4/22 A Wireless Sensor Network for Structural Health Monitoring

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Overview

- Why perform health monitoring of structures?
- What is Wisden/Mica?
  - Hardware
- Software Platform
  - Reliable Data Transport
  - Compression
  - Data/Time Synchronization
- Deployment Experience

Why monitor structures?

- Detect and localize damage in buildings, bridges, ships, and aircraft
- How?
  - Attach wireless sensors
  - The wireless sensors acquire accelerometer information and send to base station
  - Possible decentralized detection
- Can use displacement sensors, strain gauges, accelerometers
  - Sensitivity

Accelerometers

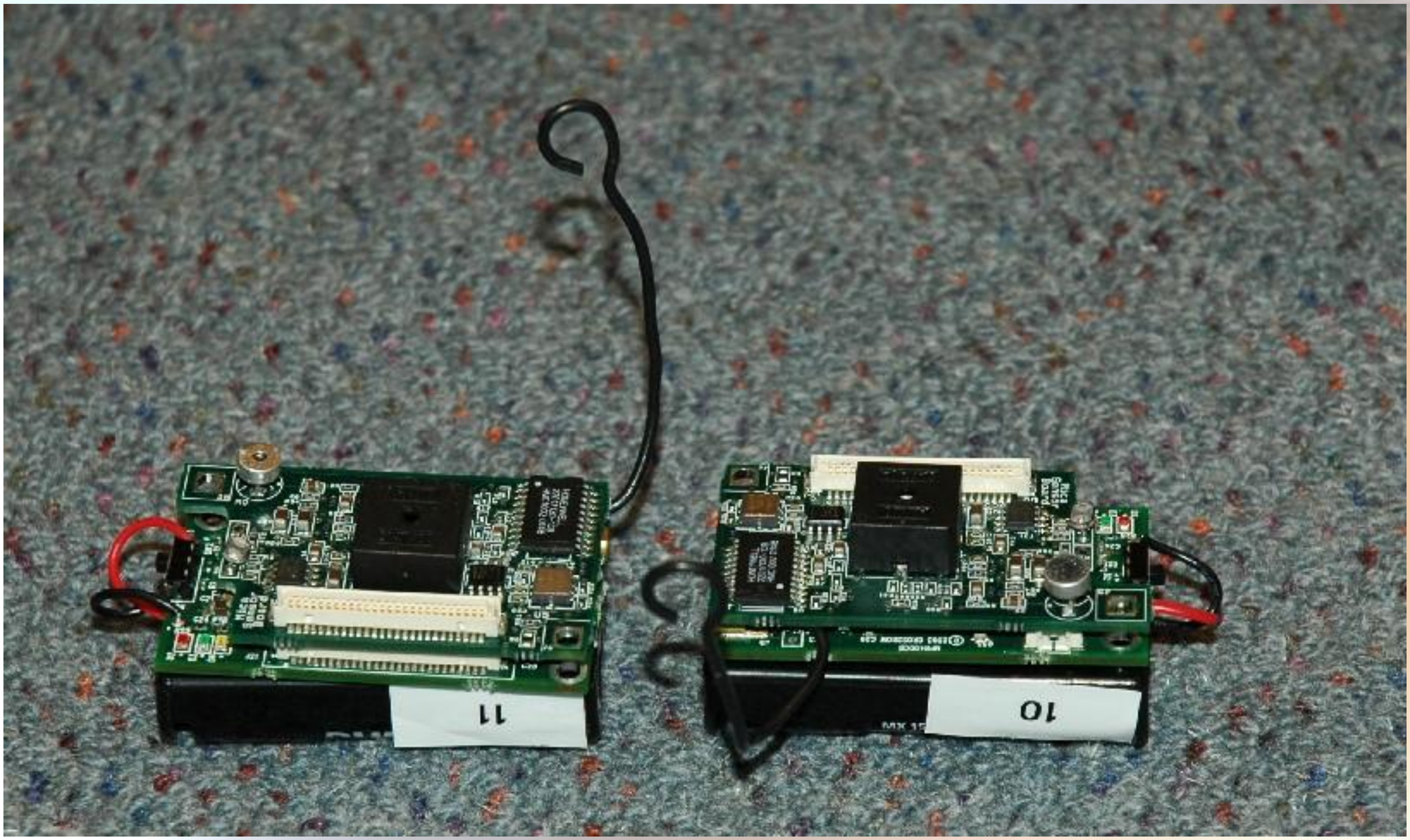
- Sensitivity – smallest measurable acceleration (micro g's)
- Dynamic range – range of accelerations device capable of measuring (1-2 g's)
- Noise – RMS value or function of the frequency of vibration
- Generate 100 2-byte samples a second for one axis (three axis is 3x)

