vectors established by averaging training data;

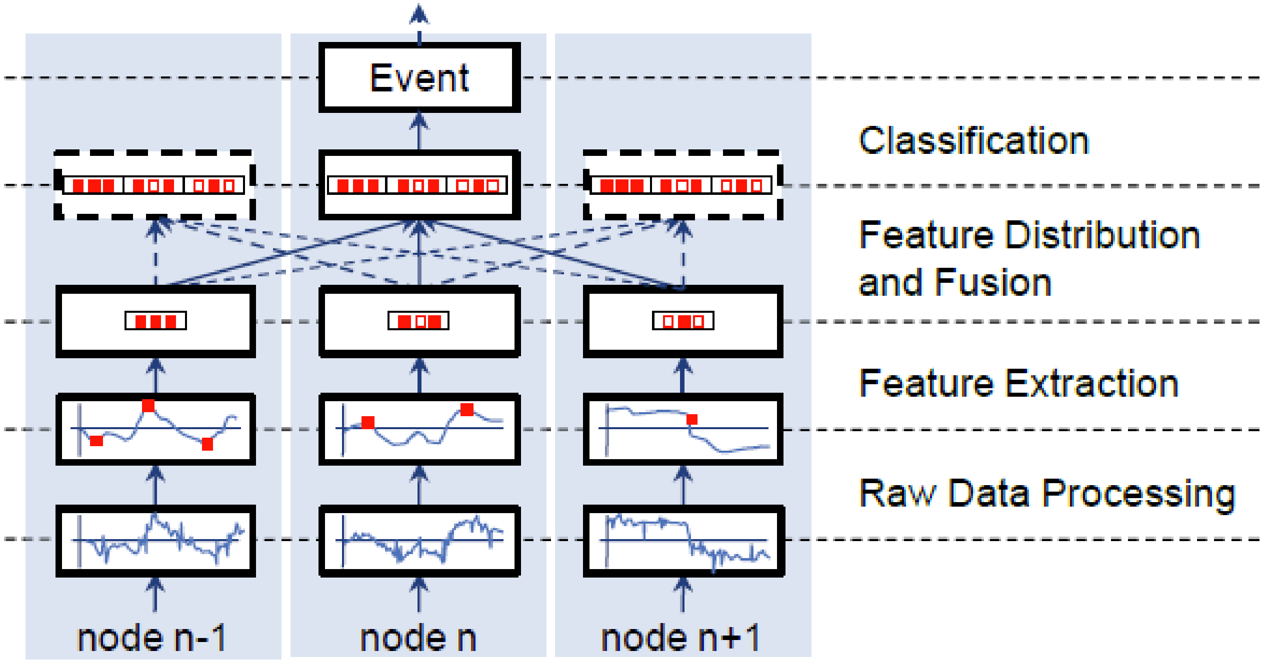
    Classify feature vector by finding nearest prototype vector

Applying Pattern Matching in WSN



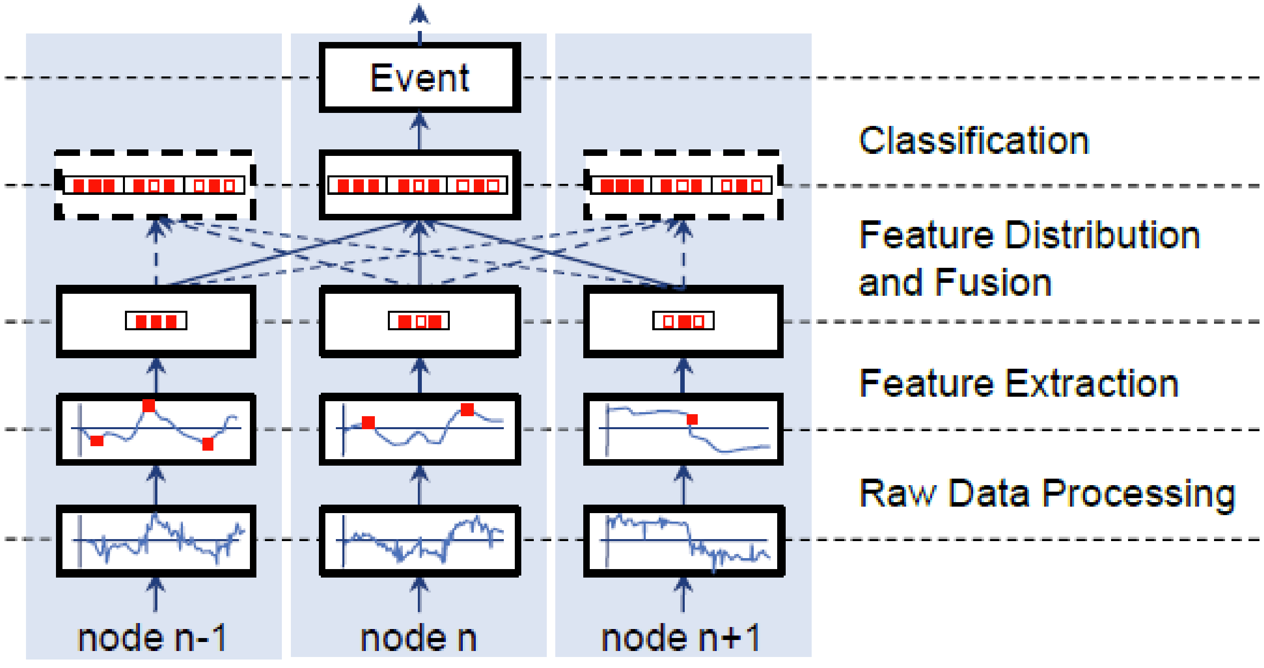
- Raw Data Processing:
  - Filter, segment, and normalize the data
  - Control sampling frequency
    - Preserve energy in phases of inactivity

