CitySense

A Vision for an Urban-Scale Sensor Network Testbed

Sensor Standards Harmonization Working Group
NIST

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Mobile Networking Systems
BBN Technologies
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Overview

Goals / Project Info

Testbed design

- Node
- Network

Sensors

Challenges

- Deployment
- Sensor Data Sharing

Questions

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Goals / Project Info

Support experimentation with wireless sensor networks at scale

- Simulations are valuable but inherently limited
- Understanding characteristics of real sensor networks in diverse environments requires real testbeds **and** real applications
- Testbeds should be **open** and easily shared by multiple research groups

Build a programmable testbed that supports

- Wireless sensor research
- Wireless networking research
- Interface with larger NSF GENI effort

Joint effort with Harvard University (Prof. Matt Welsh, DEAS, Magid Ezzati, SPH Co-PI)

- BBN taking lead on hardware design, baseline software configuration and deployment planning
- Harvard taking lead on resource management, experimental management, application: public health studies

Funded by NSF CRI over 4 years (end of first year)

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Cross-discipline Research Enabled

Sensor Networking

- Spatio-temporal data fusion
- Distributed query processing / data routing

Wireless Networking (GENI)

- Mesh routing protocols: geographic routing, Dynamic RF channel selection
- Disruption Tolerant Networks (DTN)

Urban Monitoring

- Public health studies: air pollution
- Homeland security: bio-chem, toxic gas release tracking
- Environmental impact: building efficiency, wind tunnel effects, traffic

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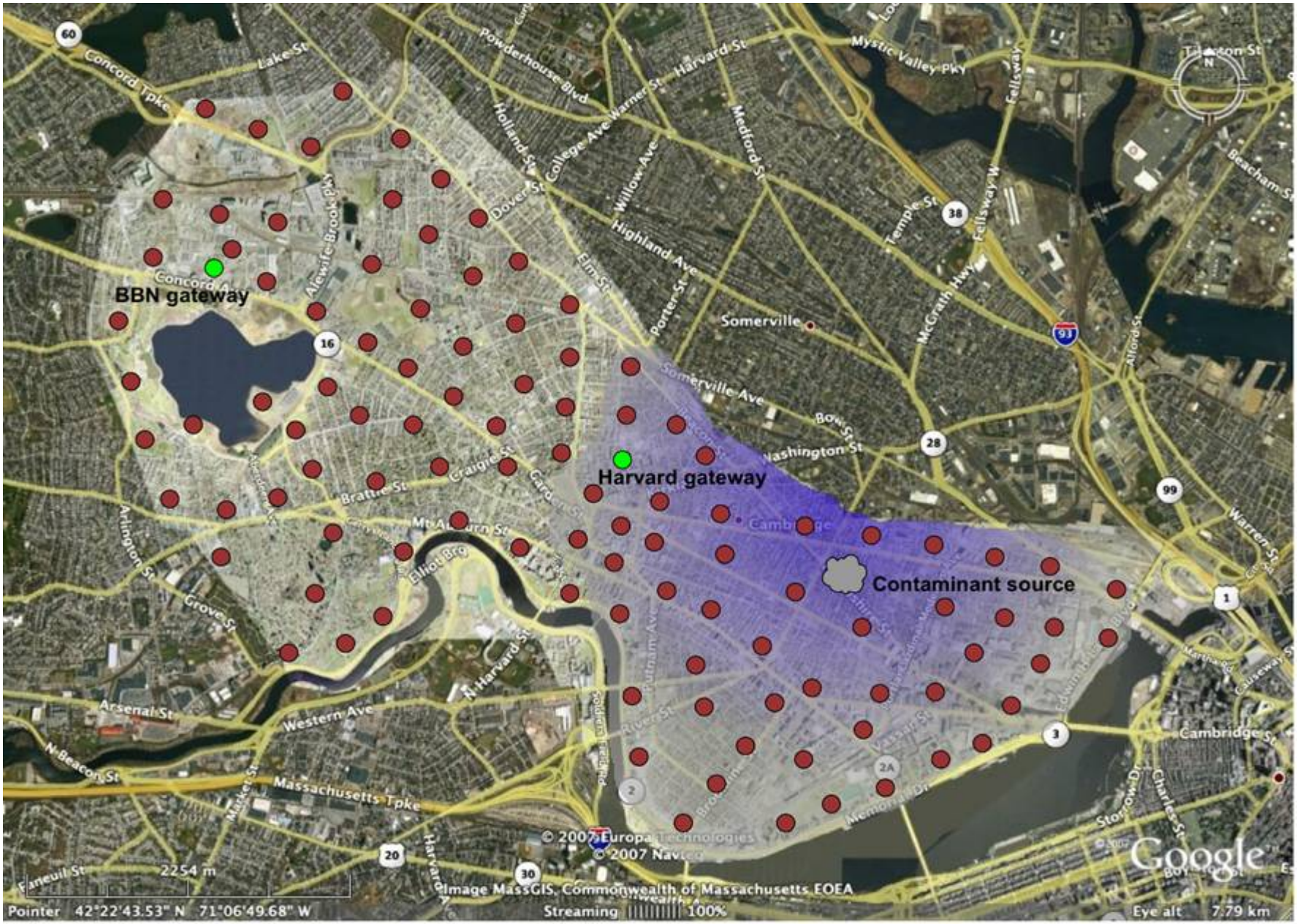
Hypothetical Deployment



