Wireless Sensor Networks
Gordon Bell
Microsoft Research

One day seminar
Macquarie University
Institute for Innovation
2006 February 7

WSNs in five *talk* segments

1. Intro: Moore's Law & Bell's Law of classes, WSN-space (functions, users-apps, network)
2. Applications (according to function): sensing, control, mobile sensing, on board/on thing -ILS/A
3. Technology (what): WSN's10 year gestation, wireless channels, networks, protocols, standards
4. Markets, industry, & startups
5. DUST Network "corporate" presentation

Take-ways: conjectures, opinions … all I know, WSN: what they are, industry formation/structure, the potential for use and companies. WSN impact as price of hardware -> $0!

Other speakers

1. G2: MRM (Mobile Resources Management)
2. Alive Technology: On body instrumentation for health and wellness measurements
3. CSIRO Research in tracking livestock
4. Dust Networks (given by me)

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1. Intro to Wireless Sensor Networks: A new computer class, what they are, & WSN function-market-technology space
"what do they do, who can use them, how do they work"

Gordon Bell, Visiting Professor
Given at the
Macquarie University Institute for Innovation
Enterprise of the Future Seminar Series
on
7 February 2006
www.research.microsoft.com/~gbell
ftp://ftp.research.microsoft.com/Users/gbell/

## Overview of Wireless Sensor Networks

- WSNs: enabled by Moore's Law… think evolution
- WSNs: a new computer class cf. Bell's Law
- What is a WSN?
- WSN Space:
  - Functionality dimension
  - Buyer-application dimensions
  - Technology: net structure, performance, etc. dimensions

Bell's Evolution Of Computer Classes

Technology enables two evolutionary paths:
   1. constant performance, decreasing cost
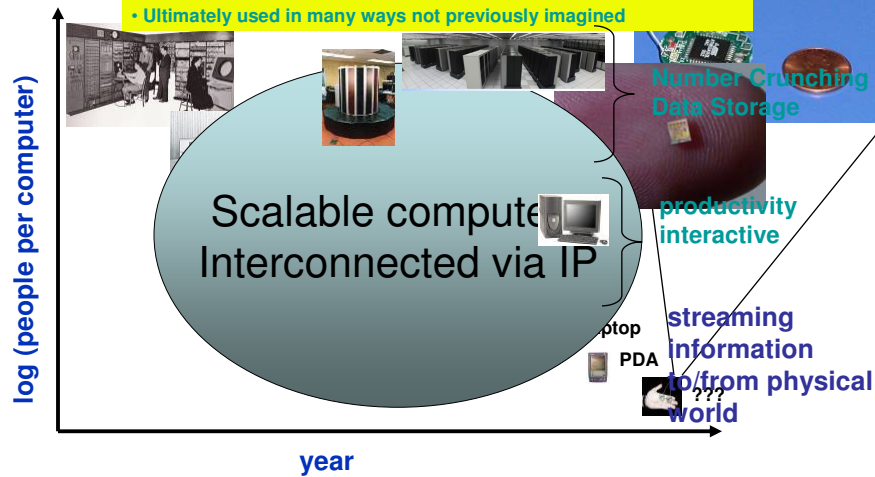   **2. constant price, increasing performance**

Log price

Mainframes (central)

Mini

WSs

PCs (personals)

??

Time
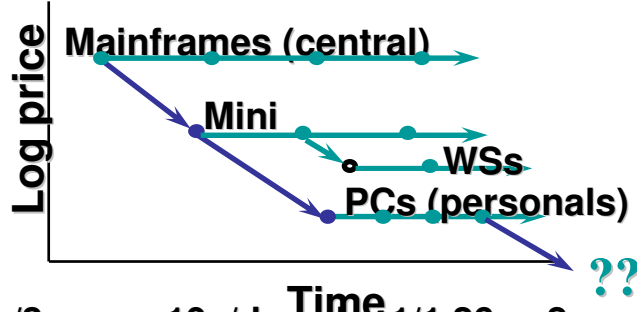
1.26 = 2x/3 yrs -- 10x/decade; 1/1.26 = .8
1.6 = 4x/3 yrs --100x/decade; 1/1.6 = .62

A New Computer Class Emerging

- Enabled by technological opportunities
- Smaller, more numerous and more intimately connected
- Ushers in a new kind of application
- Ultimately used in many ways not previously imagined

Number Crunching
Data Storage

log (people per computer)

Scalable computers
Interconnected via IP

productivity
interactive

ptop

PDA

streaming
information
to/from physical
world

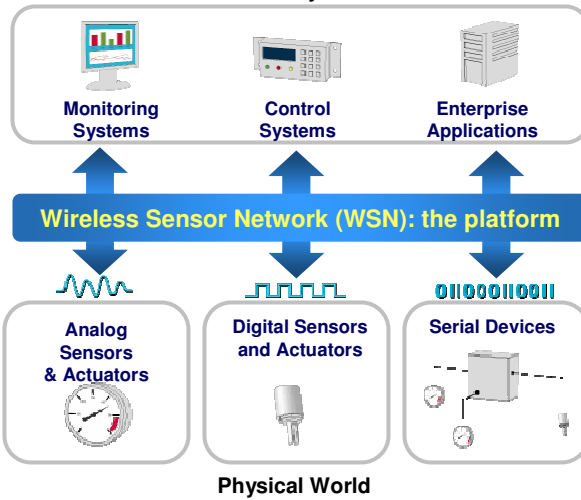???

year

David Culler UC/Berkeley

Bell's law of computer class formation to cover Cyberspace

- New computer platforms emerge based on new chip, storage, and network evolution
  - It may come from RESEARCH e.g. www, wsn!
- Computer classes consist of:
  - new platforms,
  - new networks, and
  - new interfaces i.e. cyberization ("world" → cyberspace)
- New classes enable
  - New apps and new content
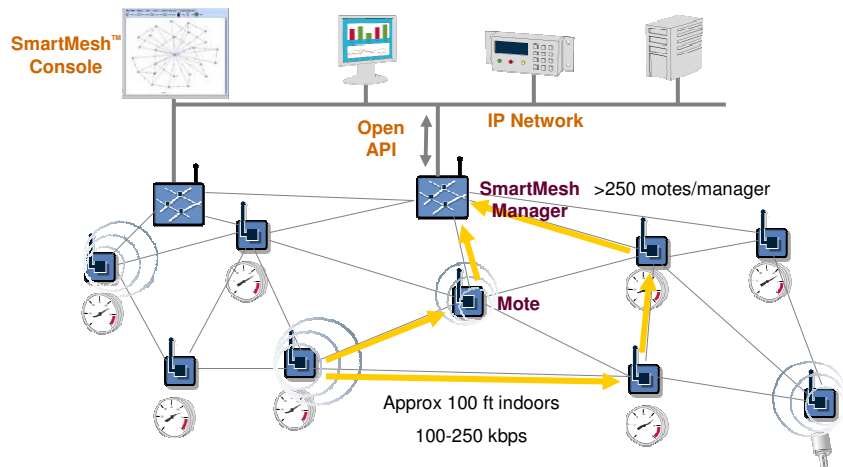- Each class evolves into a vertically disintegrated industry based on hardware & software standards

4

Wireless Sensor Networking

Decision Systems

Monitoring Systems

Control Systems

Enterprise Applications

Wireless Sensor Network (WSN): the platform

Analog Sensors & Actuators

Digital Sensors and Actuators

Serial Devices

Physical World

- Predicated on near zero wiring cost
- Increases sensor deployment
- Enables new applications and services

SmartMesh Wireless Mesh Network

SmartMesh™ Console

Open API

IP Network

SmartMesh Manager >250 motes/manager

Mote

Approx 100 ft indoors

100-250 kbps

Network Types

Star

Star-Mesh

Powered mesh infrastructure

Star-connected sensors

Full Mesh

No separate powered infrastructure

Mesh-connected sensors

Ember Enabled Devices

Ember Studio Lite

Powered infrastructure of Full Function Devices
Separate sensors of Reduced Function Devices

Multiple paths; single mote type

Venue Segmentation Map for Intelligent Device Networking & Management

The Pervasive Internet

| Buildings | Consumer | Industrial | Medical | Power | Retail | Transportation | Government / Security |

Commercial / Institutional | **Industrial** | **Residential** | **Hospital** | **Doc. Office/ Care Facility** | **Home/ In Vivo** | **Lab** | **Supply side** | **Demand side** | **Vehicles** | **Infrastructure**

- Office
- Education
- Retail
- Hospitality
- Healthcare
- Grocery
- Airports
- Stadiums
- Data Centers

- Process – Semi Fabs
- Chemical
- Pharma
- Refining
- PulpPaper
- Discrete
- Batch

- Single family
- Multi-family

- Point-of-Care (in hospital)
- ERI
- Mobile Point-of-Care

- Point-of-Care (office)

- Implants
- Point-of-Care (home)

- Point-of-Care diagnostic
- Lab diagnostic

- Generation
- Transmission

- Distribution (Utility)
- Residential
- Industrial
- Small Commercial
- Large Commercial

- Consumer
- Aircraft
- Watercraft
- Construction
- On-House Vehicles

- Fueling Stations
- Navigation Systems
- Traffic Control & Highway Systems

Devices: HVAC, Vertical Transport, Fire & Safety, Lighting, Security & Access, etc.

Devices: MRI, PDAs, Implants, Surgical Equip, Pumps, Monitors, Telemedicine, etc.

Devices: Central plants, Distributed resources, etc.

Devices: Vehicles, Roads, Gas stations, signage, etc.   M

Household | **Entertain-ment** | **Mobile** | **Machine control** | **Industrial Process Control** | **Electronics / Semicon** | **Infrastructure / Supply Chain** | **Lab** | **Point-of-sale** | **Infrastructure / Supply Chain** | **Signage / Display**

- Laundry
- Kitchen
- Environmental
- Information
- Lighting
- Security
- Climate

- Audio
- Video
- Gaming

- Audio
- Video
- Communication
- Multi-purpose

- Complex machines
- Simple/ standard machines

- SCADA
- Instrument/ sensor
- CDS

- Semicon
  - Semi Tools
  - Water Hand
  - Test Sys
- Electronics
  - T&M
  - Comp
  - Placement & Board Assembly

- Facility management
- Infrastructure

- Process equip.
- Product diagnosis

- Complex machines
- Simple/ standard machines

- Distribution centers
- Shopping centers

- In-store signage
- Remote signage
- Display equipment

Devices: TVs, VCRs, Dishwashers, Washer/ Dryers, Refrigerators, Lights, Computers, etc.

Devices: Pumps, Valves, Vats, Conveyors, Pipelines, Motors, Drives, Switches, Machines, etc.

Devices: POS Terminals, Tags, Cash Registers, Payment Terminals, Signs, etc.

Legislature | **Public Safety** | **Public Infrastructure** | **Lab** | **Vehicles** | **Material** | **Personnel** | **Security / Surveillance**

- Documents, Records
- Voting, Polling
- Other

- Police Equip. & Personnel
- Fire Equip. & Personnel
- Other Regulatory Equip. & Personnel

- Water/ Wastewater Equip. & Personnel
- Other e.g. Regulatory Equip. & Personnel

- Water Treatment
- Building Environment
- General Environment

- Land
- Air
- Sea

- Weapons
- Supplies
- Other

- People
- Machines

- Radar / Satellite
- Environment

By permission, January, 2006

Devices: Voting booths Information cards, Scanners, Public infrastructure, etc.

Devices: Weapons, Vehicles, Soldiers, Unmanned drones, etc.

M   M   M

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M

Agriculture & landscape, mining, scientific & field instrumentation

Harbor Research (where-what)* Taxonomy
Where (What) => Buyer (Suppliers & Sellers)

- Buildings (access & security, fire & safety, elevator/escalator, HVAC, lighting)
  - Commercial/Institutional (airport, data center, education, hospital, retail, … stadium)
  - Industrial
  - Residential (single|multi family units)
- Consumer (A/V, computers, lights, refrigerators, washers)
  - Household (room *laundry* & function *climate*)
  - Entertainment
  - Mobile
- *Agriculture, landscape*
  - Farms
  - Homes
  - Public spaces
- Industrial Control - K (contacts, switches, motors, valves, pumps, conveyors, pipelines, etc.)
  - Machine (simple standard, complex) K
  - Industrial process K
  - Electronics / Semiconductor mfg.
  - Infrastructure / supply chain
  - Lab (specialized sensors & instruments)
- Medical (computers/PDAs, CT/MRI, pumps, monitors, telemedicine devices)
  - Hospital (point of care, ER/OR, mobile)
  - Clinics, Doctor's offices
  - Lab (instruments)
  - Home / in vivo (implants, point of care)
- Power (monitor, control)
  - Supply (generation, distribution)
  - Demand (consumption, off-loading)

- Retail (POS,... tags)
  - Infrastructure / supply chain
  - Signage / Display
  - *Buyer behaviour* e.g. consumer tracking
- Transportation & other public infrastructures: Streets…Highways, Rivers & streams (monitoring,… traffic control
  - Vehicles (cars, aircraft, …construction)
  - Infrastructure
- Government /Security (Voting, identity, scanners, public infrastructure)
  - Legislature
  - Public safety (police, fire, … large scale disaster)
  - Public Infrastructure (landscape, public space)
  - Lab
  (Weapons, soldiers, unmanned things, etc)
  - Vehicles
  - Material
  - Personnel
  - Security / surveillance (climate and natural disasters, radar/satellite, environment)
- *Scientific & engineering pedagogy & research*
  - *Laboratory bio-medical*
  - *Natural science outdoors*
  - *Water management*
  - *Large scale physical science e.g. Earthquake, hurricanes, tornados, etc.*

*Where it is located; Who is buying; What it is used for

WSN space: The Dimensions 1/30

- Function (sense, effect, control) *what it does, generally*
  - Sub function e.g. lighting, HVAC, surveillance , process control *what it does specifically, who builds & sells it*
- Geography (global) … Asia, Europe, US *WHERE*
- Institution (commercial, consumer, … gov't) *who buys*
- Environment i.e. *where used*
  - Scale/range/container: body | room | building (homes, com'l, ind'l, military) | mobile platform | outdoors; process attached i.e. process control
  - Portable: … open space
  - Mobile: un-tethered attachment e.g. animal, pallet, person, "thing",…truck
  - Location requirements: power; RF noise; temperature; packaging & industrial design;
- Cost: (installation, operation) *how much*
- Network Performance: (see network
- Network structure & RF characteristics *how function performed*
  - Structure: pt-pt | tree | stand–alone mesh | mesh – IP network
  - Link characteristics (RF link; standards)

Functionality dimension (of WSN space)^{1/30}

- Sense… some parameter of something is measured.
- Actuate/effect… "something" gets changed
- Control (closed loop). actuators = f(sensors, state)
- Sensing (peripheral) networks
  - Provide connectivity for a large set of sense/actuate nodes
  - Detects moving items in the "sensing network"
- JAN for connecting portable or mobile items
- JAN - Just another net e.g. 802.11x, Bluetooth for bits

The Client Side of the Network

- ILSA: Identity – Location – State – Actuate   *Item tags*
  - Name as with an Bar Code or RFID tag (MRM)
  - Location – for moving item/resource
  - State of the "thing" as f(t), e.g. age, environment, interesting data e.g. temperature or vibration

WSN environment, function, structure, scalability, platform, performance,… link

- Environment: indoor | outdoor | moving object/network
- Sensee: fixed | moving items | moving network items
- Interaction with IP ne: none i.e. free standing | peripheral to IP net & www
  - Scale & topology: pair | tree | mesh *for long haul* –tree *for sensor nodes* | homogeneous, peripheral sensor/actuator mesh (with connection to IP)

- Network performance: power>battery life; data-rate & error rate; range > inter-mote distance; mote discovery time >f(scale);

- Node function: passive | sense | effect | gateway | route |… | application
- Platform characteristics: processor & O/S; network stack; standards…

- Link, Network interconnection, and protocols
  - Bluetooth -> 802.11.15.4 (wireless personal area net) -> WiFi (IP) ->Internet/www
  - Public switched and cellular nets GSM, 2G…4G
- Network noise protocol: multi-frequency; multi-path; dynamic channel assignment; retry, etc.

WSN Space

Building automation:
Energy monitoring
Environmental monitoring
Lighting control
HVAC control
Security alarming
Access control
Asset tracking

Industrial automation:
In-process monitoring
Energy monitoring
Equipment health & utilization
In-process control

Residential (see Building)::
HVAC, Lighting…Access control
Audio/Visual
Data-networks

Outdoor:
Landscape & Water
Security
Parking & traffic

Personal:
Fitness & health
Eldercare
Patient care

Basic Function
Sense
   Energy monitoring
   Environmental monitoring
   Security Alarming
   In-process monitoring
   Equipment health & utilization
   Traffic & parking monitoring
Control
   Lighting control
   HVAC control
   Access Control
   In-process control
   Consumer A/V
ILS/A
   Asset Tracking
   Fitness & health
   Eldercare

Location, mobility, scale
Indoors/Outdoors
Fixed/Portable/Mobile
Scale
   On Body
   Room
   On Equipment/process
   Building (may be LAN connected)
   Campus (CAN, LAN connected)
   Geo-dispersed

Buyer
Consumer
Research
Commercial/retail
Medical
Industrial building
Industrial process
Government
Military

Topology/Scale & Application Locus
Application:= isolated | WSN | IP service
WS/A-WS/A
   Point to point, stand-alone
WS/AN –stand alone app
WS/AN – IPN* connected
IP + WS/AN (IP used to carry S/A
WN for connecting mobile or portable S/A
Note: the app is in the IP network…
* Local and/or global IP Network

Technology vs Capability

G2 Microsystems

RF Nodes

Tag — Monitoring Nodes

Passive — Active

Active: Wide Area — Local Area

Monitoring Nodes: Local Area — Wide Area

Wide Area → Satellite/GPS

RFID EPCglobal Gen 2

Separate dedicated RF network

Sensor Motes Zigbee/802.15.4 Or 802.11

Cellular M2M modules

leverage existing RF network – 802.11

Identify ▸ Locate ▸ Monitor ▸ Manage

Size reduction as mote moves to dust:
Sense > Control > ILS

- Motes with battery approach bottle cap size
- Embedded in bottle cap
- Identity… knows its name
- Location
  - GPS
  - Identity within a friendly or ubiquitous sensing network
- State
  - Monitors what's inside
  - When opened
- Effect?
  - Tells everyone about it

Beliefs… and biases

- **Wired** sensor networks are everywhere doing everything
  - Homes, commercial & industrial buildings, science & engineering, military… Indoors and outdoors.
  - Data gathering & instrumentation, energy monitoring, HVAC, lighting, power, process control, security, …
- Sensor applications are limited by cost (and sensibility!)
  - Cost is dominated by installation of wires, thereby limiting apps
- Commercial adoption of **wireless** sensor networks is gated by reliability and power consumption…
  - Sensing and scientific & data gathering are the early adopters BECAUSE of proof of efficacy and liability concerns
  - Control apps represent more complexity and liability
  - Redundancy is critical: multiple channels & paths
- zero cost, zero size, zero power motes are inevitable… will enable infinite apps, including mobile… anything non-zero, just reduces market size
- WSNs are peripherals or edge to IP!