Applying Pattern Matching in WSN



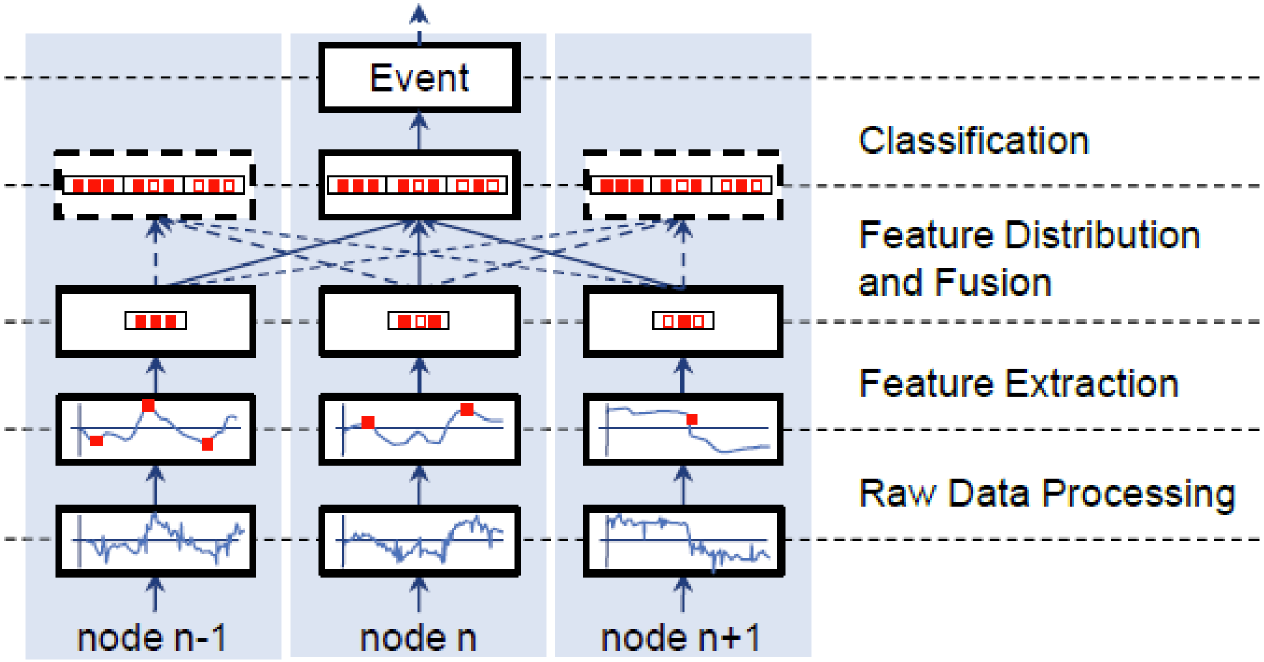
- Feature Extraction:
  - Extract application-specific set of features from raw data
  - Selection of appropriate features is part of training
    - LOOCV algorithm is used, will explain later

