Fidelity and Yield in a Volcano Monitoring Sensor Network

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Introduction

- Performed a 19 day trial of a Wirless Sensor Network application at Reventador Volcano in Ecuador
- Focused on quality of data, usefulness to scientist
  - Previous studies leave this out
- Evaluated data across
  - Robustness
  - Detection accuracy
  - Data transfer performance
  - Tming accuracy
  - Data fidelity

Existing Technology

- Expensive, sometimes large equipment
  - Only deploy a few units, spaced 200-400m apart
- Long-term deployment, several months
- Data stored locally, have to manually collect
  - Significant effort

Reftek 130: An existing seismic collection device

Problems with WSN

- High sampling rate (100 Hz), 24-bit signal
  - Lots of data
- Precise timing accuracy
  - Each message must be timestamped within 10ms of true time
- Power consumption

Solution Architecture

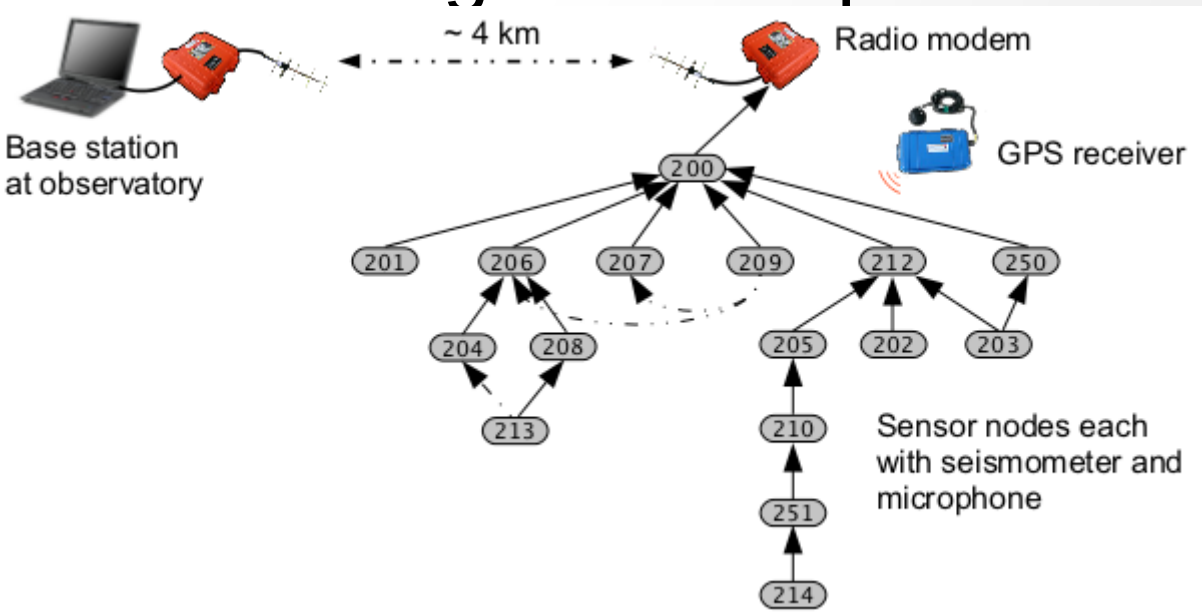
- Tmote Sky platform
  - 10 KB SRAM
  - 48 KB ROM
  - 1 MB Flash
- TinyOS
- Custom ADC, 4 channels of 24-bit depth
- 2 D-cell batteries
- Waterproof housing

Solution Architecture: Sensors & Communication

- Either 1 axis or 3 axis seismometer
- Omnidirectional microphone
  - Audible sound of explosions
- 8.5 dBi antenna
- Chipcon CC240 radio
  - Line of sight > 1 km
  - 600-1200 bytes/sec per node

Data Collection

- Infeasible to continually transmit data
- Nodes detect seismic, transmit report to base station
- If > 30% of nodes report, station requests info
- Each node uploads data through multihop routing network



Network Robustness

- Base station unreliable, bug in protocol caused 3 day outage of network
- Individual nodes: 96% uptime
  - Unrelated to depth of tree