Market vs. Cost, size, 1/power

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  - www-bsac.eecs.berkeley.edu/~pister/SmartDust/
  - www.cens.ucla.edu UCLA lab
  - …
  - http://research.microsoft.com/wn/ & http://research.microsoft.com/nec/
- WSN companies
  - http://www.cirronet.com/wireless-sensor.htm
  - www.xbow.com Crossbow
  - www.dustnetworks.com
  - www.ember.com
  - …
  - www.sensicast.com
- Standards and Consortia
  - www.zigbee.org/en (markets, specs, etc.) & http://ieee802.org/15/pub/TG4.html
- Market research and understanding
  - www.cens.ucla.edu market research space
  - www.onworld.com/html/wirelesssensorsrprt2.htm $999/136 pp.
  - …
  - www.palowireless.com/marketresearch/

2. Wireless Sensor Network Applications: Function – what do WSNs actually do?

Gordon Bell, Visiting Professor
Macquarie University Institute of Innovation
Enterprise of the Future Seminar Series
7 February 2006

Some applications of
wireless *sensor* networks… used to
sense, control, and track "things"

Applications examples
A trek along the function dimension
crossing many different user environments

- Sense
- Actuate/effect
- Control
- Sensing Networks that track "things"
- Large scale continental networks…

- IPS/A – Identity-Location-State-Actuate
  aka MRM Mobile Resource Management

WSJ 9 Jan. 2006: India Tries Microchips to Track *owner identity of* Garbage-Eating Cows

Peter Wonacott

Revered Animals Roam Streets, Slow Traffic, Cause Accidents & Clog Sewers

What is going on with these cows? Now, and in the furture?

- Name (label)… assuming it has been registered.
- Where has it been? Eaten enough?
  Charged for used resources? Been milked?
- What are the options if you:
  – Want to know more?
  – Effect its behavior?
- What's On board versus what's in infrastructure?
  Do they have GPS? … *In a decade they're likely to.*
- Infrastructure: What can you put in the IP cloud?
  – Cameras and identification versus observers
  – Network to track and report

"High Tech, Under the Skin"
By ANNA BAHNEY
NY Times Fashion & Style
February 2, 2006

•By inserting the radio frequency identification device… he planned to log on to his computer, open doors and unlock his car.

•Implanting the chip was relatively simple …chip, complete with a miniature antenna and enclosed in a glass ampoule no bigger than a piece of long-grain rice, has a small memory … and read by a scanner two to four inches away, … are a proprietary technology and cost about $200 each.

•…sells chips to people who use them for education and robotics …a disclaimer states that the company does not advise consumers to implant them in humans or animals because the tags are not sold as medical products and are not sanitized…

• he could see a day when society would deem it acceptable for babies to be tagged at birth with chips

Large Herd Animal Management using Sensor Nets

Transforming Animal Agriculture

Peter Corke
Autonomous Systems Laboratory

Feb 2006

CSIRO

Sensor network application areas

- Applications demonstrated at a research feasibility level:
  - micro-climates in vineyards
  - environmental monitoring.
- Feeding frenzy:
  - industrial monitoring and control
  - home automation
  - commercial building monitoring and control
  - automated meter reading.

- CSIRO
  - cost of data for natural science
  - the new wave of "observatories"
  - capitalize on CSIRO's strengths in ICT and in domains such livestock industry, sustainability and land and water systems.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Livestock Industry

- Animal production is big business
  - 1B cattle
  - 1B sheep
- Big issues:
  - limited labour
  - expansive/remote properties
  - environmental sustainability
    - Soil degradation
    - Water shortage
    - Licence to farm legislation
  - cost of fencing and mustering
  - Disease outbreaks

  - Doing more with less

A systems way of thinking

www.ict.csiro.au

grows grass

needs grass

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A systems way of thinking
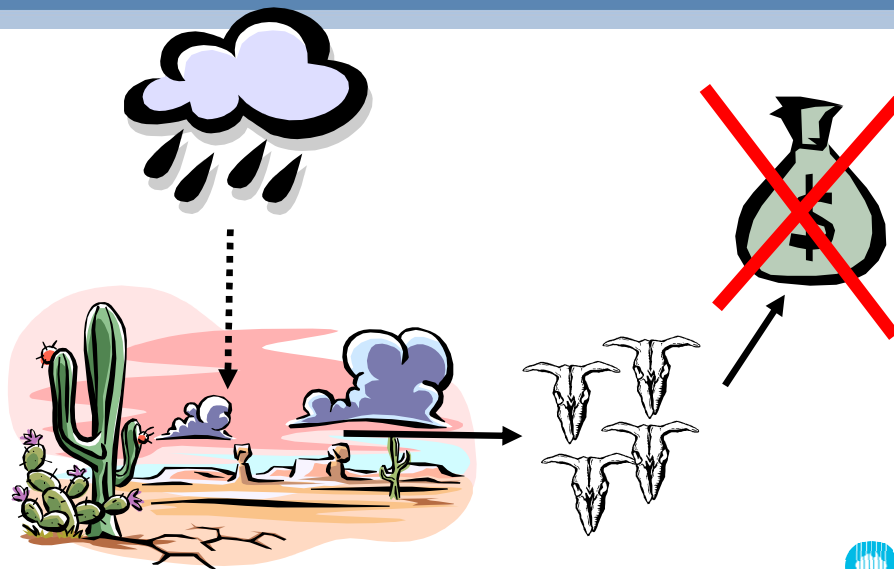
www.ict.csiro.au

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Soil moisture sensors
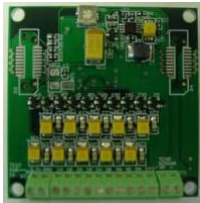
Water quality sensor

- **Sensors**
  - pH (ionode IH20)
  - Redox (ionode IH30)
  - Water Temp
  - Conductivity (TPS)
    - Across fresh and salty water ranges

Sydney in the summer … sensing _& control_
Oregon Scientific local and remote
temperature –humidity sensors

<u>Sensing versus control</u>

Can't change the weather… but I can:

1. Decide whether to go out… and what to wear
2. Open windows and average indoor-outdoor
3. Turn on and set AC

Effectors:
People
surrogates

Barney,
Microsoft c1998

2006 rebirth:
beer drinking
doll responding
to TV scan
lines

Early 2002 systems at UC/Berkeley UCLA
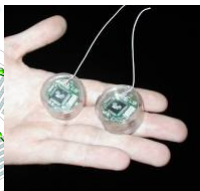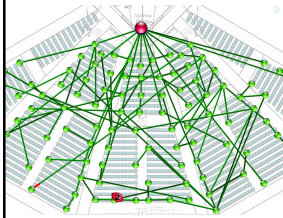
Intel Developers Forum, live demo 800 motes, 8 level dynamic network,

Motes dropped from UAV, detect vehicles, log and report direction and velocity

Seismic testing demo: real-time data acquisition, $200 vs. $5,000 per node

vs.

50 temperature sensors for HVAC deployed in 3 hours. $100 vs. $800 per node.

Elevators

Monitoring Space

CENS

EmBedded
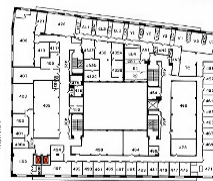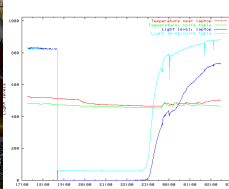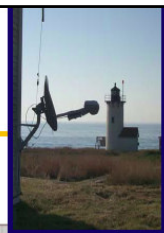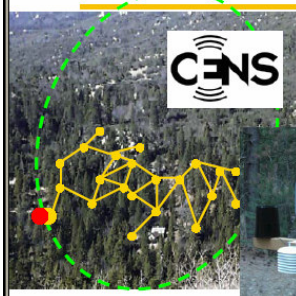
Building Comfort, Smart Alarms

Great Duck Island

Vineyards

BC 1/14/200

Sentries, UVA, OSU

nest Retreat

Ecophysiology of Redwoods

Monitoring Things

Earthquake Response, Glaser et al.

Wind Response Of Golden Gate Bridge

Mote Layout

UCLA Factor Bldg 72 channels

Intel Research

Condition-Based Maintenance
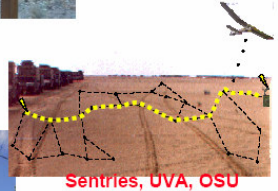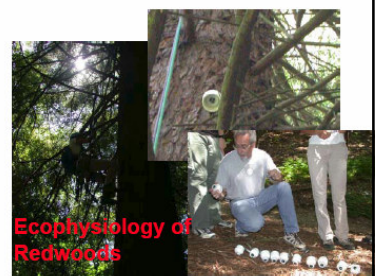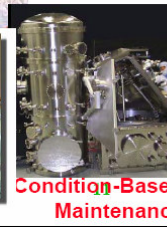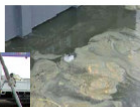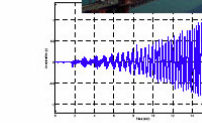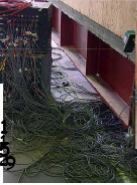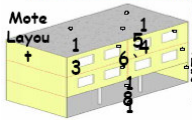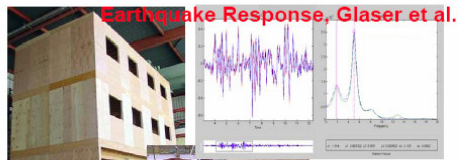
Interactions of Space and Things

ElderCare

Sensor Augmented Fire Response

Agriculture Solutions

Clinical Management

Shooter Localization - Vanderbilt, BBN

Manufacturing

Asset Management

nest Retreat
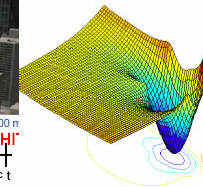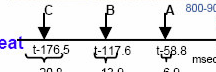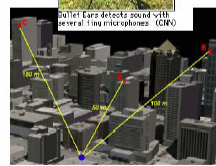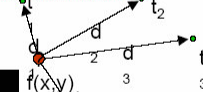
Example uses

- Env. Monitoring, Conservation biology, ...
  - *Precision agriculture, land conservation, ...*
  - *built environment comfort & efficiency ...*
  - *alarms, security, surveillance, treaty verification*
- Civil Engineering: structures response
  - *condition-based maintenance*
  - *disaster management*
  - *urban terrain mapping & monitoring*
- Interactive Environments
  - *context aware computing, non-verbal communication*
  - *handicap assistance*
    - *home/elder care*
    - *asset tracking*
- Integrated robotics
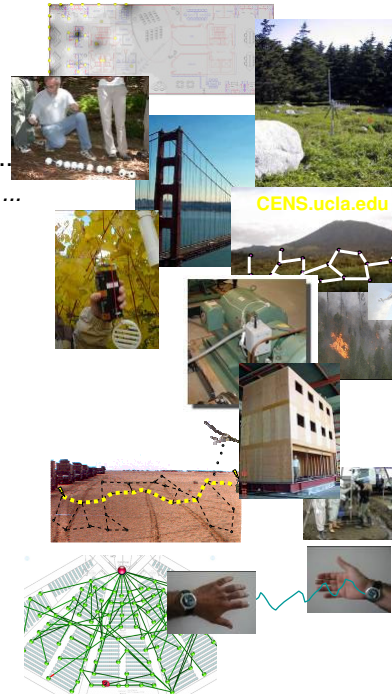
Lifetime and Scale

Sample Rate & Precision

Mobility & Disconnection

CENS.ucla.edu

A Day of Sensor Network Research at UCB (1/28)

EmBedded

•	Jan Rabaey	Ultra-low power and ultra-low cost wireless sensor nodes - an integrated perspective
→	Eric Brewer	Sensor Networks in Developing Region
→	Todd Dawson	Redwoods go wireless
•	Michael Gastpar	Information Theory and Large Sensor Network
•	Joe Hellerstein	Sensornet Tasking in the Large: Querying, Inference and Beyond
•	David Culler	Distributed System Design from a Sensor Net Perspective
→	Michael Jordan	Sensor networks as pattern recognition machines
→	Ed Arens	Price-responsive electricity management in buildings
•	Paul Wright	Industrial and Social Applications of Wireless Sensor Nets
→	Greg Fenves	Monitoring the Golden Gate Bridge
•	Kris Pister	Smart Dust and Micro Robots
→	Pravin Varaya	Sensor Networks for Traffic Monitoring
•	Jim Demmel	Mathematics of Modeling MEMS sensors
→	Alice Agogino	Lighting and Medical Personalization
→	Steve Glaser	Downhole sensor arrays and Firebugs
•	Deirdre Mulligan	Do Sensor Networks fit with Fair Information Practices
•	Pam Samuelson	Towards a Legal Framework for Sensor Networks
•	Kannan Ramachandran	Distributed signal processing for sensor networks: challenges and opportunities
•	Shankar Sastry	Conceptual Issues in Scaling Sensor Networks
•	Michael Franklin	Sensor Net implications for Database Systems and Vice Versa

1/14/2004   nest Retreat   15

Rob Poor, Ember Founder's vision

Forbes: Giving Voice to A Billion Things

"**Robert Poor** sees 50 billion embedded microcontrollers, <u>inside cars, traffic lights and air conditioners</u>, … in isolation. Then he imagines … they talk to one another.

Ember, the company that Poor co-founded in 2001, gives mundane devices the power to communicate.
"For $10 a light switch, and without having to tear up drywall, you <u>can shut off all the lights</u> in the house by one button."

Sensitech attached Ember <u>sensors in refrigerated trucks</u>. When fish from Boston reach Newark…without even cracking open the bay door…learn whether the fish got too warm.

A portfolio of Ember-linked wireless gadgets from **Control4** <u>controls lights, temperature and entertainment gear</u>."

Dust Network Example…

Another case of concurrent
East Coast and
West Coast startups.

The Best of What's New

Sensors Wireless 'Motes' to Link Factory Lights and Thermostats

Sometime in the next decade or so, cheap sensors the size of a grain of salt could give every product a pinch of savvy. Sewn into silk undies, they would tell the washing machine to be gentle. Sprinkled around a house, the sensors could be linked into networks that might help a home security system keep an eye on things. Or soldiers could scatter this so-called smart dust along enemy lines to keep watch for bioweapons.

Though shrinking fast, today's smart sensors are close to a pager in size and are doing more basic jobs. For example, the first SmartMesh devices (right), made by Dust Networks in Berkeley, Calif., will replace the miles of cabling necessary to link up lights, thermostats, and other sensors in large buildings and factories. Dust Networks' "motes" do away with the wires--and can slash the cost of installing a single thermostat from $400 to $40--by relaying data from one mote to the next. They use low-power radio signals to send short, secure bursts of data. Dust-size motes are still years off, says founder Kris Pister. But bottle cap-like devices will come within five years, he says, followed by aspirin-size ones.

Adam Aston

Energy Monitoring

- Energy Monitoring Service: monitor, analyze and reduce power consumption
- Problem: >> $100/sensor wiring cost
- Solution: Dust SmartMesh
  - Entire SmartMesh™ network installed in 3 hours (vs. 3-4 days)
  - 9 min/sensor
  - Software developed in 2 weeks (XML interface)
  - 5 months, 99.97%

23

Digital Sun:
Lawn sprinkler
control
(Interrupts power to
each sprinkler)

The S.Sense wireless sprinkler system is smarter than your average sprayer. … wireless battery-powered moisture sensors buried in your yard tell your sprinklers whether your lawn should have its usual drink, or whether there's just been a downpour. … sprinklers only turn themselves on when your lawn or flowers need water, and then turn off when the soil is appropriately moist. The system will even sound an alarm to warn of a broken or clogged sprinkler head.

