CitySense

An Open, City-Wide Wireless Sensor Network

Matt Welsh

Harvard University

School of Engineering and Applied Sciences

with Ian Rose, Geoff Mainland, Rohan Murty, Atanu Roy Chowdhury, Matt Tierney, Jonathan Hyman, Karen Feng, and William Cheng (Harvard University); Josh Bers and Abhimanyu Gosain (BBN Technologies)

CitySense Concept

An open wireless sensor network testbed
for urban-scale monitoring and experimentation

100 single-board computers with 802.11, mounted on streetlights and rooftops around a city

Sensors to monitor
air quality, weather,
noise pollution,
road traffic...

Programmable by
anyone!

Why CitySense?

Expand sensor networking testbeds beyond indoor deployments with mote-class devices

- Outdoor testbed with large coverage area
- Powered nodes with substantial CPU/memory/radio bandwidth
- Provide blueprint for future sensor network designs and deployments

Shared resource open to research community

- Draw on experience with PlanetLab, MoteLab, Emulab, and others

Provide bridge to broader research communities

- Homeland security, public health, environment
- NSF GENI initiative
- Educational impact at graduate, undergraduate, and K-12 levels

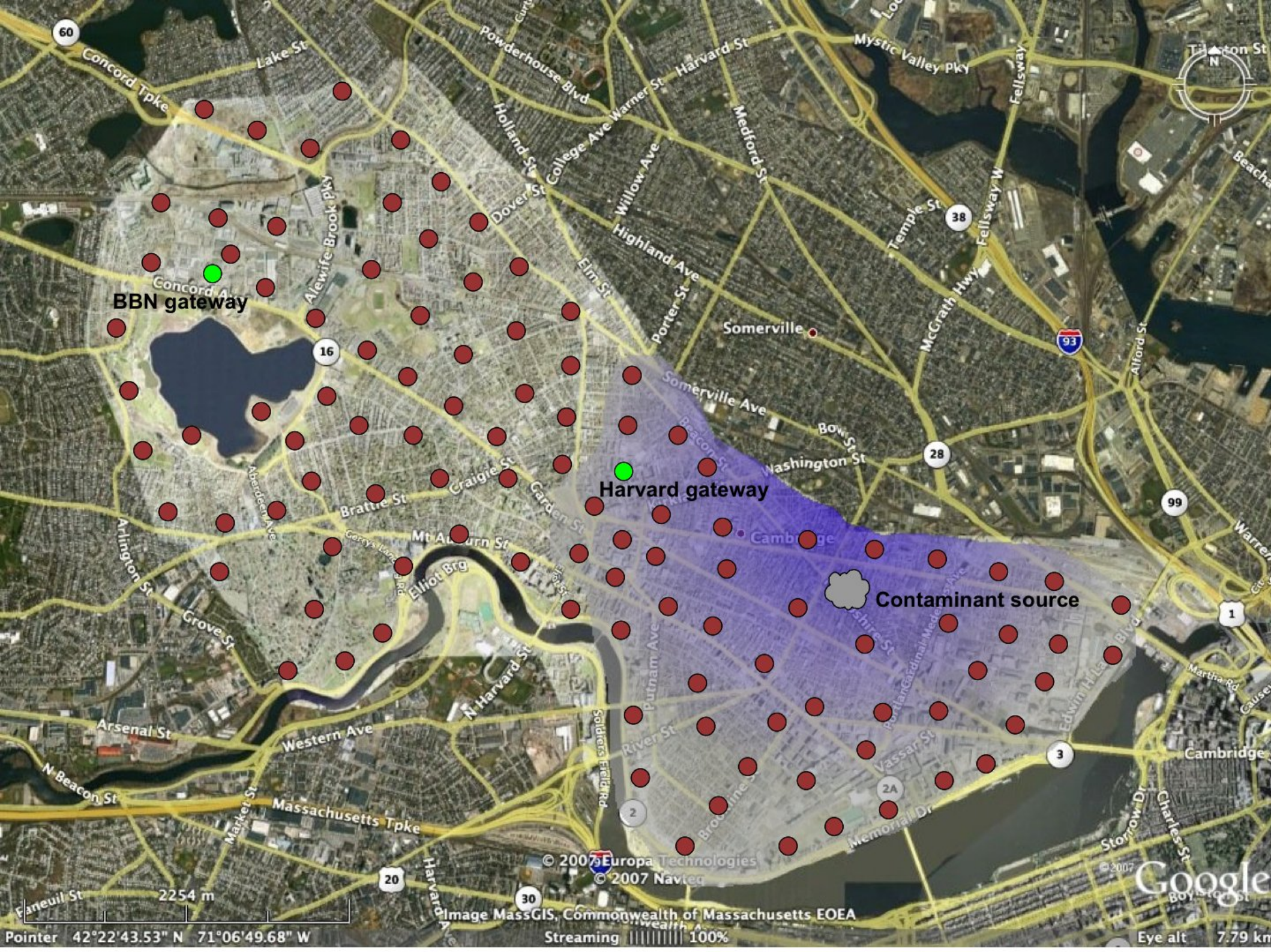
BBN gateway
Harvard gateway
Contaminant source
Somerville
Cambridge
Concord Tpke
Lake St
Powderhouse Blvd
Harvard St
Mystic Valley Pkwy
Fellsway
Holland St
College Ave
Warner St
Willow Ave
Medford St
Dover St
Highland Ave
Elm St
Porter St
Temple St
Fellsway W
McGrath Hwy
Alewife Brook Pkwy
Somerville Ave
Bow St
Washington St
Alford St
Craigie St
Garden St
Brattle St
Aberdeen Ave
Arlington St
Grove St
Mt Auburn St
Elliot Brg
Putnam Ave
River St
Vassar St
Memorial Dr
Edwin H Land Blvd
Martha Rd
Storrow Dr
Charles St
Western Ave
Arsenal St
N Beacon St
Massachusetts Tpke
Market St
N Harvard St
Soldiers Field Rd
Harvard Ave
Faneuil St
2254 m
© 2007 Europa Technologies
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Image MassGIS, Commonwealth of Massachusetts EOEA
© 2007 Google
Pointer 42°22'43.53" N 71°06'49.68" W
Streaming 100%
Eye alt 7.79 km