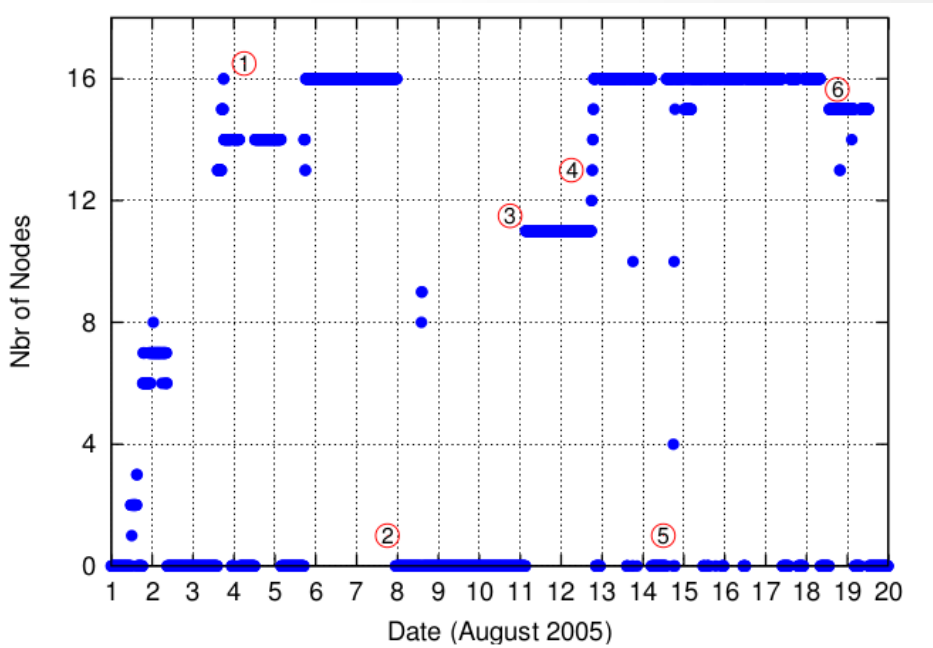
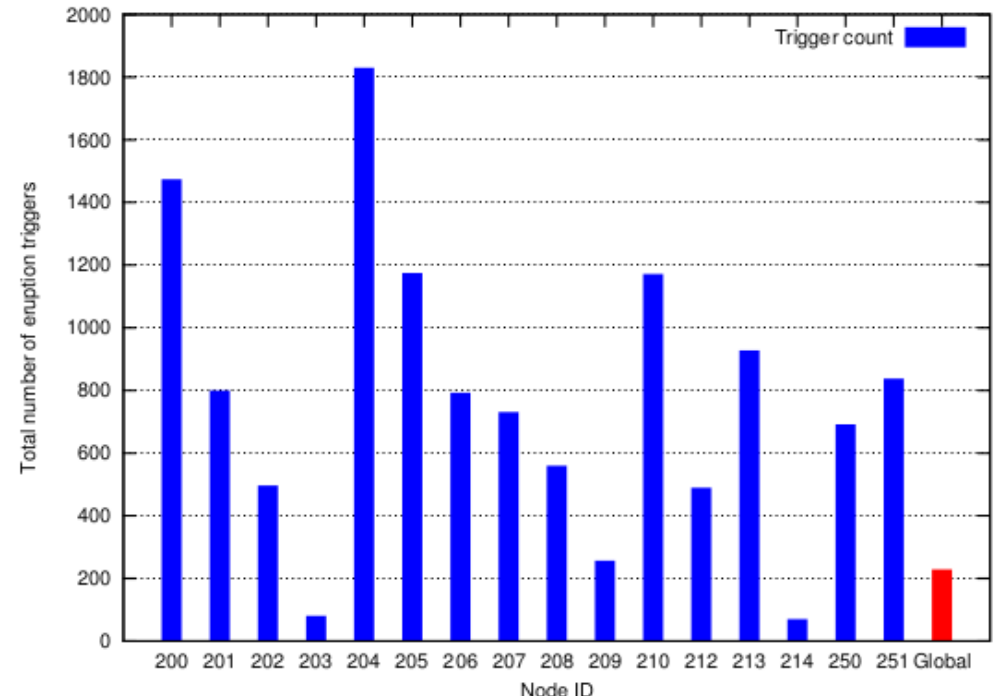
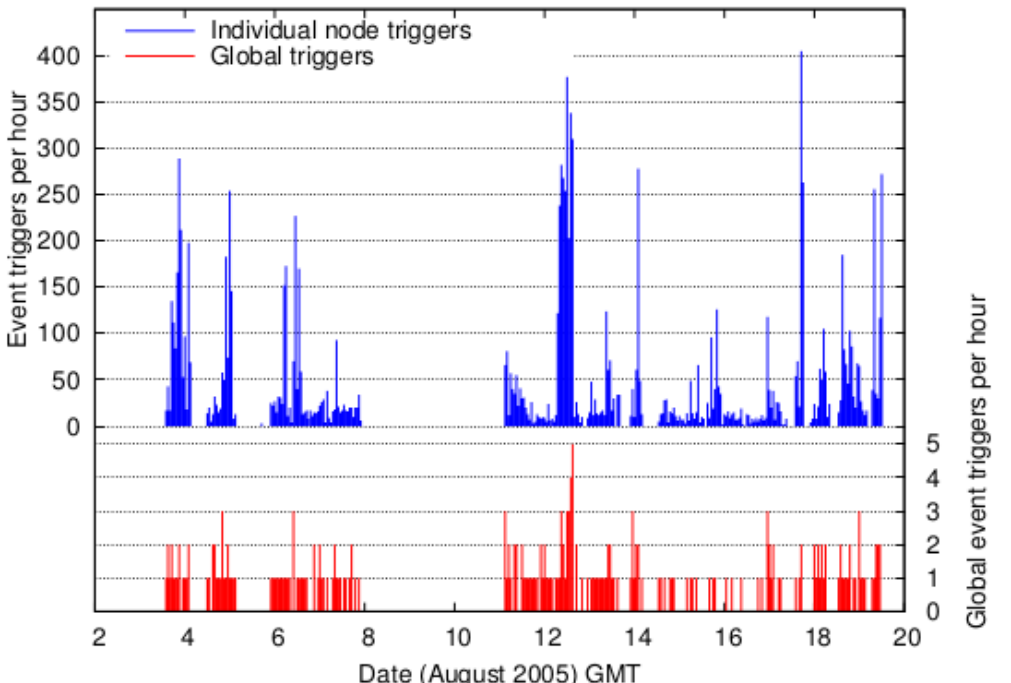