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CitySense Testbed

Deploy outdoor testbed of 100 embedded PCs across a city

- Currently in negotiation with Cambridge, MA.
- Linux-based embedded PCs with meteorological and air quality sensors
- 802.11a/b/g interface with multihop wireless networking backbone: Use existing open-source standard: OLSR, HSLS

Current Status

- Project began in Sept. 2006.
- 10 node single-radio prototype running at BBN and Harvard
- 2 outdoor nodes continuously gathering weather sensor data
- Time synchronization between nodes using NTP
- Remote synchronization of baseline software over the air.

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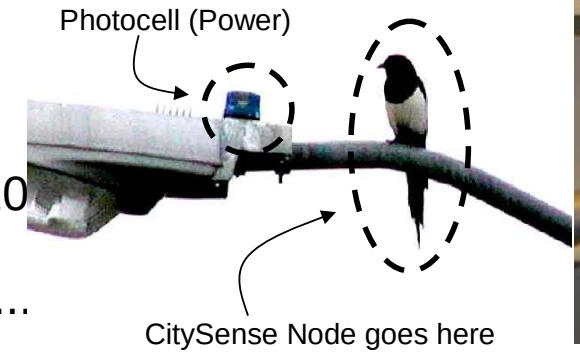
CitySense Node Design

Single Board Computer
- Soekris net4826 embedded PC 266 MHz Geode running Linux
- 256 MB of RAM+flash, 1 GB USB flash drive

Networking
- Two Atheros 802.11a/b/g radios, 7-10 dBi omni antennas

Sensors driven by app requirements
- Vaisala Weather Sensor (temp, humidity, pressure, wind, rain, ...)
- *Air particulate sensor (PM10 for air quality studies)
- *Gas sensors (CO^2, CO, O^3...
- ~~Microphones? Cameras?~~



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CitySense sensor package

Vaisala Weather Transmitter WXT510

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

Robust packaging for outdoor environments

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

Serial interface for configuration and data access

Other Sensors

On order / available

- CO^2: Vaisala GMP343
- RF- Use existing radios as sensor in ISM bands: 802.11b/g/a (2.4 & 5.2 GHz)

Wish-list:

- Particulate density: PM 2.5 and PM 10
- Acoustic dB monitoring

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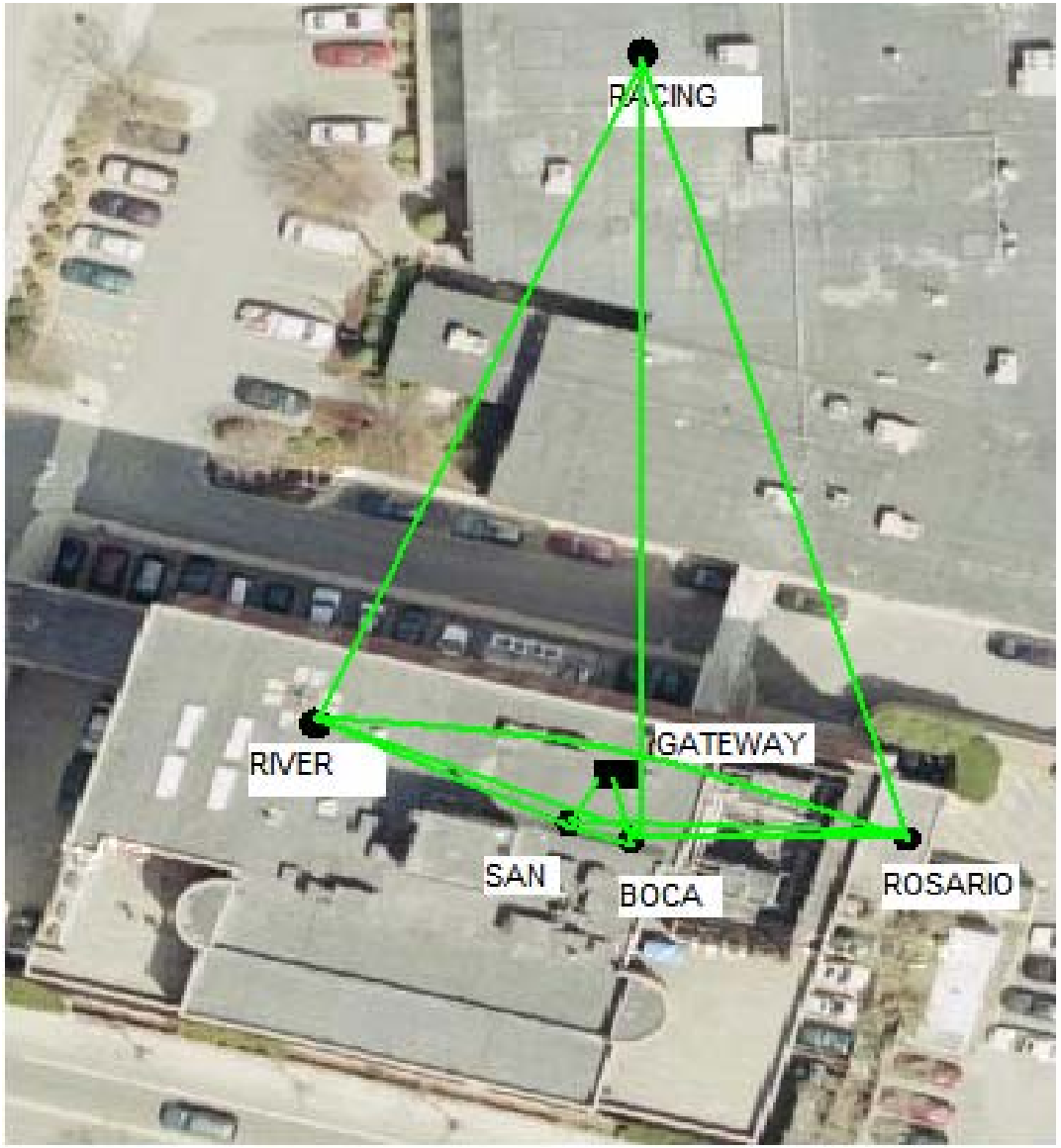
BBN Roof Network Topology



