WSN Applications

~Clinical Monitoring~

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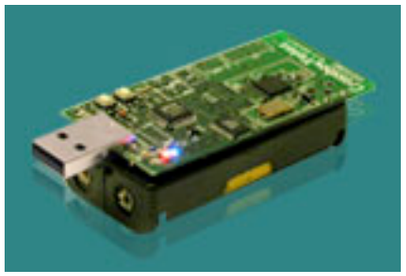
Agenda

- Hardware available for projects
- Talk about possible projects among yourselves (15 mins)
- Reliable Clinical Monitoring using WSN
- Next class:
  - TinyOS
  - **first critique due on Thursday, Sept 2nd before 11:59am**

Hardware



TelosB
19 available

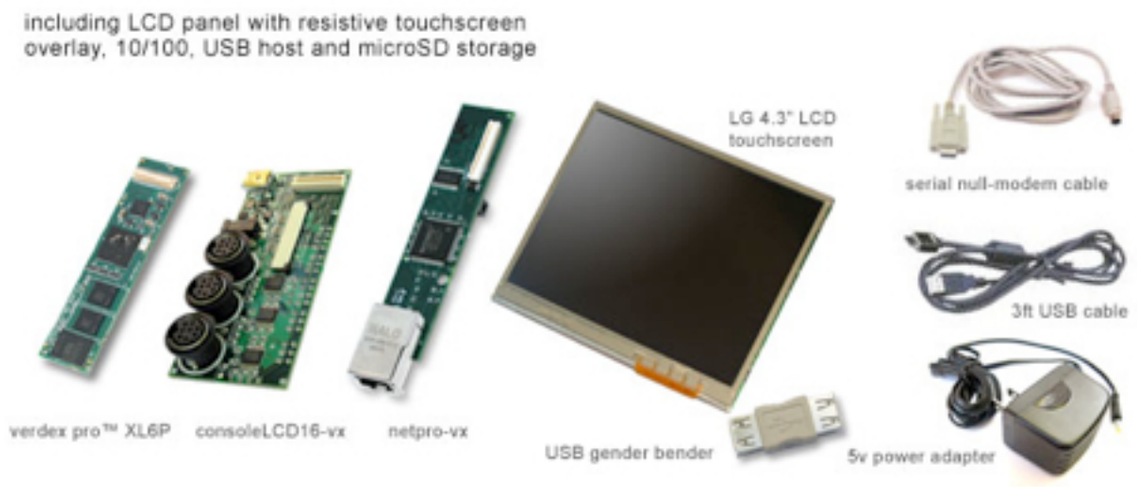
IRIS
30 available
20 sensor boards with light + temp sensors

?

LOTUS
5 available
2 sensor boards

http://www.memsic.com/products/wireless-sensor-networks/wireless-modules.html

Hardware



LCD pro pack

1 available

Overo

2 available

http://www.gumstix.com/store/product_info.php?products_id=202

Reliable Clinical Monitoring using Wireless Sensor Networks: Experiences from a Step-down Hospital Unit

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Motivation

- Clinical deterioration in hospitalized patients
  - 4-17% suffer from adverse events such as cardiac or respiratory arrest.
  - Up to 70% of such events could have been prevented.
- Early detection of clinical deterioration based on vital signs
  - clinical deterioration is often preceded by changes in vitals
- Real-time patient monitoring is required
  - wired patient monitoring equipment in Intensive Care Units
  - most general hospital units collect vitals manually
  - wireless telemetry systems too expensive for wide adoption

Goal: reliable wireless clinical monitoring for general hospital units

Our Approach

1. Build a clinical monitoring system using sensor networks.
2. Deploy it in a general hospital unit over 7 months.
3. Clinical trial with 46 hospitalized patients.
4. Holistic system reliability study: network and sensor.
5. Demonstrate potential for clinical event detection.

System Architecture

- Base station
  - Laptop connected to Wi-Fi
- Relays
  - Plugged into wall outlets
  - Redundant deployment
    - coverage
    - fault tolerance
- Portable pulse oximeter
  - pulse oximeter + microcontroller + radio
  - battery operated

Reliable Network Architecture

Problem: Patients in general hospital units are ambulatory.

Solution: Two-tier architecture for end-to-end data delivery.

1 Dynamic Relay Association Protocol (DRAP): Patient -> 1st relay

- Dynamically associate the patient node with a relay
- Single-hop protocol handles patient mobility
- Simplify power management in patient nodes (send only)

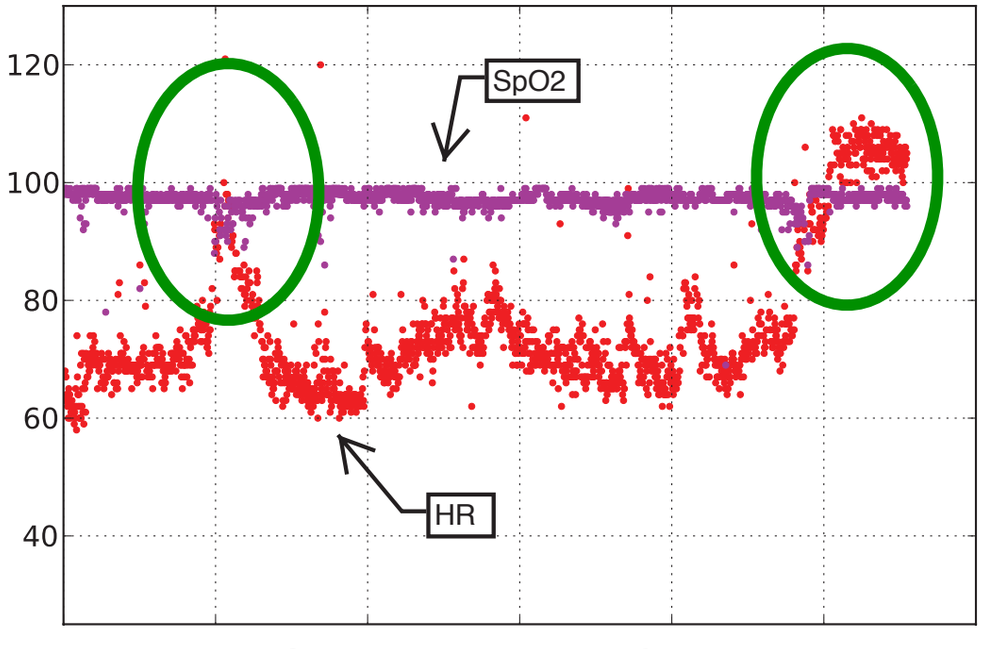
2 Stationary relay network: 1st relay -> … -> base station