Applying Pattern Matching in WSN



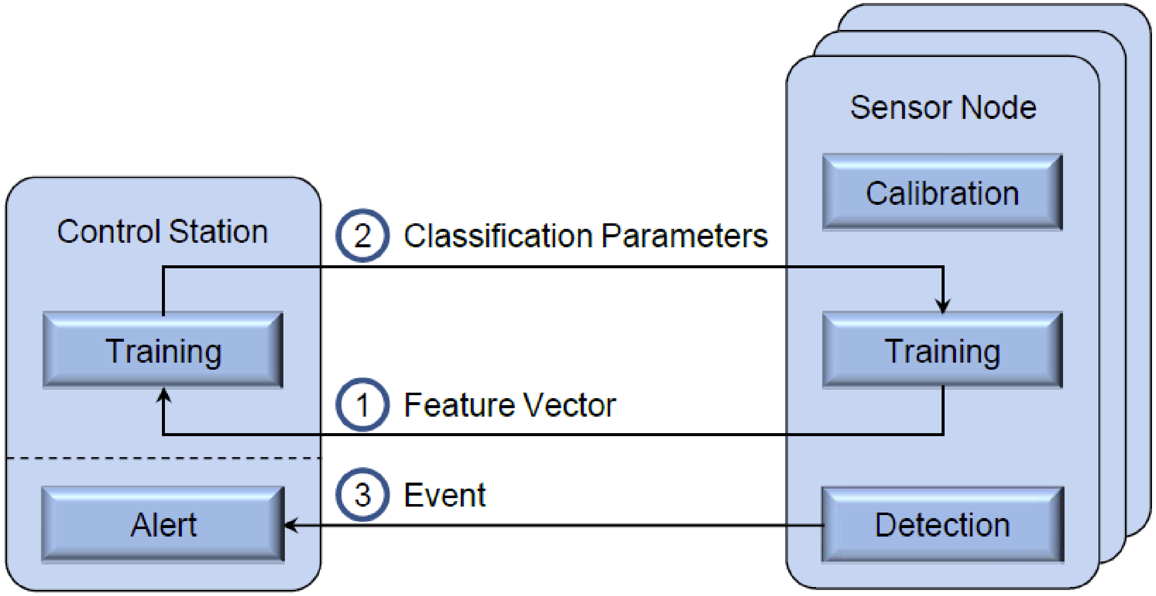
- Feature Distribution / Fusion:
  - Broadcast features to n-hop neighborhood (usually n= 1)
  - Retransmit features in case of transmission failures

Applying Pattern Mattching in WSN



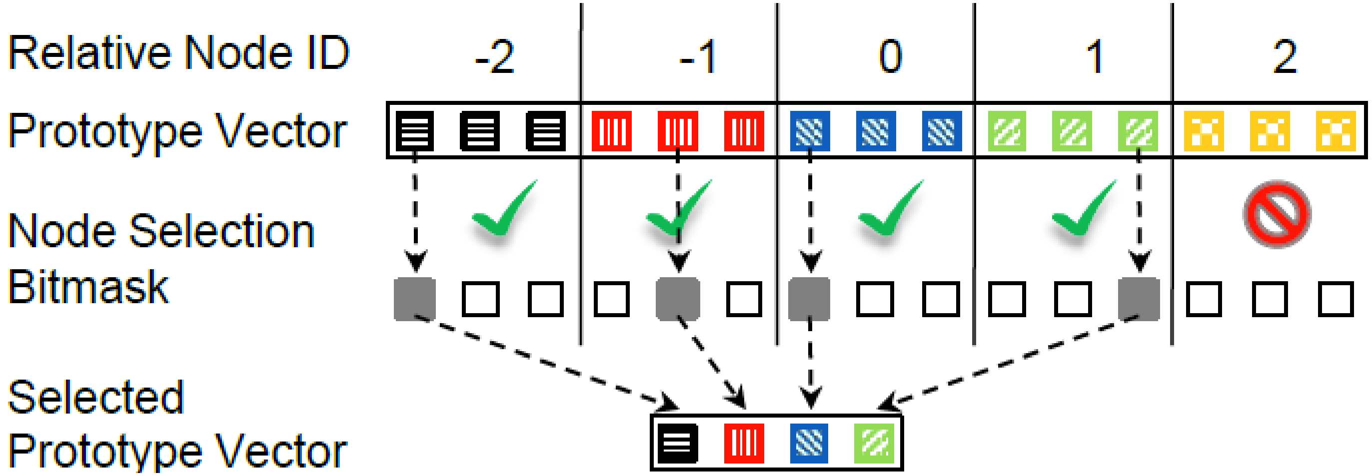
- Classification / Reporting:
  - Combine local and received features into feature vector
  - Classify feature vector
- Report event to base station or locally log event for user-initiated retrieval
- Base station can further fuses classification reports

System Design



- Training
  - Expose sensor network to series of training events
  - Extract all supported features and transmit them to control station
- Setup
  - Select best subset of features, calculate prototype vector for each event
  - Configure nodes to only extract/transmit selected features, setup prototype vectors
- Detect and report events

