



CitySense

An Open, City-Wide Wireless Sensor Network

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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

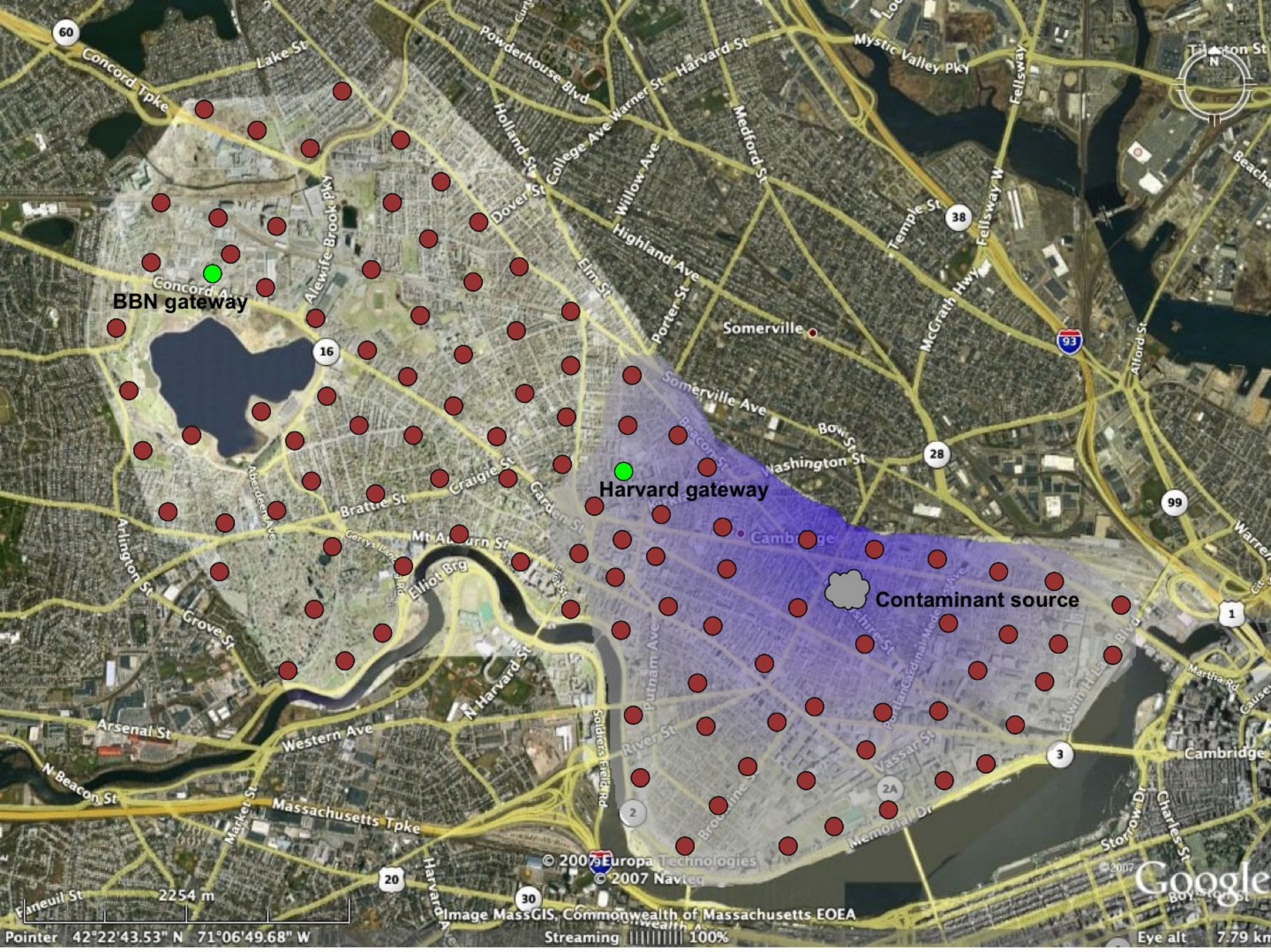
- Outdoor testbed with large coverage area
- Powered nodes with substantial CPU/memory/radio bandwidth
- Provide blueprint for future sensor network designs and deployments

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

© 2007 Europa Technologies

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Image MassGIS, Commonwealth of Massachusetts EOE

