A Framework of Intelligent Sensor Network with Video Camera for Structural Health Monitoring of Bridges

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Outline

- Introduction
- Structural Health Monitoring (SHM)
- Framework Details
  - Network Layout
  - Vibration Sensing
  - Event Detection
- Test-bed overview and demonstration Video
- Conclusion

Introduction

- Wireless sensor networks have been used in various areas
- Advances in Micro Electro-Mechanical Systems (MEMS) propose the use for civil structural health monitoring
- Higher data rate requirements
- Our framework for this task augmented with video cameras

Structural Health Monitoring

- Constantly monitor status of the structure
- Detect abnormal behavior
- Localize structural damage
- Various SHM Systems
  - Visual Inspection by Humans
  - Tomography (Ultrasound, X-rays etc.)
  - Vibration & Strain Monitoring
  - ...

Structural Health Monitoring

- Essential characteristics
  - Large number of sensors
  - Sensor types
    - Vibration
    - Tilt
    - Strain
  - Data acquisition system for data recording
  - Centralized data interpretation

Structural Health Monitoring

- Drawback of conventional wired system
  - Expensive
  - Huge mesh of cables
  - Centralized processing only
  - Larger response time
  - Less Fault-Tolerant

Structural Health Monitoring

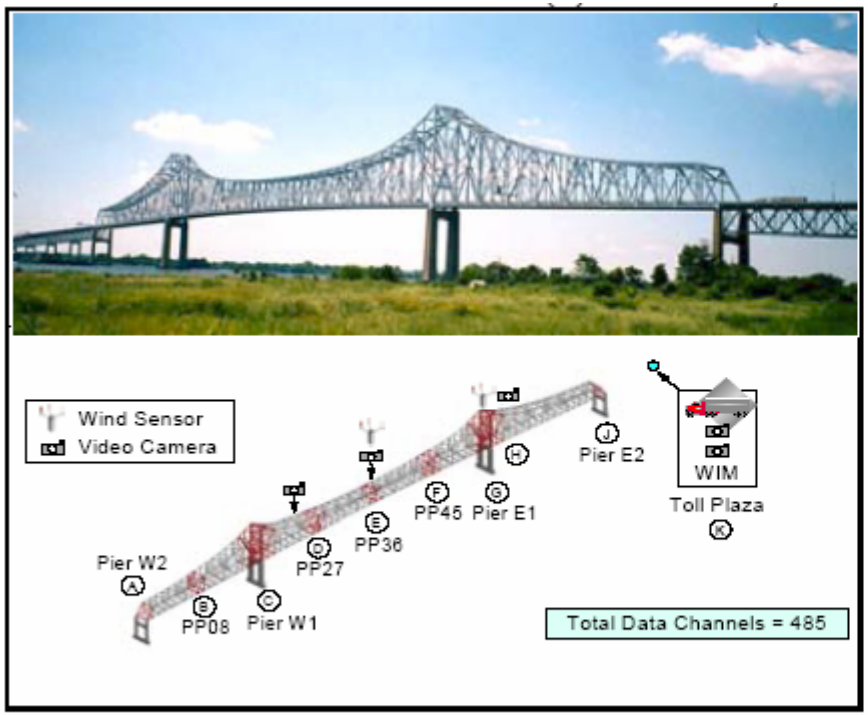
- Advantages of using a wireless system
  - Inexpensive
  - Wireless data communication
  - Distributed processing possible
    - Improved response time
    - Near real-time performance
  - More fault-tolerant system
    - Redundancy
    - Modularity
  - Scalability

SHM of Bridges

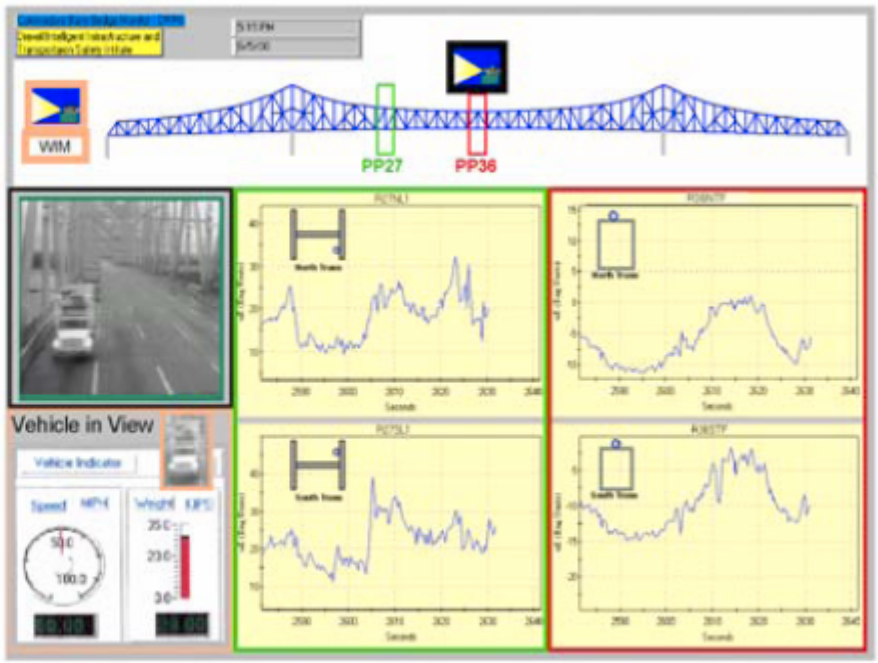
- Need of visual surveillance
  - Traffic monitoring
  - Activity detection
- Autonomous correlation between
  - Video
  - Other sensor data (e.g. vibration, strain)
- Intelligent sensing and actuation