Use Case

- "A transportation agency is ready to declare a newly built bridge open, but allows a team of structural engineers one or two days to measure structural properties by, for example, driving a large truck through the bridge."
- Small nodes can be quickly taped
- Large nodes with heavy batteries may require mounting

Wisden Hardware

- Use off-the-shelf Mica-2s w/ 16 bit vibration card and TinyOS



Wisden Hardware

- Power is turned on/off to minimize expenditure
- Modify on-board microprocessor software to permit continuous sampling
- Tri-axial accelerometer 16-bit samples at 100 Hz requires 4.8 Kbps.
- Chipcon radio can reliably achieve 10 Kbps

Wisden Software

- Requires:
  - Vibration data delivered reliably to PC
  - Data be time-synchronized
- Not all data samples are necessary, only samples occurring during events
- The data is compressed using a simple run-length encoding scheme
- Error correction and detection uses hybrid hop-by-hop and end-to-end schemes
- Data time-stamping at base station

Software/Reliable Data

- Must transmit from node to base station
  - Related work shows link losses up to 30% common
- Routing tree where parent is selected based on node with most powerful link
- Store vibration data in EEPROM then transmit to parent
- Gap in sequenced packets indicates loss

Software/Reliable Data

- Loss is repaired through hop-by-hop and end-to-end scheme. Also, cache maintains recently transmitted packets thus memory becomes issue.
- End-to-end relies on base station having significant memory
- During tests, children switch parent's then original parent's missing packets list never cleared
  - Watchdog timer clears list when full
  - No radio, sends dummy packet