Streaming 100%

Google

Eye alt 7.79 km

Pointer 42°22'43.53" N 71°06'49.68" W

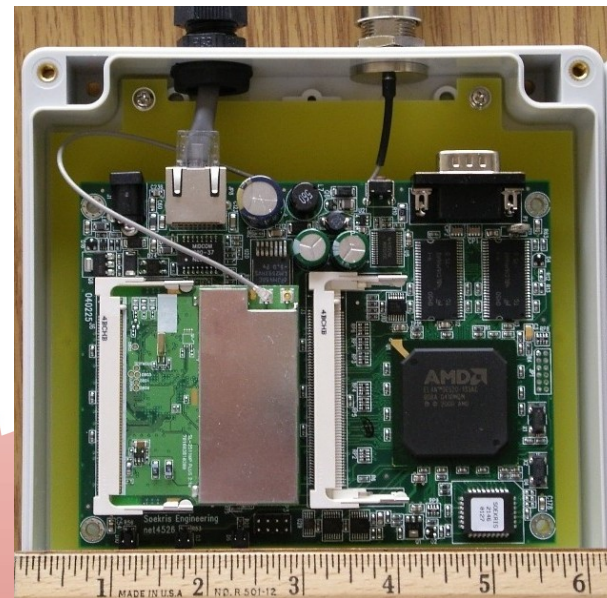
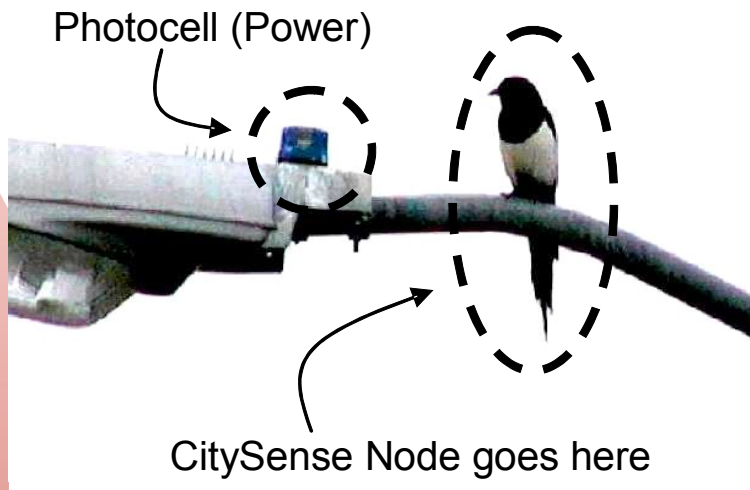
CitySense Node Design

Soekris net4826 embedded PC

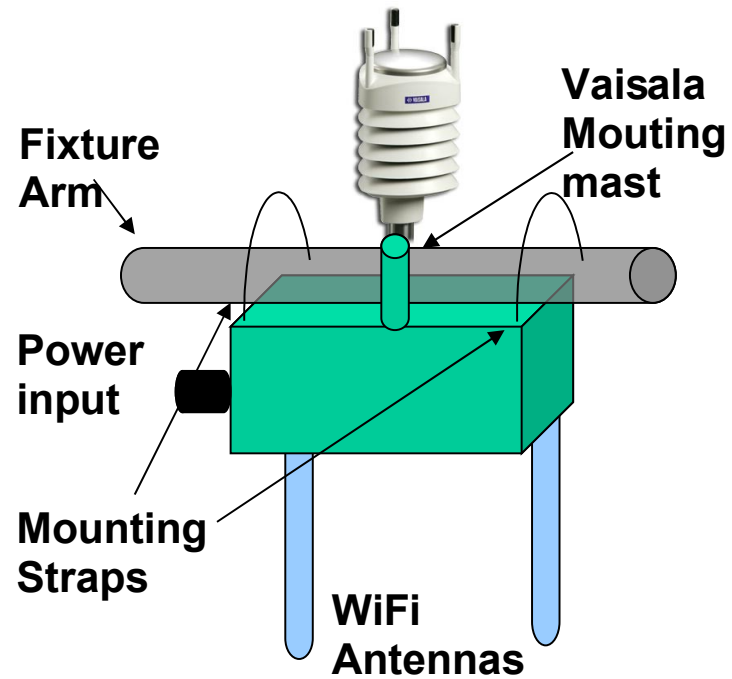
- 256 MB of RAM+flash, 2 GB USB flash drive
- NEMA-6x rated enclosure
- Running FreeBSD (Linux wireless drivers simply not stable)