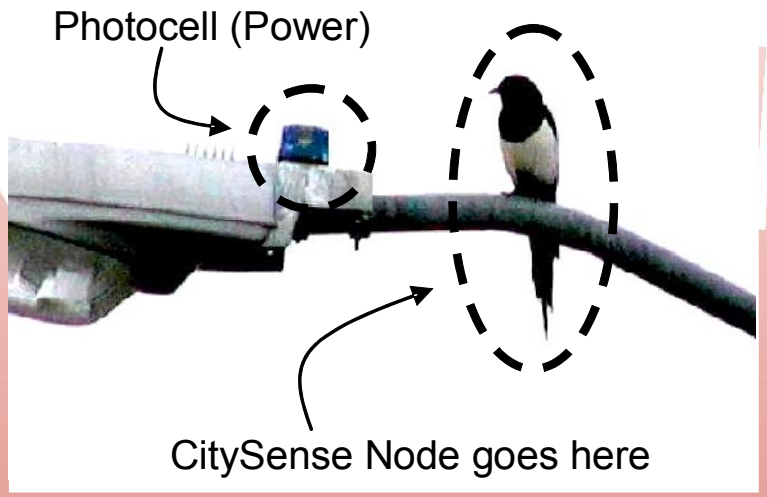
CitySense Node Design

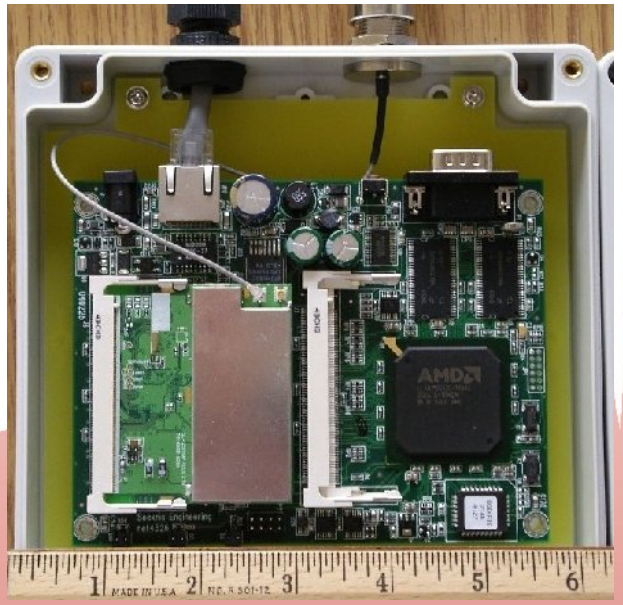
Soekris net4826 embedded PC

- 256 MB of RAM+flash, 2 GB USB flash drive
- NEMA-6x rated enclosure
- Running FreeBSD (Linux wireless drivers simply not stable)