- Reuse well tested mesh routing protocol: CTP
- Isolated from patient mobility
- Wall-plugged => no need to worry about energy

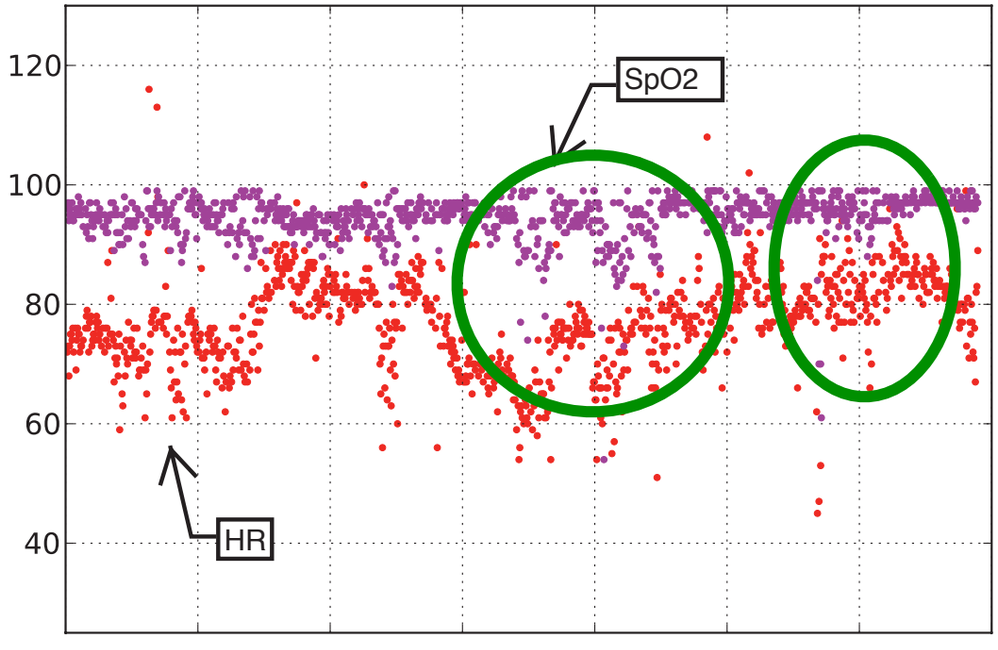
Clinical Deployment

- Step-down cardiac care unit
  - 16 patient rooms, 1200 m^2
- Network
  - 18 relays: redundant network
  - Longest path: 3-4 hops
  - Channel 26 of IEEE 802.15.4
- Pulse and oxygenation collected every 30 or 60 seconds
- 46 patients enrolled
  - >41 days of monitoring
  - 2-68 hours per patient
  - 5 patients excluded from analysis
  - Up to 3 patients at a time

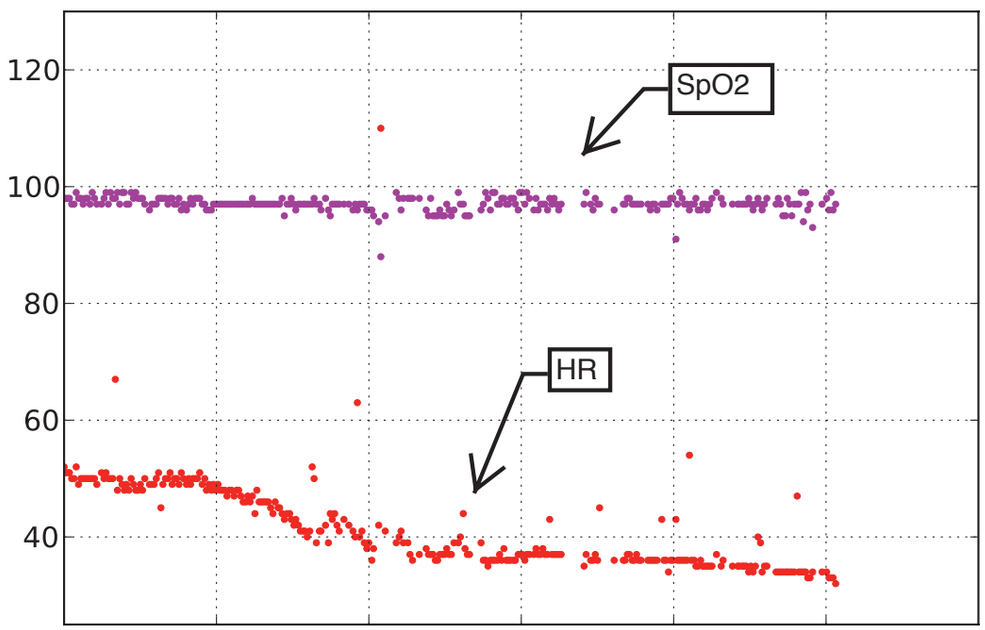
Potential for Detecting Clinical Deterioration