Bidirectional Links

Sensor Nodes

Gateway Server

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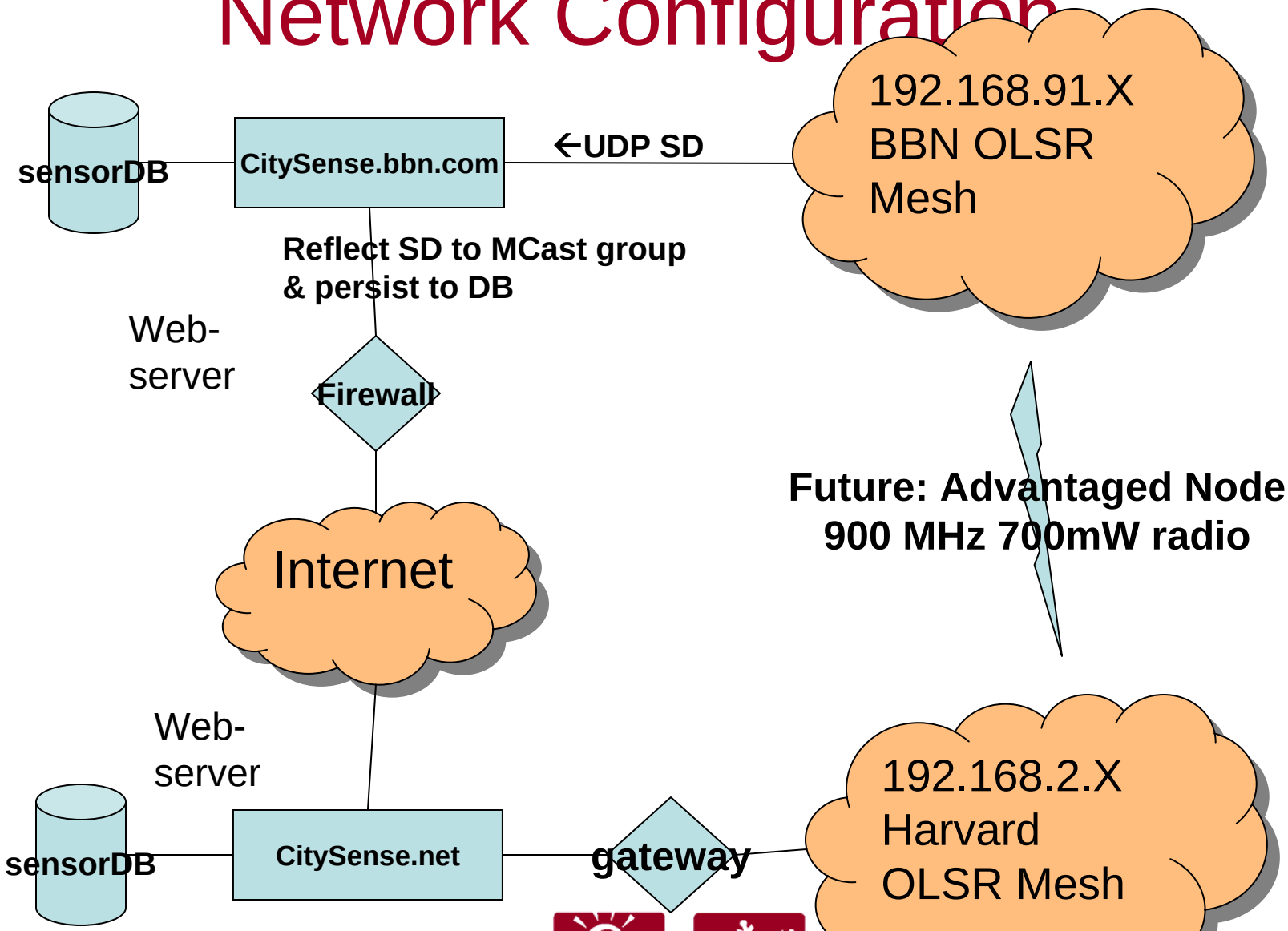
Harvard – BBN Network Configuration



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Testbed Challenges

Resource management and sharing
- How to support many applications? Fairness? Security? Sandboxing?