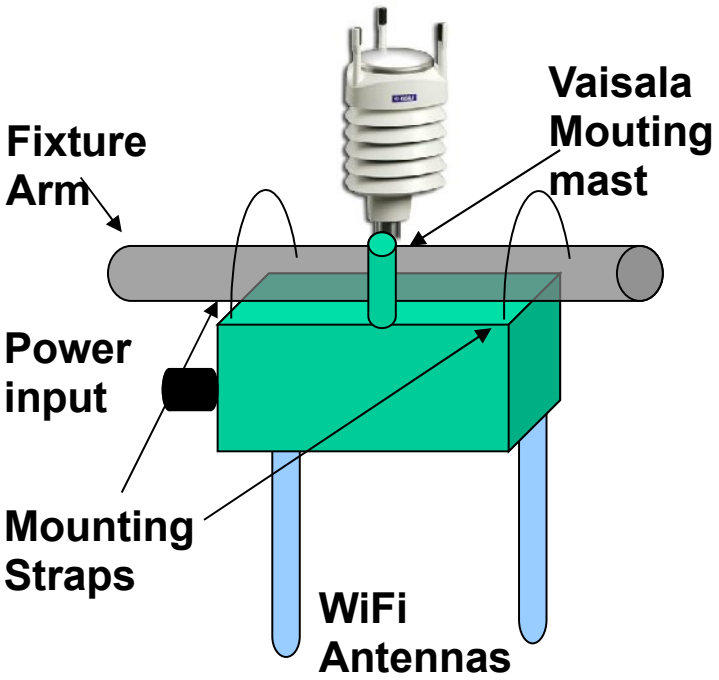
Dual 802.11 radios on orthogonal bands

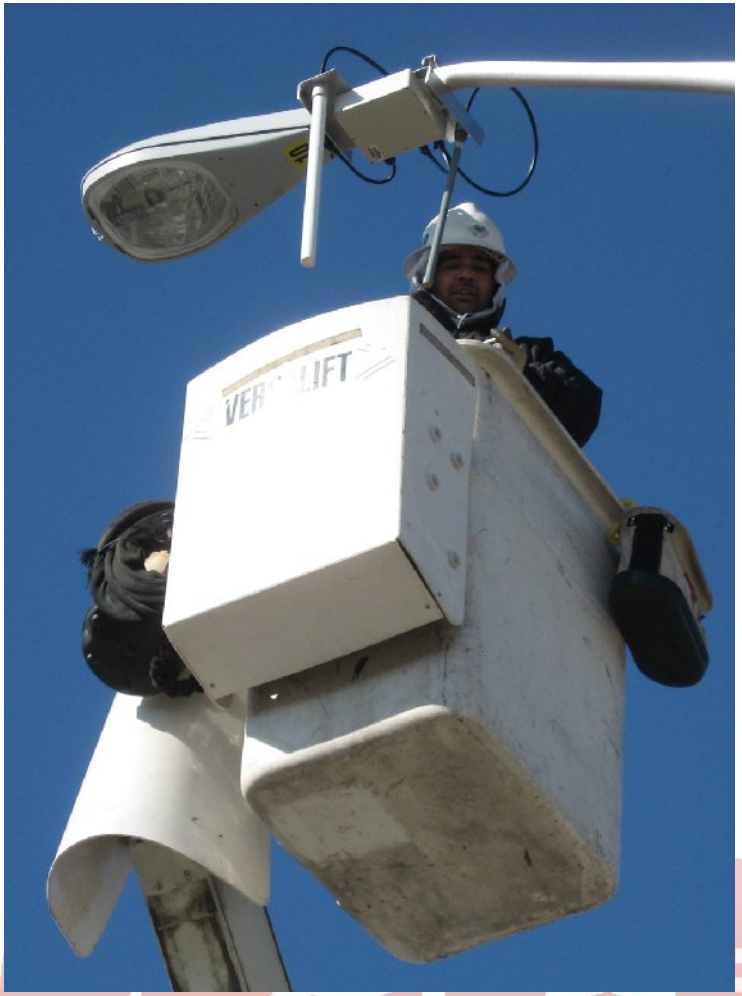
- One radio for backhaul connectivity, using mesh routing
- Second radio for experimental use