Dual 802.11 radios on orthogonal bands

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



CitySense Node Prototype

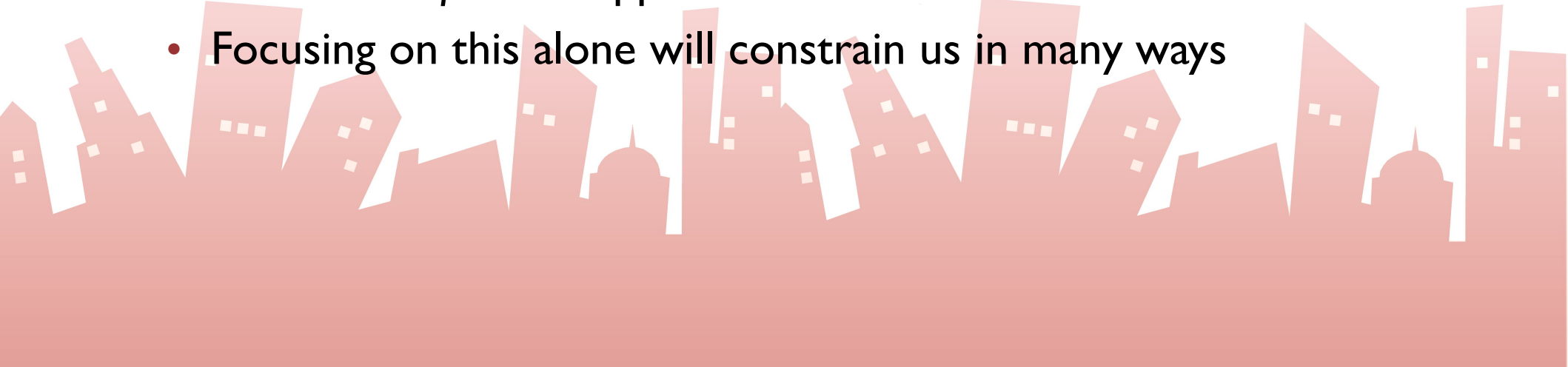


Target Application Domains

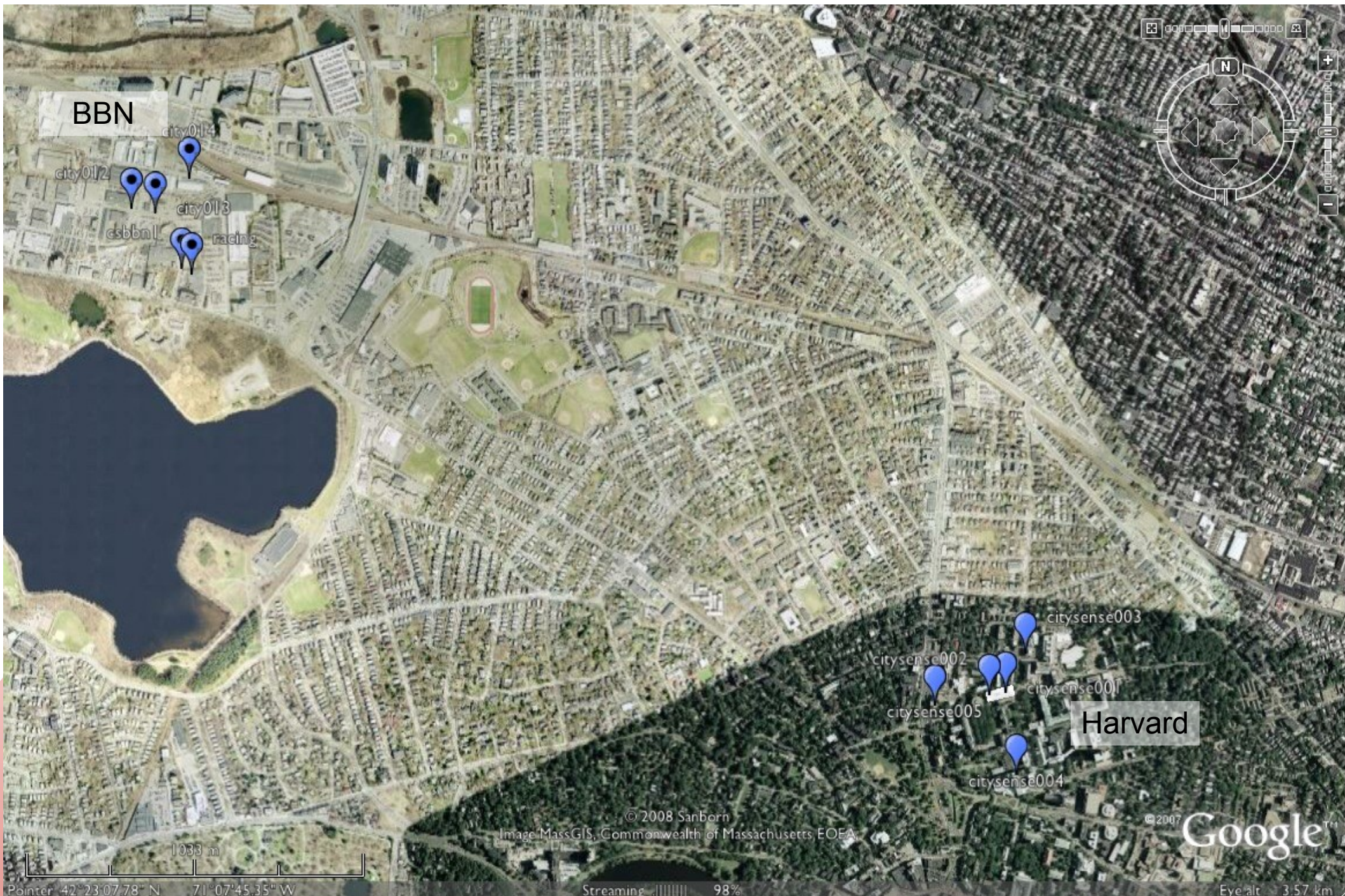
- **Homeland security applications**
 - Bio/chemical plume detection and tracking, urban surveillance
- **Public health studies**
 - Air quality and exposure levels, related to road traffic and weather
- **Urban and participatory sensing**
 - Combine data from static CitySense sensors, and mobile sensors carried by individuals or mounted on vehicles
- **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: CO₂, NO, O₃ etc.