Figure 4: **Nodes reporting over time.** *This figure shows the number of nodes reporting over each 10 min window during the 19-day deployment period. The annotations (1) through (6) are described in the text.*

Event Detector Accuracy

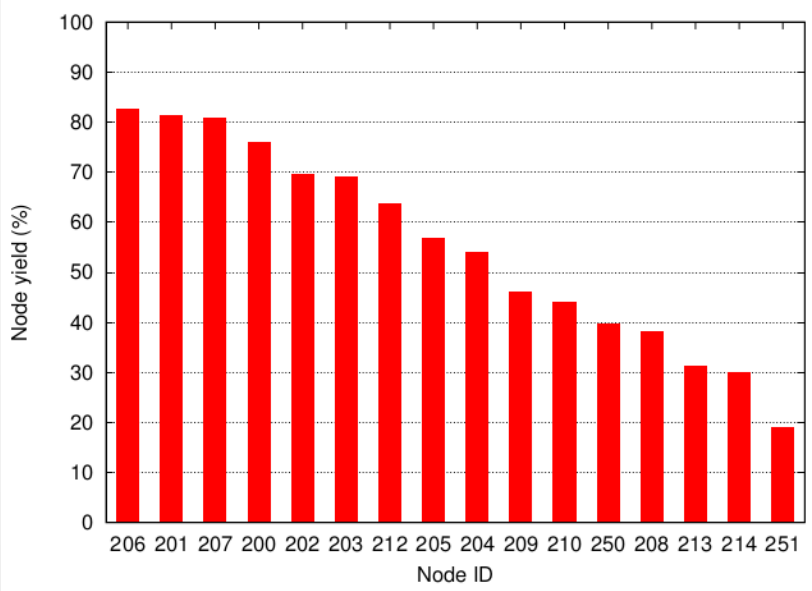
- High variation in detections per node
- 5 global event triggers / hr
- Zero false positives
- Missed a large number of back eruptions during data upload
  - Bursty activity makes volcano analysis a hard application
- Highly variant, dependent on whether or not network was up