CitySense Node Prototype





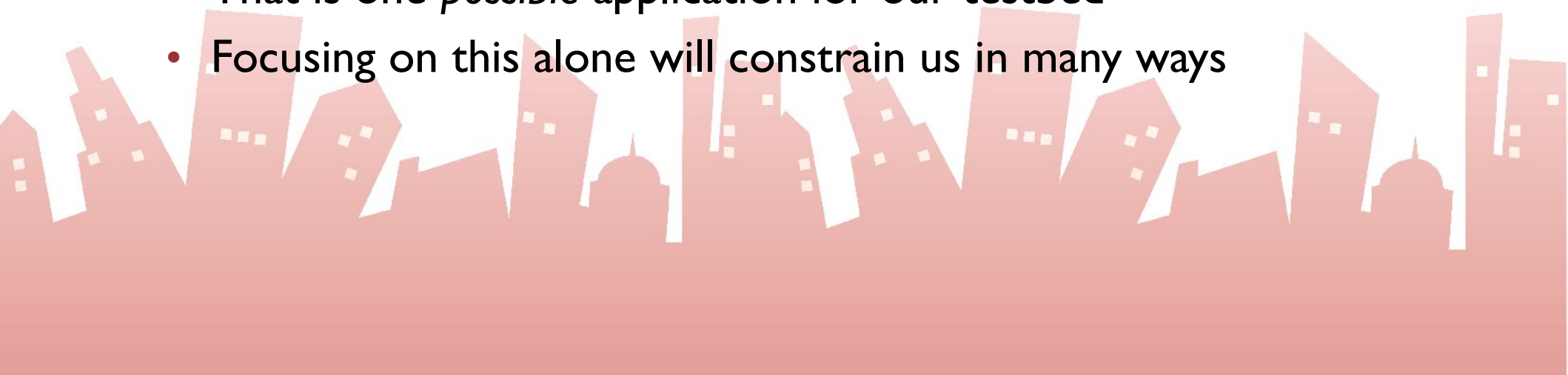
Harvard Rooftop Installation

Target Application Domains

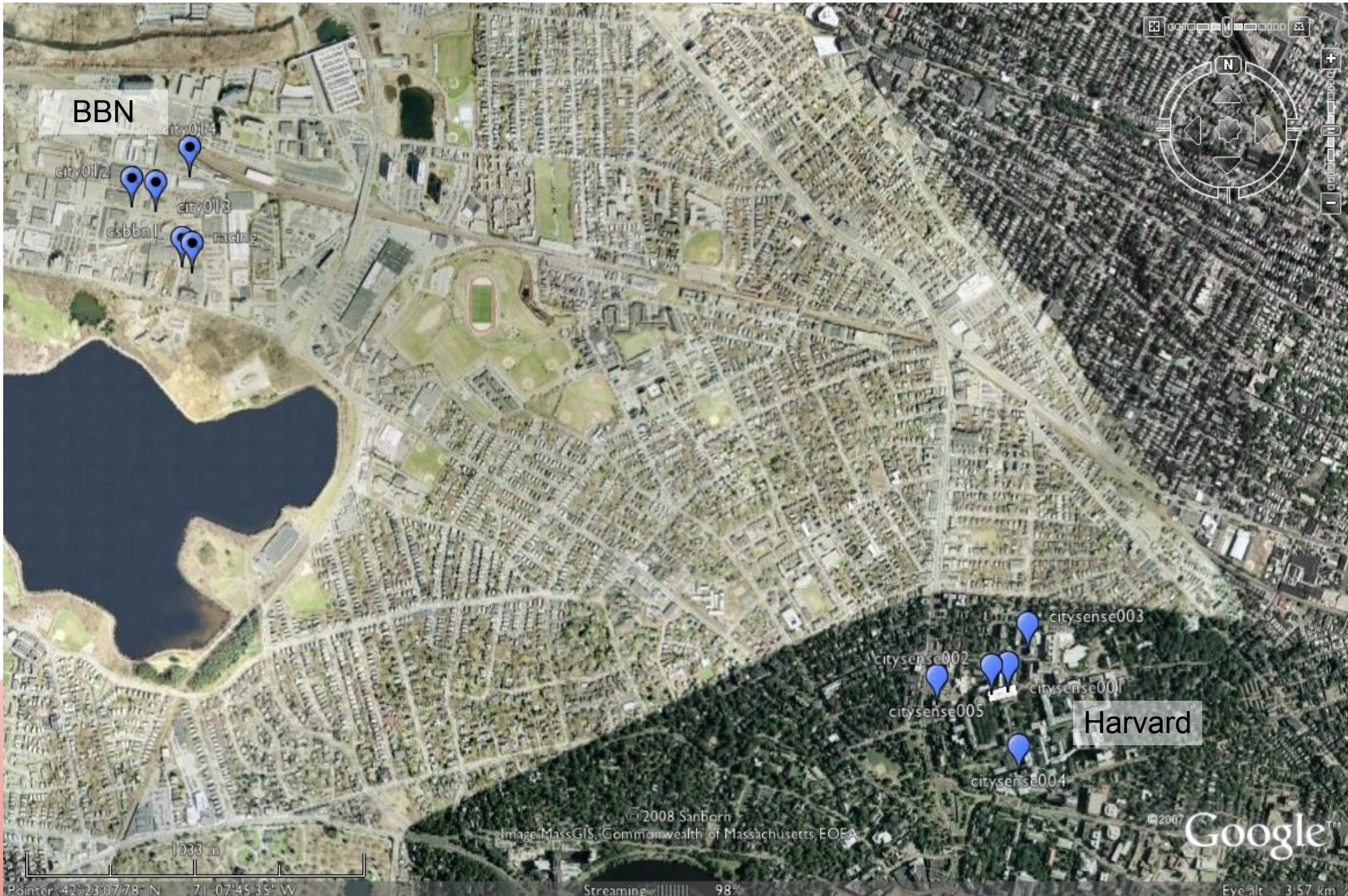
- Public health studies
  - Air quality and exposure levels, related to road traffic and weather
- Urban and participatory sensing
  - Combine data from static CitySense sensors, and mobile sensors carried by individuals or mounted on vehicles
- Homeland security applications
  - Bio/chemical plume detection and tracking, urban surveillance
- Novel distributed systems and applications
  - City-scale wireless network monitoring, location-enhanced social networking, wireless content distribution
- Goal is to be open-ended
  - Can't anticipate up front all possible use cases.

