A Wireless Sensor Network for Structural Monitoring

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Presented by Fei Sun

Motivation

- Detect and localize damage in buildings, bridges, etc.
  - Collect and analyze structural response to ambient or forced excitation.
- Problem with current solutions:
  - Powerful data acquisition system: a centralized device includes sophisticated signal conditioning, processing and analysis functions
    - Expensive, not flexible, small coverage, difficult to install
  - Data logger:
    - Lacks analysis capabilities
    - Requires storage and high-bandwidth transmission capabilities

Challenges

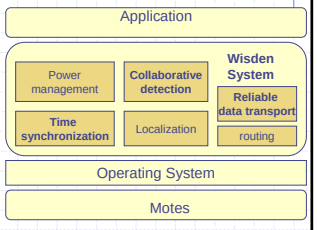
Challenges:
- Limited bandwidth, memory, local processing capabilities
- High packet loss
- Lack of time synchronization

No power Management In this version

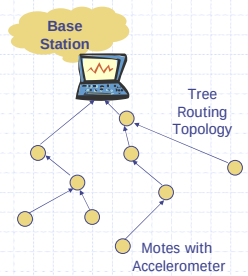
Requirement	Wisden Solution
Higher data rates	Data Compression
Loss-intolerant data transmission	Reliable data transport
Time synchronization	Data synchronization that avoids synchronizing clocks network-wide.

Wisden – System Overview

- Abstraction of a data acquisition system
  - Current Wisden functions as a ***data logger*** as it lacks the on-line data processing capabilities present in data acquisition systems.
  - Implicit requirements
    - Sampled data reliably delivered to BS
    - Samples are time-synchronized



Wisden – System Overview



(no purge of EEPROM)
Purge EEPROM
(manual configuration)
Self-configuration

Time Stamp Synchronization

Hop-by-Hop End-to-End Error Recovery

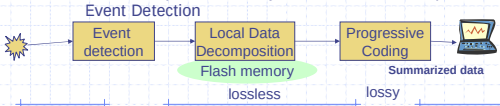
Local Data Compression

Compression

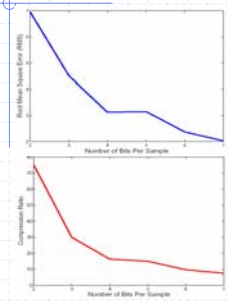
- Event detection (current implementation)
  - Advantage: only transmitting samples that exceed a certain threshold, utilizing the fact that structures will experience relatively few of these
  - Limitations:
    - Restricts the type of events that could be detected
    - Do not reduce the user-perceived latency of data acquisition

Compression

- Progressive Storage and Transmission
  - Store raw data in local cache
  - Transmit compressed cached data in near-real time
    - Limits the amount of data that can be accessed
  - Compress vibration data by a factor of 20
    - Reduce acquisition latency to < 1 min when coupled with Event Detection



Compression: Evaluation

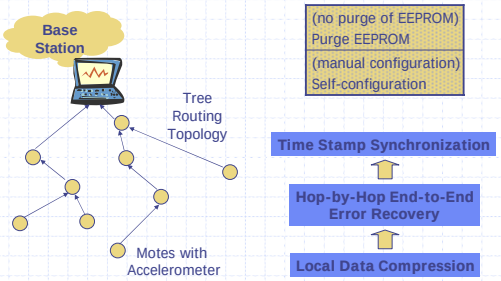


- Integer-integer wavelet decomposition
- Quantization
- Signal shareholding
- Run-length encoding
- Bitstream

	Computation Time	Memory Utilization
Wavelet Decomposition	6.44ms	288bytes
Uniform Quantizer	0.32ms	7bytes
Run-length Encoder	6.30ms	20bytes

Table 1: Performance of 128-sample 4-level transform

Wisden – System Overview

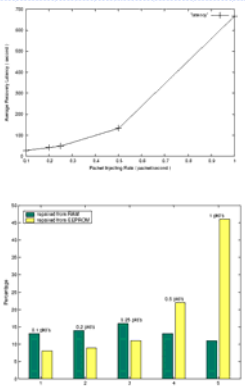


Reliable Data Transport

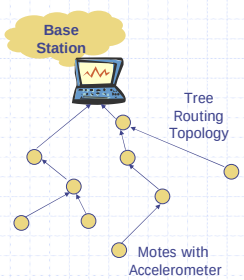
- Hop-by-hop recovery
  - Necessary for performance optimization
  - NACK-based reliability scheme
  - Track sequence number on a per source basis
  - Each node maintains a list of missing packets
- End-to-end recovery
  - Heavy packet losses may result in more lost messages than can fit in the mote's memory
  - Topology change could cause loss of missing packet list information
  - Base station does not have constraint on storage

RDT Evaluation

- When sending rate increases, average recovery latency increases due to packet recovery as a dominant part of latency
- > 0.25 packet/sec end-to-end dominates recovery latency

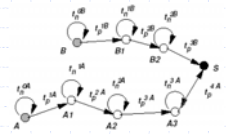


Wisden – System Overview



TimeStamping Data

- Example



$$\tau_A - T_A = \tau_B - T_B$$

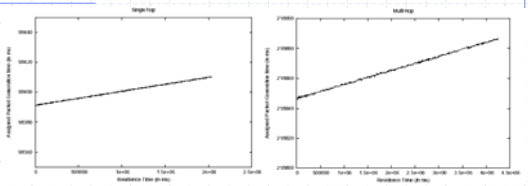
Sample time from local clock At Base Station

$$T_A = \sum_{i=0}^{i=3} t_n^{iA} + \sum_{i=1}^{i=4} t_p^{iA}$$

Residence time

Propagation time (ns, 100 meters)

TimeStamping Data



- **Limitations (**Impacted by clock drift**):**
  - Residence times are long, then the timestamp can be significantly skewed
  - Clock drift can change the sample clocking
- **Results:**
  - In the absence of drift, we would have expected horizontal line.
  - The slop of the line corresponds to a drift of 10ppm
- **Implications:**
  - 10ppm drift indicated that a sample can stay in the network for at most 1000 seconds (about 15 minutes) before timestamp error exceeds 10ms

Conclusion

- Wisden is a wireless structural data acquisition system that incorporates
  - Data Compression
  - Reliable Transport
  - Time Synchronization

Critique

- No real deployment
- Did not give a result of how well the system detects and localize damage
- No consideration of power management
- Manually configure sending rate
- Data is not sent in real-time

Related Work – Intel Sensys'05

- Power management
- Location of mote deployment
- Two kinds of motes: Mica2 vs. iMote
- Hierarchal network
  - Mica2/iMote, Stargates, Server
- Real-time data streaming
  - Limits the sampling rate to 19.2 Khz (too low)
- Real deployment
  - Found that higher frequency radio (Mica2) is more reliable, due to the metal environment