- Vaisala CO₂ sensor
- Siemens GasFET sensor array on a chip based on semiconducting metal oxides



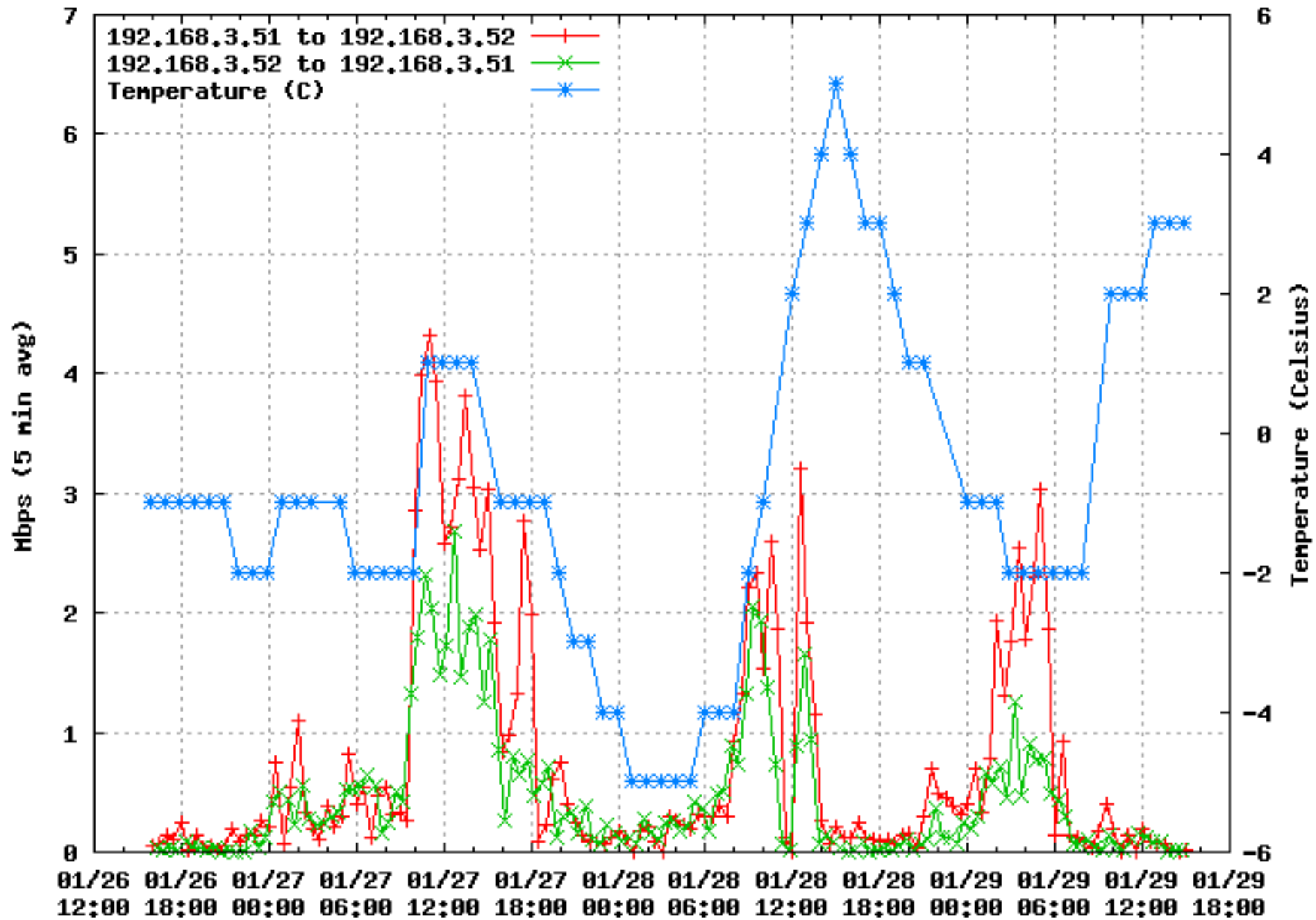
