Introduction to Wireless Sensor Networks

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Infrastructure-based networks

Typical wireless network: Based on infrastructure (E.g., GSM, UMTS, WiFi, …)

Base stations connected to a wired backbone network. Mobile entities communicate wirelessly to these base stations

Mobility is supported by switching from one base station to another

Infrastructure-less networks

What happens when:

- No infrastructure is available? – E.g., in remote areas
- It is too expensive/inconvenient to set up? – E.g., in remote sites
- There is no time to set it up? – E.g., in disaster relief operations

Infrastructure-less networks

We try to construct a network without infrastructure, using networking abilities of the participants

This is an **ad hoc network** – a network constructed “for a special purpose”

Without a central entity (like a base station), participants must organize themselves into a network (self-organization)

Challenges for ad hoc networks

Without a central infrastructure, things become much more difficult!

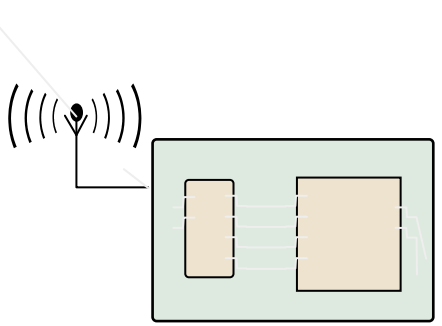
Problems are due to

- Lack of central entity for organization available
- Limited range of wireless communication
- Mobility of participants
- Battery-operated entities

Wireless sensor networks

A Wireless Sensor Network is a self-configuring network of small sensor nodes communicating among themselves using radio signals, and deployed in quantity to sense, monitor and understand the physical world.

Wireless Sensor nodes are called **motes**.



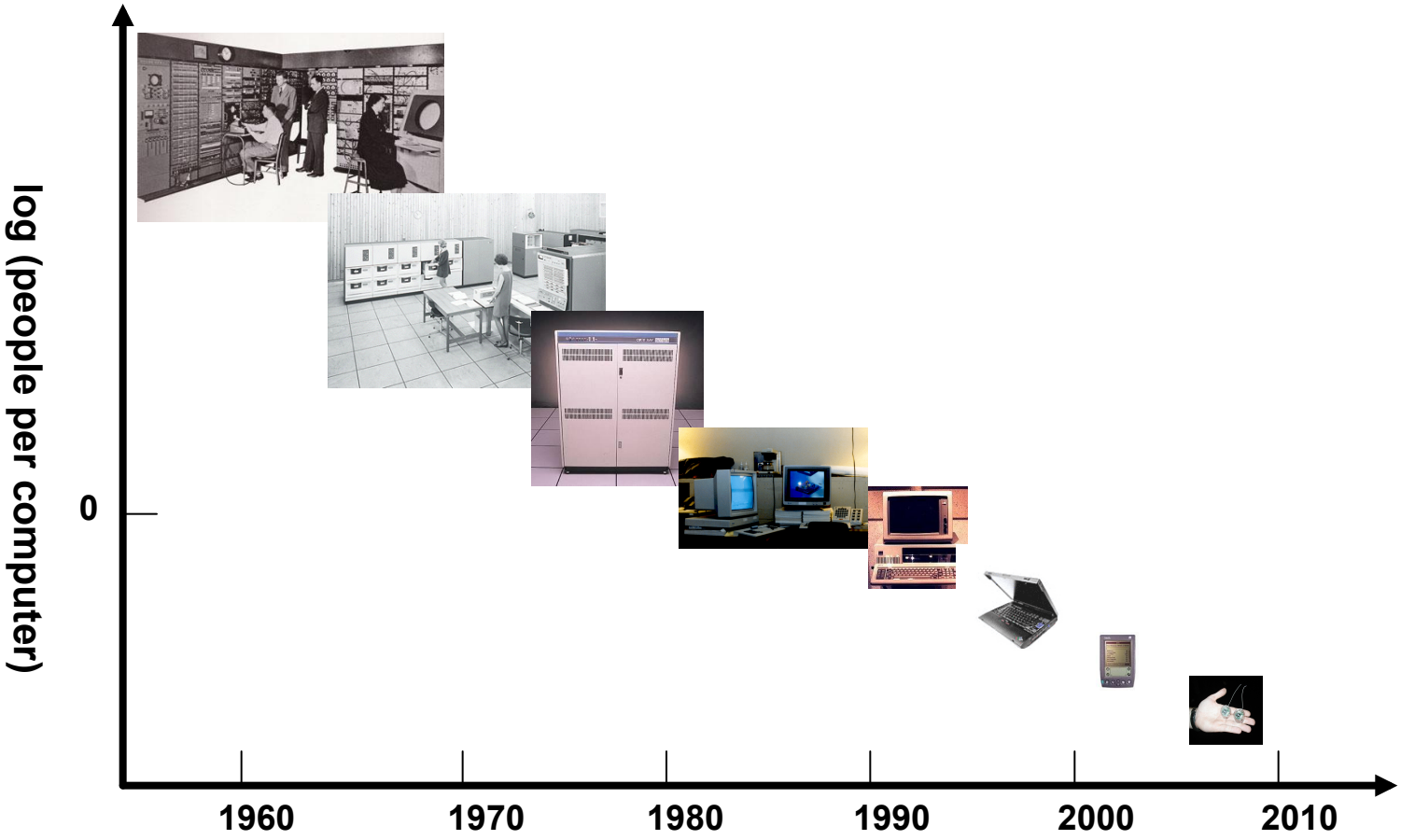
Wireless sensor networks

WSN provide a bridge between the real physical and virtual worlds.