SHM of Bridge

- An example of wired SHM system
  - Drexel University / Commodore Barry Bridge



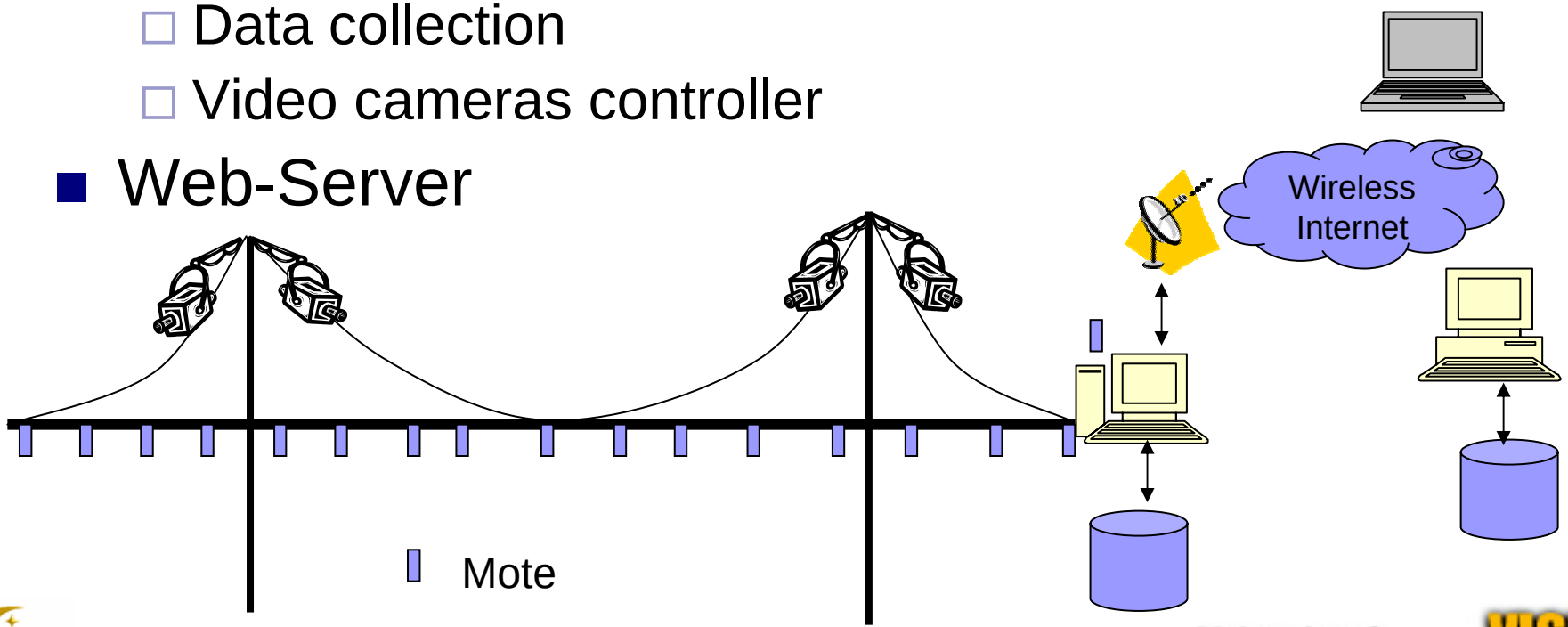
(b) Field studies on a long span bridge



(c) Health monitor interface example for a long span bridge

Proposed Framework

- Wireless sensor nodes
- Central station
  - Data collection
  - Video cameras controller
- Web-Server