CitySense Networking

- 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

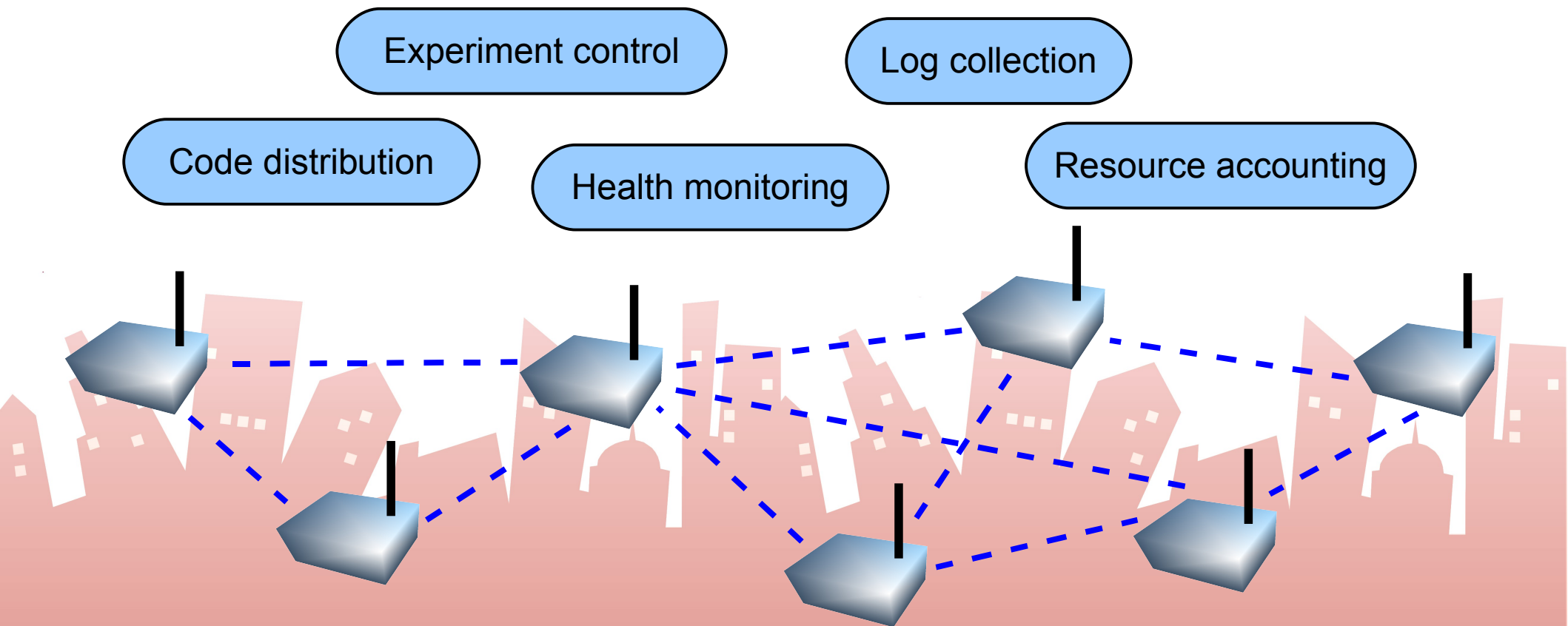
Two nodes on same rooftop – 50m apart!