Feature Selection

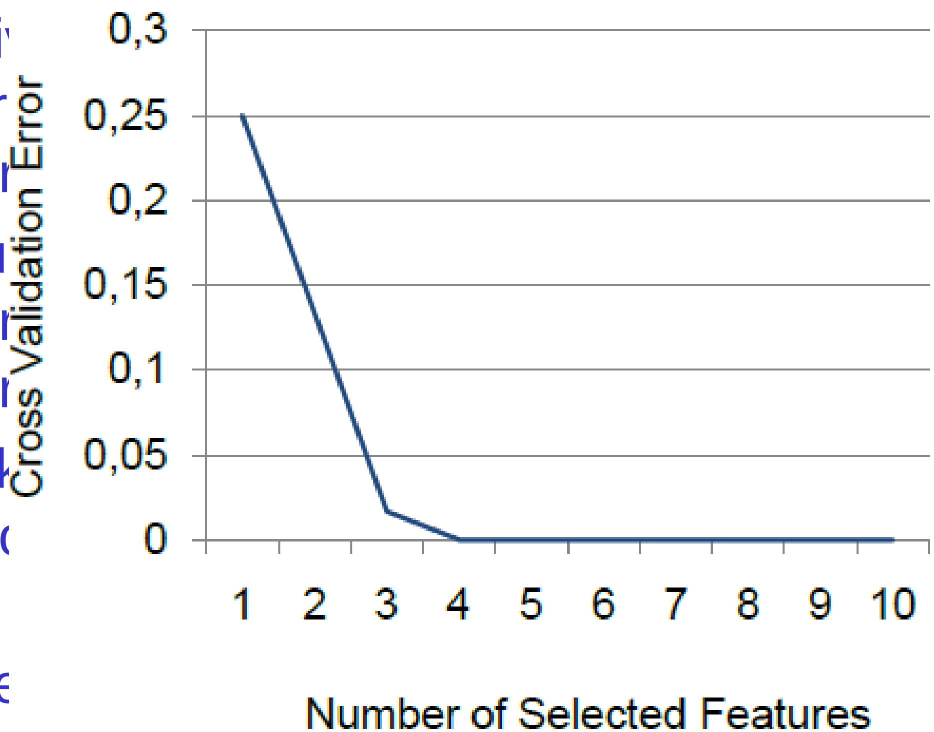


- Two selection steps:
  - ➢ If #feature vectors received from a node is too small, discard all features from that node
- Select only high quality features
  - ➢ With LOOCV