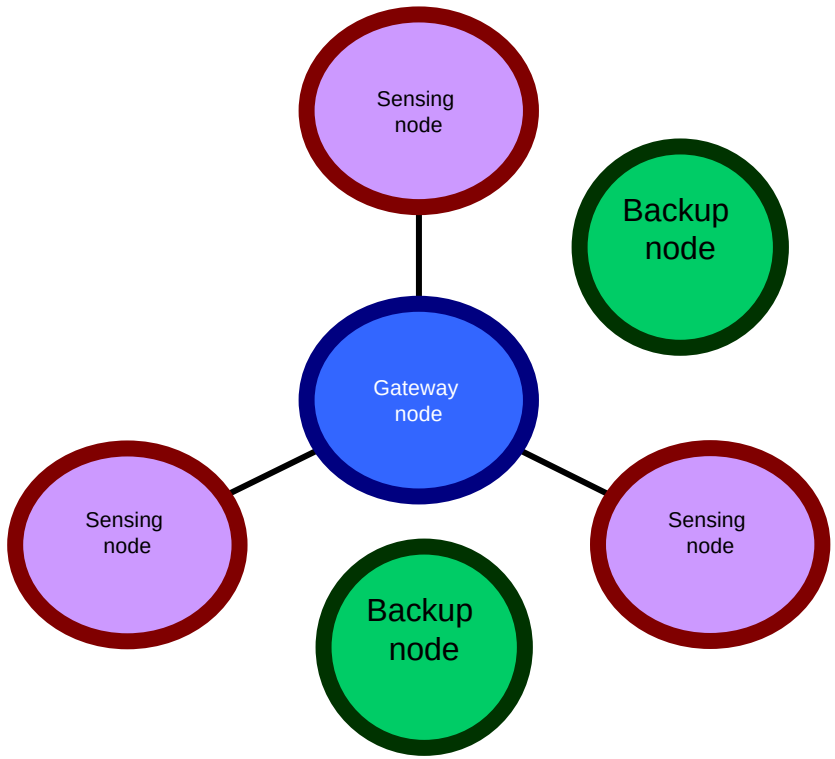


Sensor Network

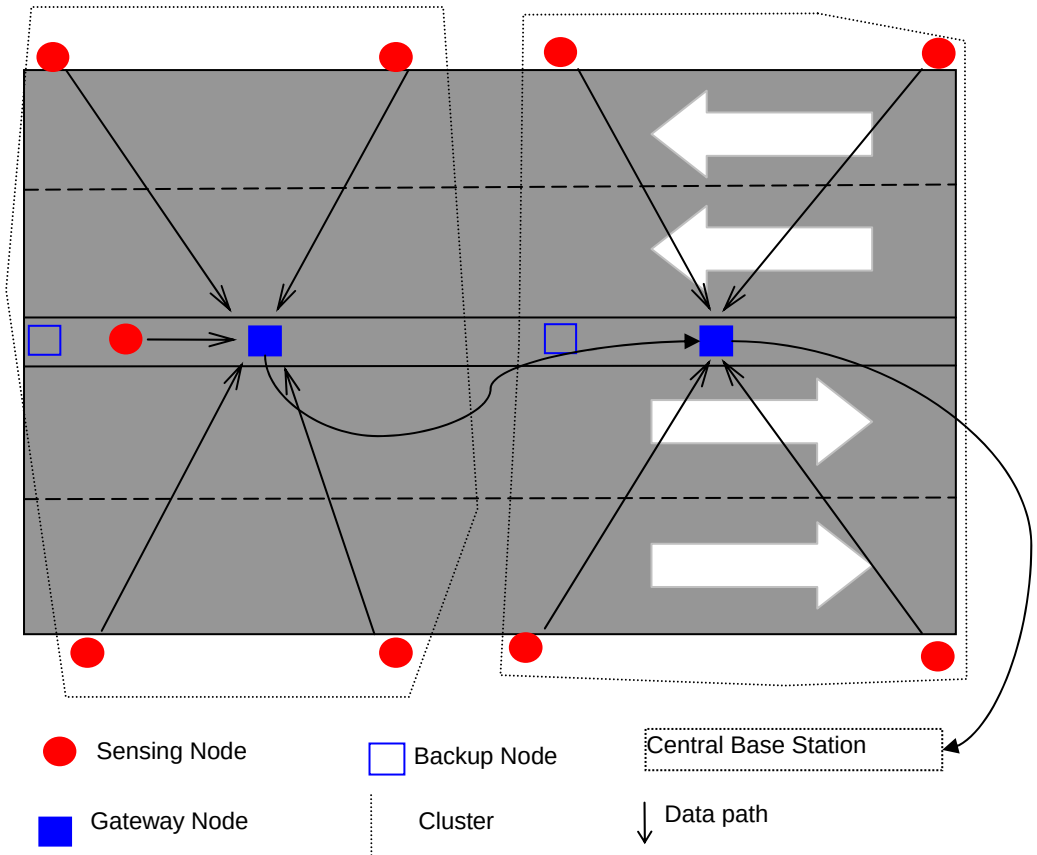
- Mica motes
- MTS series sensor boards
- Sensors used
  - Accelerometer
  - Temperature
- Stationary video camera
  - Pan/tilt/zoom feature
  - Controlled through central station