Some non-goals of this project...

- Reinvent mesh networking
  - Great deal of work has been invested in this; commercial solutions are out there.
  - Let's build upon the best work in this area and look at what can be done using mesh network as a foundation.
  - We will support *other* research groups wanting to experiment with new mesh routing protocols
- Provide public Wifi access
  - That is one *possible* application for our testbed
  - Focusing on this alone will constrain us in many ways



Current Deployment



Vaisala weather sensor

Weather Transmitter WXT510

- Wind speed and direction
- Precipitation
- Barometric pressure
- Temperature
- Relative humidity

Well-calibrated sensor, robust packaging for outdoor use

- Designed for precise measurement of environmental conditions
- More accurate than typical component sensors used on motes

RS232 interface for configuration and data access

Other possible sensors

Air quality: PM10 particle concentration

- TSI SidePak personal aerosol monitor

Noise pollution

- Want to avoid use of microphones: Use specialized hardware just to measure overall dB level

Gases: CO_2, NO, O_3 etc.

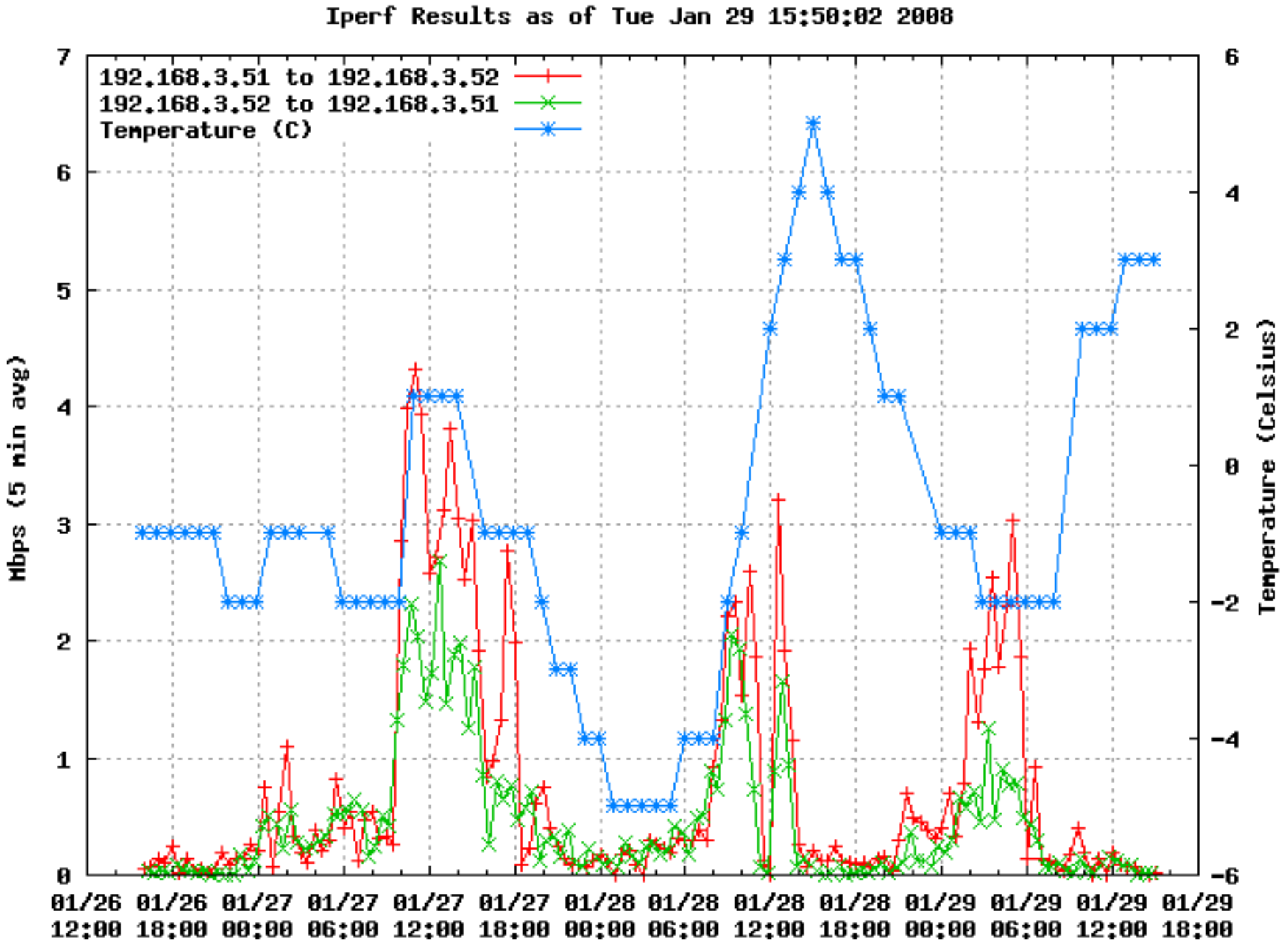
- Vaisala CO_2 sensor
- Siemens GasFET sensor array on a chip based on semiconducting metal oxides