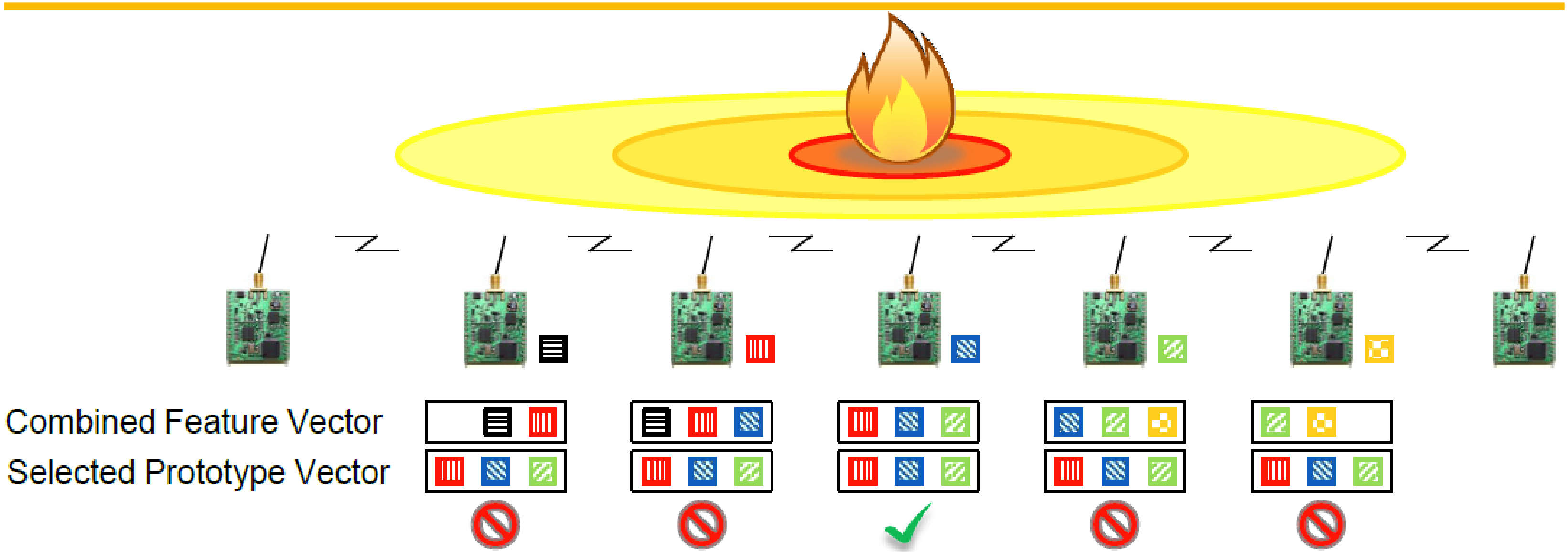
Feature Selection

- Leave-one-out Cross Validation (LOOCV):
  - Iterati
    featur
    vector
  - Calcu
    vector
    vector
  - Check
    error (
    using
  - Iterate
    vectors to pick, average
    classification errors

- Feature selection algorithm:
  - empty set of
  - select one
    th largest
    in LOOCV
  - eature to set
    d features
  - ntil no
    feature
    results in noteworthy
    reduction of error



Example



- Setup:
  - Nodes in a line, one feature per node
- Nodes are configured to recognize one single event
  - Identified by prototype vector with three features from: the left, local, and right nodes
- Event detection (all nodes):
  - Sample and process raw data
  - Extract feature
  - Distribute and calculate feature vector
  - Perform classification
- Central node detects (and reports) event; other nodes ignore event

Experimental Evaluation --- Setup

- Sensor nodes attached to fence of construction site
  - One node per fence element (3.5m wide, 2m high)
- ScatterWeb MSB sensor node:
  - TI MSP430 16-bit microcontroller (5 KB RAM, 55 KB flash)
  - ChipCon 1020 radio transceiver (operating at 868 MHz)
  - Freescale Semiconductor MMA7260Q 3-axis accelerometer
- Four different events:
  - Trained and evaluated with 15 samples per event at the same location