Network Architecture

- Clusters based network
- Cluster head
  - Gateway node
- Cluster member
  - 2-5 Sensing node
  - Backup nodes (Gateway, Sensing)
- Multi-hop to base station through cluster heads

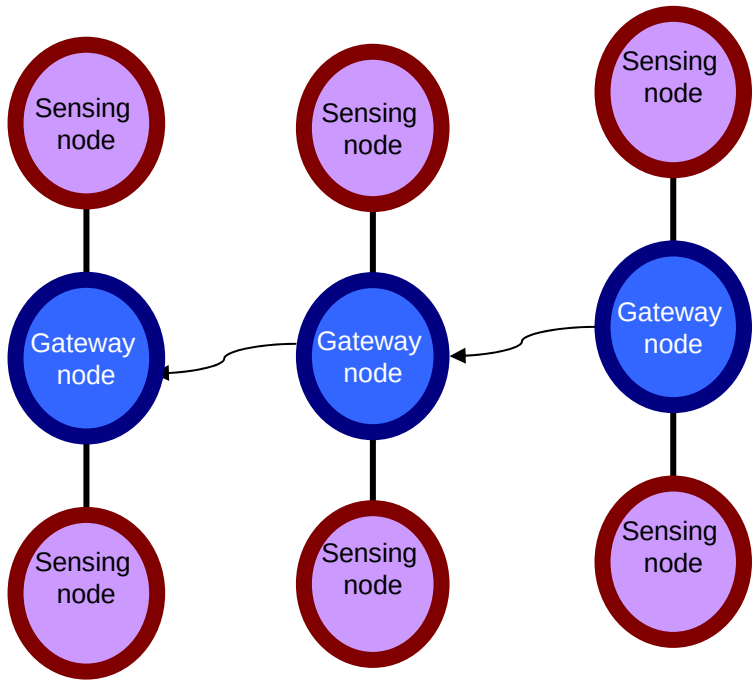


Node Layout on Bridge



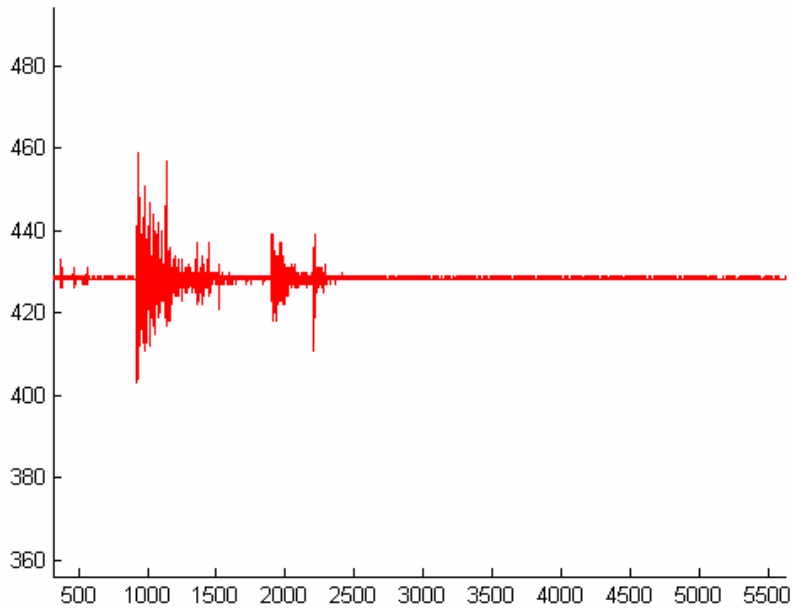
Neighbor Discovery

- Central station to gateway node
- Gateway node to gateway node progressive list
- Gateway node to sensing node progressive list



Vibration Sensing

- Vibration data from Accelerometer
- 2-axis of vibration
- Induced vibration through impact hammer
- Response from lab model of steel bridge
- Sensor with Mica2 mote



Vibration Sensing

- Sampling frequency requirements
  - 100Hz-200Hz
  - Higher data rate
  - Smaller network battery life
  - e.g. 6 nodes @ 150Hz x 2 axis