Software/Reliable Data

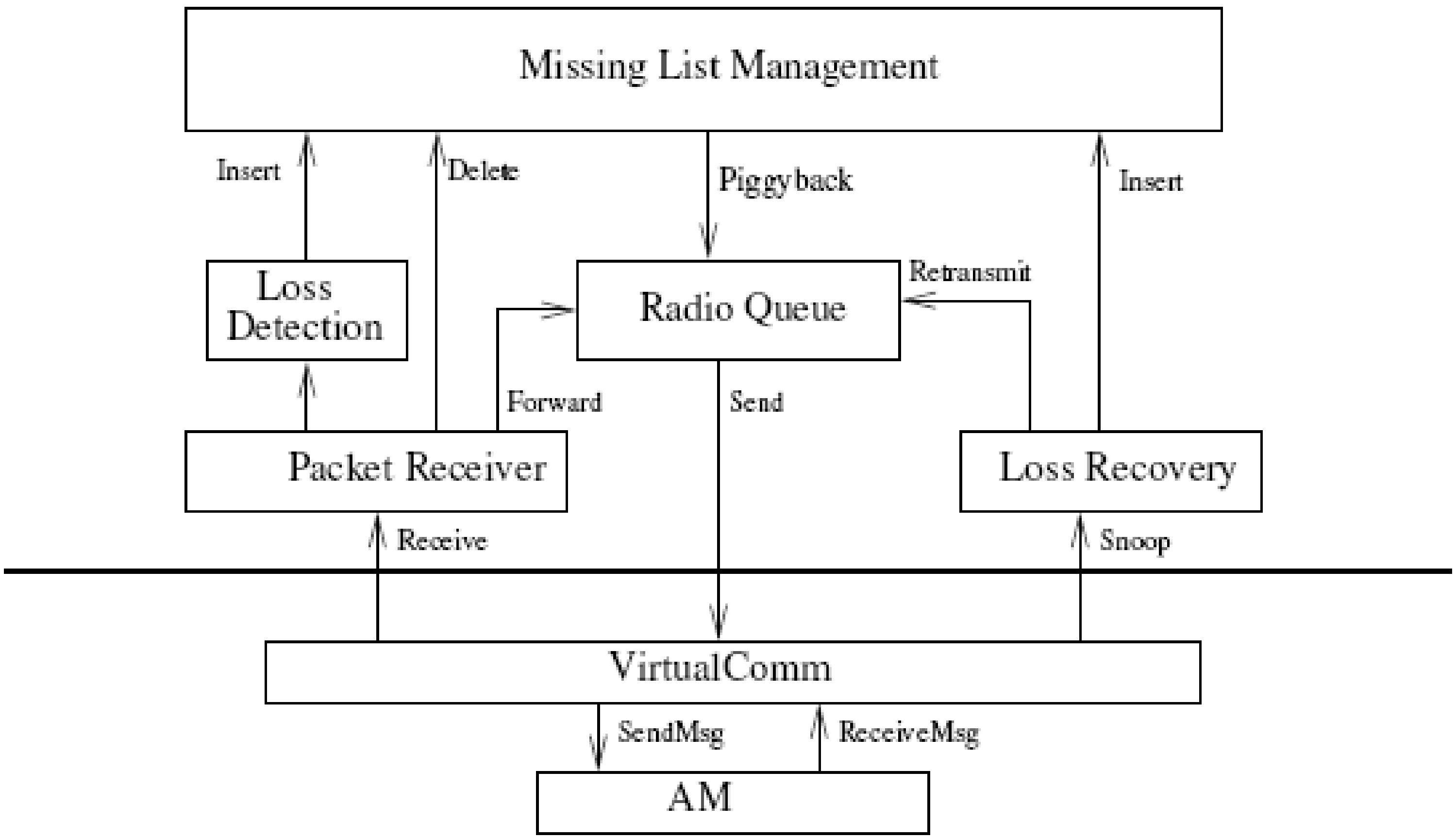


Figure 1: Block Diagram of Reliability Implementation

Software/Compression

- Only data that meet event detection threshold is transmitted
- Low-resolution compressed summaries of near real-time data is transmitted
- How does the codec work?

Software/Time Synchronize

- Samples time stamped at base station
- Time spent at each node summed up
- Clock drift could be problematic, but experimental tests showed not big deal
- Radio transmission time is in nanoseconds
- Timestamp as close to first byte and when first received as possible