Experimental Evaluation --- Events

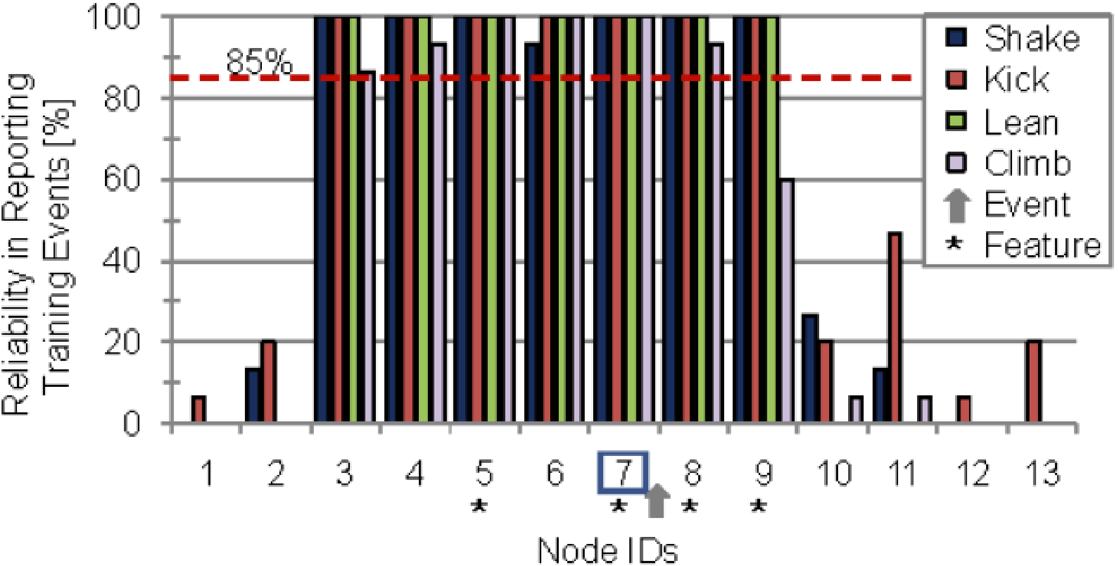
Shake

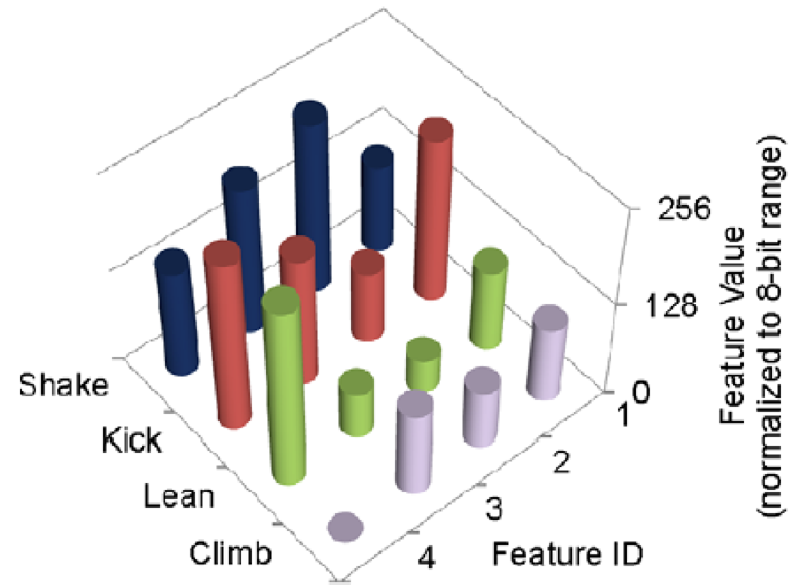
Kick

Lean

Climb

Results --- Feature Selection



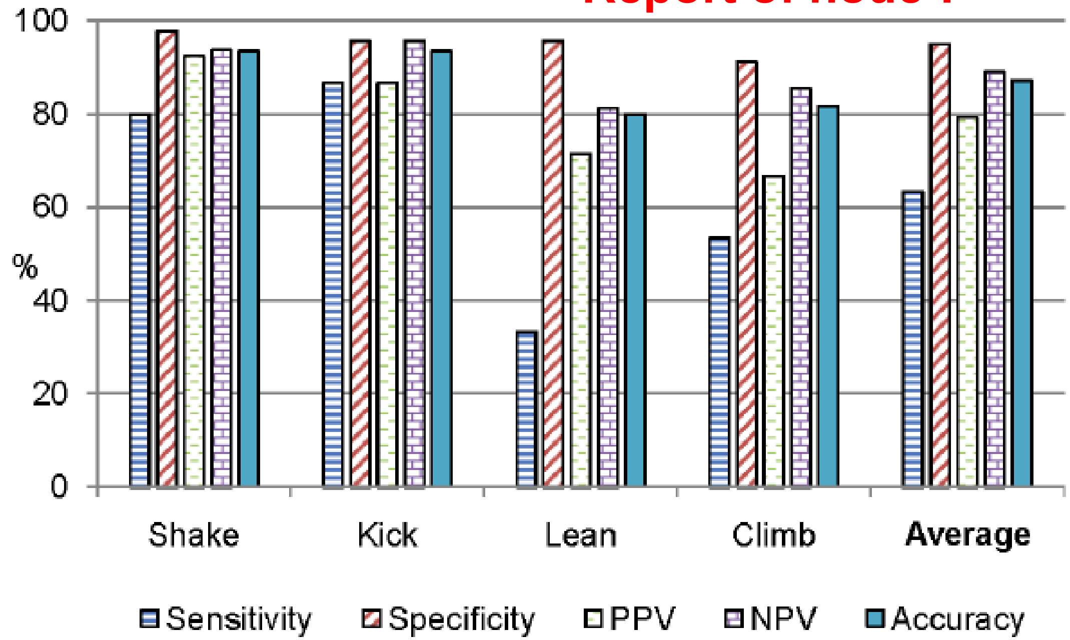


- Seven nodes were reproducibly affected by events
- Features from nodes #3 to #9 are deemed reliable enough
  - >85% reports
- Quality-based feature selection results in 4 features
- Selected features:
  - ID #1: Histogram-based feature from node #5
  - IDs #2 to #4: intensity features from nodes #7~ #9

Experimental Evaluation --- Metrics

- Sensitivity = TP / (TP+FN)
  - Proportion of correctly detected events in all events of that type
- Specificity = TN / (TN+FP)
  - Proportion of correctly ignored events in all events of another type
- Positive Predictive Value (PPV) = TP / (TP+FP)
  - Proportion of correctly detected events in all detections of that type