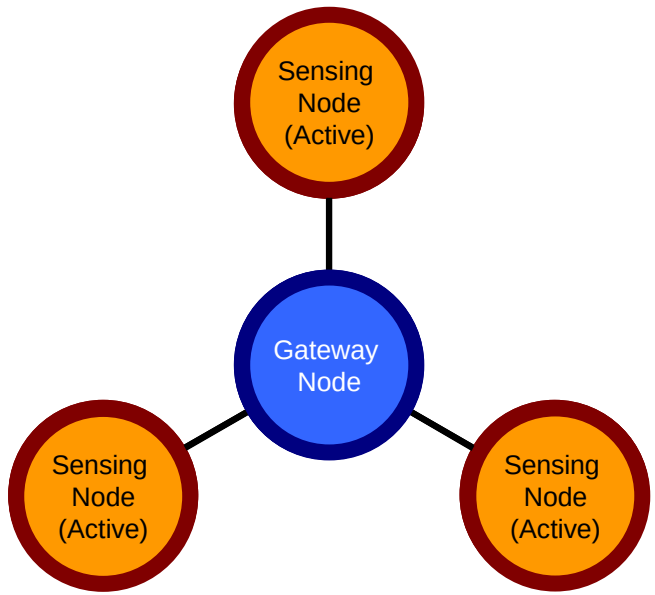
    ~ 216 KB/min
- Solution: Adaptive Sampling

Adaptive Sampling

- Exploit silent zones
- Transmit only useful data
- Modes of Sensing Nodes
  - Sleep mode
  - Passive sensing
    - Low sampling frequency ~80Hz
    - Only two sampling nodes/cluster
  - Active sensing
    - Higher sampling frequency ~ 150Hz
    - Limited time period (45 secs)
    - Stored in Flash memory
    - Transferred through cluster head in allocated time slice

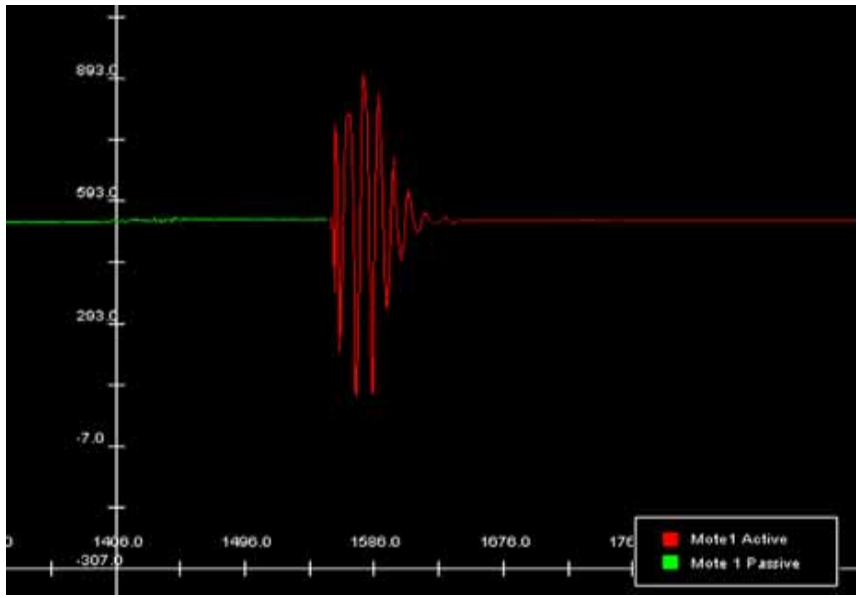
Adaptive Sampling

- 1 passive/rest sleep
- High vibration event detected
- All active
- Active for limited time
- Round-robin passive sensing
- How to detect events?



Event Detection

- Vibration Events
- Activity metric on 1-D vibration data
- A good solution
  - Thresholded Mean Shift Vector



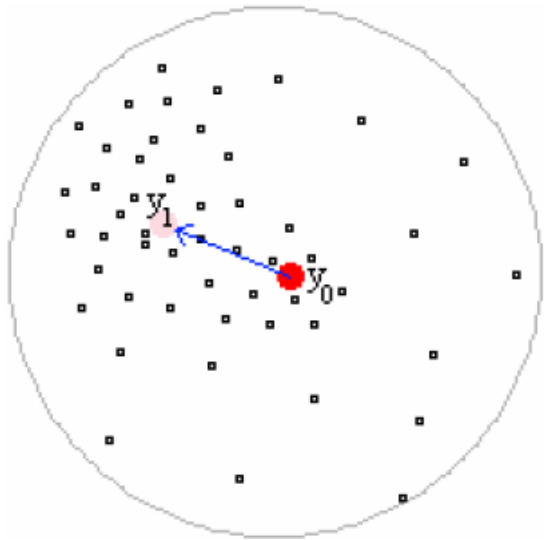
Mean Shift Vector

- Always points towards the direction of maximum increase in density
- Online model: Can be applied in an iterative fashion

$$M_h(\mathbf{y}) = \left[\frac{1}{n_x} \sum_{i=1}^{n_x} (\mathbf{x}_i - \mathbf{y}_0) \right]$$