Programming models and languages
- What is the right programming abstraction for a city-wide sensor network? ssh into every node? SQL? Something in between?

Robustness and administration
- How to administer and maintain a network of 100+ nodes over a wireless mesh, without physical access or wired backhaul?
- Separate management/control radio

Data Sharing
- Common Data Schema: SensorML, IEEE1415

City Political Hurdles
- Press coverage / City politics
- Public acceptance / privacy issues
- Benefits to City: K-12 summer workshop, using Sensor data to support green initiatives

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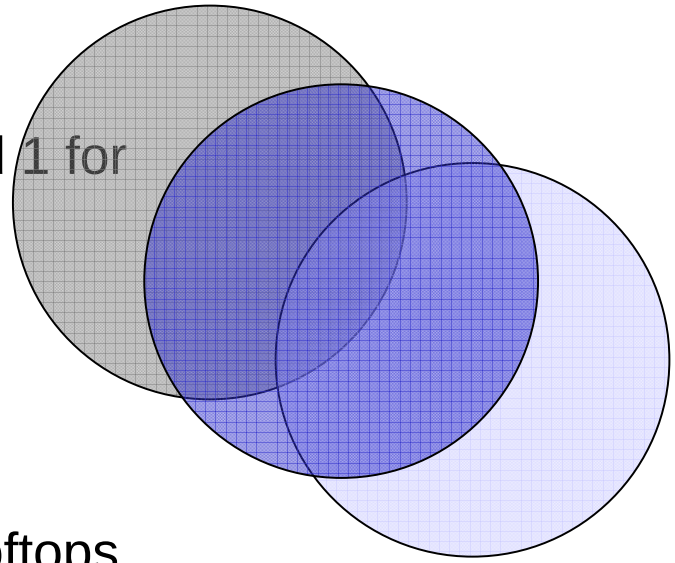
Deployment Challenges



Wireless Network Connectivity

- Two radios: 1 for experimental usage and 1 for management/control.
- 802.11a, 802.11b/g, 900MHz(?)
- RF Range estimates: 802.11a (5.3 GHz)
  - Hata Urban Model: 400 meters
  - R^4 propagation model: 500 meters
- Measurements: @ 66 meters on BBN rooftops
  - 802.11b/g: Received signal strength: -58 dBm → max ~ 200 meters,
  - 802.11a : RSSI: -72 dBm → max ~ 100 meters
- Goal: Bi-connectivity for no single point of failure

Must be experimentally validated!

Long multi-hop wireless chains cause degraded TCP perf. (>6 hops)

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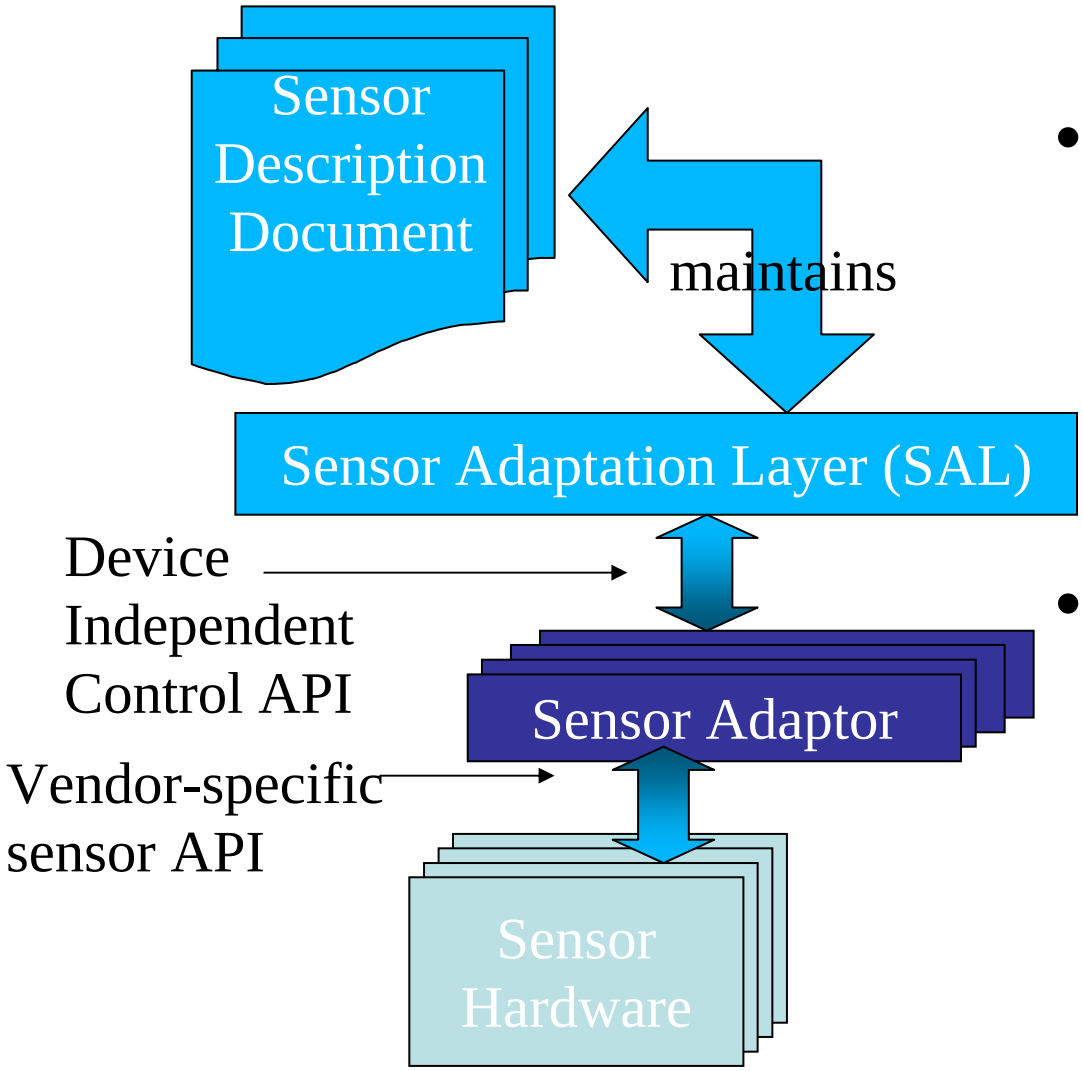
Plug-and-Play Sensors