Pulmonary edema



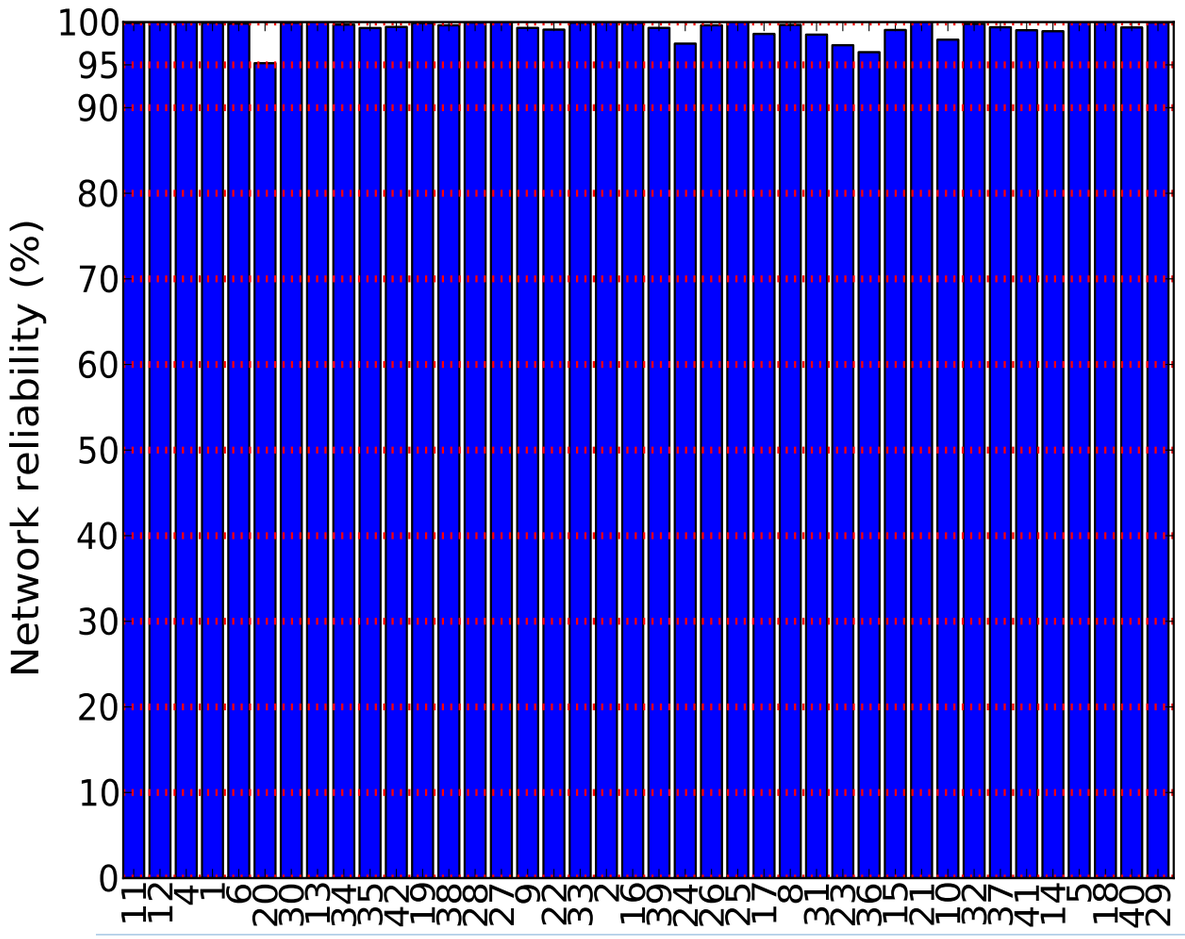
Sleep apnea

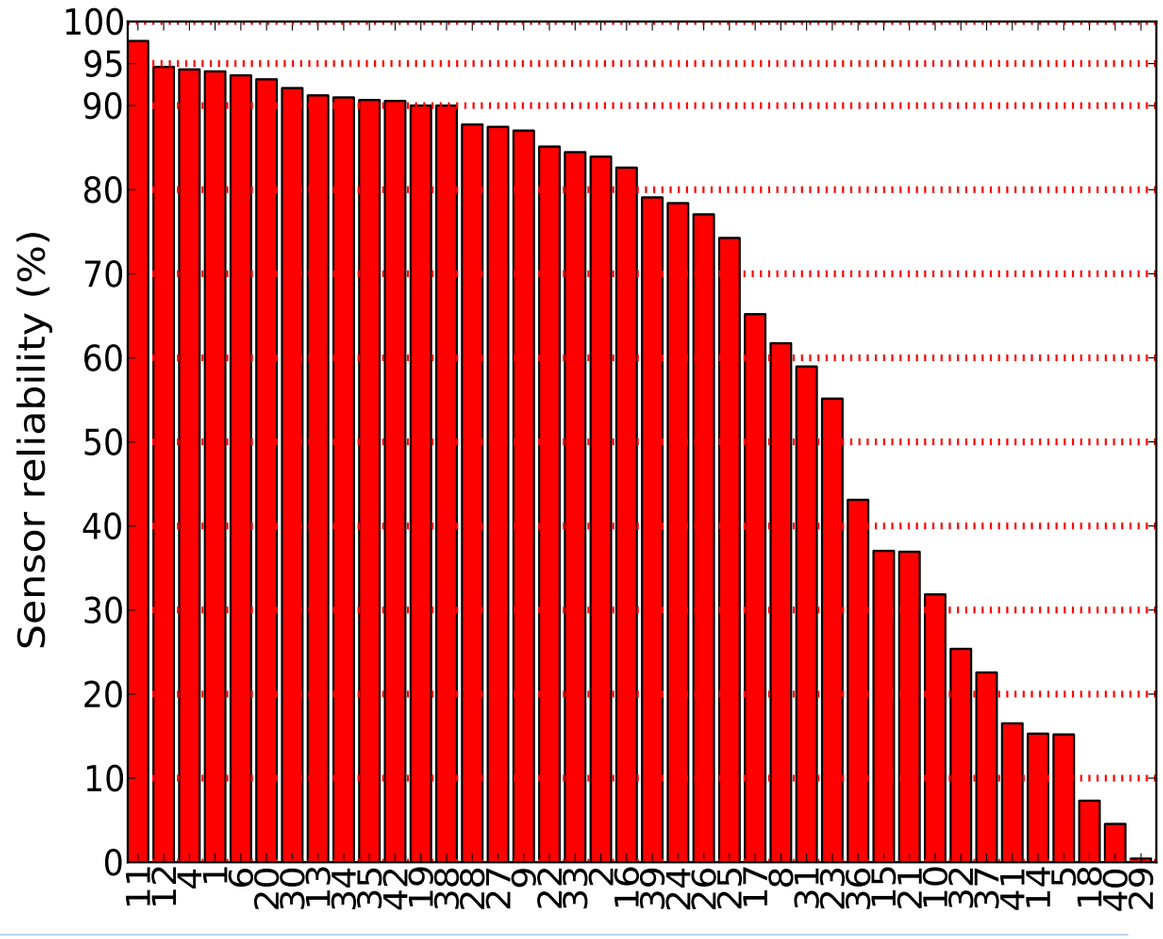


Bradycardia

System Reliability

- Network reliability >95% for all patients.
  - Effectiveness of DRAP+CTP
- Median sensing reliability > 80%.
  - But 29% of patients with sensing reliability < 50%
- System reliability dominated by sensing reliability.