where,

n_x is the number of points
y_o is the last mean value
x_i is ith sample

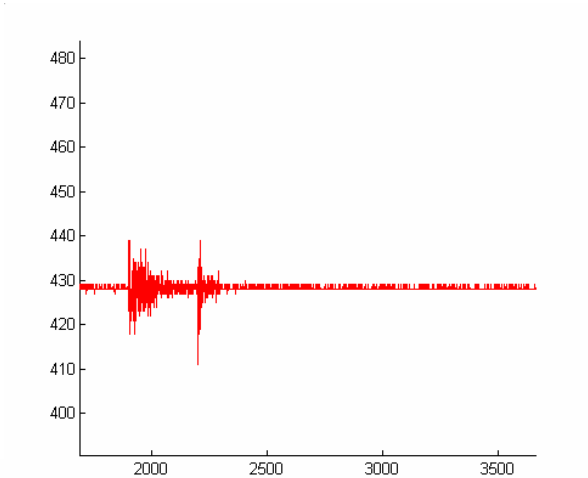


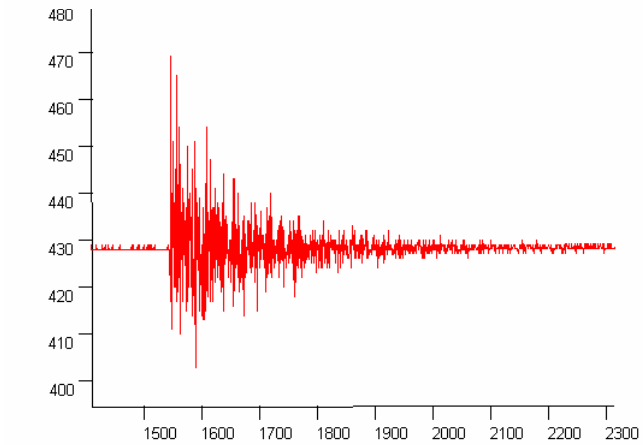
Interesting Events

- SENSE_EVENT
  - Suppression of unnecessary data
  - Lower mean shift threshold T_L
  - Change sensing mode (Passive/Active)
- CAMERA_EVENT
  - Critical event notification for visual inspection
  - Higher mean shift threshold T_H
  - Trigger video camera request in cluster

Event Detection

- SENSE_EVENT
  - Mean shift threshold T_L exceeded
  - True positive
- CAMERA_EVENT detected
  - Mean shift threshold T_H exceeded
  - True positive





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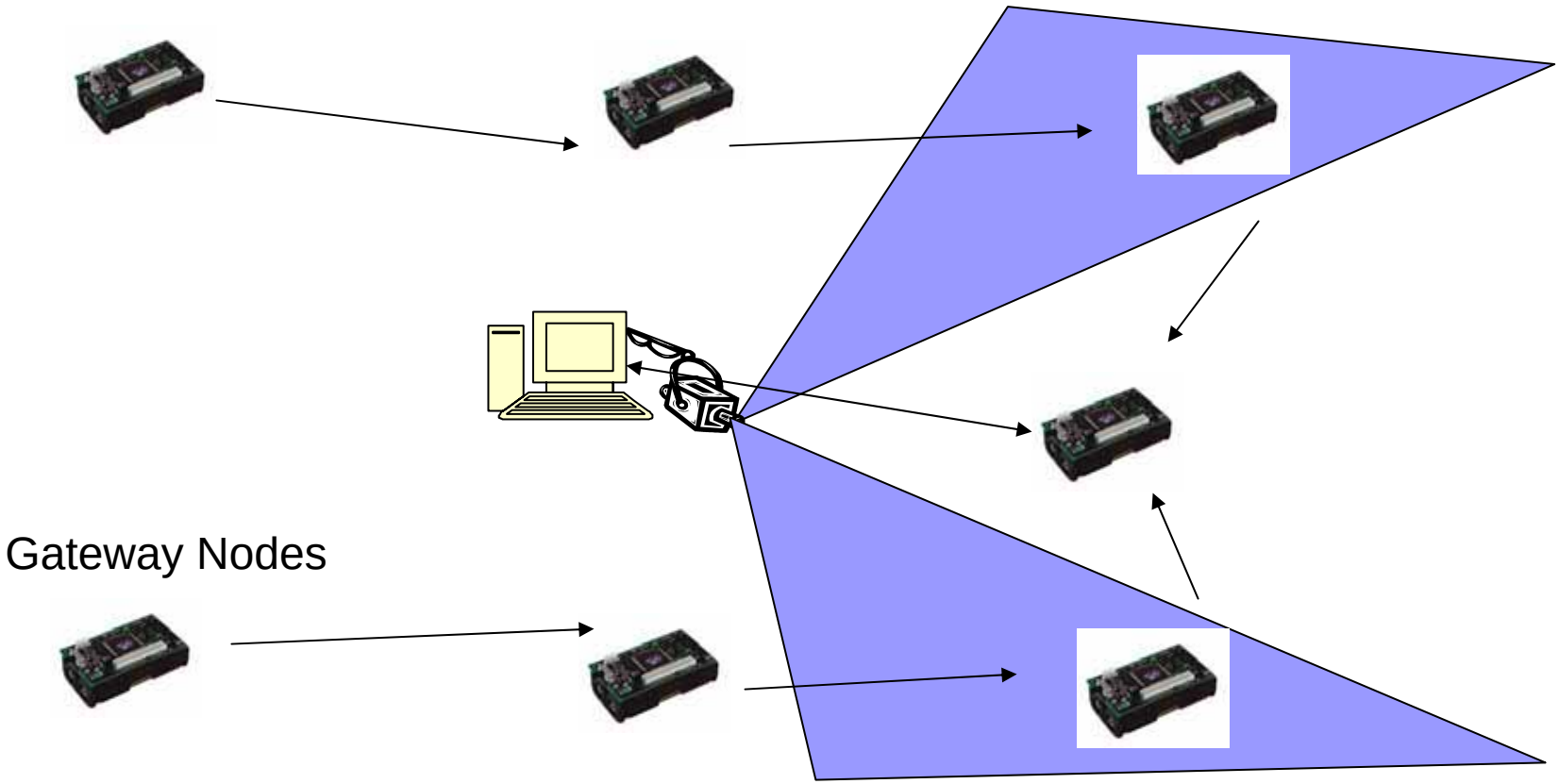
Camera Events