- Enables easy addition of new sensors
- Adaptation layer defines a common meta-data for sensors to declare themselves to the shared infrastructure
- Meta-data are used to allocate nodes to applications based upon their sensing requirements

Sensor Data Schema

Raw from device (based NEMA-like ascii format)

```
rosario : Thu May 31 19:32:36 2007 :
0R1,Dn=165D,Dm=268D,Dx=325D,Sn=0.2M,Sm=0.4M,Sx=0.6
M
racing : Thu May 31 19:32:37 2007 :
0R3,Rc=14.744I,Rd=53964s,Ri=0.00I,Hc=0I,Hd=0s,Hi=0
I
rosario : Thu May 31 19:32:38 2007 :
0R2,Ta=16.2C,Ua=69.4P,Pa=1020.2H
```

Processed Using a o-o data model

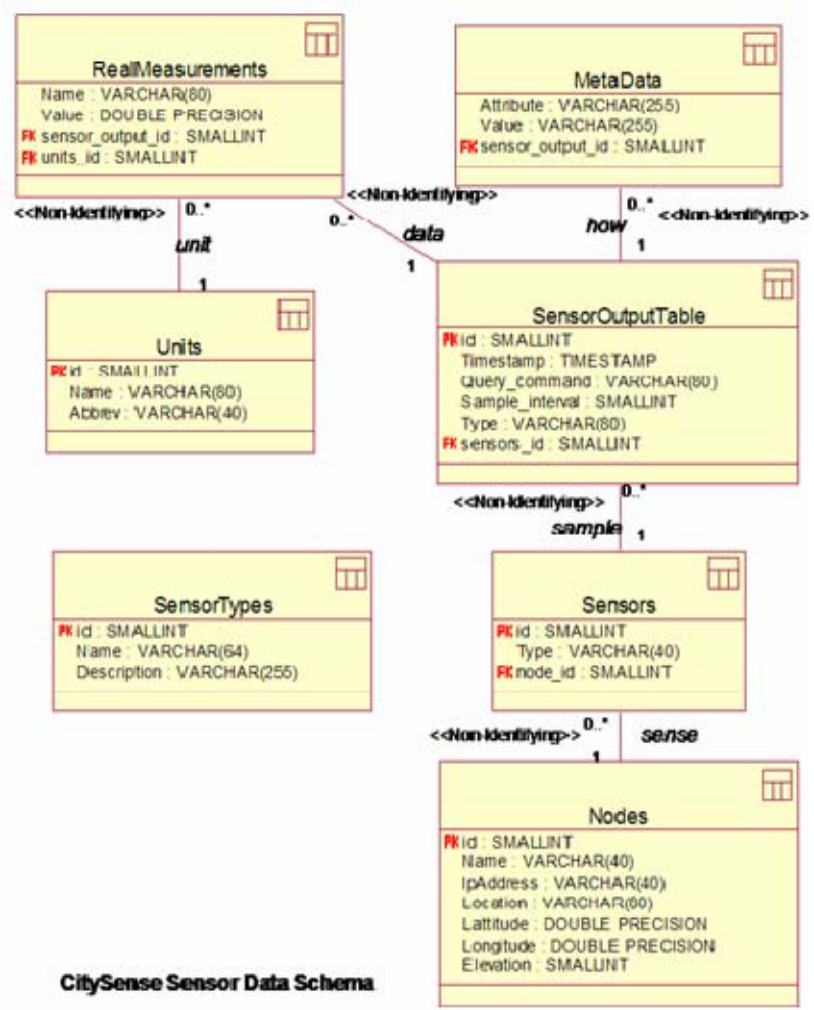
Sensor data: Parsed into : Sensor-node=null Device-type=VAISALA WXT510 Device-name=0 Timestamp=Tue Jun 26 07:48:12 EDT 2007 Sample Interval=-1 Query command=N/A