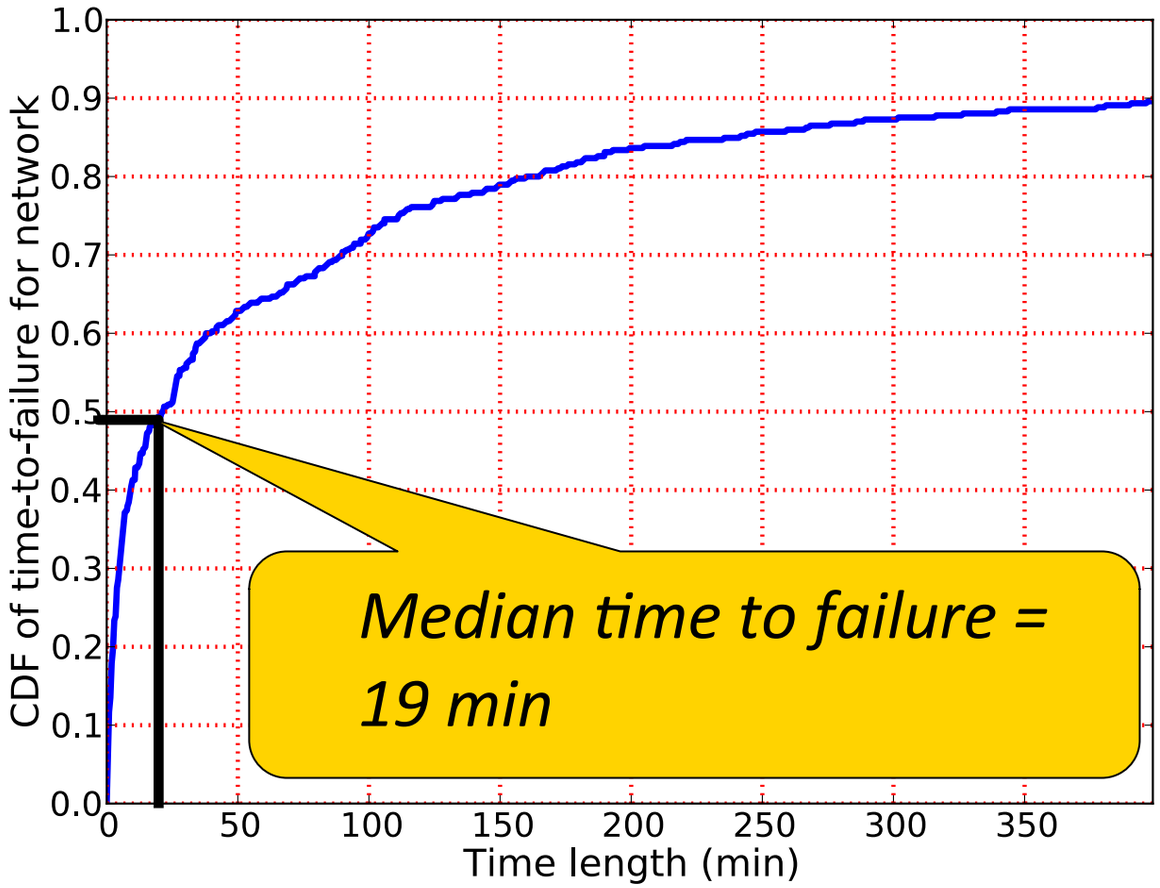




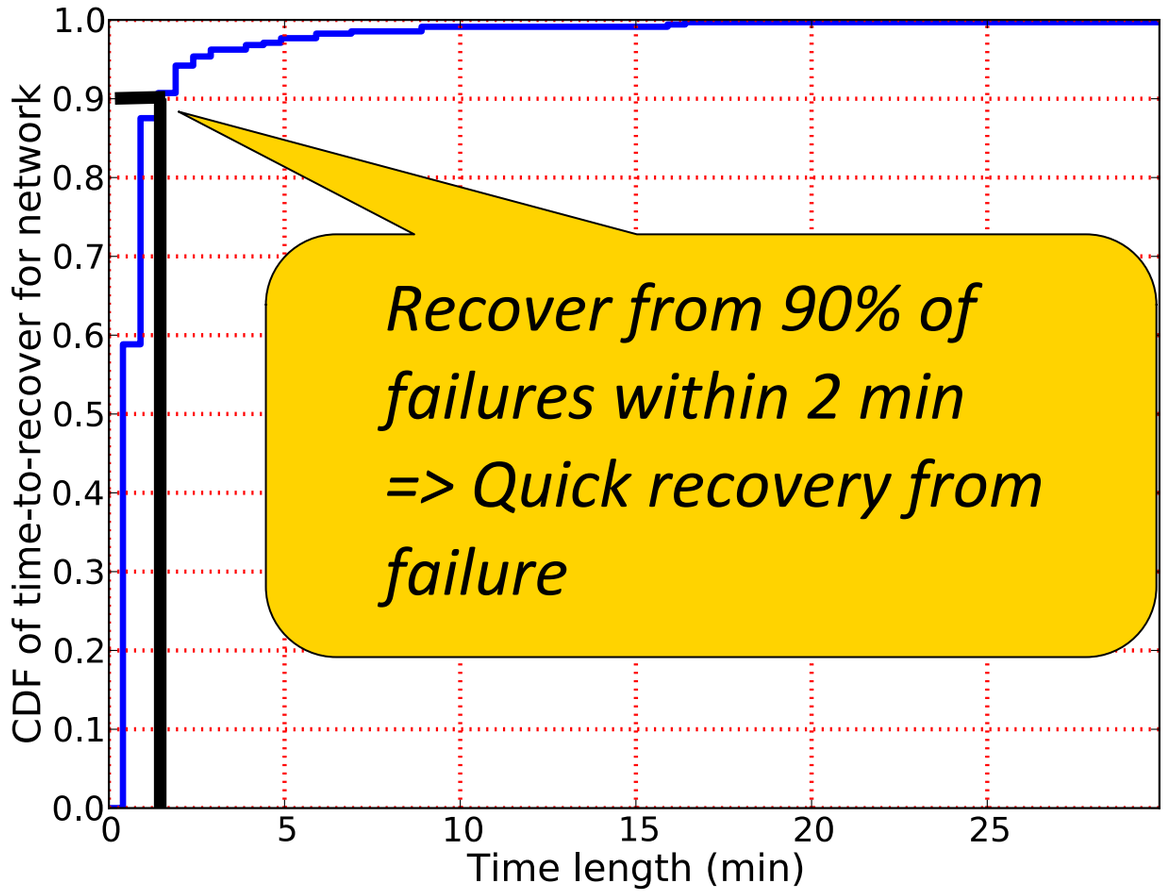
Network Reliability

- Time-to-failure
  - Time interval during which a system continuously operate till a failure occurs.
- Time-to-recovery
  - Time interval from the occurrence of a failure till when the system recovers.