CitySense Networking

- Most nodes will use wireless mesh for connectivity
  - A few nodes will have wired connectivity and act as gateways
- Dual radio node design
  - "Backhaul" radio for management and monitoring mesh
  - "Experimental" radio for user applications
- Backhaul radio
  - Ubiquiti SR9 radio: 900 MHz, 802.11 b/g, 700 mW tx power
  - > 1 km range possible
  - Mesh configured using OLSR or other existing protocol
- Experimental radio
  - Wistron CM9 802.11a/b/g: 2.4/5.3 Ghz, 60 mW tx power

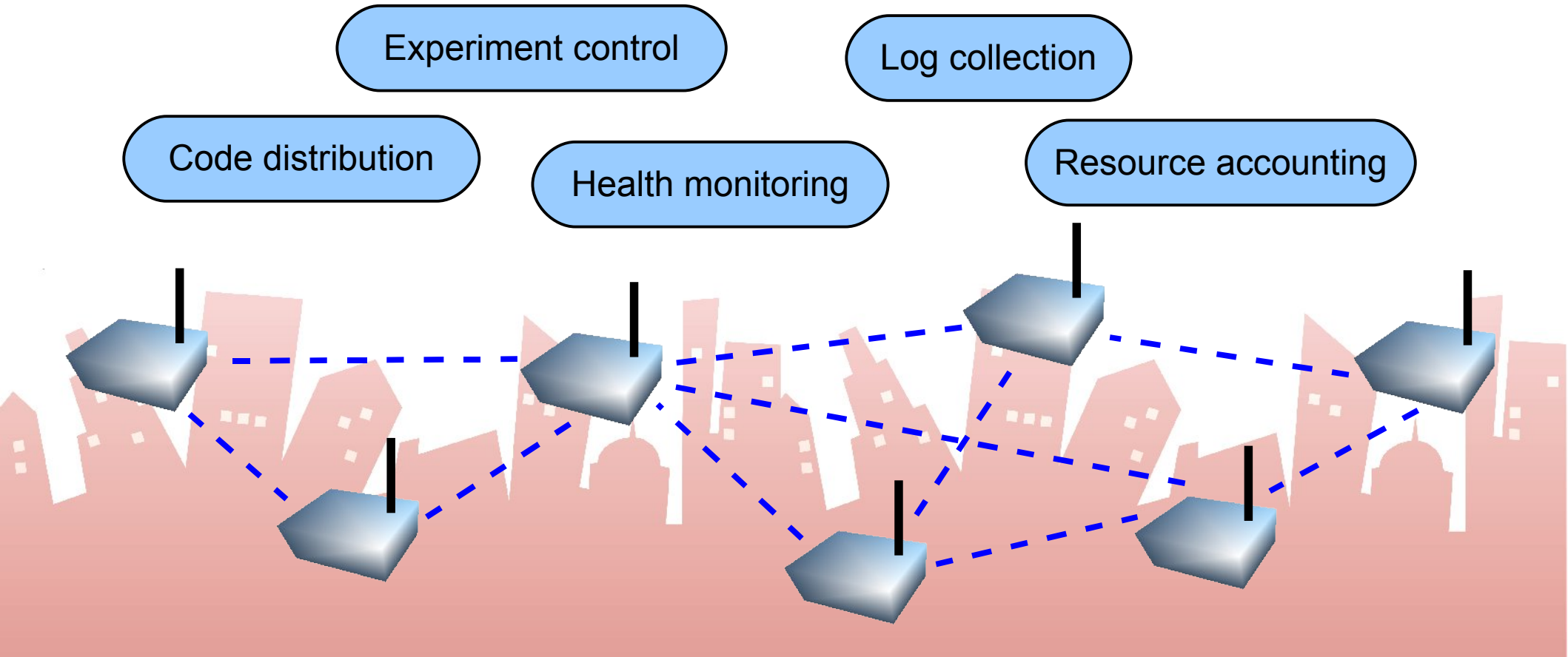
Link variability

Two nodes on same rooftop – 50m apart!