Sensor Measurements: net.citysense.sensors.PTHMeasurements@276af2

airTemperature value=16.2 unit=DEGREE_CELSIUS

relativeHumidity value=69.4 unit=PERCENT

airPressure value=1020.2 unit=HUNDRED_PASCAL



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Live Demos

Network / Weather Monitoring

http://citysense.bbn.com/

http://citysense.net

Node OS management

http://www.citysense.net/nagios/cgi-bin/status.cgi?host=all

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Acknowledgements / Questions?

CitySense team:

- BBN: Scott Loos (PM), Abhimanyu Gosain (Tufts intern), Gary Thomas, Dave Whittemore
- Harvard: Geoff Mainland, Rohan Murty, Amal Fahad, Jon Hyman, Kevin Bombino, Matt Tierney

For more information:

- Josh Bers (jbers@bbn.com)
- http://www.citysense.net

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Backup

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Existing Test Beds

Planet Lab is a geographically distributed platform for deploying, evaluating, and accessing planetary-scale net-work services

ORBIT is a two-tier laboratory emulator/field trial network testbed designed to achieve reproducibility of experimentation, while also supporting evaluation of protocols and applications in real world settings

Mote-Lab, a Web-based sensor network testbed, consists of a set of permanently deployed sensor network nodes connected to a central server which handles reprogramming and data logging while providing a web interface for creating and scheduling jobs on the testbed

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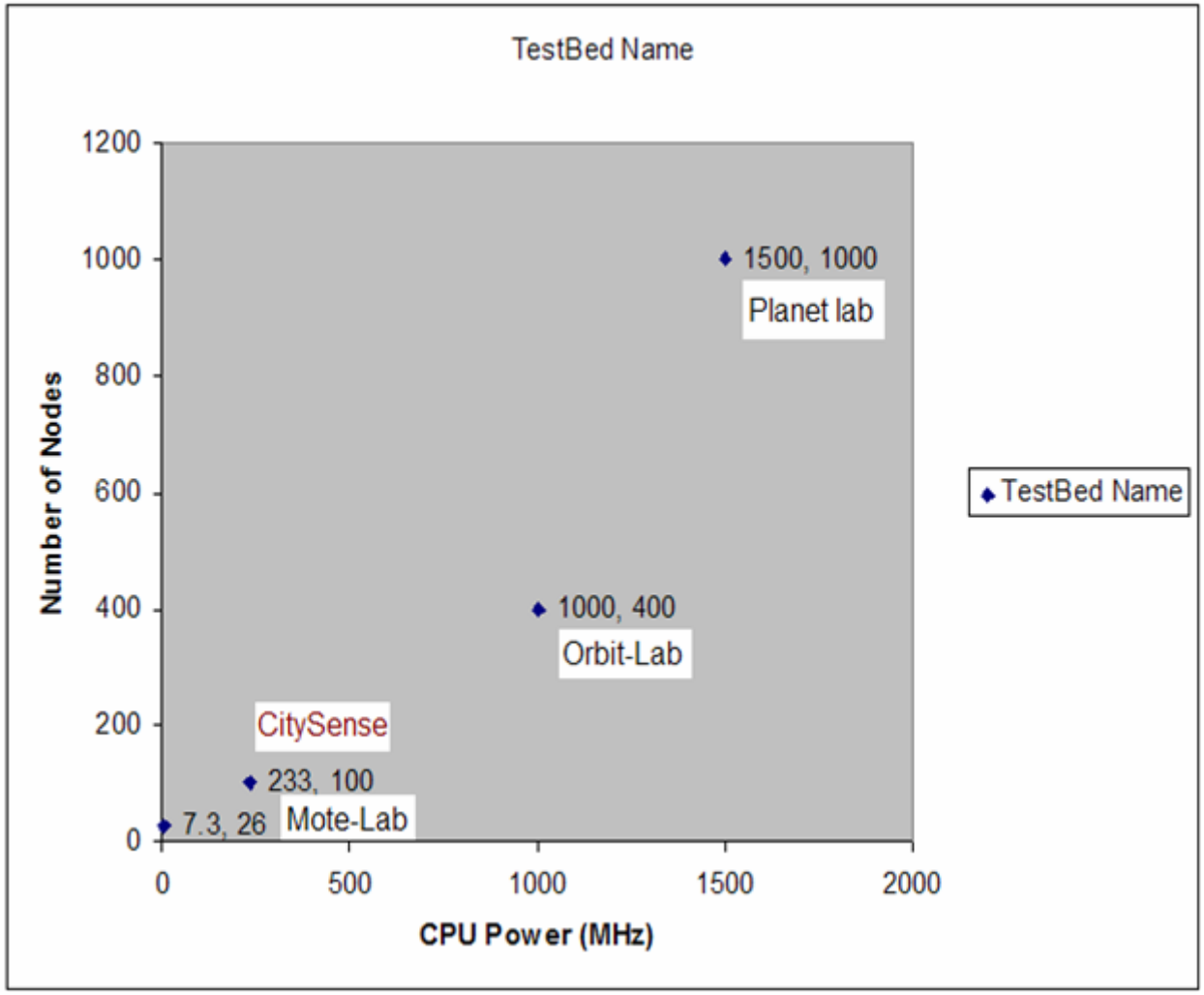
Comparison of test beds