Iperf Results as of Tue Jan 29 15:50:02 2008



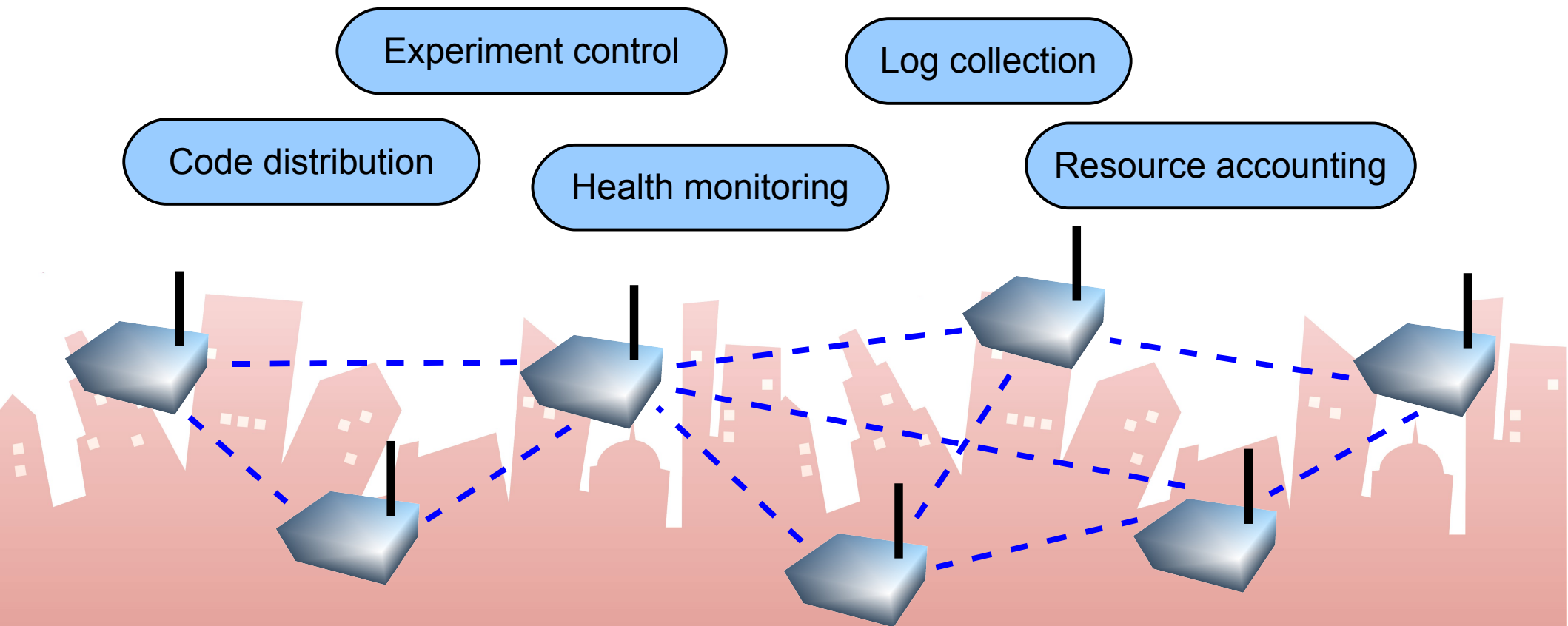
Distributed Services in CitySense

- 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.