Digital Sun: features, benefits, specs

- **Features**
- Conserves water
    - Reduces irrigating cost up to 30%
    - Turns off sprinklers when it rains
    - Reduces irrigation runoff pollution
- Easy-to-install
- Keeps plants looking healthy all year
- **Benefits**
- Easy-to-install _wireless_ system
    - Extendable range wireless network
- Works in landscape or agricultural
- **Enhances any existing or new sprinkler systems**
- Reliable dielectric moisture sensors

- **Specifications**
- Sensors: Moisture, Temperature, Light
- Frequency: 916 MHz
- Max Range: 50 ft. per node
- Network: Secure & reliable
- Power: 1 AA lithium battery (lasts up to 1 year)
- Size: 6" long x 1.9" diameter (1.1" barrel)

Wireless Sensor Networking
Crossing the Chasm

Nest Retreat

15 January 2004
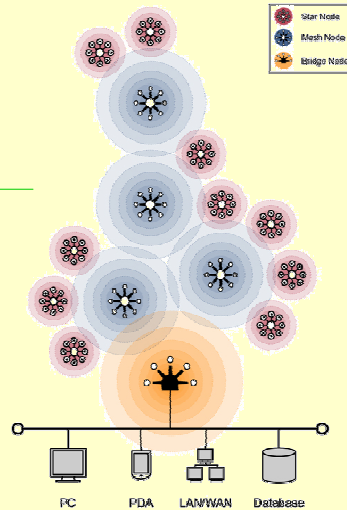
Initial Application
ART

Harvard University Art Museums
FOGG ART MUSEUM

Sterling & Francine
CLARK ART INSTITUTE

RISD Rhode Island School of Design

UNIVERSITY OF MICHIGAN

ISABELLA STEWART GARDNER MUSEUM
Inspiration. Imagination. Innovation.
THE CENTENNIAL

OHIO STATE
THE OHIO STATE UNIVERSITY

- High value to customer
- Builds expertise
- Competitive advantage
- Under the radar
- Drives partnerships with System Integrators
- Estimate $0.6B total market size

Berkeley NEST Retreat 1/04   Courtesy, Sensicast

SENSICAST OAS FOR CULTURAL ASSET PROTECTION

WIRELESS SENSOR NETWORKS: A NEW APPROACH TO SECURITY

Protecting the artwork within your institution from every possible threat is an unending task. Constantly changing exhibits create cost-prohibitive barriers for wired asset alarm systems. Real-time asset protection before, during, and after operating hours is difficult. In this high-alert climate, additional man-power may be required to ensure proper screening of patrons and bags at the entrance, provide adequate perimeter security, and deter vandals, thieves, or even curious patrons from touching, destroying, or removing precious artifacts. Existing object alarm systems may attempt to help, but are typically very expensive and result in too many false alarms, either overtaxing a museum security force or

---

The Ever Present Threat: Smart, Networked Appliances
full fledged control?
… research effort? … Hope?

REUTERS
KNOW. NOW.

🖨 Print this article

Close This Window

Study to learn power of smart grids, appliances

Wed Jan 11, 2006 7:30 PM ET

By Bernie Woodall

LOS ANGELES (Reuters) - Right now in homes across the United States, the water heater is pretty much a loner and the clothes dryer is dumb as a stone.

But within 10 years, "smart" power grids passing information back and forth with "intelligent" home appliances may save enough energy during peak electricity demand to keep utilities from building expensive substations and major transmission lines, say backers of a year-long experiment that begins this month.

Control:
Sense, detect, effect

Sensing Networks:
Tracking the movement of some thing throughout the sensor network is "interesting"

- Monitoring environment
- Fixed|portable network, sensor locations known
    - Need location for each sensor e.g. fixed or GPS… and then be able to detect location and movement of things e.g. cars, people among sensors
- Items may or may not have an identity per se
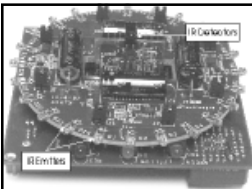
Xerox Research PARCTAB & ActiveBadge

The PARCTAB system is a research prototype developed at Xerox PARC to explore the capabilities and impact of mobile computers in an office setting and of palm-sized mobile computers that can communicate wirelessly through infrared transceivers to workstation-based applications.

These principles and assumptions have driven the design:

•*Extreme portability.*
The device is designed to be carried or worn at all times, much like a pager.
•*Constant connectivity.*
The system assumes the palm-top unit is always connected to the network.
•*Location reporting.*
The location of each PARCTAB is always known to system software.

The advantage of assuming constant connectivity is that the device can use the computing power on the network.

PARCTAB has been under development since early 1992.
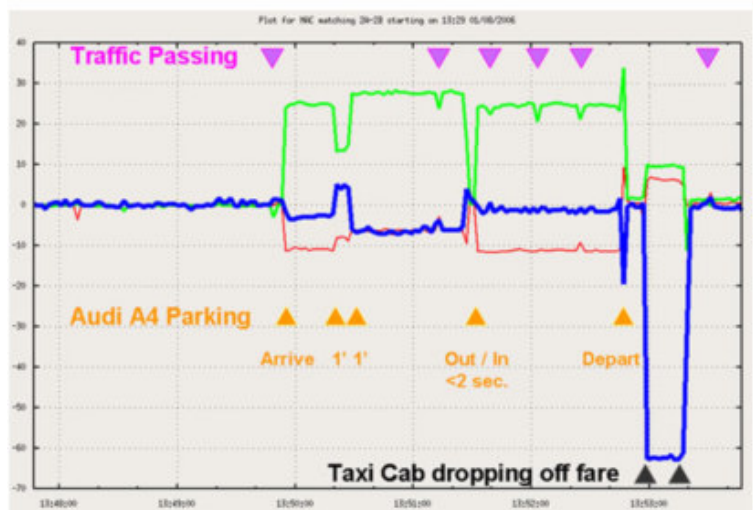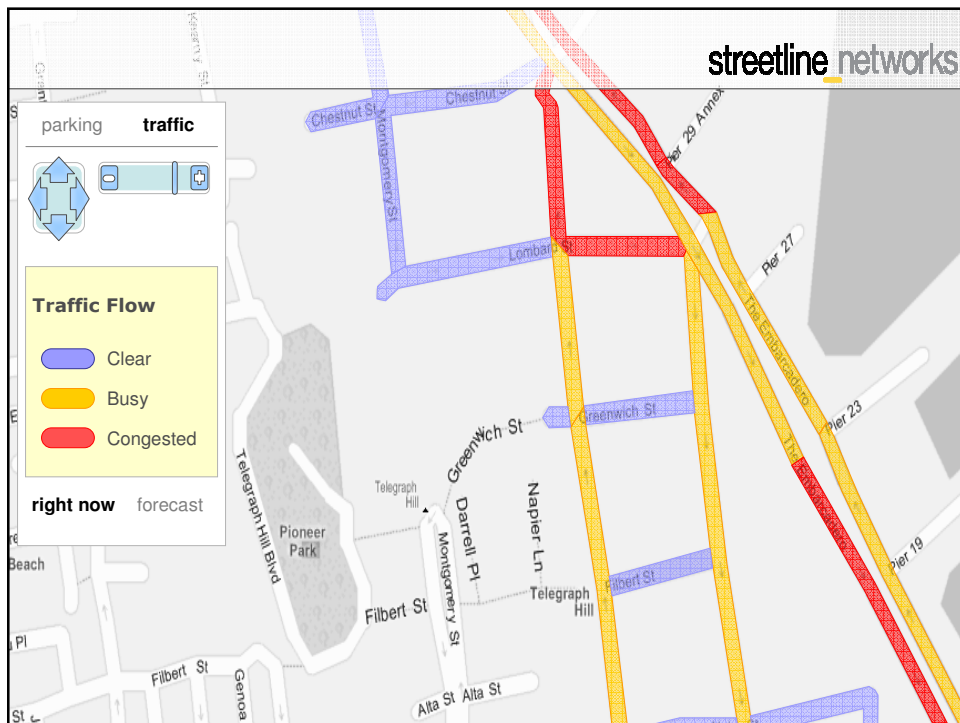In March 1993 the first system was released for general (non-project) use.

- Vehicle sensor detects both parking and traffic
- Reliable wireless networking
- Self-powered with 10-year life
- 4" x 4" standard package installs in less than a minute
- Low installed cost

Streetline

SAIC & Dust Networks

Passive IR

Passive IR and Camera

1.5 in

SAIC
An Employee-Owned Company

DUST

2.5 in

2.5 in
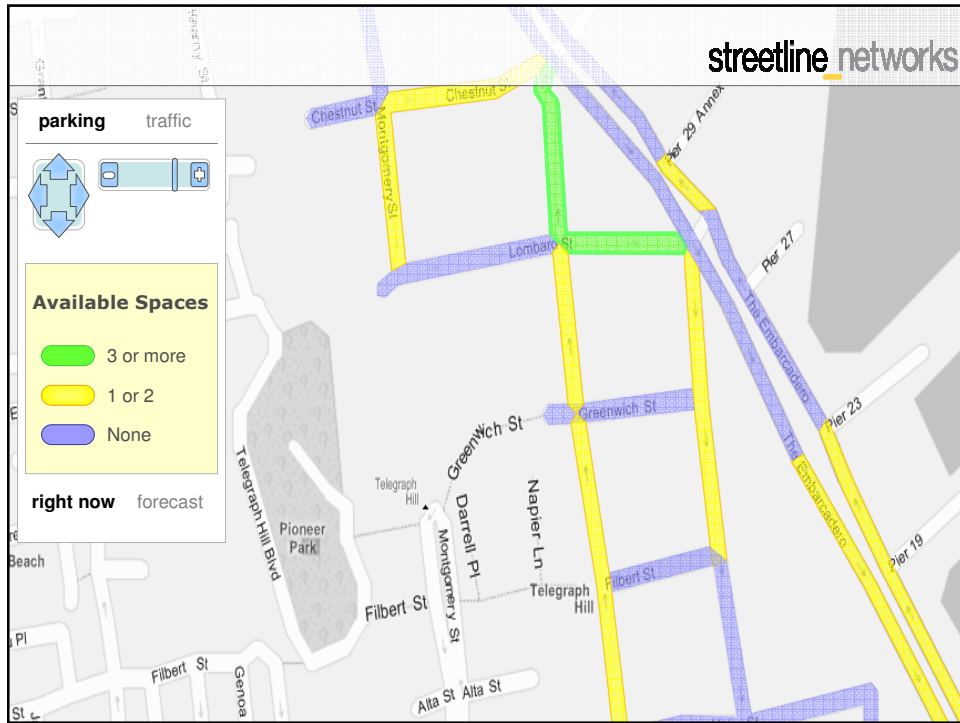
MEMS and GPS
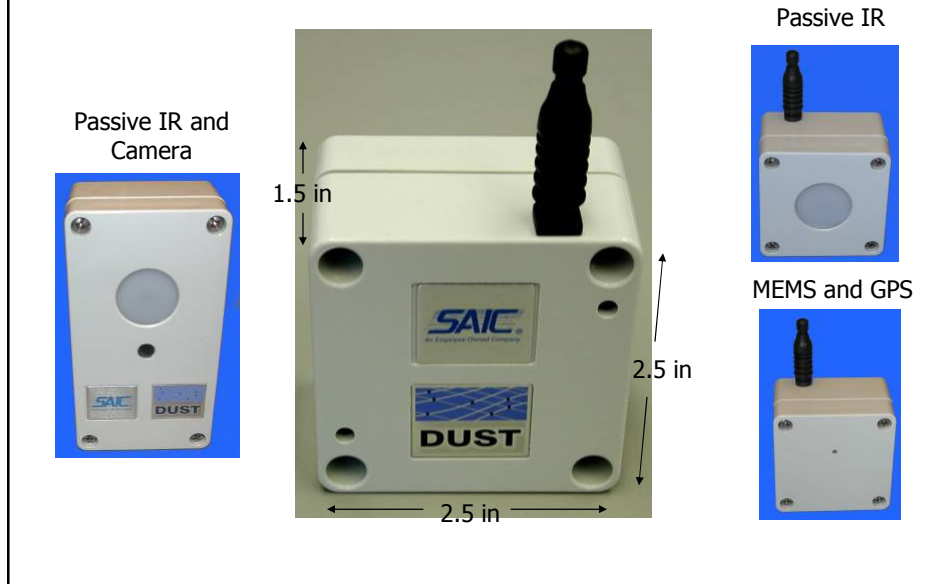
Perimeter Security - MARFORPAC

Objectives:

Develop and demonstrate an ultra-low-power, low-cost, reliable wireless sensor network for widespread and persistent surveillance of borders and perimeters.

Deploy and demonstrate at the at the Marine Corps Air Station (MCAS) near Yuma, Arizona

- Addresses a need to detect intruders, smugglers and scrappers at the CMAGR
- Provides a proving ground and relevant data collections for production and deployment

Key Participants:

MARFORPAC, MCWL, MCAS, SAIC, and Dust Networks

UK: 3M cameras, 300 images/persons/day,
…3.6 K licenses/hr.

ILS: Identity, Location, and State aka MRM (Mobile Resources Management)

- The ILS device is on a "thing" being monitored
  - High cost assets
  - People
  - Eventually everything
- ILS device "knows" its location
  - GPS
  - In a network "field" e.g. communication tower, LAN IP
- ILS device provides value by sensing "thing"
  - Calendar, temperature, vibration, trajectory, whatever
  - "State" can also be part of the IP cloud
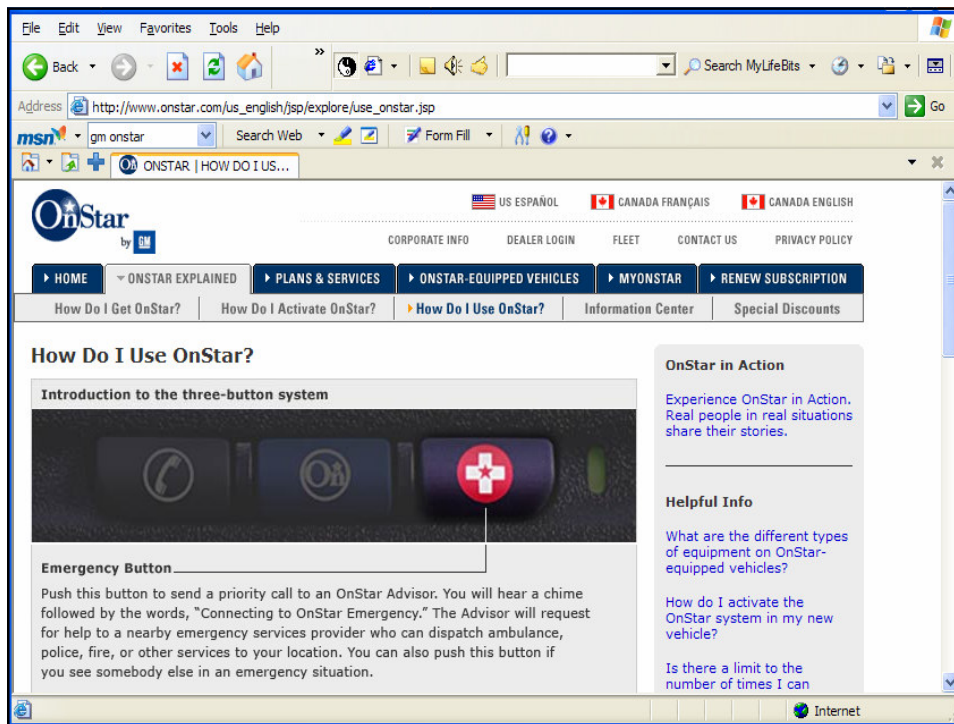
Qualcomm Fleet, Trailer, Resource Tracking

System Overview On-board the vehicle, the OmniTRACS solution sends and receives data from the satellite. The satellite relays information to and from the QUALCOMM Network Operations Centers (NOCs), which communicates with the customer's fleet management center.

‣ Additional connectivity to third-party devices and peripherals using OmniExpander™

‣ Driver authentication

‣ Wireless panic button

‣ Driver and vehicle performance monitoring

‣ Trailer/vehicle monitoring

‣ Tamper-detection alerts

‣ Automated Arrival and Departure

‣ Remote vehicle disablement

- ▸ Automatic satellite vehicle positioning
- ▸ Two-way text and data communications
- ▸ QTRACS® fleet management solution to display data from OmniTRACS solution
- ▸ Customizable reports
- ▸ AS/400 server, Windows® server, or Web-hosted operation
- ▸ Reliable message delivery
- ▸ QUALCOMM Network Operations Centers (NOCs)

- ▸ QUALCOMM Professional Services support seamless data integration with:
  - Back-office applications
  - SensorTRACS® performance monitoring solution
  - JTRACS Pro® vehicle monitoring solution
  - TrailerTRACS® asset management solution
  - T2™ Untethered TrailerTRACS® asset management solution

Strategic Management and Reduced Costs

The OmniTRACS solution opens a new world of strategic fleet and equipment management. The Automated Arrival and Departure (AA&D) feature records vehicle arrival and departure times without driver intervention. This enables dispatchers to monitor driver performance, bill accurately, and verify and inform customers of detention events or any other unforeseen delays. Armed with this data, carriers can negotiate better fee arrangements and charge customers who are responsible for excessive delays.

Creating customized reports with the OmniTRACS solution makes it easier to keep track of key information. For example, by evaluating data accumulated over time, transportation fleet managers can

SOLUTION PLATFORMS

OmniTRACS® Mobile Communications Solution »

QUALCOMM's OmniTRACS solution operates on one of the world's lar wireless data networks. Our nationwide two-way satellite...

More >>

T2™ Untethered TrailerTRACS® Asset Management Solution »

Increase the security of your tethered and untethered trailers with the Untethered TrailerTRACS asset management solution...

More >>

TrailerTRACS® Asset Management Solution »

QUALCOMM has been in the trailer-tracking business for a decade, wit than 35,000 installed tethered units. Our advanced...

More >>

35

SPOT Overview

Services

msn

Microsoft Outlook

MSNBC News

MSNBC THE WEATHER CHANNEL weather.com

And more...