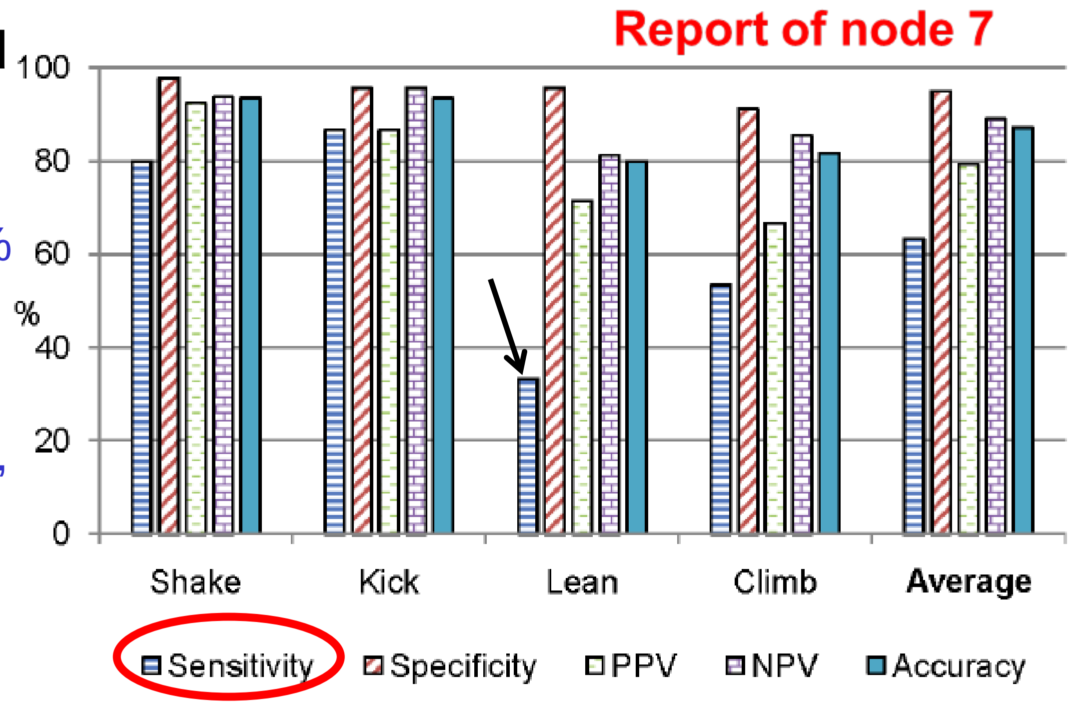
Report of node 7



- Negative Predictive Value (NPV) = TN / (TN+FN)
  - Proportion of correctly ignored events in all detections of another type
- Accuracy = (TP+TN) / (TP+TN+FP+FN)
  - Proportion of true results in the population

Experimental Evaluation --- Feature Fusion

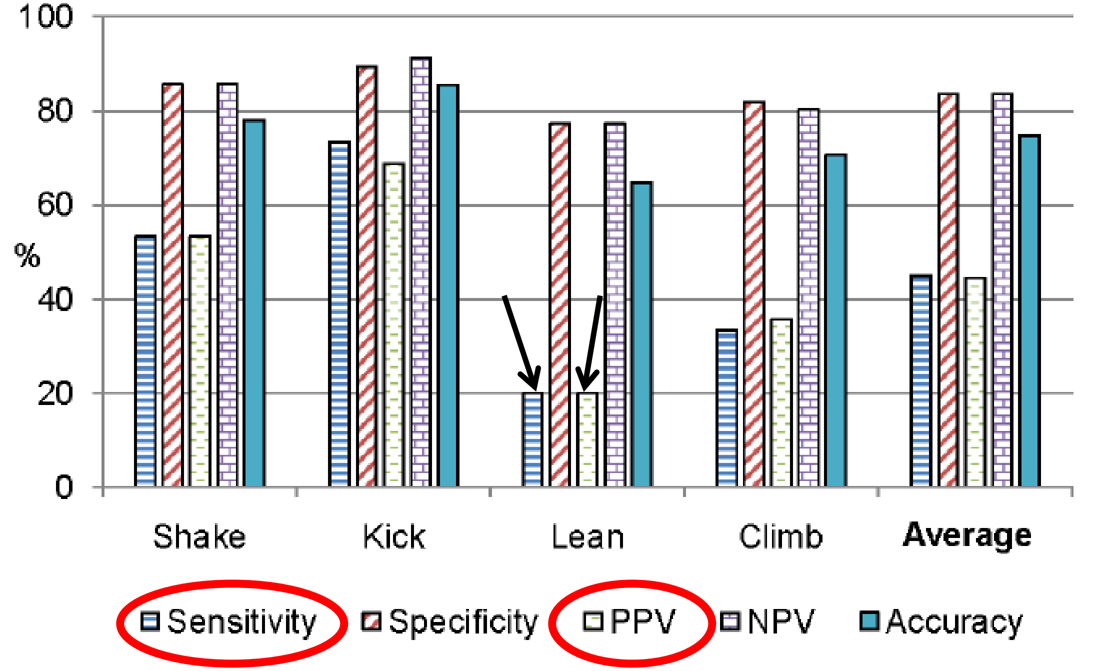
- Shake and kick events detected reliably
  - All metrics above 80%, shack and kick has accuracy of 93.3%
- Detection of lean or climb events not as accurate
  - Sensitivity is comparatively low, while specificity remains high
  - Too many events are falsely rejected due to prototype regions being too small
  - Training runs were too similar to each other, prototype regions only enclose part of required space
- Overall accuracy of 87.1% for all events