Software/Time Synchronize

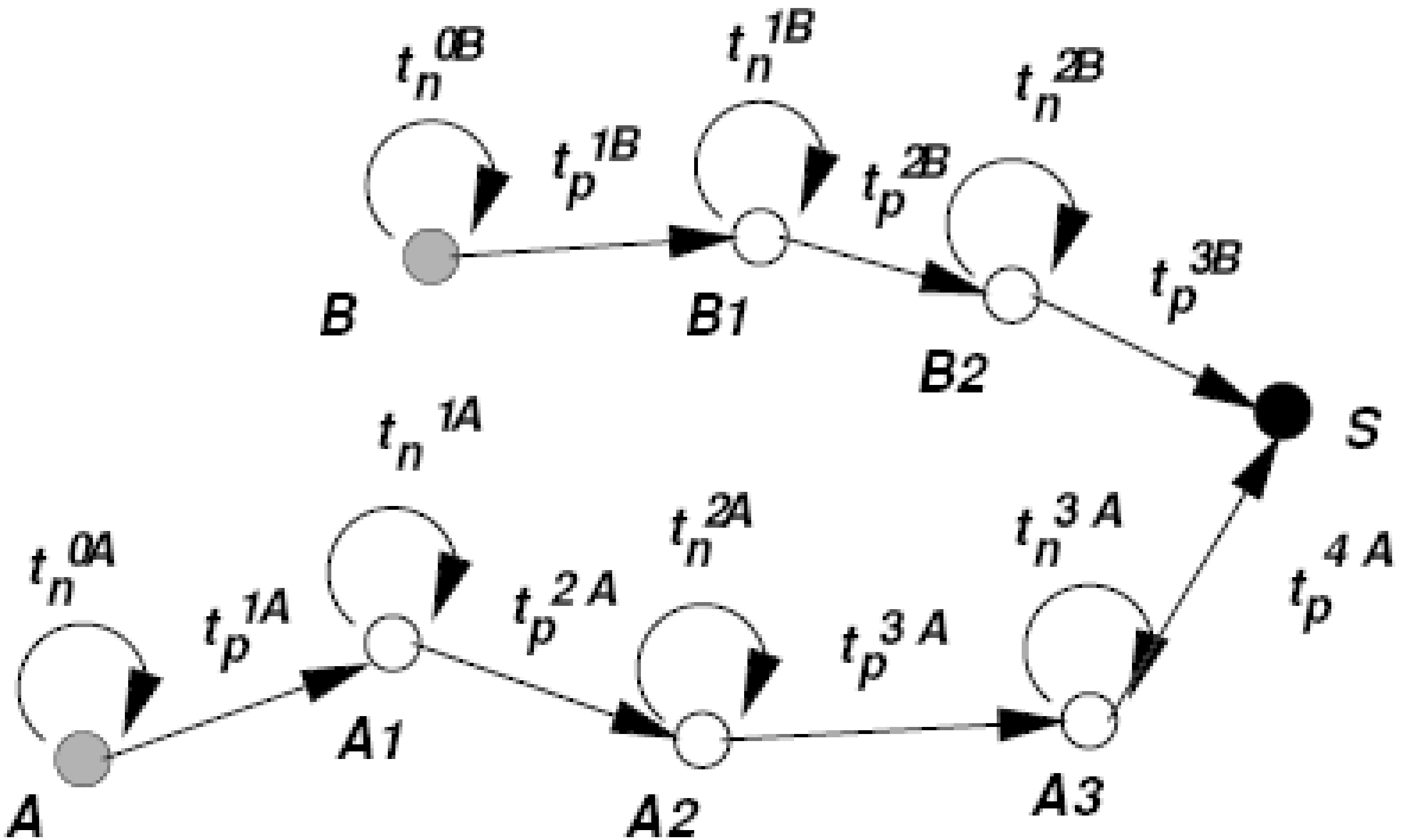


Figure 10: Time synchronization example.