Network

MSN Operati — Dedicated Ku-band Satellite Feed — 12 kbps/radio station FM subcarrier broadcast

Frame Relay

WAN

US:
All 50 states
Top 100 MTAs
219 FM stations
177M reach

Canada:
Top 12 cities
24 FM Stations
12.5M reach
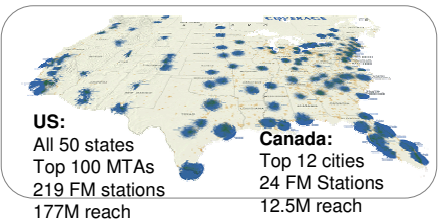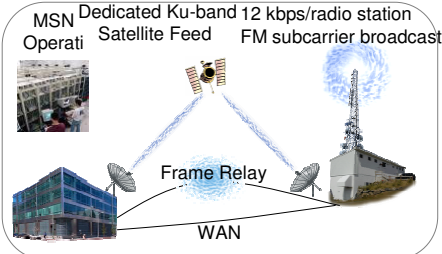
Watches

Small Footprint CLR & Applications
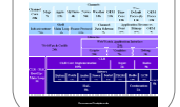
OEM Modules

Components:
LCD, Battery, Module, Case & Strap

ARM720
512K ROM
384K SRAM
FM SCA Radio

National Semiconductor
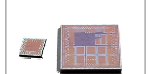
What Are Smart Personal Objects?

PC Peripherals   **Smart Personal Objects**   **Consumer Appliances**   **PCs and Servers**

Smart Personal Objects

- Everyday devices whose core functionality is amplified and improved with the addition of software
- Devices that provide people the personalized information they want, when they want it
- A new computing space that compliments existing technology and provides a new method for people to remain connected to their world

SPOT
Smart Personal Objects Technology

- Makes Smart Personal Objects smarter, connected and essential information tools for people
- Incubated in Microsoft Research for the past three years
  - Developed a new hardware platform to enable low power, low cost, connected devices
  - Extends the reach of .NET architecture into a smaller and broader class of devices

Health and wellness
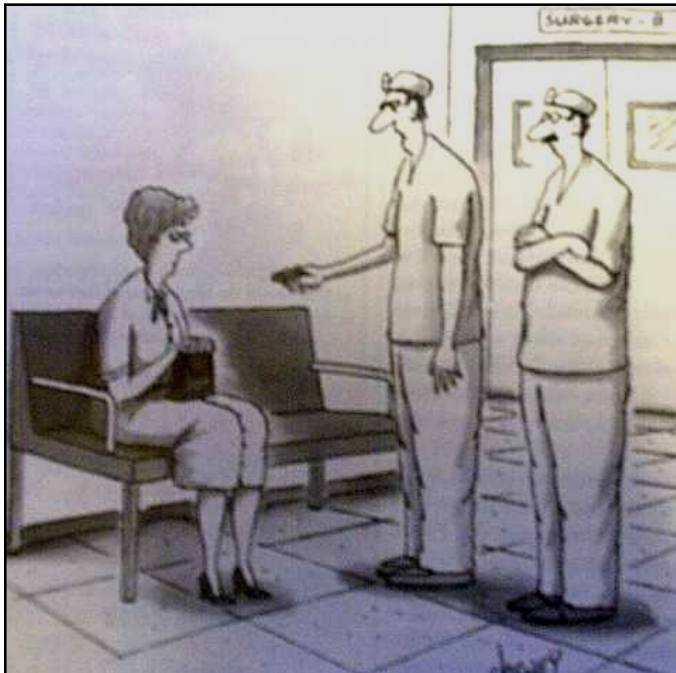
Health Monitoring: "Your husband just died, … here's his black box"

"High Tech, Under the Skin"
By ANNA BAHNEY
NY Times Fashion & Style
February 2, 2006

- By inserting the radio frequency identification device… he planned to log on to his computer, open doors and unlock his car.
- Implanting the chip was relatively simple …chip, complete with a miniature antenna and enclosed in a glass ampoule no bigger than a piece of long-grain rice, has a small memory … and read by a scanner two to four inches away, … are a proprietary technology and cost about $200 each.
- …sells chips to people who use them for education and robotics …a disclaimer states that the company does not advise consumers to implant them in humans or animals because the tags are not sold as medical products and are not sanitized…
- he could see a day when society would deem it acceptable for babies to be tagged at birth with chips

Health: Number 1 market need…

Network must be open!

For openers… audio, pix, T, P, ECG, … 1 GB

2-WAY WRIST RADIO

Why we need low power, wireless
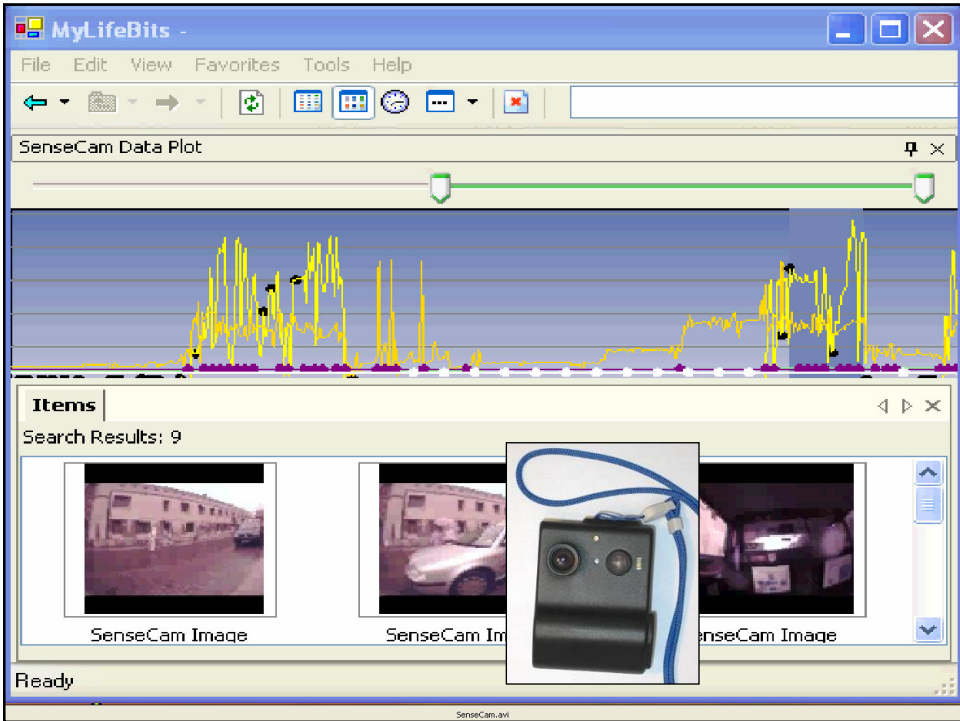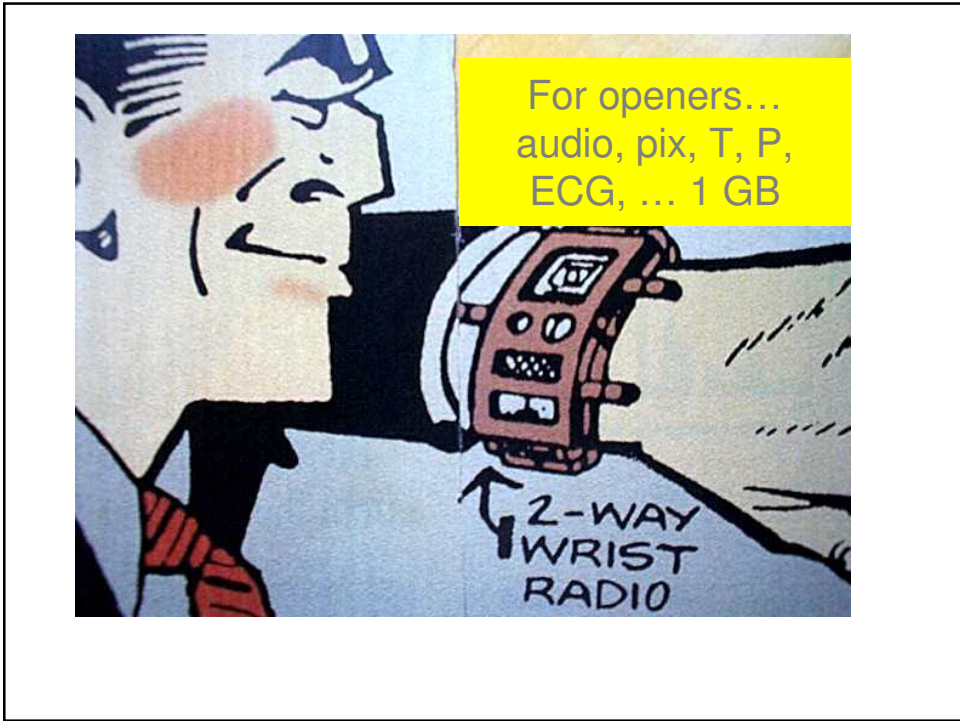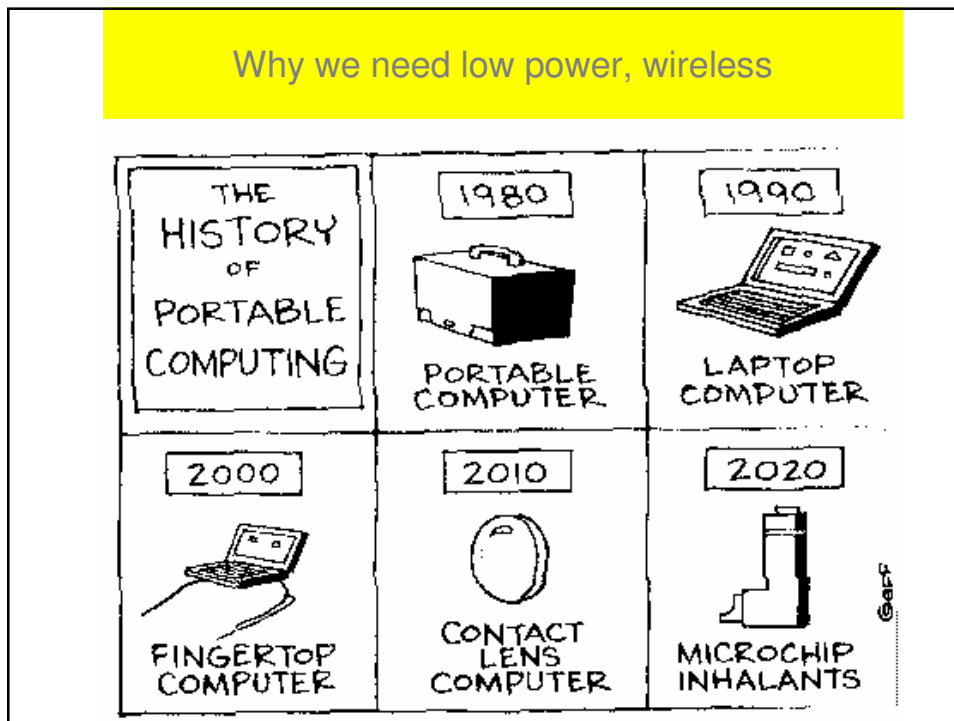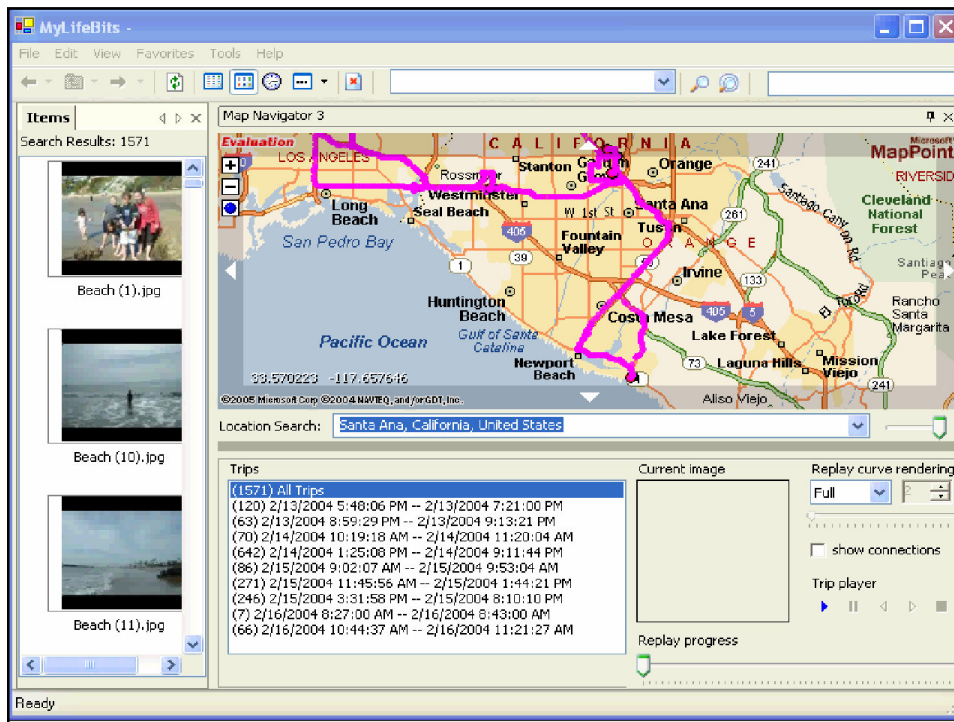
The A/V/real time data future:
capture modes/devices

St. Jude Pacemaker

Body Media's BodyBugg

BELL, CHESTER 25 JUN 2004 9:15:07AM *BP Before Pacemaker* 995263
71 yrs Male pg 1 of 2

PR .*TYPE 1 SECOND DEGREE A-V BLOCK (WENCKEBACH), - - - - PR PROGRES. LONGER; DROPPED BEAT
QRSD 95 VENTRICULAR RATE = 53 DX;PACEMAKER
QT 519 .*FIRST DEGREE A-V BLOCK - - - - - - - - - - - - PR INTERVAL > NORMAL LIMITS
QTc 527 .*LEFT ANTERIOR FASCICULAR BLOCK - - - - - - - QRS AXIS -40 DEG., I;40 INFERIOR 030004168289
  . PROBABLE LEFT ATRIAL ABNORMALITY - - - - - - - - P' -.10 MV AND 40 MSEC IN V1 Requested by
--AXES-- . LATE PRECORDIAL R/S TRANSITION - - - - - - - - - QRS NEGATIVE IN V5 OR V6 AL-AHMAD
P 57 . INFERIOR INFARCT, OLD - - - - - - - SIGNIFICANT Q-WAVES IN 2,3 & AVF Tech 52
QRS -53 - ABNORMAL ECG -
T 56 --CONTINUED ONTO NEXT SHEET-- Edited C-HP7S9
  PREVIOUS ECG: 31 JUL 2000 9:38:50AM, CONFIRMED BY SAH - AB
STANFORD UNIVERSITY HOSPITAL - SCIATICA STUDY (S) Mark Perlroth, M.D. - 26 JUN 2004 3:11:59PM

Loc 10057 25 mm/sec 10.0 mm/mV F ~ 0.15-150 8

995263 10/31/2005 11:02:18 AM BELL, CHESTER G STANFORD UNIVERSITY HOSPITAL
  Born 1934 Male Dept: 72
Rx:
Dx: Oper: 54

Rate 68 $ I,II,III,V1,V2,V3 MEASUREMENTS NOT USED IN MORPHOLOGY ANALYSIS BY COMPUTER XL18
PR $ DX:786.50/414.01
QRSD 148 . PREDOMINANTLY VENTRICULAR-PACED RHYTHM,............PREDOMINANT PACEMAKER RHYTHM
QT 420 CAPTURE RATE = 68 060009952631
QTc 447 . Requested by:
  DR.M.MCCONNELL
--AXIS--
P 62 .
QRS -79 - ABNORMAL ECG -
T 97 PRELIMINARY-MD MUST REVIEW

LOC 10000-0002 Speed:25 mm/sec Limb:10 mm/mV Chest:10 mm/mV 60% 0.15-150 Hz HP7S9 04729

Contactless electrodes for ECG & EEG
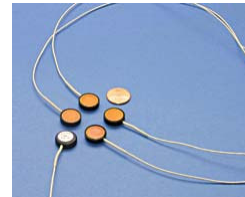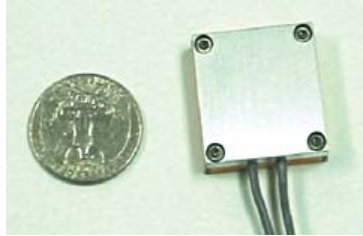
Staying Healthy in a Wireless World

"When all things have a digital identity"
Seminar, Macquarie Institute for Innovation
7th February 2006

Bruce Satchwell
CEO Alive Technologies

The Need

- Rapidly Ageing Population
- Longer Lifespan
- Increase in Chronic Diseases including Cardiovascular, Diabetes, and Obesity
- Rapidly increasing cost of healthcare (currently 15% of GDP in US with projections of 25% of GDP)
- Desire to stay in own home

The Solution ??

- Disease Management
- Wellness Management
- Self Care
- Enabling Technologies
- Cyborg (Human Machine Hybrid)

Alive Technologies

- Develops wireless health screening, diagnostic and monitoring systems for worldwide markets

- Based in Queensland Australia

- **Applications:**

- Chronic Disease Screening and Management (inc. Cardiovascular diseases, diabetes, COPD, asthma, sleep apnea)

- Health ,Fitness and Wellness

AliveSport Mobile Monitor

Alive Bluetooth Heart Monitor

•Measures ECG, Heart Rate, activity , body position and falls (using accelerometers), with internal SD card storage

•connects to Bluetooth phone or access point with 100m range

•Real time remote monitoring on the internet using browser interface

•Applications include holter monitoring for heart arrhythmias, home cardiac monitoring, cardiac rehabilitation, sleep apnea screening, and health and fitness
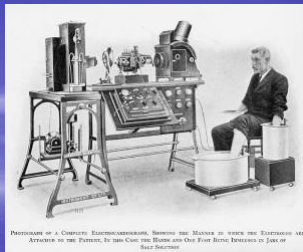
Alive Mobile 12 Lead ECG

•6 and 12 lead ECG integrated into cable

•Connects via serial, USB or Bluetooth to PDA, Pocket PC Phone, PC or access point

•Applications for Pocket PC, Windows.