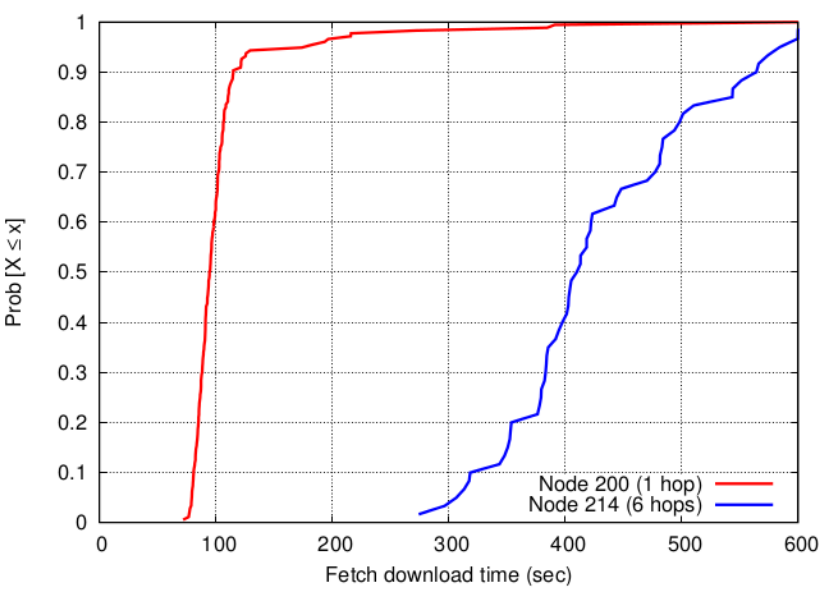




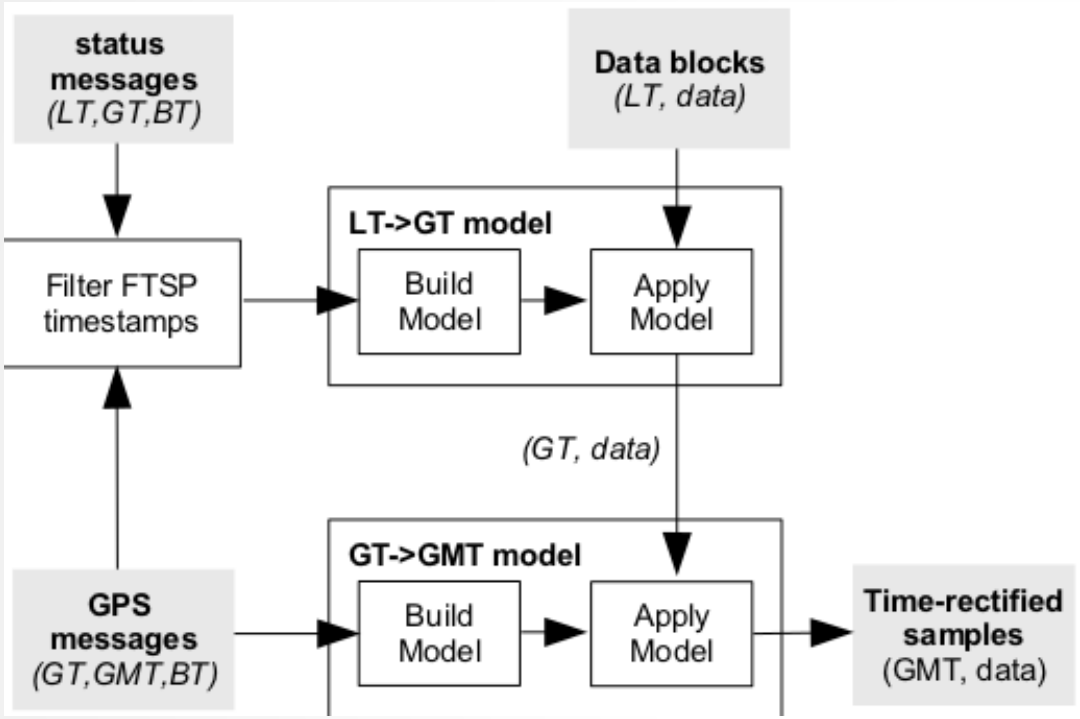
Transfer Yield / Latency

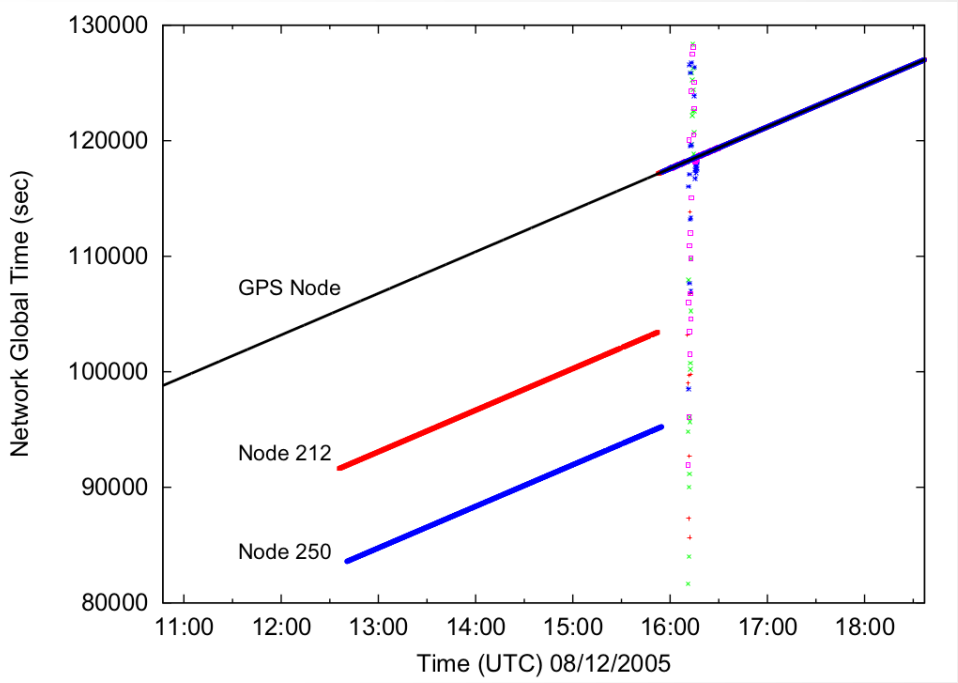
- Yield 68% for whole network
  - High variability for each node
- Yield worsened the further out nodes were
- Mean fetch time: 186 seconds





Time Protocol





- Flooding Time Synchronization Protocol (FTSP)
  - MicaZ sensor node used as root, has GPS
  - Every second, recorded GPS time and FTSP time, send out status message
  - Nodes would label packets with FTSP time
  - Use models to convert local time → FTSP → GMT

Time Rectification

- Applied a piecewise linear transformation between times
- Works even when FTSP time has failed
- Hard to measure accuracy since no ground truth
- 5 / 29 evens occur outside error window of 10ms as measured at base station