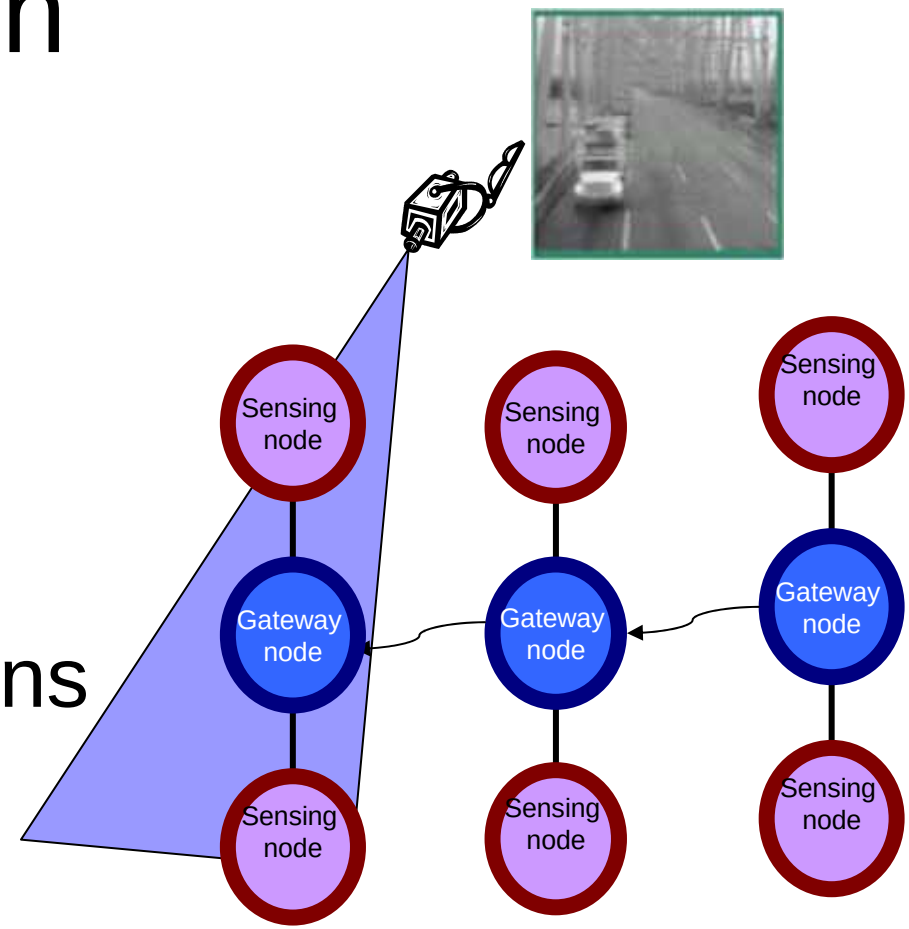


Camera Event

- Stationary wireless sensor nodes
- Controlled gateway node deployment
- Stationary pan/tilt/zoom video camera
- Central station attached to both video camera and WSN
- Registered gateway nodes with approximate 1-D distance