CDF of time-to-failure



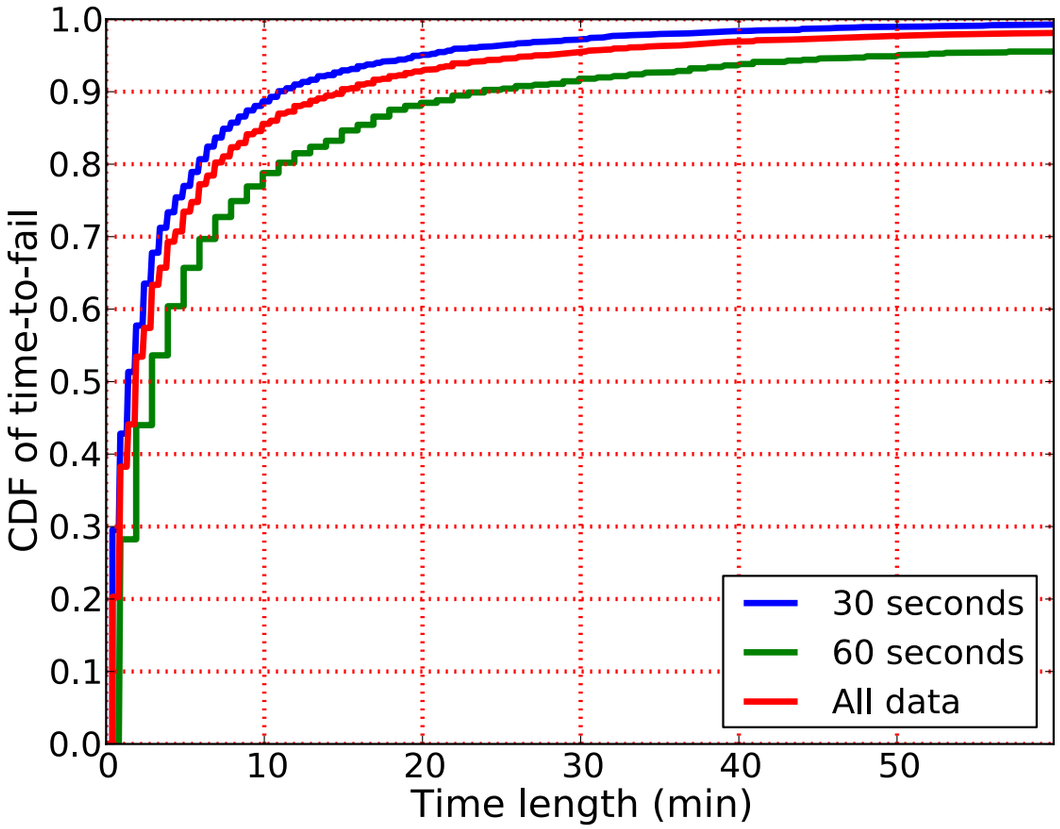
CDF of time-to-recovery



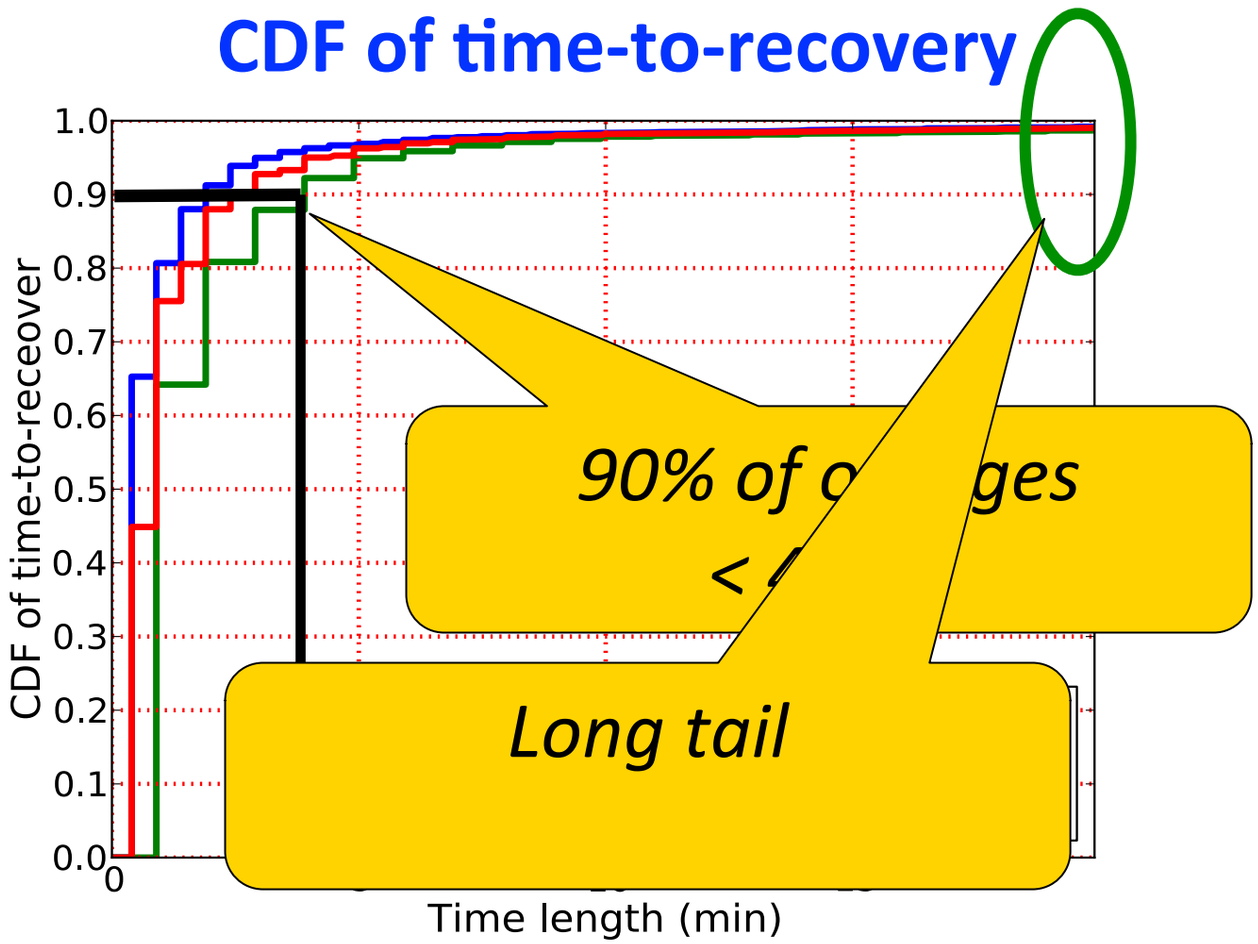
Sensing Reliability

- Failures are common: median time-to-failure < 2 min
- Recover from 90% of sensing failures within 4 min
  - Transient failures caused by human movement
- Long-tailed distribution for time-to-recovery
  - Sensor disconnection

CDF of time-to-failure