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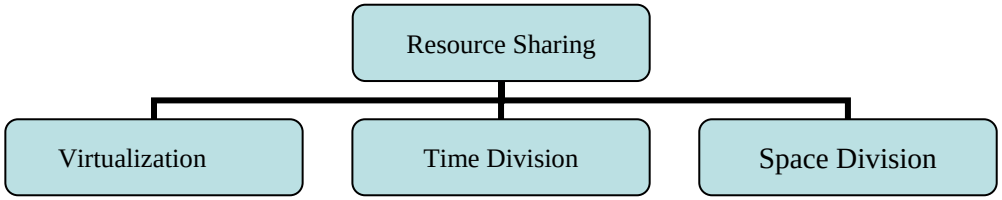
Resource Sharing



Virtualization

This is a three stage process:

(1) A service manager first contacts a resource broker to select (discover) a set of candidate nodes that constitute a slice

(2) It then contacts the nodes in that set to initialize a network of virtual machines (this involves a per-node admission control decision)

(3) A set of resources is allocated to the manager, also called a sliver.

(4) It launches the service in the resulting slice.

Time Division

- In this case, the entire wireless network is partitioned in time across the different experiments. Each experiment is assigned a time slot during which each physical node in the system activates the virtual node corresponding to this particular experiment.

Space Division

- This is the most simple approach, where physical resources are partitioned in space. Each experiment is assigned a set of physical nodes such that transmitting nodes from different experiments do not interfere with each other

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Time Division/Space Division Multiplexing

ORBIT Radio Grid Testbed uses Time Division Multiplexing for wireless virtualization.

- Experiment Management Service. It has a Node Handler that functions as an Experiment Controller. It multicasts experiment scripts to the nodes. It keeps track of each step and sends the information to each node at the appropriate time. The Node Agent software component resides on each node and listens to commands from the Node Handler and reports information back to the Node Handler.
- The combination of these two components controls the testbed and enables the automated collection of experimental results.
- Although only one experiment can run on the testbed at a time, automating the use of the testbed allows each one to run quickly, saving the results to a server.

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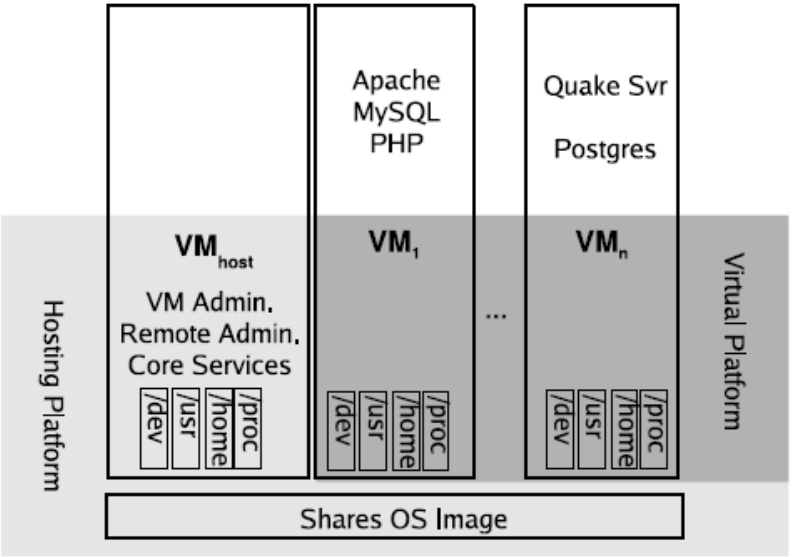
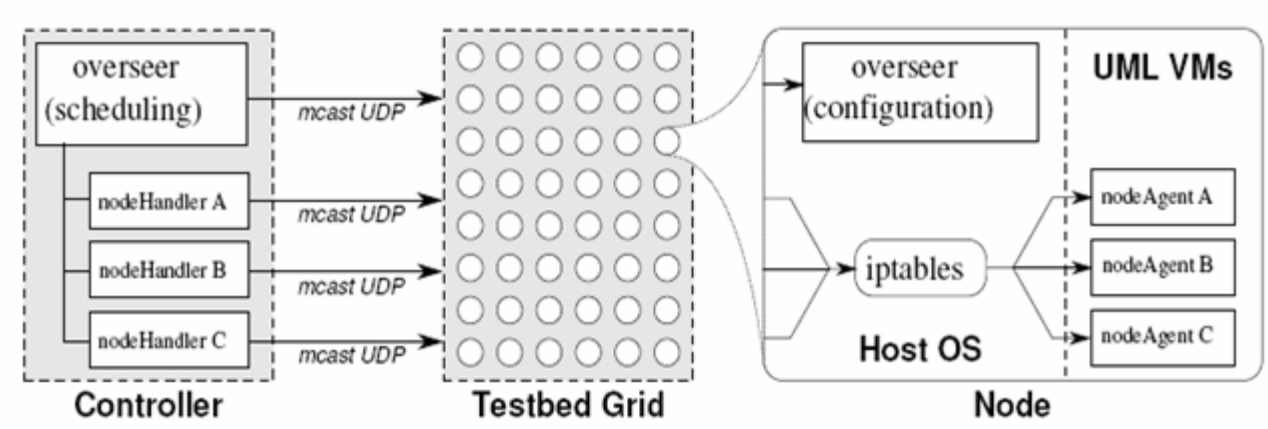