•Remote Java applet viewer for browser

•Customers include John Hopkins Hospital (PIERS) and Lausanne Ambulance Service

Bluetooth Pulse Oximeter

- Measures oxygen saturation, heart rate and plethysmograph waveform
- Transmits to remote server and java applet browser viewer in real time.
- Bluetooth range up to 100m to access point, PDA phone or PC
- Small, wearable, low power design
- internal memory
- applications include
  - sleep apnea monitoring
  - home oxygen therapy monitoring
  - asthma monitoring

Alive Diabetes Management System

Automatic wireless transmission of blood glucose readings to a central web based database (initial clinical trial underway in France)

46

Tactex Bed Monitor…pressure sensitive material

BED SENSOR DISPLAYED AT WHITE HOUSE CONFERENCE ON AGING

The Tactex bed sensor is made of **fiber-optic pressure sensing material** first designed for Canadian Space Agency robotics.

The Tactex bed sensor is a modular, wireless device that can **reliably and unobtrusively monitor when a patient gets out of bed, the quality of sleep, and vital signs e.g respiration and heart rate**.

Current bed sensors are simplistic … uncomfortable for patients, hard to position and plagued with false alarms, …The US market for patient monitoring systems is expected to increase to $8.2 B.

Tactex plans to begin field trials of in early 2006.
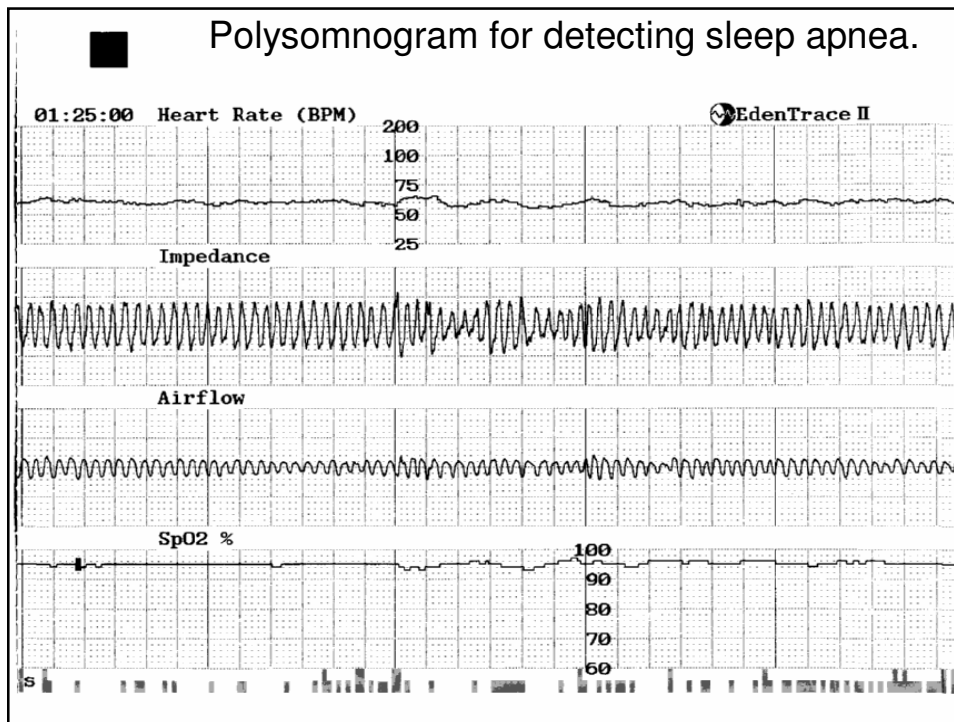

E-Neighbor, Health Hero, smart bed

E-Neighbor … detect unusual activity in a senior's residence -- If the shower runs too long, the refrigerator stays closed, the system "calls to ask if they're O.K. If the person does not respond, the system can call or send an e-mail alert to someone else. ….. cost about $300, plus $20 a month. … he sees a diagram of the floor where his mom lives and an icon of where she is. …, he has access to everything from her blood pressure to visitors she's seen. A wireless "help" button around her neck signals her location. Medical staffers transmit her vital signs and other data across the network. If Chris notices a pattern or event, … he can call the staff.

…her diabetes worsened and memory loss undermined her ability to care for herself. She gave permission to use the monitoring system, and the access it affords has relieved much of his anxiety about well-being.

Researchers are perfecting in-home devices that monitor weight, blood pressure, and other vital signs of seniors with chronic diseases and send a report to doctors or caregivers. Health Hero Network's Health Buddy, currently available only through medical providers. The 5-inch by 9-inch box is placed in the home and attached to, say, a weight scale or a blood-glucose monitor. Pushing buttons to answer questions that appear on a small display, the user can alert medical personnel to danger signs such as rapid weight loss.

SENSORS WHILE YOU SLEEP
With a "smart" bed … U. VA's Medical Automation Research Center in Charlottesville, a patient need only lie down to check and transmit medical information. Expected to be called the NAPS bed, for non-invasive analysis of physiological signals, it has wireless sensors that measure pulse rate, breathing, and restlessness. … the bed going on sale for about $1,000 by the end of 2006…"to be effective, there should be a caregiver in the loop" who can read and interpret the data.

Polysomnogram for detecting sleep apnea.

Sensors with IP On Everything
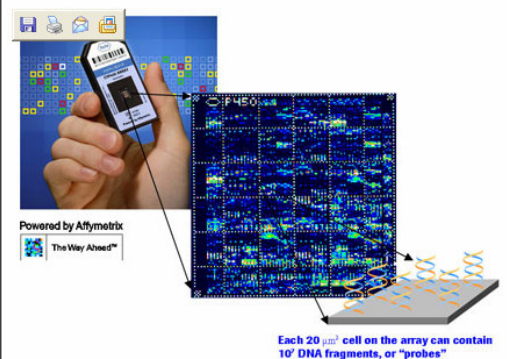
Affymetrix GeneChip Arrays

Functional Genomics methods

Chips

Slides
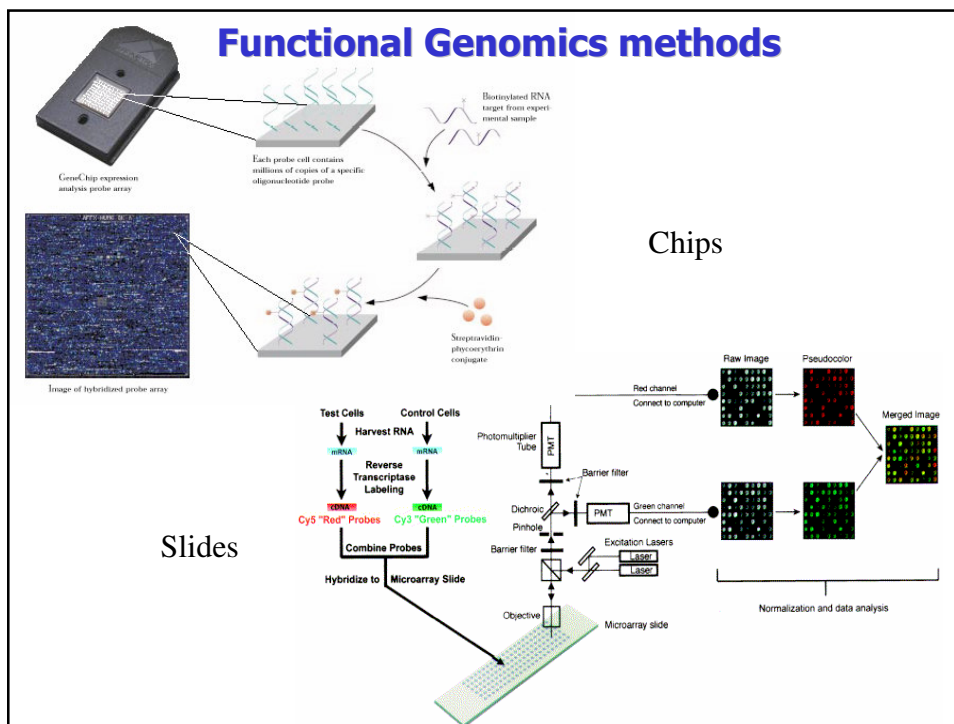
SIONEX - SENSOR CHIPS FOR CHEMICAL & BIOLOGICAL DETECTION DEVICES

Sionex's platforms incorporate its microDMx™ chips for utilization in a wide range of biological and chemical detection devices, ranging from handheld devices and control components to sensor modules. microDMx™ technology separates and detects ionized compounds based on their differential mobilities through the sensor chip. Ionized compounds have mobilities that are a function of their charge, mass and cross-sectional area.

Effector: Squiggle linear motor

New Scale has developed several prototype assemblies to demonstrate OEM product applications of the SQUIGGLE motor.

Consumer devices: mobile phone cameras

The SQUIGGLE motor is ideal for use in mobile phone cameras, using ...less battery power than electromagnetic ... unique design delivers both short-range motion (auto focus) and long-range motion (optical zoom).

...integrate ...ized motor technology into working camera modules for the customer's phone design. Modules may incorporate

PROTOTYPE - FOCUS AND ZOOM ASSEMBLY for phone cameras. Piezoelectric SQUIGGLE motors move two lenses along a guide, with auto focus travel of 2 mm and optical zoom travel of 8 mm.

SQUIGGLE MOTORS are available in 2.4 x 2.4 mm and 3.4 x 3.4 mm standard body sizes for evaluation by OEM product designers.
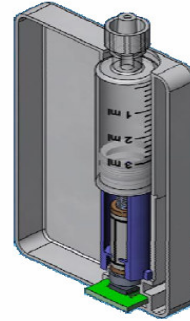
DESIGN CONCEPT –WEARABLE DRUG PUMP. The SQUIGGLE enables smaller, more comfortable drug pumps with high dosing accuracy and reliability.

Laboratory measurements
for Science and Engineering

- Pedagogy
- Outdoor monitoring of the infrastructure e.g. roads, water, etc.
- Seismic and weather monitoring
- Outdoor laboratory instruments with robots
- Large scale
  - CERN millions of detectors, petabytes of data
  - Detecting threats at national and international scale
  - Undersea sensor nets, 100s of kilometers

The MIT iDAT Project is a major educational initiative designed to empower both school and university students throughout the world with the ability to measure and investigate a huge range of phenomena by providing them with a wide range of extremely simple to use miniature wireless sensors. The project is funded by the MIT iCampus initiative which is supported by Microsoft and is being undertaken by the MIT BioInstrumentation Laboratory.

Development of 50 iDAT Sensors covering many areas of science and engineering

iDAT wireless USB sensor network

Displacement, CO, CO_2, EMG, pH, Light, Flow, Resistance, Respiration, Pressure, Current, Voltage, Angle, Sound, Velocity, Charge, Magnetic, Blood-O_2, Conductivity, Heart-Rate, Capacitance, Inductance, Temperature, Humidity, EKG, Force, O_2, Radioactivity, Acceleration

The sensors commonly used in teaching physics, electrical engineering, mechanical engineering, biological engineering, chemistry, biology, physiology, psychology, earth science, architecture and material science were surveyed (see figure below) and a common set of 50 sensors selected (see figure

Remote outdoor sensing

…wireless sensors can be installed where landline telephony is not accessible.

Kasanoff (Clemson) predicts several types of wireless sensors:

-- Sensors on road surfaces that will glow when ice is present

-- Sensors and cameras on bridges that will detect when cars or trucks exceed legal weight limits

-- Sensors on beaches & waterfronts that detect signs of pollution or acts of sabotage.

The Incorporated Research Institutions for Seismology are using wireless modems that will be used throughout the country for seismographic data collection. The shared database is to be used to explore the earth's interior.

Seismic monitoring will allow IRIS to reinforce the efforts to mitigate potential earthquake and volcanic hazards …

UCLA CENS:
Center for Embedded Networked Sensors

NIMS--Networked Infomechanical System
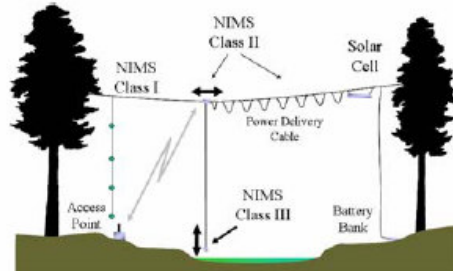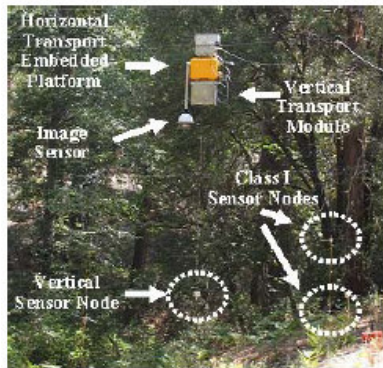
SensorNet: A detection & alert system for chemical, radiological, biological, nuclear, explosive threats

Neptune Project: Sensor Network, U. Washington

Autonomous Underwater Vehicle · Current Meter · Rover · Camera & Lights · Acoustic Doppler · Nutrient Monitor · Wave Sensor
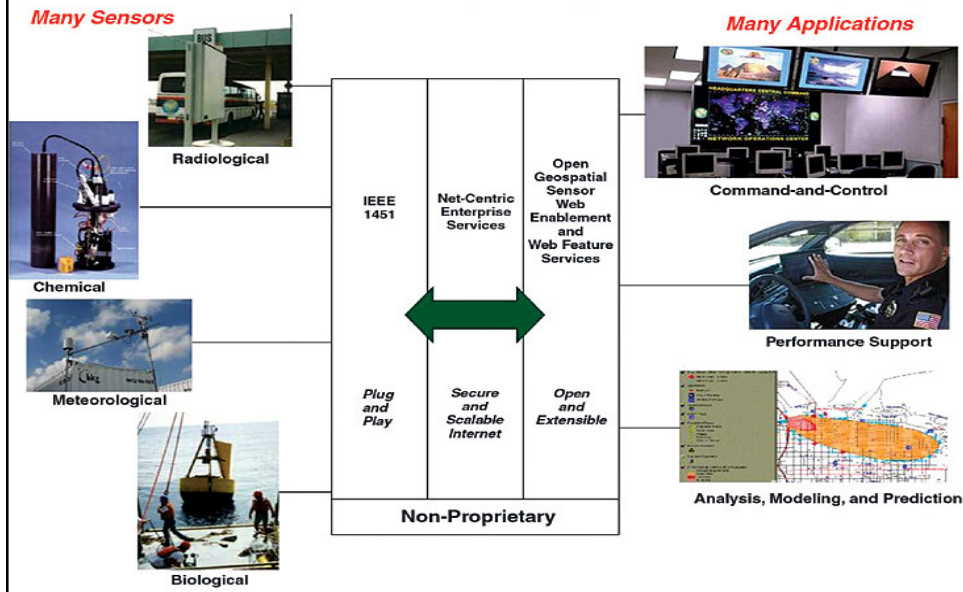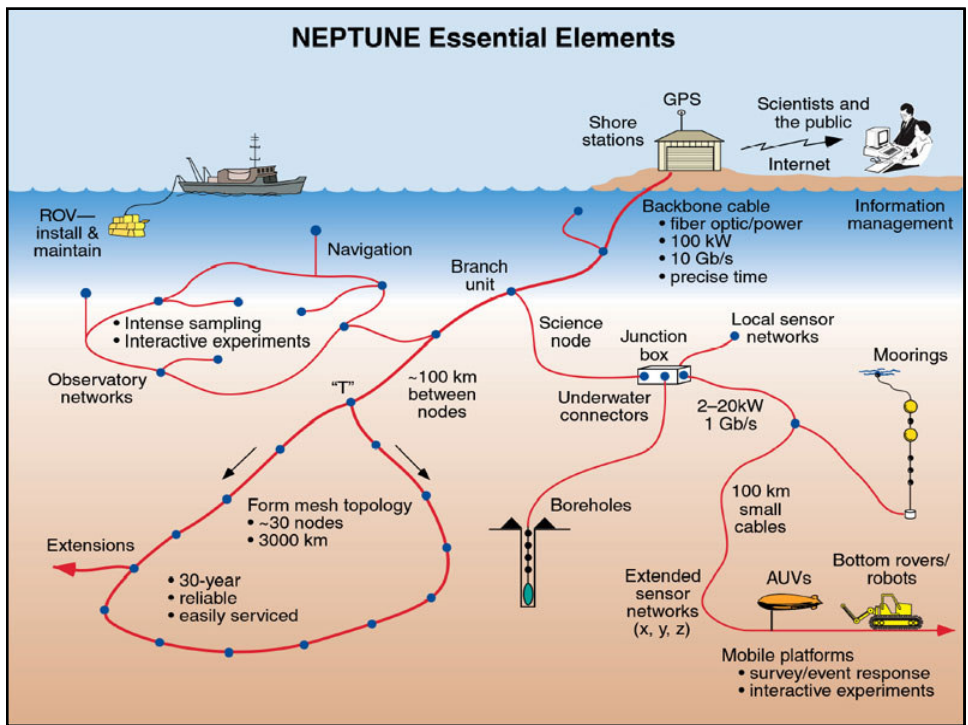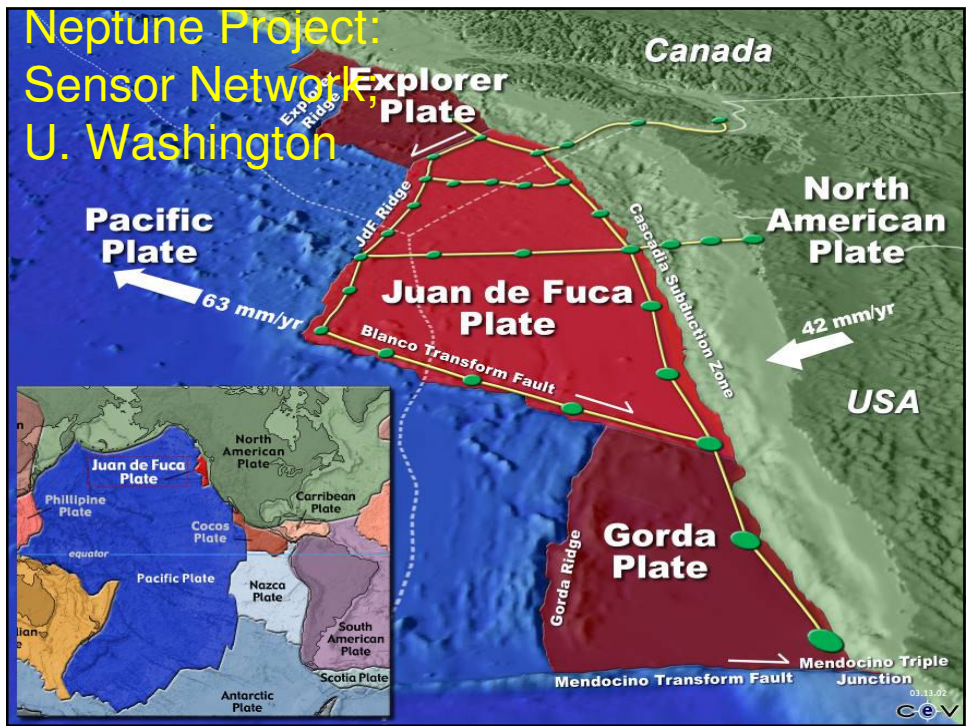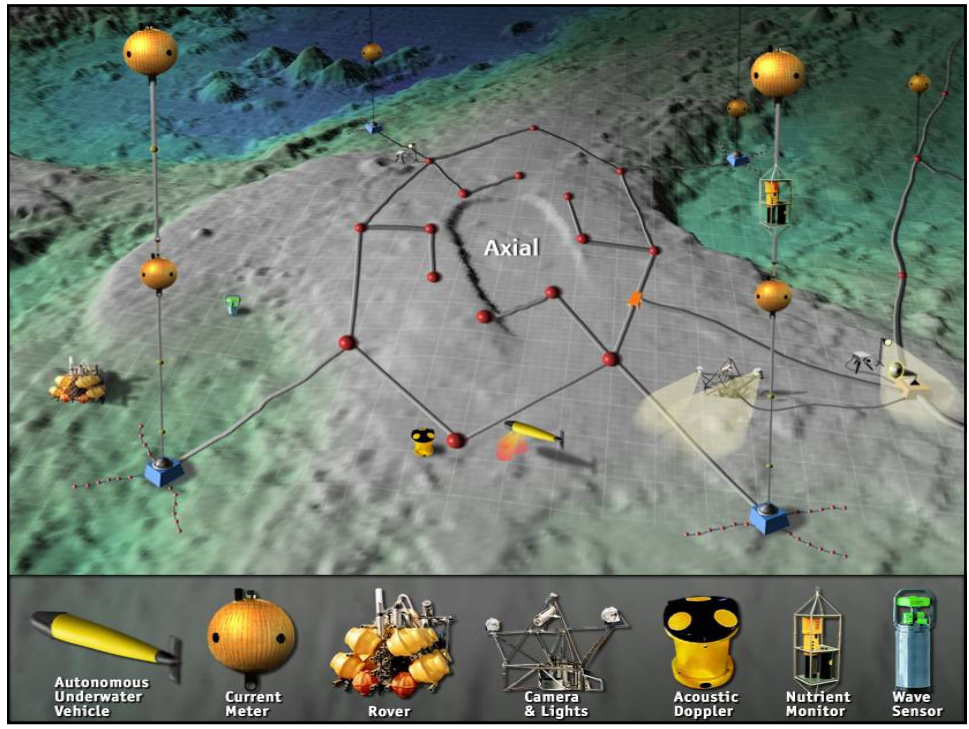
NEPTUNE USERS