Allow the ability to observe the previously unobservable at a fine resolution over large spatio-temporal scales.

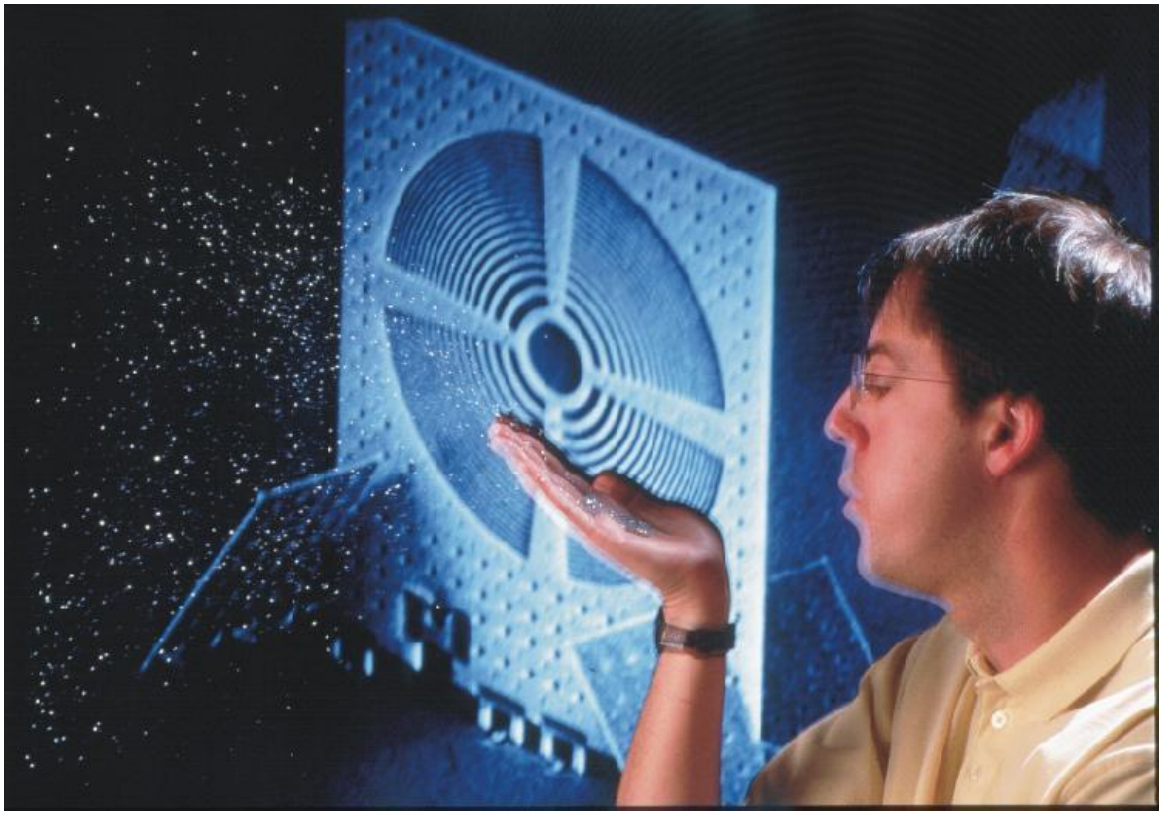
Have a wide range of potential applications to industry, science, transportation, civil infrastructure, and security.

Wireless sensor networks



[Culler:2004]