Container Based Virtual Machine Monitor used in Planet Lab



Experiment management Service in Orbit Lab

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Next Steps

- Build out to a 30 node testbed this summer
- Finalize node packaging and deploy on ~6 streetlights nearby
- Perform RF range testing
- Build a node health watchdog
- Work with City to develop written memorandum of agreement

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Educational Impact

Working with Tufts CEEO to develop K-12 curriculum in sensor networks

- Give simple interface for students to access and visualize sensor data
  - Get hands-on feel for spatio-temporal correllation of physical phenomena: temperature
  - Intro to RF-propagation
- Summer workshop for area students

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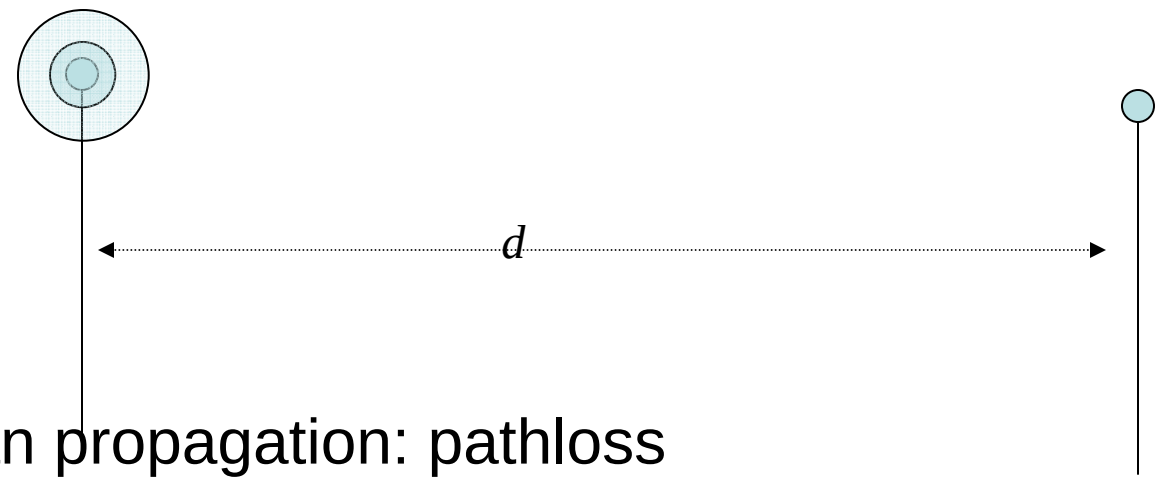
RF propagation

Power drops proportional to the square of the distance (free space): expanding sphere

Friis

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{16\pi^2 d^2 L},$$



Urban propagation: pathloss exponent, α, 3-5 due to absorption, reflection

$$P_{dBm}(d) = P_{dBm}(d_0) - 10\alpha \log_{10}\left(\frac{d}{d_0}\right) + \varepsilon$$

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Wireless Traffic Analysis

NODE TOPOLOGY	OLSR Traffic (Kbps)	NTP traffic (Kbps)	Weather Data Traffic (Kbps)
4 Nodes (1 Weather Sensor)	8.858	0.0061	0.3155
4 Nodes (2 Weather Sensors)	7.7361	0.1146	0.9132
5 Node Network (2 Weather Sensors)	14.0699	0.0153	1.0001

As measured via tcpdump on intermediate node, boca in promiscuous mode: inbound and outbound traffic.

Actual size of weather data: 0.5 Kbps per node

- Bigger observed numbers due to multi-hopping on broadcast medium

Need to adjust OLSR defaults to limit traffic in relatively static network

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Related Work / Facilities

WINLab, ORBIT Rutgers [Raychaudhari]
ENL, USC motes [Govindan]
sMote, Berkeley [Culler]
RoofNET, MIT [Morris, et. al]
U Colorado [Sicker & Grunwald]
NEON UCLA [Estrin]

Others…
Community networks:
CUWin, Corpus Christie, TEX, etc.
TFA-Rice Houston [Camp, Knightly, et al.]

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