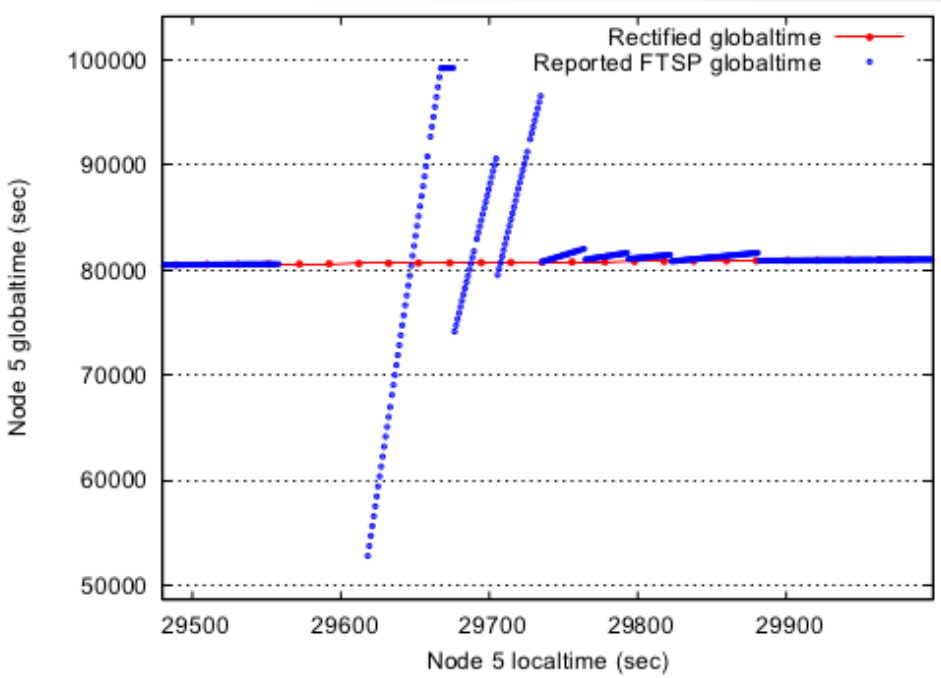
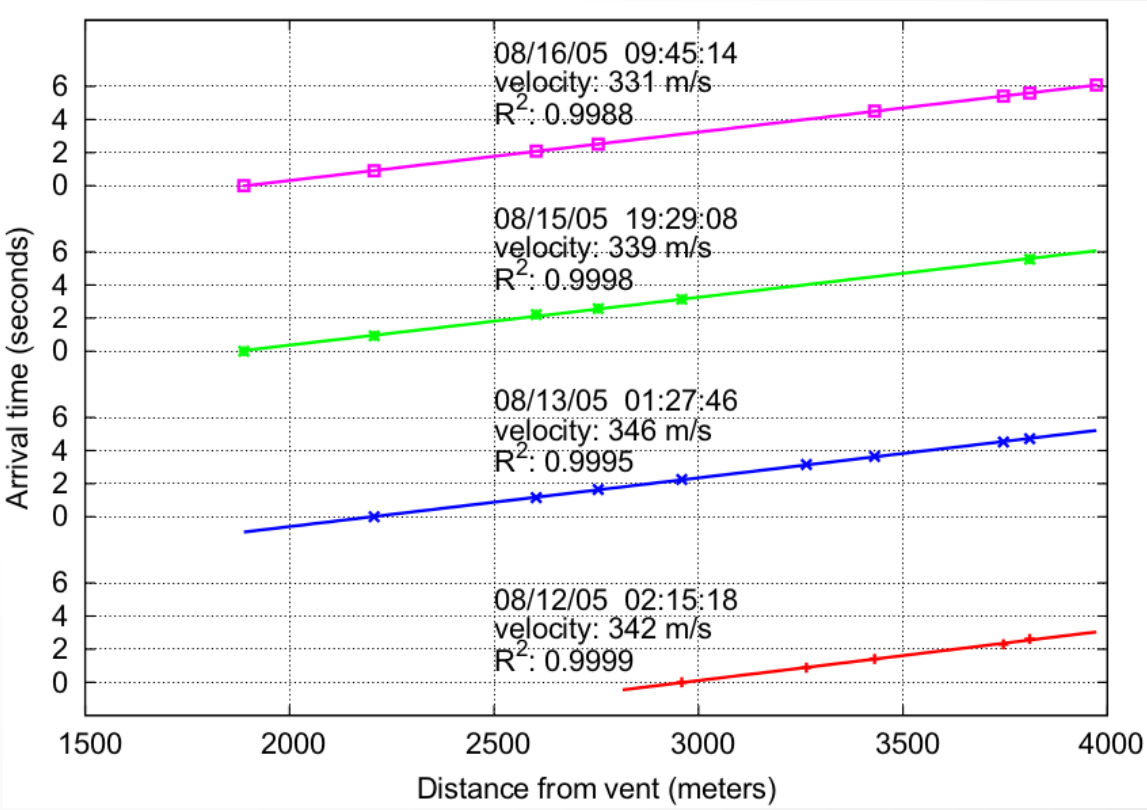


Figure 13: **Time rectification example.** *The raw (LT, GT) pairs collected from the node show that it experiences a period of FTSP instability. The time rectification process removes the errant timestamps creating an accurate mapping between LT and GT created using a linear regression on the remaining timestamps.*

Data Fidelity: Infrasonic

- Very accurate, extremely precise
- Mean speed of sound: 339.5 m/s



Data Fidelity: Seismic

- Harder to tell when event starts
  - Processed 15 events to determine arrival time
- Patten of wave arrival times can be used to estimate where source was
- Consistent results
  - Speed envelope of 1500 m/s