Node Registration

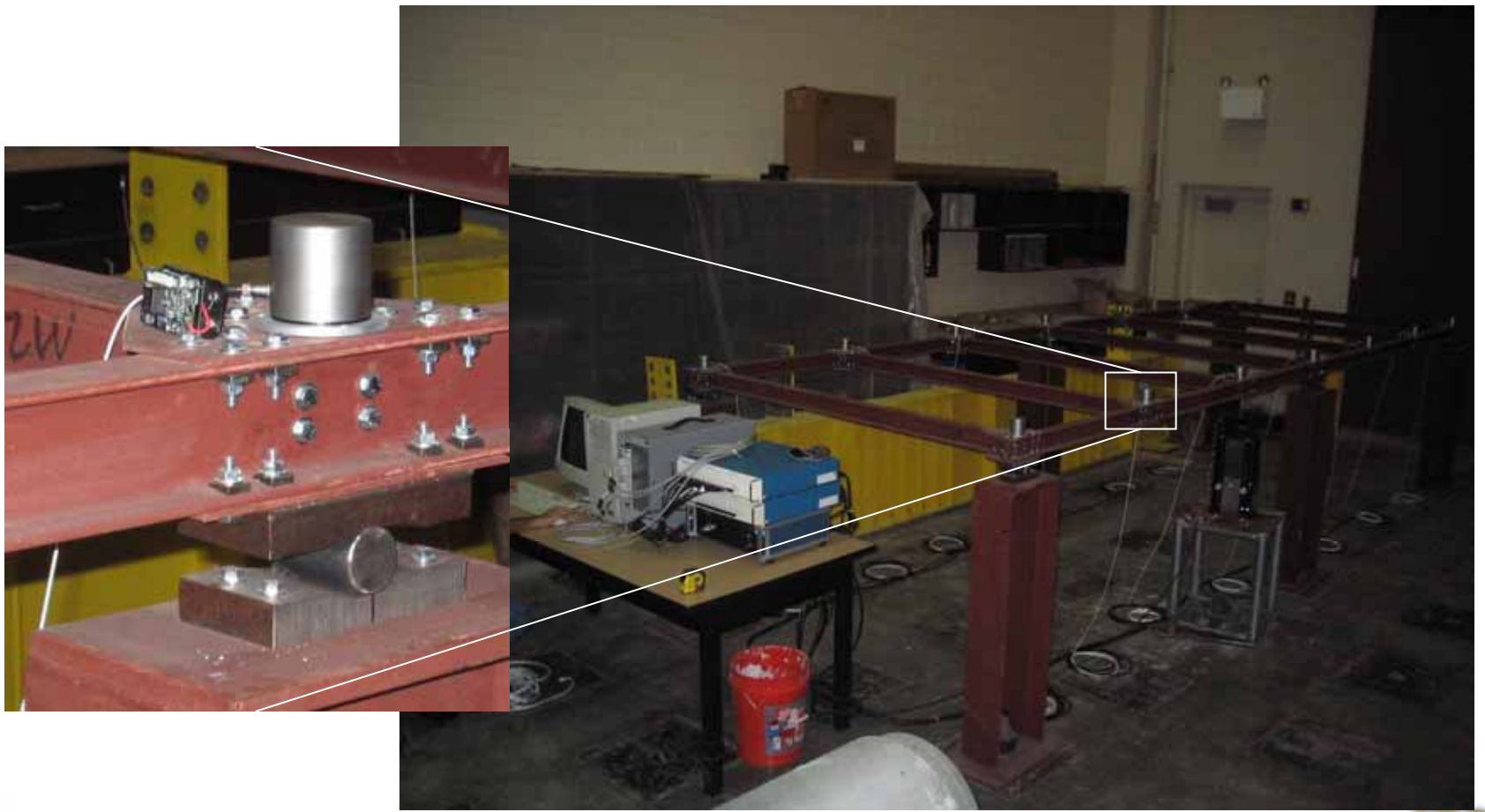
- Utilizing the gateway node-gateway node progressive list
- Registering approx. gateway node positions
- FOV wide enough to cover the cluster



Optimizations

- Single time-stamp and current sampling frequency transmitted for the whole data packet
- Mean-shift vector test after 45secs of active sampling
- Data packing for transmission saves ~38% of unused buffer

Test-bed Setup



Test-bed Setup

Demo Video

- Overview of the test-bed
- Vibration induced by impact hammer
- Event detection by sensing nodes
- Camera motion

Conclusion

- Wireless sensor network have a promising application in the area of SHM
- Distributed processing enhances the system effectiveness
- Domain specific knowledge for data compression
- Tested in controlled lab environment, effectiveness of the system remains to be seen in real-life situation