Elementary/secondary schools
Undergraduates (projects, classes)
Graduates (including non-majors)
Science/engineering community
Related industries
Public - structured (e.g., aquariums)
Public - unstructured (e.g., media, www)
Decision-makers
National legislature
Government agencies
State/provincial entities
Non-governmental organizations

NEPTUNE Constuction Partners

University of Washington
Monterey Bay Aquarium Research Institute
Jet Propulsion Laboratory California Institute of Technology
Woods Hole Oceanographic Institution
Institute for Pacific Ocean Science and Technology (Canada)

Summary

Functionality dimension (of WSN space)[1/30]

- Sense… some parameter of something is measured.
- Actuate/effect… "something" gets changed
- Control (closed loop). actuators = f(sensors, state)
- Sensing (peripheral) networks
  - Provide connectivity of a large set of nodes
  - Detects moving items in the "sensing network"
- ILSA: Identity – Location – State -- Actuate
  - Name as with an Bar Code or RFID tag
  - Location – for moving item/resource
  - State of the "thing" as f(t), e.g. age, environment, interesting data e.g. temperature or vibration
- JAN - Just another net e.g. 802.11x, Bluetooth for bits
- JAN for connecting portable or mobile items

Venue Segmentation Map for Intelligent Device Networking & Management

The Pervasive Internet

Buildings | Consumer | Industrial | Medical | Power | Retail | Transportation | Government / Security

Commercial / Institutional
- Office
- Education
- Retail
- Hospitality
- Healthcare
- Grocery
- Airports
- Stadiums
- Data Centers

Industrial
- Process
  - Semi Fabs
  - Chemical
  - Pharma
  - Refining
  - Pulp/Paper
- Discrete
- Batch

Residential
- Single family
- Multi-family

Devices: HVAC, Vertical Transport, Fire & Safety, Lighting, Security & Access, etc.

Hospital
- Point-of-Care (in hospital)
- ER
- Mobile
- Point-of-Care

Doc. Office / Care Facility
- Point-of-Care (office)

Home / In Vivo
- Implants
- Point-of-Care (home)

Lab
- Point-of-Care diagnostics
- Lab diagnostics

Devices: MRI, PDAs, Implants, Surgical Equip, Pumps, Monitors, Telemedicine, etc.

Supply side
- Generation
- Transmission

Demand side
- Distribution (Utility)
- Residential
- Industrial
- Small Commercial
- Large Commercial

Devices: Central plants, Distributed resources, etc.

Vehicles
- Cars/trucks
- Aircraft
- Watercraft
- Construction
- Off-Hiwai vehicles

Infrastructure
- Fueling stations
- Navigation systems
- Traffic Control & Highway systems

Devices: Vehicles, Roads, Gas stations, signage, etc. M

Household
- Laundry
- Kitchen
- Environmental
- Information
- Lighting
- Security
- Climate

Entertainment
- Audio
- Video
- Gaming

Mobile
- Audio
- Video
- Communication
- Multi-purpose

Devices: TVs, VCRs, Dishwashers, Washer/Dryers, Refrigerators, Lights, Computers, etc.

Machine control
- Complex machines
- Simple/standard machines

Industrial Process Control
- SCADA
- Instrument/sensor
- CDS

Electronics / Semicon
- Semicon
  - Semi Tools
  - Wafer Hand
  - Test Sys
- Electronics
  - T&M
  - Comp
  - Placement & Board Assembly

Infrastructure / Supply Chain
- Facility management
- Infrastructure

Lab

Devices: Pumps, Valves, Vats, Conveyors, Pipelines, Motors, Drives, Switches, Machines, etc.

Point-of-sale
- Complex machines
- Simple/standard machines

Infrastructure / Supply Chain
- Distribution centers
- Shopping centers

Signage / Display
- In-store signage
- Remote signage
- Display equipment

Lab
- Process equip.
- Product diagnosis

Devices: POS Terminals, Tags, Cash Registers, Payment Terminals, Signs, etc.

Legislature
- Documents, Records
- Voting, Polling
- Other

Public Safety
- Police Equip & Personnel
- Fire Equip. & Personnel
- Other Regulatory Equip. & Personnel

Public Infrastructure
- Water Wastewater Equip. & Personnel
- Other e.g. Library, etc.

Lab
- Water Treatment
- Building Environment
- General Environment

Devices: Voting booths Information cards, Scanners, Public infrastructure, etc.

Vehicles
- Land
- Air
- Sea M

Material
- Weapons
- Supplies
- Other M

Personnel
- People
- Machines M

Security / Surveillance
- Radar / Satellite
- Environment

Devices: Weapons, Vehicles, Soldiers, Unmanned drones, etc.

By permission Harbor Research, Inc.   1.800.595.9368   info@harborresearch.com   http://harborresearch.com/
January, 2006

M   Agriculture & landscape, mining, scientific & field instrumentation

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Harbor Research Taxonomy
Where (What) => Buyer (Suppliers & Sellers)

- **Buildings** (access & security, fire & safety, elevator/escalator, HVAC, lighting)
  - Commercial/Institutional (airport, data center, education, hospital, retail, … stadium)
  - Industrial
  - Residential (single|multi family units)
- **Consumer** (A/V, computers, lights, refrigerators, washers)
  - Household (room *laundry* & function *climate*)
  - Entertainment
  - Mobile
- *Agriculture, landscape*
  - Farms
  - Homes
  - Public spaces
- **Industrial Control - K** (contacts, switches, motors, valves, pumps, conveyors, pipelines, etc.)
  - Machine (simple standard, complex) K
  - Industrial process K
  - Electronics / Semiconductor mfg.
  - Infrastructure / supply chain
  - Lab (specialized sensors & instruments)
- **Medical** (computers/PDAs, CT/MRI, pumps, monitors, telemedicine devices)
  - Hospital (point of care, ER/OR, mobile)
  - Clinics, Doctor's offices
  - Lab (instruments)
  - Home / in vivo (implants, point of care)
- **Power** (monitor, control)
  - Supply (generation, distribution)
  - Demand (consumption, off-loading)

- **Retail** (POS,… tags)
  - Infrastructure / supply chain
  - Signage / Display
  - *Buyer behaviour* e.g. consumer tracking
- **Transportation & other public infrastructures:** Streets…Highways, Rivers & streams (monitoring,… traffic control)
  - Vehicles (cars, aircraft, …construction)
  - Infrastructure
- **Government /Security** (Voting, identity, scanners, public infrastructure)
  - Legislature
  - Public safety (police, fire, … large scale disaster)
  - Public Infrastructure (landscape, public space)
  - Lab
  - (Weapons, soldiers, unmanned things, etc)
  - Vehicles
  - Material
  - Personnel
  - Security / surveillance (climate and natural disasters, radar/satellite, environment)
- *Scientific & engineering pedagogy & research*
  - *Laboratory bio-medical*
  - *Natural science outdoors*
  - *Water management*
  - *Large scale physical science e.g. Earthquake, hurricanes, tornados, etc.*

WSN Space

Building automation:
Energy monitoring
Environmental monitoring
Lighting control
HVAC control
Security alarming
Access control
Asset tracking
Industrial automation:
In-process monitoring
Energy monitoring
Equipment health & utilization
In-process control
Residential (see Building):
HVAC, Lighting…Access control
Audio/Visual
Data-networks
Outdoor:
Landscape & Water
Parking & traffic
Security
Personal:
Fitness & health
Eldercare
Patient care

Basic Function
Sense
    Energy monitoring
    Environmental monitoring
    Security Alarming
    In-process monitoring
    Equipment health & utilization
    Traffic & parking monitoring
Control
    Lighting control
    HVAC control
    Access Control
    In-process control
    Consumer A/V
ILS/A
    Asset Tracking
    Fitness & health
    Eldercare

Buyer
Consumer
Research
Commercial/retail
Medical
Industrial building
Industrial process
Government
Military

Location, mobility, scale
Indoors/Outdoors
Fixed/Portable/Mobile
Scale
    On Body
    Room
    On Equipment/process
    Building (may be LAN connected)
    Campus (CAN, LAN connected)
    Geo-dispersed

Topology/Scale & Application Locus
Application:= isolated | WSN | IP service
WS/A-WS/A
    Point to point, stand-alone
WS/AN –stand alone app
WS/AN – IPN* connected
IP + WS/AN (IP used to carry S/A
WN for connecting mobile or portable S/A
Note: the app is in the IP network…
* Local and/or global IP Network

The end

3. Wireless Sensor Networks: Technology basis, products, and direction

Gordon Bell, Visiting Professor
Macquarie University Institute of Innovation
Enterprise of the Future Seminar Series
7 February 2006

WSN

- Origin of WSNs – an example of how new technology creates an industry…
- UC/Berkeley including TinyOS
- Technical trade-offs: data-rate, noise, power, range,
- Future: where will Moore's Law lead us
- Zigbee: Standard effort

Timeline… "it takes 11 years!"-Mead

- 1994: Kaiser and Pister build first UCLA motes
- 1995: Crossbow founded, by UC/Berkeley student
- 1996: UCLA Low Power Systems for Wireless Microsensors Paper;
  1997 Pister "Smart Dust" proposal to DARPA optical comm, solar power
- 1997, 2001 Poor's MS, PhD. Theses @ MIT Media Lab. Two WSNs.
- 1998 Sensoria founded to exploit sensors (Kaiser)
- 1998 RF motes designed by Seth Hollar (MS thesis).
  Pister suggests collaboration, leading to UC/Berkeley NEST
- 1998: WINS UCLA Workshop (GB keynote)
- 1998 Graviton funded by KPCB > 11/02: Xsilogy > 12/04: SYS Technology
- 1999 WeC mote, McLurkin (MS thesis), Crossbow start sales 2000/2001
- 2001 COTS based components, Berkeley's first mote provided:
  - 1 in.^{3} : Temperature, humidity, barometric pressure, light intensity, tilt & vibration, magnetic field sensors, transceiver, uprocessor, & battery!
  - 20 meter range; Lifetime:1 week continuous; 2 years,1% duty cycle
- 2001 Network Embedded Software Technology (NEST) June kickoff.
- 2001 Ember founded (Poor & Wheeler)
- 2002 Dust Networks founded (Pister), July

The challenges

- Wireless channels: speed, noise
- Power (to listen) CSMA CA (carries sense, multiple access, collision avoidance)

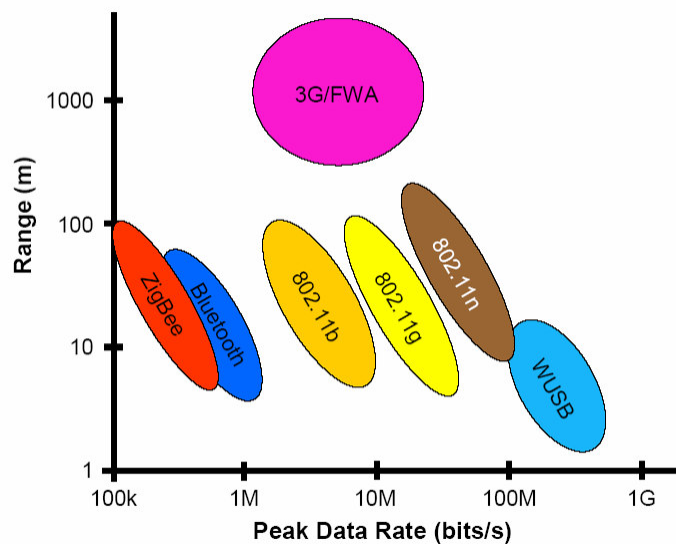| Technical Challenges |
|---|

- Reliability
  - 50 motes, 1 failure/10 years →
    - MTBF = 5 centuries
  - 99.9% → 1 packet per mote per day
    → 1 packet per hop per week
- 10 year battery life (~100μA, every mote)
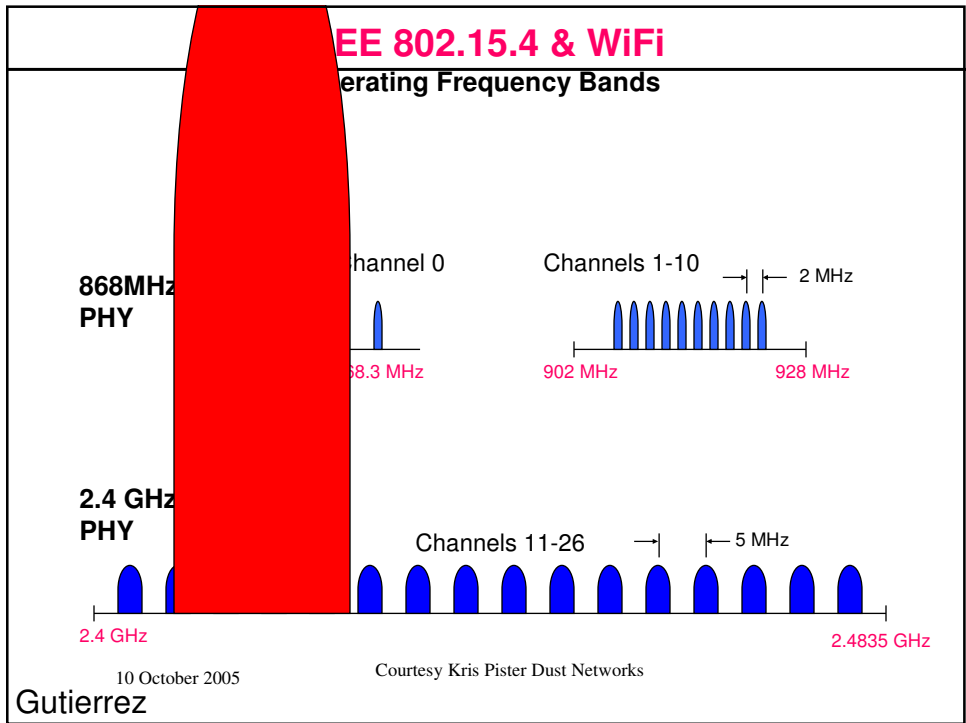- -40 to +85 C
- FCC regulations
  - Compliance
  - Interference

10 October 2005   Courtesy Kris Pister Dust Networks

Peak data rates vs range for wireless protocols

Power consumption versus data rate

Application Data Rate (bps)