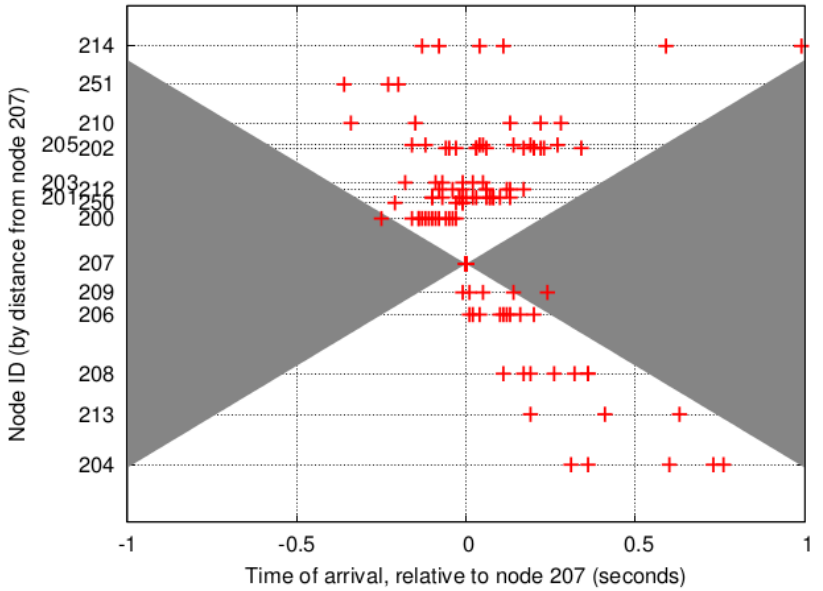


Figure 19: **Time of arrival of each node over multiple events.** *This graph shows the spread of arrival times for each node. The arrival time and distance is relative to node 207. The arrival time for each node is fairly consistent over multiple events, with the exception of node 214. The shaded area indicates a move-out velocity of less than 1,500 m/s.*