- Sensitivity = TP / (TP+FN)
- Specificity = TN / (TN+FP)

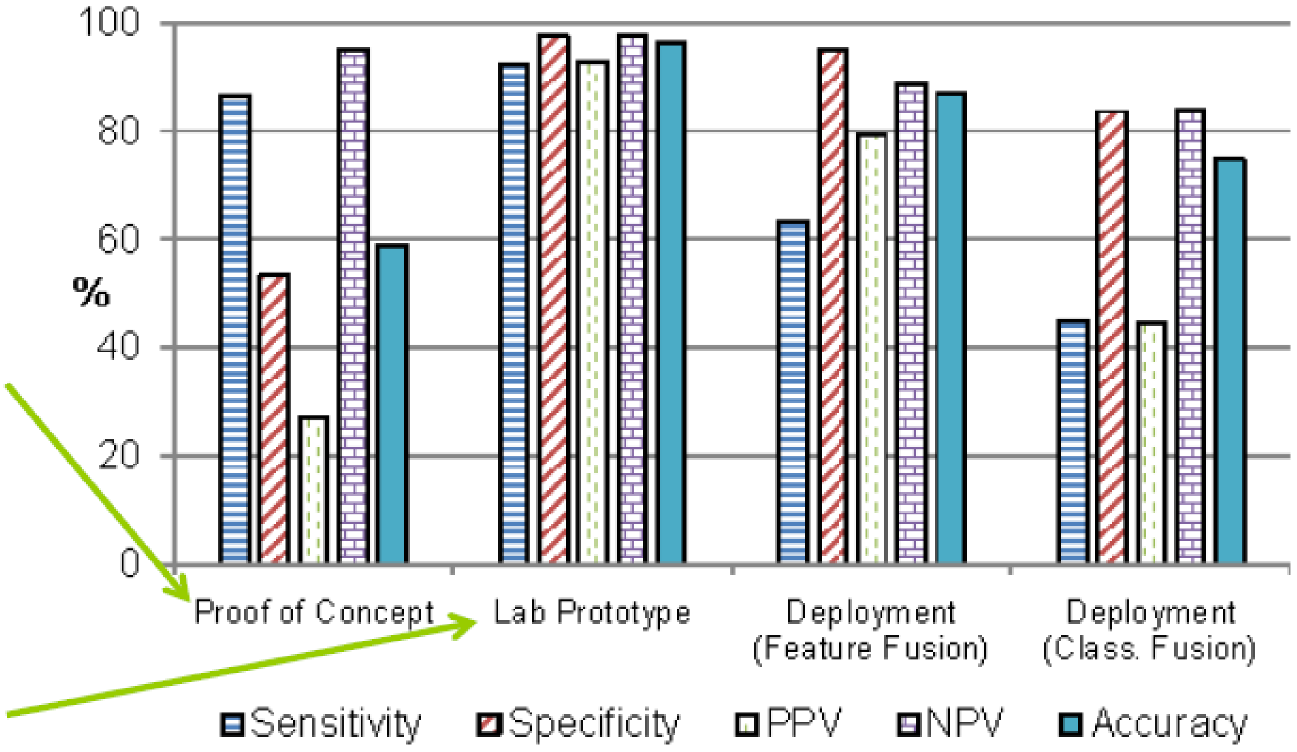
Results --- Classification Fusion

- Sensitivity and PPV decrease considerably
  - Sensitivity=TP/(TP+FN)
  - PPV=TP/(TP+FP)



- Classification Fusion: base station counts incorrect classification if
  - correct classification is falsely rejected on central node 7, while incorrect classification is reported from another node
  - node reports incorrect classification with higher confidence (shorter distance to prototype vectors) than that of correct classification
- Overall accuracy of 74.8%

Comparison with Prior Work



- Improvement over proof-of-concept implementation
  - Improvement of 28.8% (feature fusion, classification fusion was not supported)
- Unable to reach same level of accuracy as lab experiments
  - Manual feature section, accuracy of 96.3%

Conclusion

- Build a system for distributed event detection in WSNs
  - No external coordination or processing required
  - Trainable to detect different classes of application-specific events
- Has real deployment and the event detection accuracy shows improvements over prior work.
- But, further performance improvement is still needed in future.

Discussion

- How to make the design more energy efficient?
  - Reduce sampling, duty cycling …
- This is a general solution that has two common assumptions about the setup of the deployed WSN. What are they?
  - Sensor nodes must be placed uniformly within the deployment area
    - Is this really enough?
  - The physical effects of the events to be observed must propagate evenly in all parts of this area.
    - Is this really needed?
- Do we need to conduct training in multiple locations?