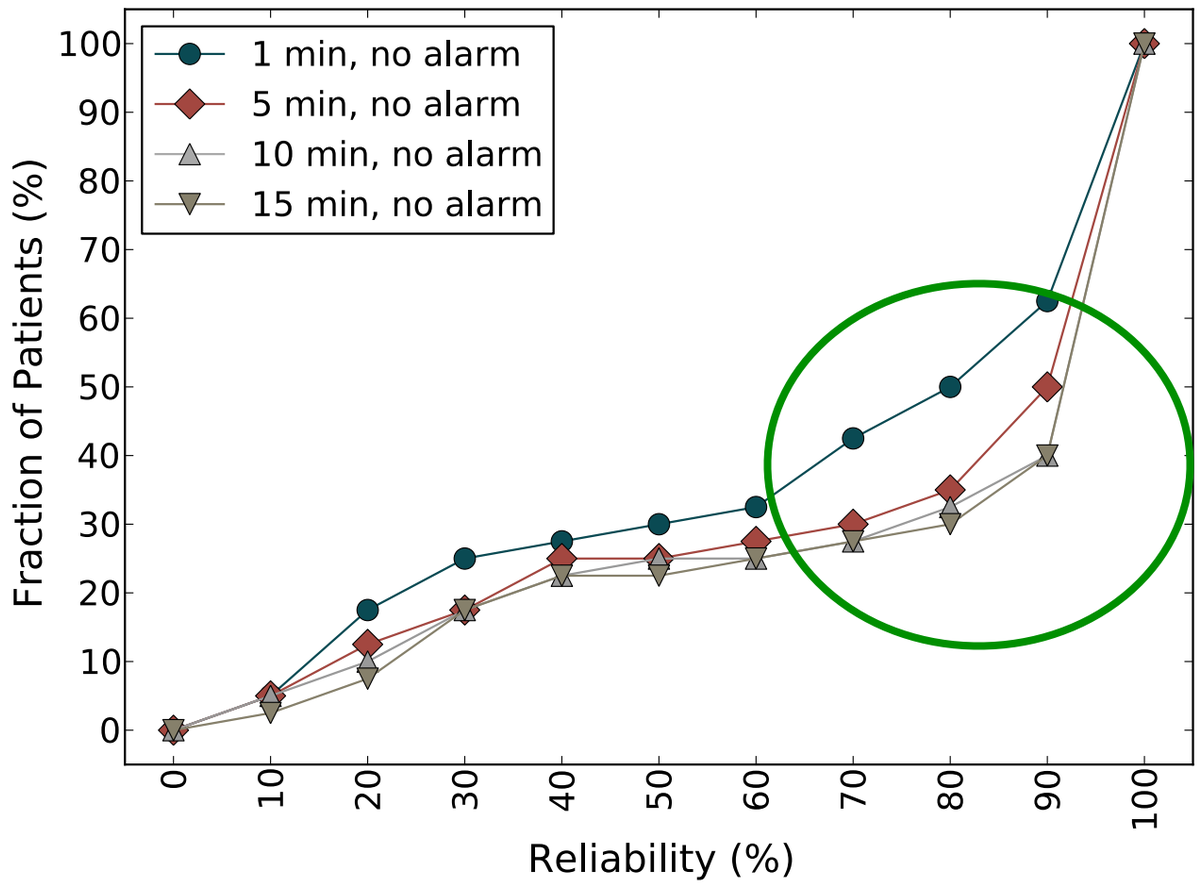


CDF of time-to-recovery



Relax Sampling Rates

- Increase required sampling period to 5, 10, 15 min
  - Oversample at 1-2 reading/min
  - Considered a success if one valid measurement per required sampling period
  - Still orders of magnitude higher rate than manual measurement
- Higher reliability at a sampling period of 5 min
  - Diminishing return at longer sampling periods