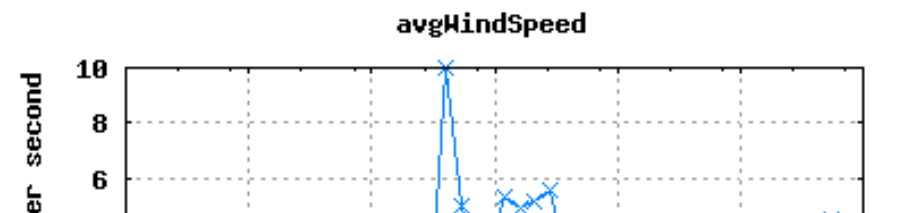
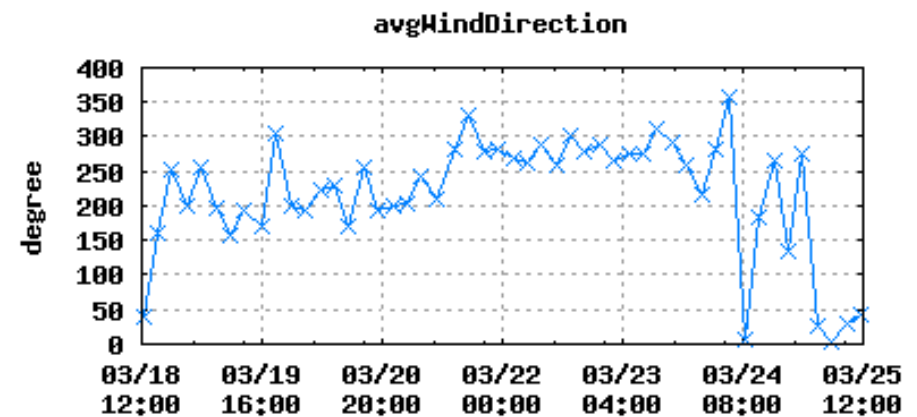
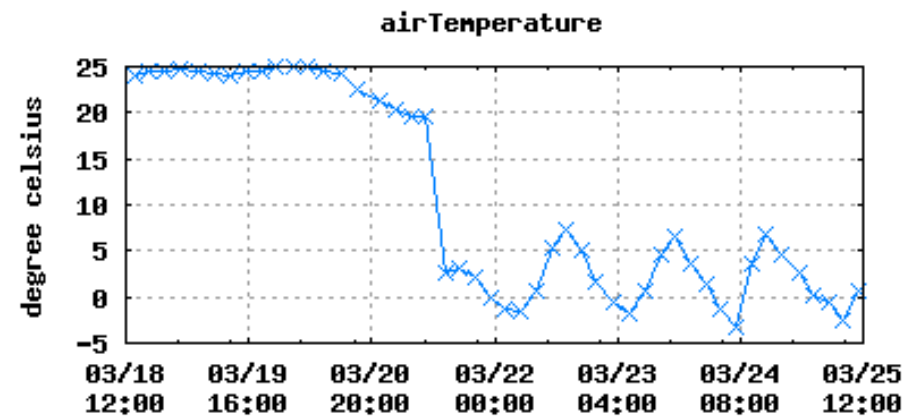
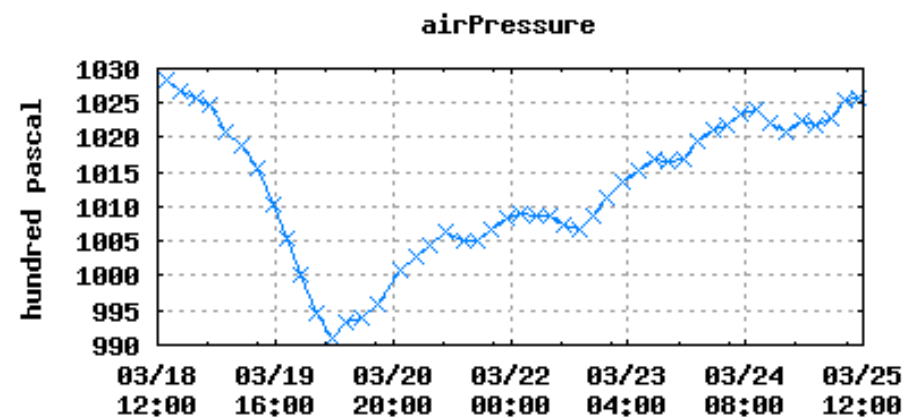


Remote Maintenance

- 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.microsoft.com/sensormap/>



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
- 15 nodes as indoor testbed at Harvard
 - Wired to Ethernet for rapid development and debugging
- Plan to roll out an additional 20 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