- 100M
- 1 M
- 10k
- 100
- 1

1yr cr2032

1yr AA

2 weeks AA

802.11 a,b,g

802.15.4

Cordless phones

Improved Hardware

Software/algorithms

10μ   100μ   1m   10m   100m   1   10

Average Power consumption (W)

EE 802.15.4 & WiFi
Operating Frequency Bands

868MHz PHY

Channel 0

868.3 MHz

Channels 1-10

2 MHz

902 MHz   928 MHz

2.4 GHz PHY

Channels 11-26

5 MHz

2.4 GHz   2.4835 GHz

10 October 2005

Courtesy Kris Pister Dust Networks

Gutierrez

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Radio Reliability in a Crowded Spectrum

- **UWB** *ultra wideband*
  - **Unclear potential for duty cycling**
- **DSSS** *direct-sequence spread spectrum* **doesn't cut it**
  - **Helpful, but only about 10dB**
- **+20 dBm doesn't cut it**
  - **Helpful, but expensive in batteries**
  - **802.11 & cordless phones & portable bar code**
- **Must frequency hop**
  - **Precise time synchronization required…**
  - **Lots of channels, lots of bandwidth, better scaling, …**
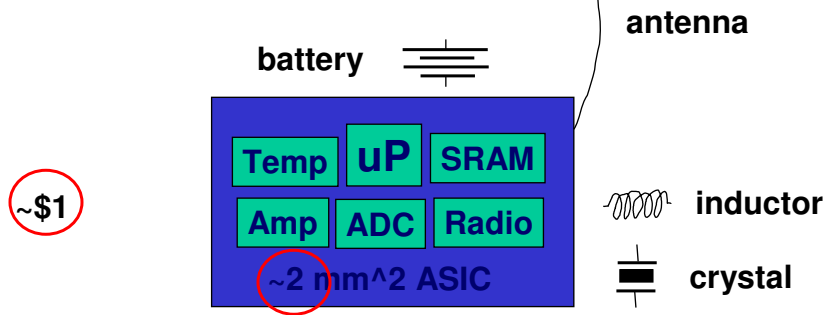
10 October 2005   Courtesy Kris Pister Dust Networks

Future directions
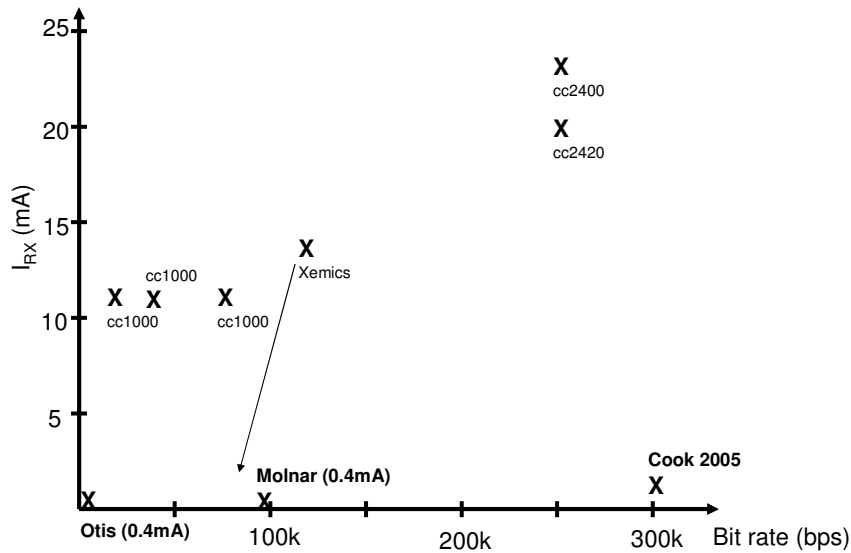
Mote on a Chip? (circa 2001)

- Goals:
  - Standard CMOS
  - Low power
  - Minimal external components

antenna

battery

Temp	**uP**	**SRAM**
Amp	**ADC**	**Radio**

~2 mm^2 ASIC

~$1

inductor

crystal

10 October 2005   Courtesy Kris Pister Dust Networks

Radio Performance em250

X em250

X cc2400

X cc2420

X Xemics

X cc1000   X   X cc1000

Cook 2005
X

Molnar (0.4mA)
X

X
Otis (0.4mA)

I_{RX} (mA)

25

20

15

10

5

100k   200k   300k   Bit rate (bps)

10 October 2005   Courtesy Kris Pister Dust Networks

Size reduction as mote moves to dust:
Sense > Control > ILS

- Motes with battery approach bottle cap size
- Embedded in bottle cap
- Identity… knows its name
- Location
  - GPS
  - Identity within a friendly or ubiquitous sensing network
- State
  - Monitors what's inside
  - When opened
- Effect?
  - Tells everyone about it

WSN environment, function, structure, scalability, platform, performance,… link
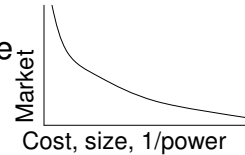
- Environment: indoor | outdoor | moving object/network
- Sensees: fixed | moving items | moving network items
- Interaction with IP nets: free standing | peripheral to IP net & www
  - Scale & topology: pair | tree | mesh *for long haul* –tree *for sensor nodes* | homogeneous, peripheral sensor/actuator mesh (with connection to IP)

- Net performance: data-rate & error rate; range > inter-mote distance; power>battery life; mote discovery time
- Node fcn: passive | sense | effect | gateway | route |… | application
- Link, Network interconnection, and protocols
  - Bluetooth -> 802.11.15.4 (wireless personal area net) -> WiFi (IP)
  - Public switched and cellular nets GSM, 2G…4G
- Noise tolerance techniques: multi-frequency; multi-path; dynamic channel assignment; retry, etc.

- Platform characteristics… processor & O/S, network stack, standards…

Network structure and Link characteristics

- Network structures… GB expectation
  - point-to-point | Star (for simple functions)
  - Stand-alone with simple function in net
  - *Stand-alone 802.11.15.4 net to support end S/A…*
  - Peripheral Sensor/Actuator Nets connecting to IP or PSN
    - IP net enacts function (e.g. data gathering, analysis, control)
    - IP used to get wired and wireless coverage
- Radio Link and Network interconnections
  - Bluetooth -> 802.11.15.4 (wireless personal area net) -> WiFi (IP)
  - Public switched and cellular nets GSM, 2G…4G

Beliefs… and biases

- **Wired** sensor networks are everywhere doing everything
  - Homes, commercial & industrial buildings, science & engineering, military… Indoors and outdoors.
  - Data gathering & instrumentation, energy monitoring, HVAC, lighting, power, process control, security, …
- Sensor applications are limited by cost (and sensibility!)
  - Cost is dominated by installation of wires, thereby limiting apps
- Commercial adoption of **wireless** sensor networks is gated by reliability and power consumption…
  - Sensing and scientific & data gathering are the early adopters BECAUSE of proof of efficacy and liability concerns
  - Control apps represent more complexity and liability
  - Redundancy is critical: multiple channels & paths
- zero cost, zero size, zero power motes are inevitable… will enable infinite apps, including mobile… anything non-zero, just reduces market size
- WSNs are peripherals or edge to IP!

Market vs. Cost, size, 1/power

The End

Zigbee: Cast of 1000s
building a WSN using words on 679 pages

ZigBee technology: general characteristics

- Data rates of 250 kbps and 20 kbps
- Star topology, peer to peer possible **Star is fatal, especially with single frequency**
- 255 devices per network
- CSMA-CA channel access
- Optional Guaranteed Time Slot
- Fully handshaked protocol for transfer reliability
- Low power (battery life multi-month to nearly infinite) **2 nets: powered and sensor parts**
- Dual PHY (2.4GHz and 868/915 MHz)
- Extremely low duty-cycle (<0.1%)
- Range: 10m nominal (1-100m based on settings)
- Location Aware: Yes, but optional

ZigBee Alliance

Copyright 2002 The ZigBee Alliance, Inc.

ZigBee Stack Architecture

ZigBee Network Communication Model (Tree)

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ZigBee Network Communication Model (Mesh)

ZigBee Coordinator (FFD)

ZigBee Router (FFD)

ZigBee End Device (RFD or FFD)

Mesh Link

11
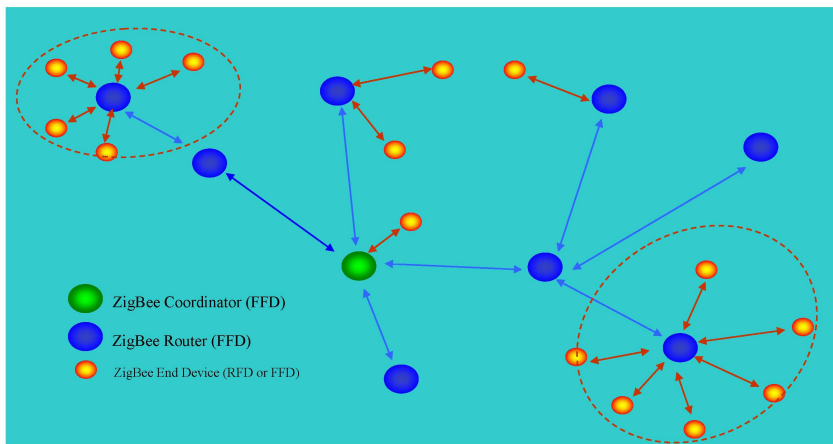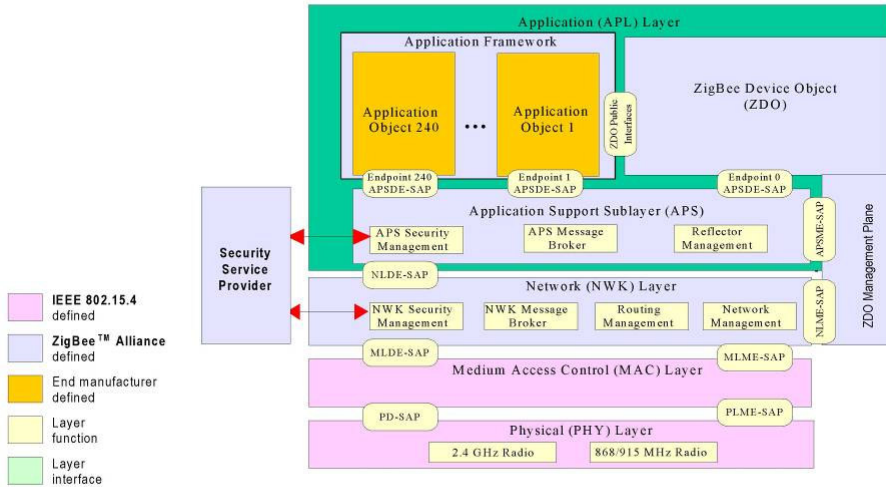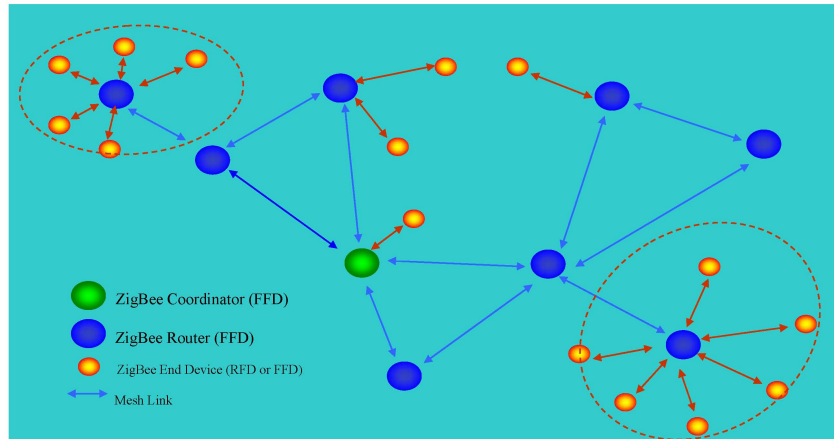
Are WSNs *another independent* network, or are they edge i.e. peripheral nets to the IP world?

- Can Zigbee create an isolated network, independent of LANs, Internet, & www… What's wrong with WiFi?
  - Time to get a large scale network architecture "right"
  - Cost to install and maintain a second network versus using the robust, large scale wired/wireless IP intranet/internet
  - "Application" versus sensors|effectors are in "IP" world
    - Sensor nets does data collection, alarms, etc. into databases
    - Controllers are computers…
  - Each vendor will have their own network due to app's need
- Zigbee consists of 2 networks and 3 components
  - Powered nodes to maintain just a communication network
  - Sensor|effector nodes that do the work
  - Co-ordinator nodes – that will have to be gateways to IP

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4. Wireless Sensor Network: Market, industry structure, startups

Gordon Bell, Visiting Professor
Macquarie University Institute of Innovation
Enterprise of the Future Seminar Series
7 February 2006

Looking at the market & Industry…

- The n-body problem… it takes an infrastructure
- Too many alternatives, too little time & resources
- Zigbee view
- Market reports… buying understanding
- Sensicast then and now
- Ember and various affiliations
- WSN Apps Characterization: wire replacement!
- Some projections… as the hardware -> $0.0

Layered Applications Structure →Market Map: All roads from components to paying customers

End users

Systems Integrators & Distributors

Maintenance
Installation
Planning
Network integration
Packaging, testing

Independent SW Vendor Apps

WSN vendors (chips, software, systems)

Sensor manufacturers

Radio & other components
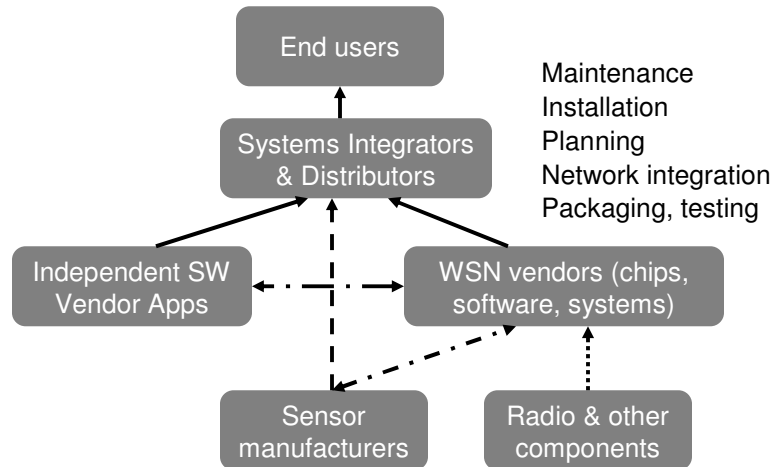
Deciding where to focus: too many choices; too little time & resources

- What: Is the product and what do the users need?
  - Mapping product to customer apps and requirements
- Who: will buy?
- How will it be made and sold: OEMs, direct, etc.
  - Create a market map from sensors… customers
  - What partners are needed?
    - Sensor suppliers, ISV applications, system integrators, databases, special networking, other software
- How *rapidly* is the market & industry likely to develop?
  - Will it move to new applications? Versus a wire substitute?
  - What is the ultimate structure of the industry as hardware -> $0
- Resources & Plan: Sales, marketing, & business development

Low Data Rate WPAN Applications (Zigbee)
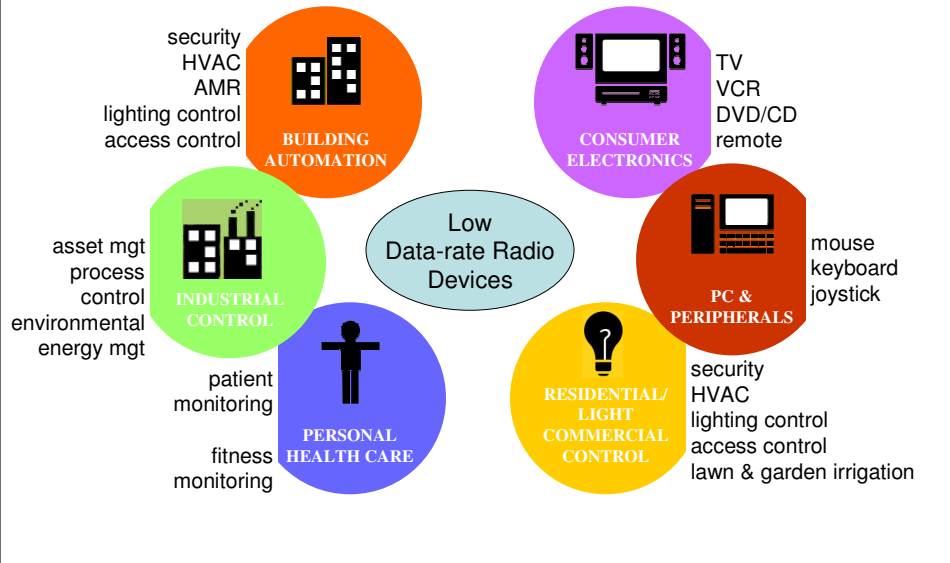
The ZigBee Alliance: target markets
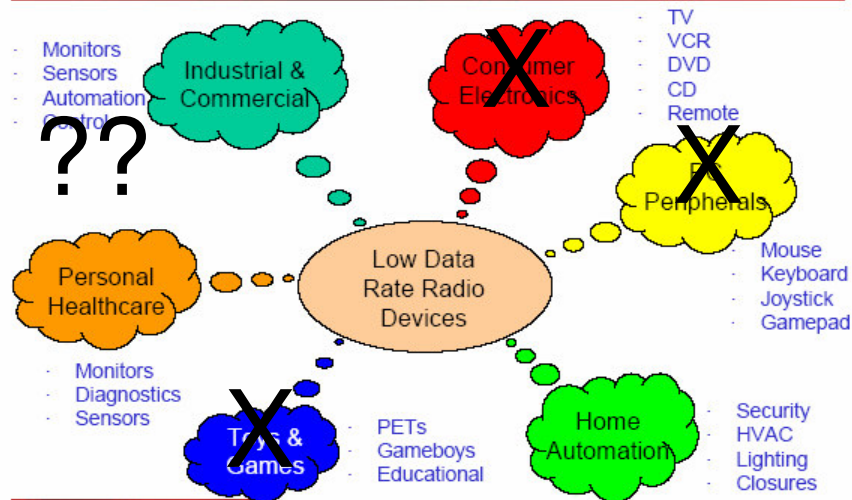
Consumer vs Enterprise Class

Consumer Class
- *Cost* more important than reliability
- Convenience driven
- Deployed in small area
- Device driven
- Point-to-point

Enterprise Class
- *Reliability* more important than cost
- Installation & operation cost driven
- Deployed in large areas
- System & control driven

CONSUMER ELECTRONICS

PC & PERIPHERALS

PERSONAL HEALTH CARE

RESIDENTIAL/ LIGHT COMMERCIAL CONTROL

BUILDING AUTOMATION

INDUSTRIAL CONTROL

DEFENSE

~~Sensor Networks Take Off!~~

Industry Analysts Take Off!