Implementation Schematic

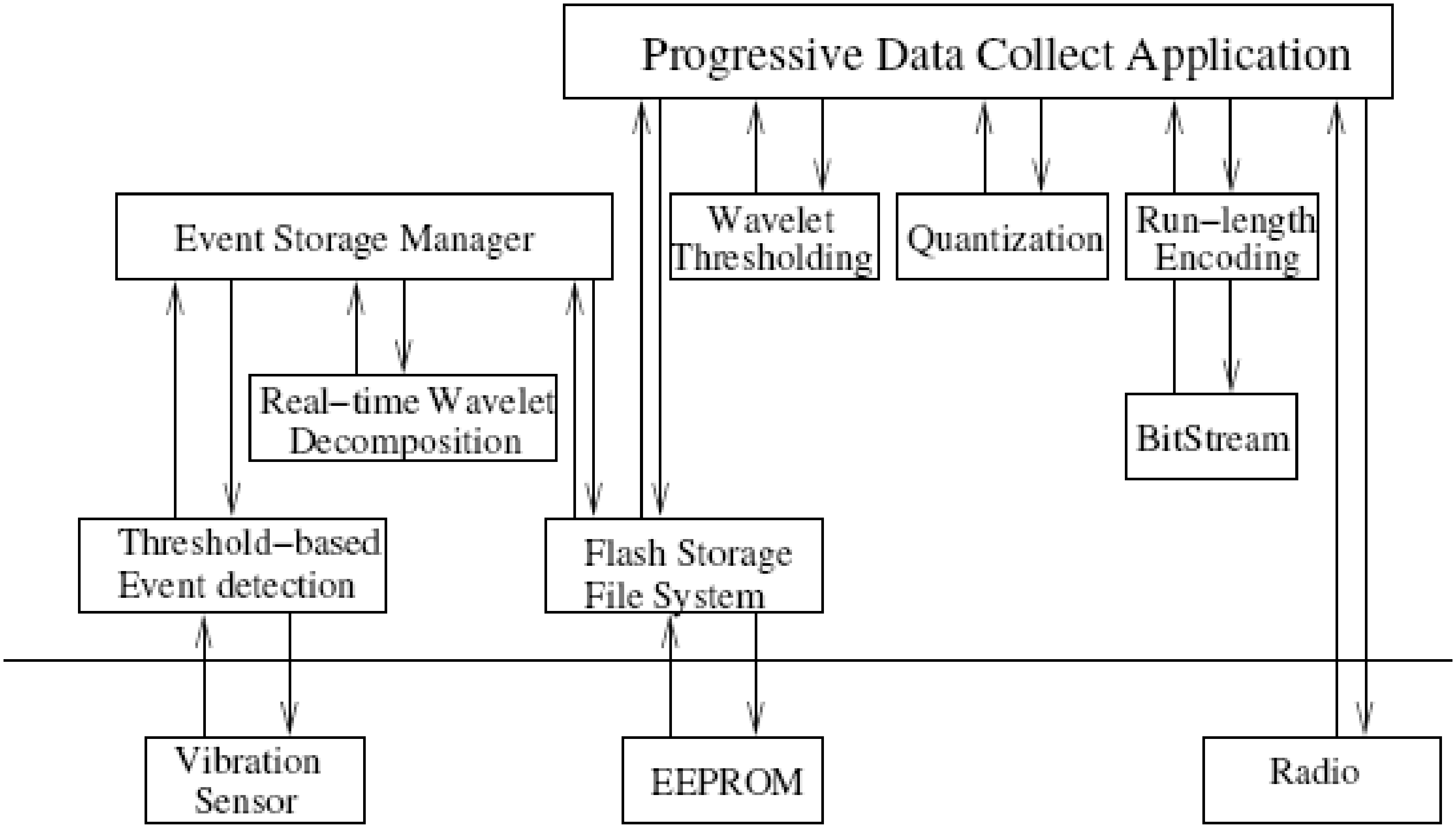


Figure 5: Component Diagram of Mote implementation

Experimental Results

- Deploy 25 Mica-2 nodes with artificial traffic
  - 10 as relays and 15 generate artificial traffic
- 100% reliability when packets ranged from .1 packet/sec to 1 packet/sec
- However, at 2 packet/sec per node very few packets received
- Due to clock drift, sample stay in network at most 15 mins

Test Case I

- 40 ft long and 20 ft wide, repeatedly hit with 2-by-4 for 20 seconds
- Average resident time 142 seconds

Figure 14: The Ceiling Structure

Test Case II

- Taken from different paper
- Uses Mica-z's with higher data rate
- Discovered realistic structures heavily damped and require higher frequency sampling (let's say at least 200 Hz)
- Vibrations last 0.5 second and barely enough for good data sample
- Memory limit stored samples for 60 seconds

Test Case II

- Mica-2: 22.17 pkts/sec
- Mica-z: 153.37 pkts/sec
- Redesigned compression scheme
- Wisden achieve 100% delivery
- 9.5% of total packets required retransmission and 2.5% retransmitted more than once
- 7.7% of packets recovered end-to-end and only 1.8% recovered from cache (most likely due to small cache)