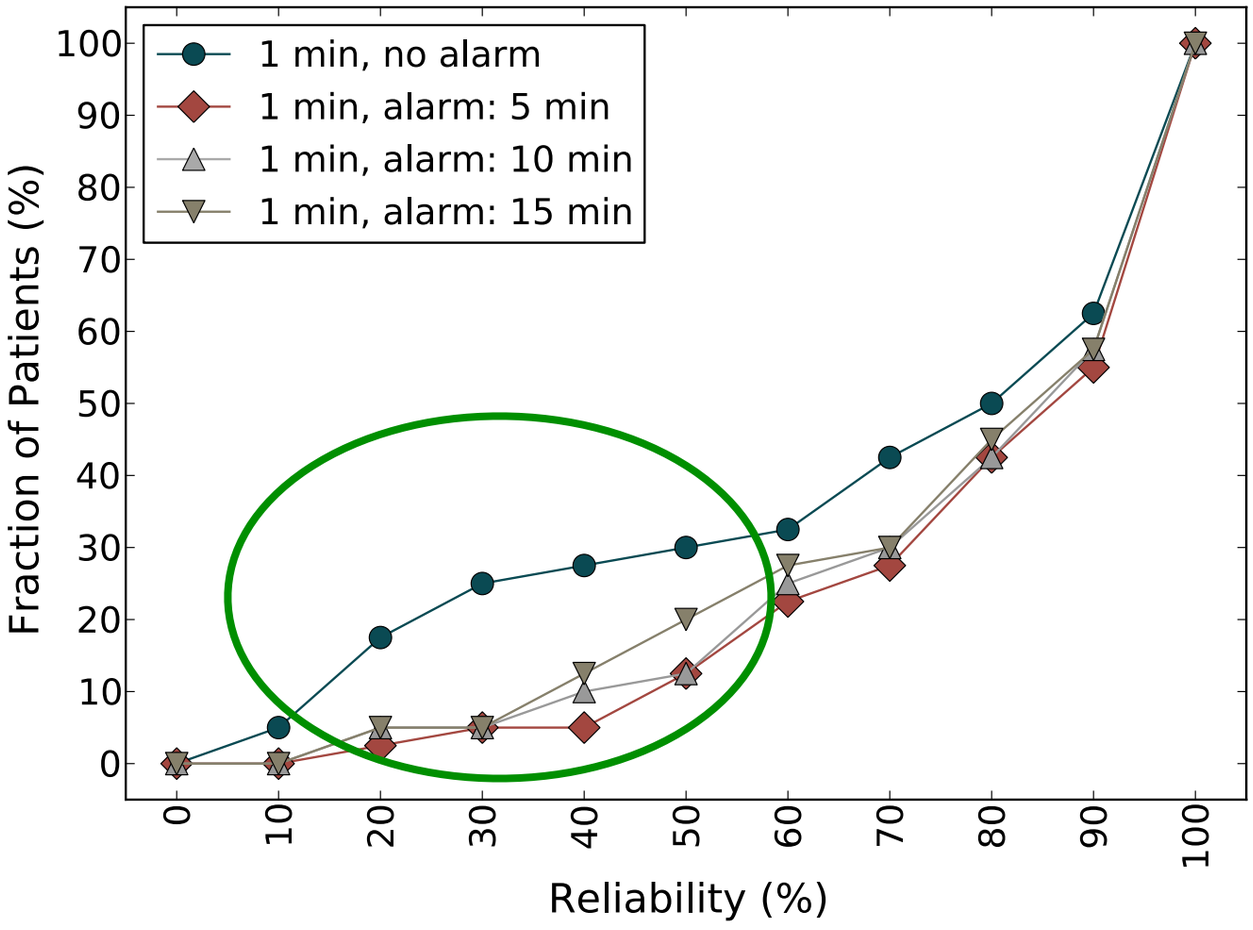


Sensing reliability at different sampling rates

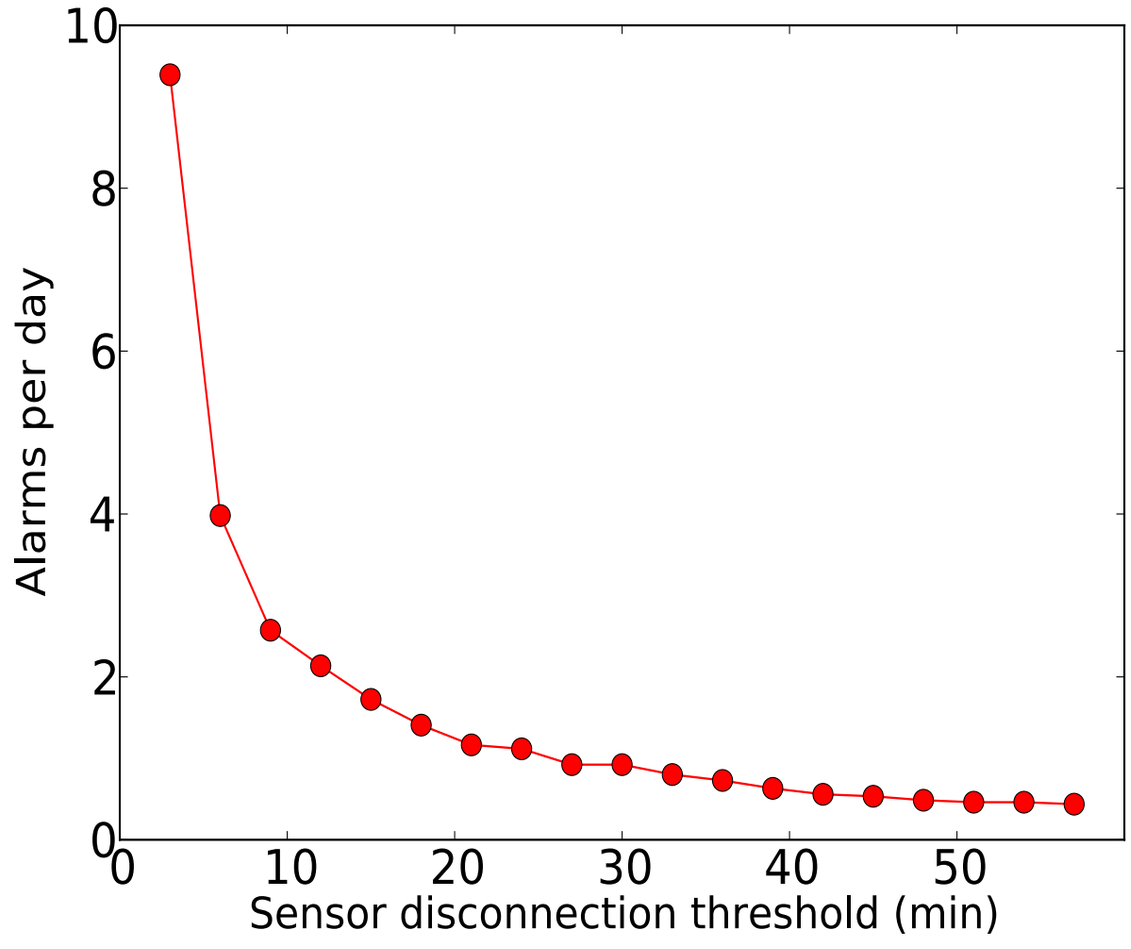
Sensor Disconnection Alarms

- Automatically notify nurse after receiving no data for a timeout threshold
- 15 min timeout balances #alarms vs. reliability gain
  - Infrequent alarms: 1.55 interventions per patient, per day
  - Similar reliability to 5 and 10 min timeouts

Sensing reliability with different timeouts

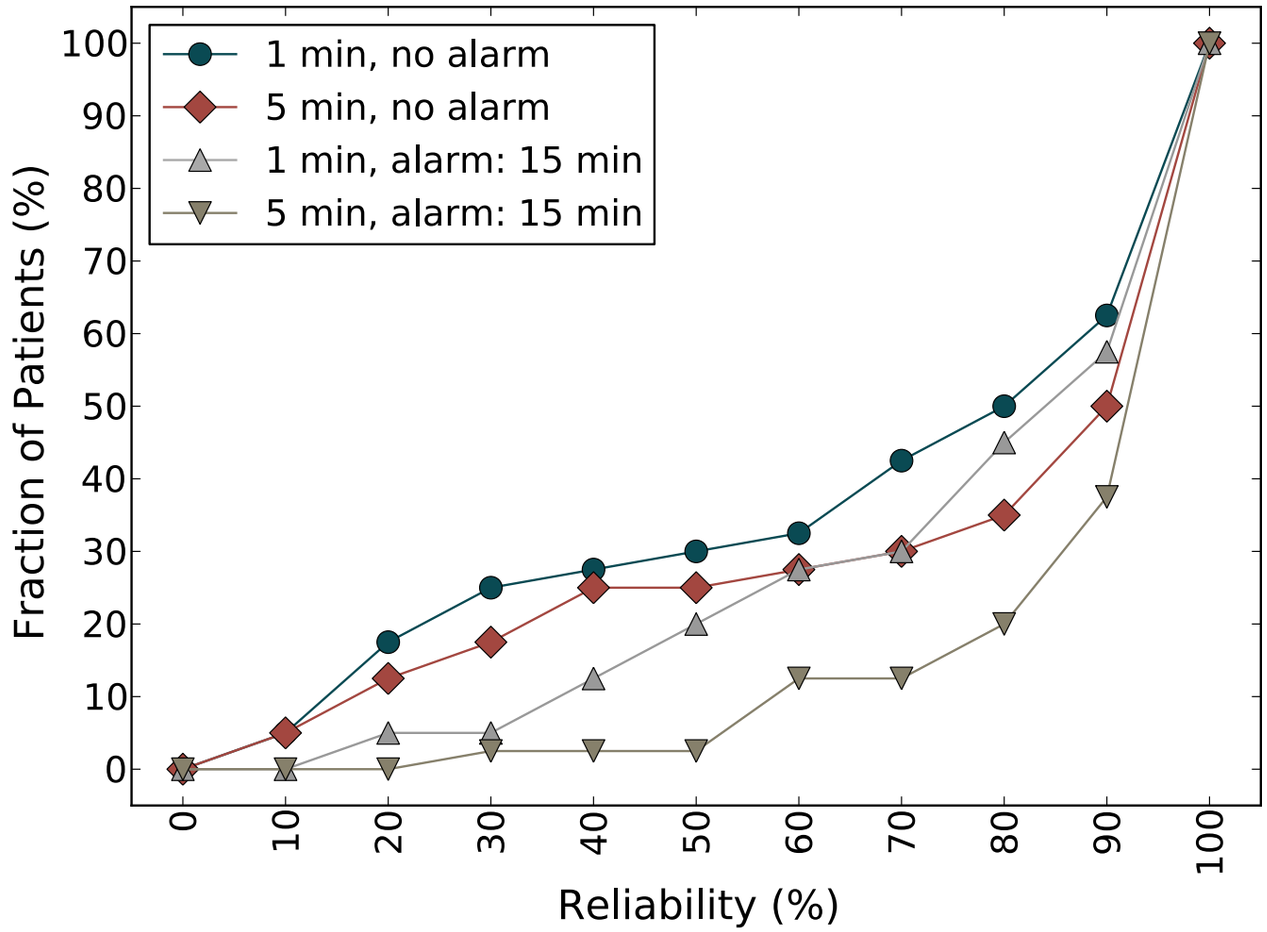


#alarms per day



Putting them together

- Disconnection alarms and oversampling are complementary.
  - Disconnection alarms => handles sensor disconnection
  - Oversampling => handles intermittent failures caused by movement
- 88% of patients with >70% sensing reliability with 5 min sampling period and 15 min timeout



Wireless Sensor Networks vs. Wi-Fi

- More energy efficient than Wi-Fi at low data rate
  - Common vital signs have low data rate.
  - Nurses are too busy to change batteries!
- Low deployment cost
  - Mesh networks without wired infrastructure.
  - Ease adoption (e.g., field hospitals, rural areas).
  - Even major hospitals may not guarantee full Wi-Fi coverage.
- Sufficient reliability
  - Median network reliability > 99% in our clinical trial.
  - Even a wired network would improve reliability only marginally.

Conclusion

- Wireless clinical monitoring for general hospital units.
- Clinical trial in a step-down hospital unit
  - Highly reliable network
  - System reliability dominated by pulse oximeter sensors
    - Oversampling
    - Disconnection alarms
  - Potential for detecting clinical deterioration

- On-going: real-time clinical event detection
  - Integration with electronic medical records
  - Event detection based on machine learning
  - Automatic alarms for early intervention
  - Larger clinical trial of event detection system