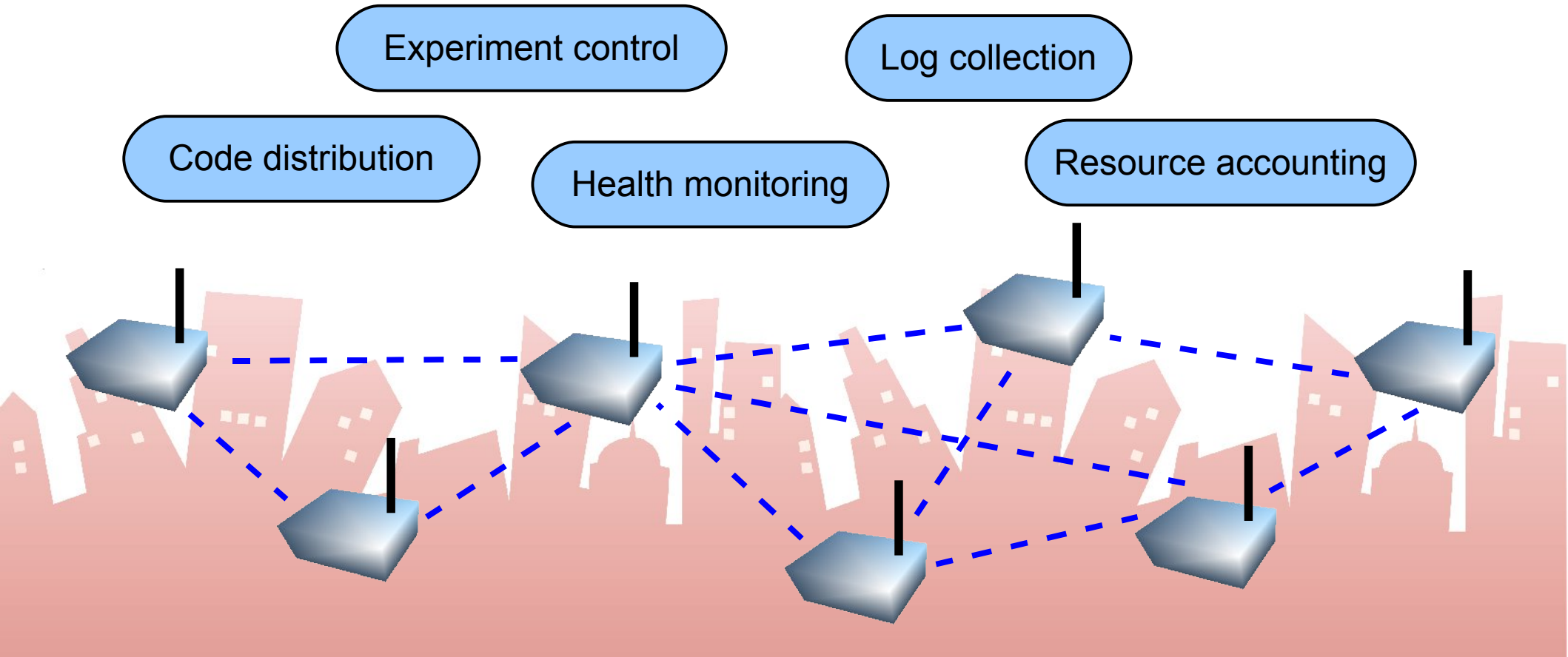
Distributed Services in CitySense

- How to design distributed services to run efficiently and robustly over a slow, unreliable mesh network?



Distributed Services in CitySense

- Guiding principles: Asynchronous messaging, weak consistency, frequent recovery.