Units (Millions) vs year: Wi-Fi nodes, Handsets, Wireless Sensor Nodes (2003–2007)

$8.1B market for Wireless Sensor Networks in 2007
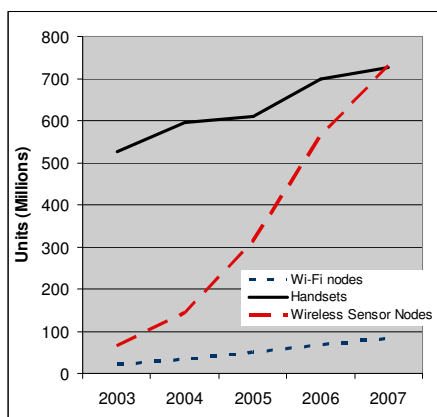
Source: InStat/MDR 11/2003 (Wireless); Wireless Data Research Group 2003; InStat/MDR 7/2004 (Handsets)

Microsoft WNS Workshop 10/05   Courtesy of Kris Pister

WW LR-WPAN Component Revenues by Industry

WDRG, 2003

$748,000,000 in '03

($ US millions)

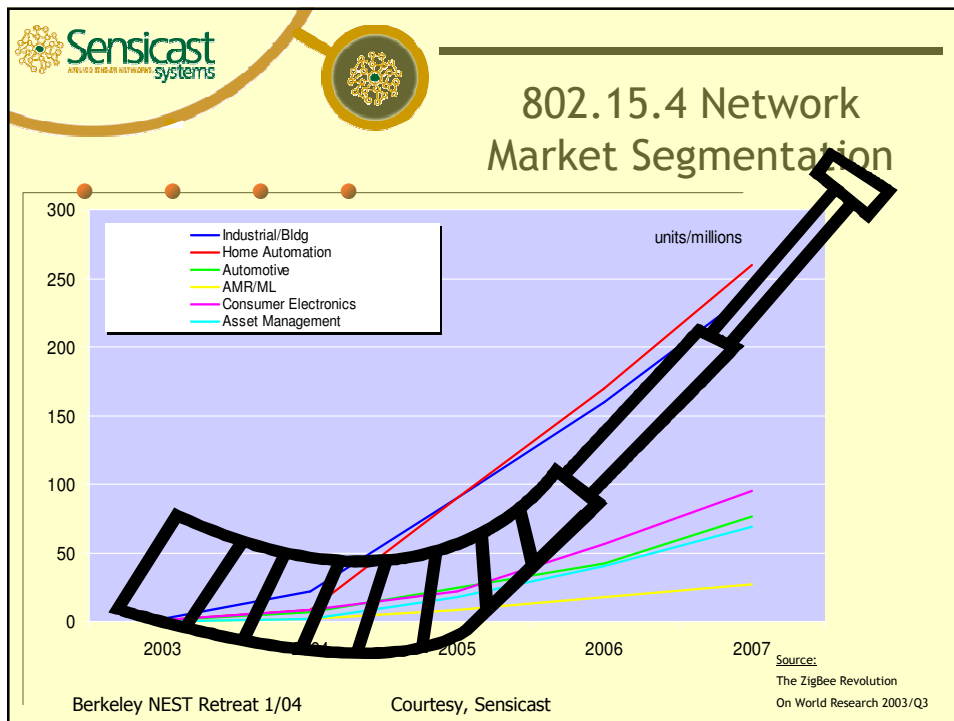| Industry	2003	2004	2005	2006	2007	CAGR
Home Automation	$ 39	$ 79	$ 321	$ 821	$ 1,273	101.0%
Automotive	$ 192	$ 615	$ 1,345	$ 2,022	$ 2,033	60.4%
Building and Industrial Automation	$ 748	$ 1,333	$ 2,648	$ 3,910	$ 3,873	38.9%
Consumer Electronics, Toys and Games	$ 164	$ 275	$ 384	$ 528	$ 585	29.0%
Others (incl DoD, Asset Mgmt., Healthcare, Custom Apps)	$ 33	$ 74	$ 216	$ 377	$ 419	65.8%
Total	$ 1,176	$ 2,377	$ 4,914	$ 7,659	$ 8,183	47.4%

802.15.4 Network Market Segmentation

Berkeley NEST Retreat 1/04   Courtesy, Sensicast

Source:
The ZigBee Revolution
On World Research 2003/Q3

Latest projection… same group

Wireless Sensor Networks
Thousands of End Points Deployed, 2005-2010

Y-axis (Thousands): 50,000 / 40,000 / 30,000 / 20,000 / 10,000 / 0

X-axis: 2005, 2006, 2007, 2008, 2009, 2010
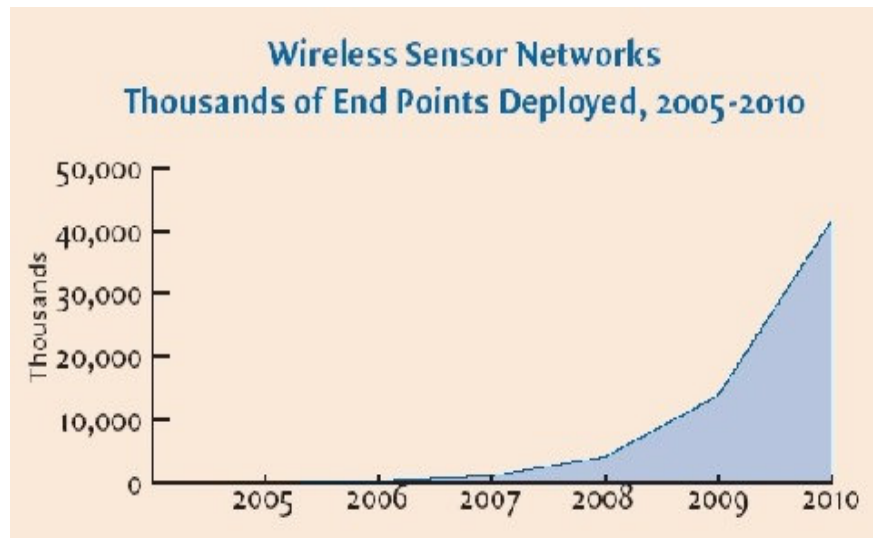
Ember

- Established mid 2001
- 50+ million invested; over 50 employees
- OEM strategy: chips, stacks, and tools

Ember

Some of Ember's customers that have already successfully launched wireless sensing and control applications include:

- Andover Controls
- Eaton
- Raymarine
- SK Telecom
- Philips Lighting
- Control4
- NURI Telecom

Some of the proven Ember-enabled applications are:

Home Automation & Control	Security Systems, Entertainment Systems, Lighting Control, HVAC Control
Building Automation	HVAC Control, Lighting Control, Access Control, Refrigeration Control
Automatic Meter Reading	Residential Demand Response, Power Distribution Diagnostics, Level Sensing
Industrial Automation	Temperature Sensing and control, Pressure sensing, Flow control

http://harborresearch.com/smartsphere/main.php?company=Ember&id=335&em...

WSN space

- Function (sense, effect, control) *what it does, generally*
  - Sub function e.g. lighting, HVAC, surveillance , process cont. *what it does specifically, who builds & sells it*
- Institution (commercial, consumer, … gov't) *who buys*
- Environment i.e. *where used*
  - Fixed Location => packaging, power, industrial design, noise, temp. containers [room, building (homes, commercial, industrial, mobile platform)], outdoors, process attached i.e. process control,
  - Portable: … open space
  - Mobile: un-tethered attachment e.g. animal, item, pallet, person, … truck
- Network structure and characteristics *how function is performed*
  - Platform (open|close; WS-WS | WN+WS | IP+WN+WS | IP + WSN)
  - Network (RF, power> battery life, data-rate, noise > error-rate, topology, scale, distance, protocols, etc.)
- Cost (installation, operation) *how much*
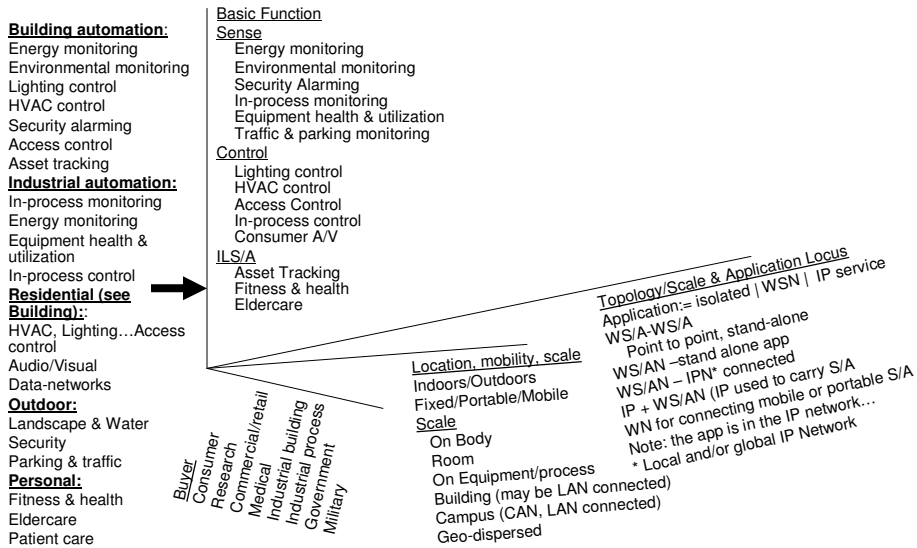- Geography (global) … Asia, Europe, US *WHERE*

Venue Segmentation Map for Intelligent Device Networking & Management

Harbor Research Taxonomy
## Where (What) => Buyer (Suppliers & Sellers)

- **Buildings (access & security, fire & safety, elevator/escalator, HVAC, lighting)**
  - **Commercial/Institutional (airport, data center, education, hospital, retail, … stadium)**
  - **Industrial**
  - **Residential (single|multi family units)**
- **Consumer (A/V, computers, lights, refrigerators, washers)**
  - **Household (room *laundry* & function *climate*)**
  - **Entertainment**
  - **Mobile**
- *Agriculture, landscape*
  - **Farms**
  - **Homes**
  - **Public spaces**
- **Industrial Control - K (contacts, switches, motors, valves, pumps, conveyors, pipelines, etc.)**
  - **Machine (simple standard, complex) K**
  - **Industrial process K**
  - **Electronics / Semiconductor mfg.**
  - **Infrastructure / supply chain**
  - **Lab (specialized sensors & instruments)**
- **Medical (computers/PDAs, CT/MRI, pumps, monitors, telemedicine devices)**
  - **Hospital (point of care, ER/OR, mobile)**
  - **Clinics, Doctor's offices**
  - **Lab (instruments)**
  - **Home / in vivo (implants, point of care)**
- **Power (monitor, control)**
  - **Supply (generation, distribution)**
  - **Demand (consumption, off-loading)**

- **Retail (POS,… tags)**
  - **Infrastructure / supply chain**
  - **Signage / Display**
  - *Buyer behaviour* **e.g. consumer tracking**
- **Transportation & other public infrastructures: Streets…Highways, Rivers & streams (monitoring,… traffic control**
  - **Vehicles (cars, aircraft, …construction)**
  - **Infrastructure**
- **Government /Security (Voting, identity, scanners, public infrastructure)**
  - **Legislature**
  - **Public safety (police, fire, … large scale disaster)**
  - **Public Infrastructure (landscape, public space)**
  - **Lab**
  - **(Weapons, soldiers, unmanned things, etc)**
  - **Vehicles**
  - **Material**
  - **Personnel**
  - **Security / surveillance (climate and natural disasters, radar/satellite, environment)**
- *Scientific & engineering pedagogy & research*
  - *Laboratory bio-medical*
  - *Natural science outdoors*
  - *Water management*
  - *Large scale physical science e.g. Earthquake, hurricanes, tornados, etc.*

WSN Space

Building automation:
Energy monitoring
Environmental monitoring
Lighting control
HVAC control
Security alarming
Access control
Asset tracking
Industrial automation:
In-process monitoring
Energy monitoring
Equipment health & utilization
In-process control
Residential (see Building)::
HVAC, Lighting…Access control
Audio/Visual
Data-networks
Outdoor:
Landscape & Water
Security
Parking & traffic
Personal:
Fitness & health
Eldercare
Patient care

Basic Function
Sense
   Energy monitoring
   Environmental monitoring
   Security Alarming
   In-process monitoring
   Equipment health & utilization
   Traffic & parking monitoring
Control
   Lighting control
   HVAC control
   Access Control
   In-process control
   Consumer A/V
ILS/A
   Asset Tracking
   Fitness & health
   Eldercare

Buyer
Consumer
Research
Commercial/retail
Medical
Industrial building
Industrial process
Government
Military

Location, mobility, scale
Indoors/Outdoors
Fixed/Portable/Mobile
Scale
   On Body
   Room
   On Equipment/process
   Building (may be LAN connected)
   Campus (CAN, LAN connected)
   Geo-dispersed

Topology/Scale & Application Locus
Application:= isolated | WSN | IP service
WS/A-WS/A
   Point to point, stand-alone
WS/AN –stand alone app
WS/AN – IPN* connected
IP + WS/AN (IP used to carry S/A
WN for connecting mobile or portable S/A
Note: the app is in the IP network…
* Local and/or global IP Network

Beliefs… and biases

- **Wired** sensor networks are everywhere doing everything
  - Homes, commercial & industrial buildings, science & engineering, military… Indoors and outdoors.
  - Data gathering & instrumentation, energy monitoring, HVAC, lighting, power, process control, security, …
- Sensor applications are limited by cost (and sensibility!)
  - Cost is dominated by installation of wires, thereby limiting apps
- Commercial adoption of **wireless** sensor networks is gated by reliability and power consumption…
  - Sensing and scientific & data gathering are the early adopters BECAUSE of proof of efficacy and liability concerns
  - Control apps represent more complexity and liability
  - Redundancy is critical: multiple channels & paths
- zero cost, zero size, zero power motes are inevitable… will enable infinite apps, including mobile… anything non-zero, just reduces market size
- WSNs are peripherals or edge to IP! Are a part of cyberspace not an end.

Market vs. Cost, size, 1/power
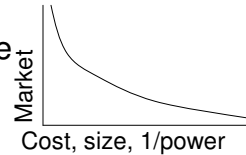
The end

G2 Microsystems Inc

The SmarTag Company

Digital Identity

February 2006


MRM Applications

There are a large number of specific applications where ultra low power MRM solutions will solve the immediate needs of companies and provide rapid ROI.

Industry	Asset Tracking Initiatives
Oil & Gas	• Track personnel • Lower inventory costs by tracking of spare parts. • Deep well monitoring
Chemical	• Track personnel • Tracking of hazardous materials across distribution channel
Automotive	• Manage line sequencing of parts from suppliers • Improve operation of production lines
Pharmaceutical	• Reduce inventory and meet FDA requirements of bio-medical product tracking across the supply chain

| Industry	Asset Tracking Initiatives
Retail – High Value Consumables	• Remote monitoring of in-store refrigeration units • Tracking of refrigerated shipments
Automotive	• Eliminate counterfeit parts and lower inventory costs by tracking spare parts
Government	• Emergency Response Personnel tracking • Improve visibility and security of military assets • Improve security of ports and custom facilities
High Tech	• Improve customer service and lower inventory costs by tracking spare parts

G2C501
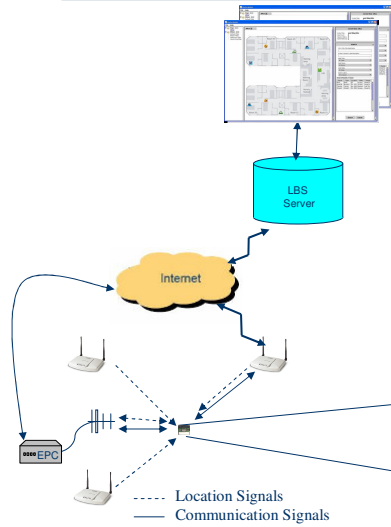
Integrated Circuit with:
- ✓ **Multiple Location Technologies**
  - o **Location by Proximity**
  - o **RSSI**
  - o **TDOA**
  - o **EPC**
  - o **125Khz Magnetic Signpost**
- ✓ **802.11b system on chip**
- ✓ **64KB SRAM with 4Mb off-chip Flash option**
- ✓ **Field programmable**
- ✓ **Sensor Interface for temp, pressure, humidity, motion, shock, light, chemical, …**
- ✓ **802.11i security**
- ✓ **Works with multiple software solutions**
- ✓ **Samples 1QCY06**
- ✓ **Production 3QCY06**
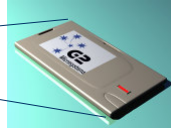
- • **Size: 80 x 50 x 5 mm**
- • **Max battery life 1-4 yrs**
- • **Tag Cost = $12-$20**

- - - - - Location Signals
——— Communication Signals

Technology vs Capability

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