Data Fidelity: Seismic Comparison

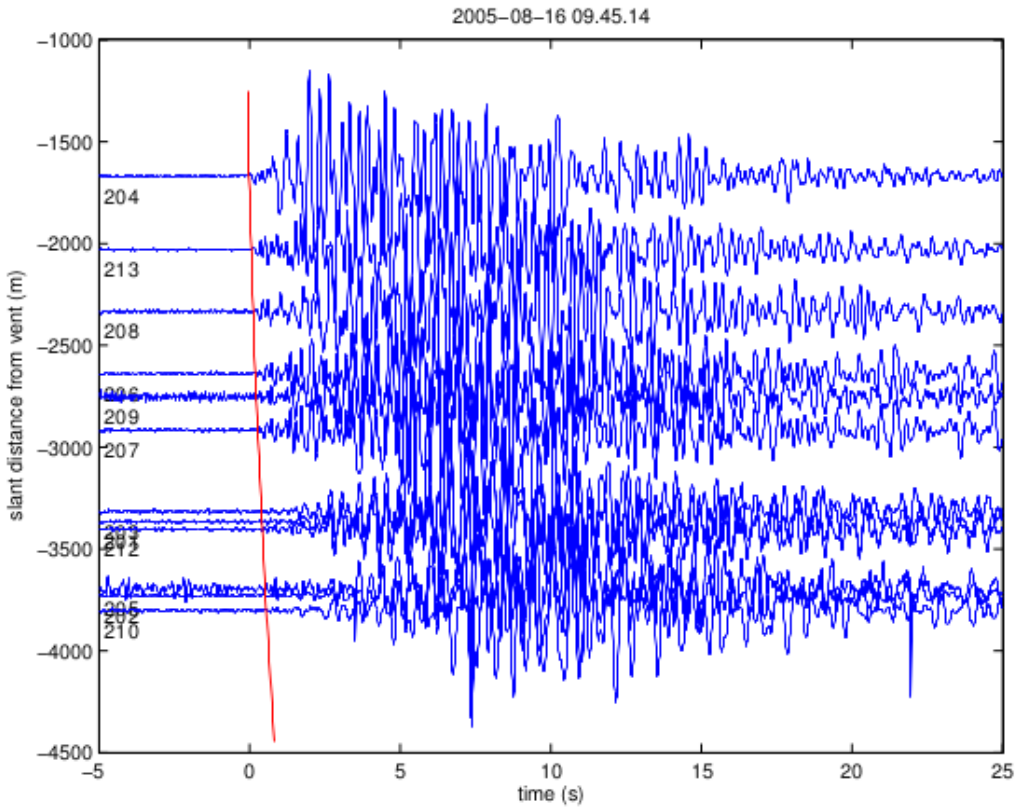


Figure 20: **Explosion earthquake event at 08/16/2005 09:45:14 GMT.** *P-wave arrivals have been identified manually and a second-order polynomial (solid line) is fit to the arrivals. The arrival time move-outs are consistent with a shallow near-vent source.*

Explosion

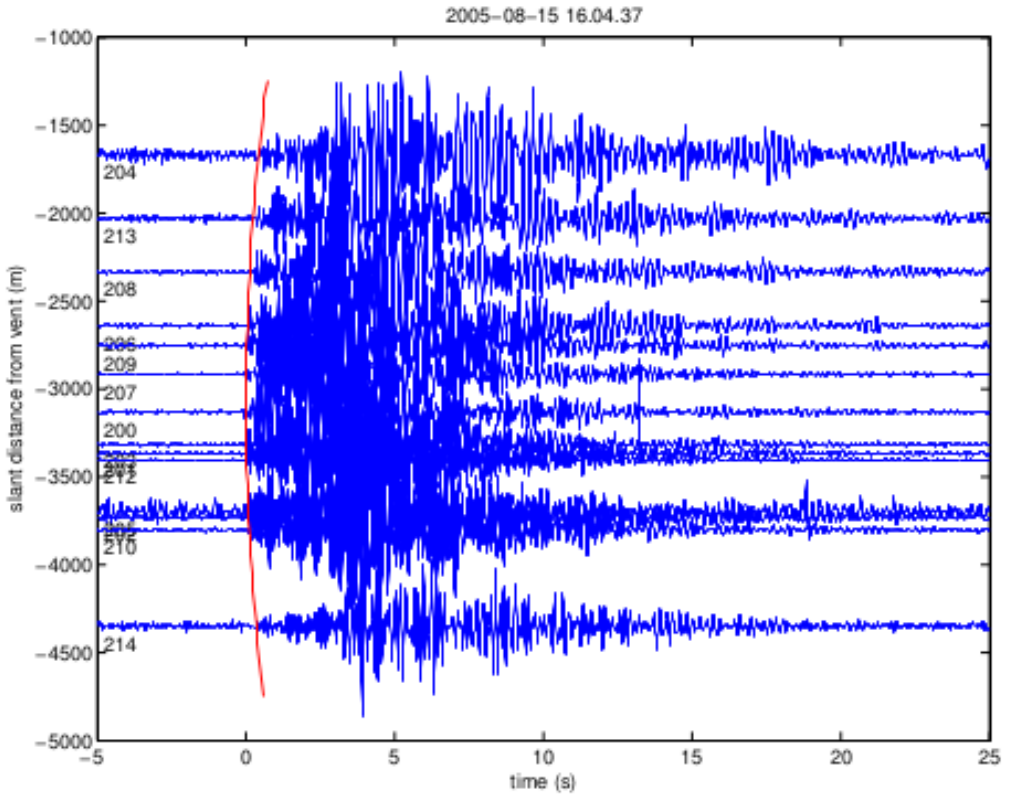


Figure 21: **Tectonic earthquake event at 08/15/2005 16:04:37 GMT.** *In this event, seismic waves are first recorded near the middle of the sensor array. This is due either to a source closer to the center of the array, variations in velocity structure, or most likely both.*

Earthquake

Related Work

- Little prior work
- Environmental systems
  - No high sampling rate, transmits all data
- Condition-based maintenance
  - NetSHM
    - No global time sync
    - Nodes closer to each other
- Volcano data is bursty and variable

Lessons Learned

- Failures in remote areas are costly
- Ground truth and self-validation is critical
  - Wouldn't have been able to resolve time bugs
- Devote more time to evaluate base station

- Listen to scientists!

Conclusion

- Looks promising, needs more testing
- Plan to continue with volcanoes, want 50-100 node network
- Reducing power consumption
- Collaborative signal processing in-network