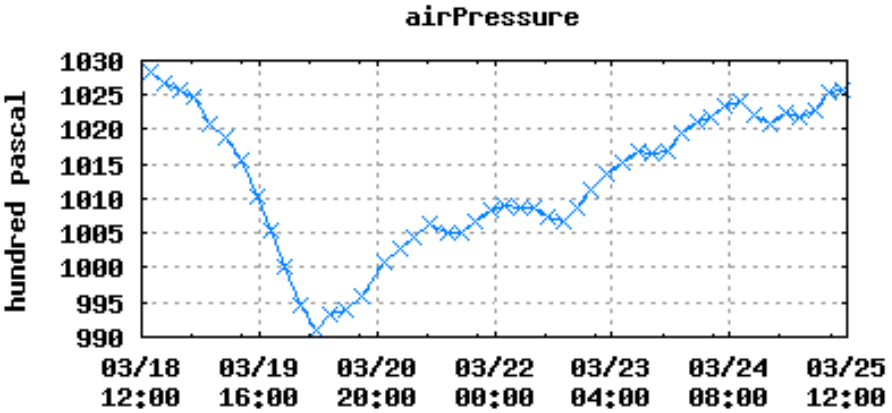


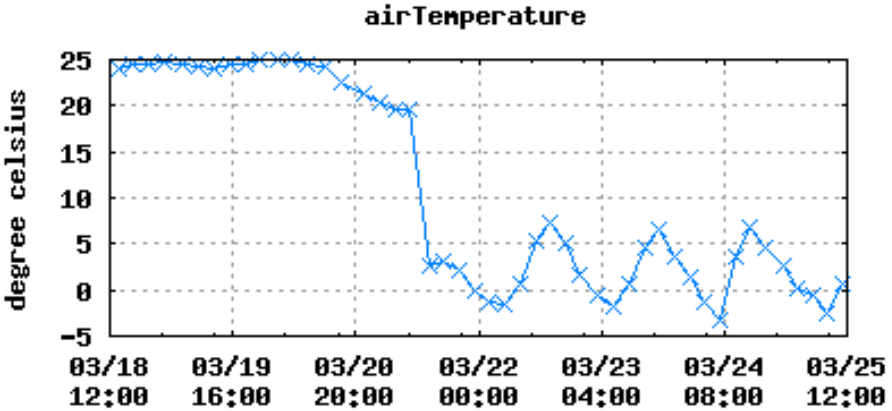
Remote Maintenance

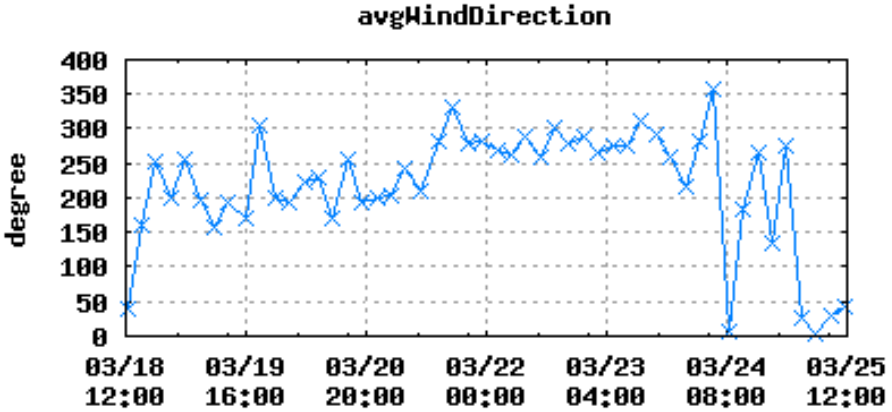
- We will not have physical access to nodes once deployed!
  - Need to ensure that nodes can be recovered to "known good" state in case of software crash or hang
- Soekris supports on-board hardware watchdog
  - Daemon checks node health and clears watchdog register only if things seem to be OK
  - Force reboot if network connectivity lost, memory leak, etc.
- Hardware grenade timer
  - Use cheap lamp timer to do hard reset once a day
  - (Nearly) foolproof and no need for fancy software support

Data Visualization

- http://atom.research.mi







Some surprises and lessons so far...

- Mesh routing not a closed book
  - Current efforts largely community-driven, lack of empirical evaluation
  - Difficult to reproduce previously reported results.
- Link variability much higher than expected
  - Plan to design for this as the common case, rather than expending much effort to fix it.
- Must rethink testbed architecture for untethered nodes
  - Can't import Emulab, PlanetLab, or ORBIT designs wholesale

Deployment status and plans

- 10 nodes deployed outdoors around Harvard and BBN campuses
- 20 nodes as indoor testbed at Harvard
  - Wired to Ethernet for rapid development and debugging
- Plan to roll out an additional 30 nodes this summer
- Ultimate goal: 100 nodes deployed throughout a city – current target is Cambridge, MA

Collaborators

Majid Ezzati: Co-PI Harvard School of Public Health → Urban pollution studies

Ken Mandl: Director of CHIP's program Childrens Hospital, Boston → real-time tracking of ER symptom reports

David Gute: Tufts University EE department: water quality sensors

Tom Little: BU EECS: video sensors

Chris Rogers & Marina Bers: Tufts EE: Educational Outreach → K-12 curriculum in sensor nets.

Summary

CitySense presents huge opportunity for the sensor network community

- Develop, deploy, and experiment with sensor networks at scale in complex real-world outdoor urban environment
- Shared research facilities for supporting diverse research groups

Still plenty of systems research territory

- Testbed management, monitoring, and control over unstable mesh backhaul
- Resource sharing and sandboxing for underprovisioned networks

CitySense is supported by grants from the National Science Foundation and Microsoft Corporation.

- For more information: http://www.citysense.net or mdw@eecs.harvard.edu