Wireless sensor networks

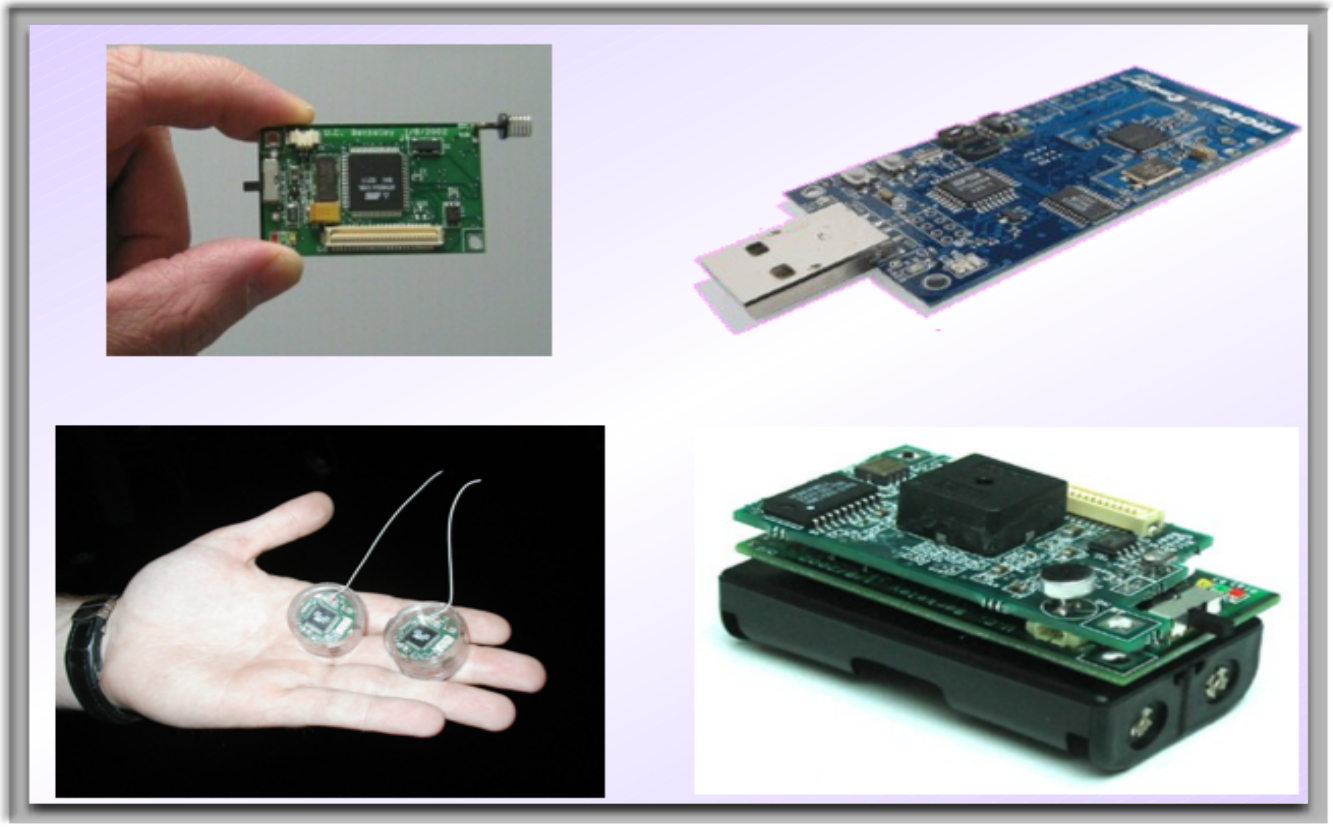


Next Century Challenges: Mobile Networking for "**Smart Dust**"

J. M. Kahn,
R. H. Katz,
K. S. J. Pister

(MobiCom 1999)

Mote Anatomy



Mote Anatomy

Processor in various modes (sleep, idle, active)

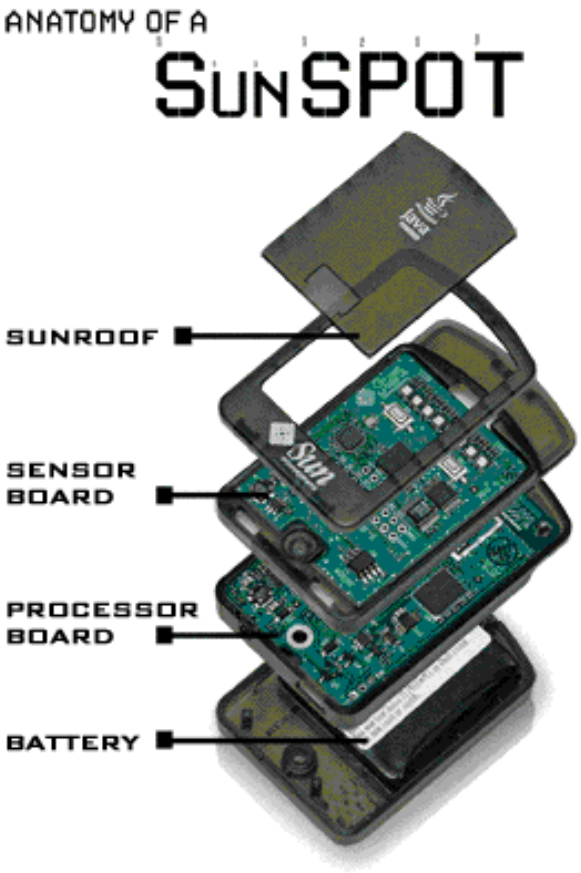
Power source (AA or Coin batteries, Solar Panels)

Memory used for the program code and for in-memory buffering

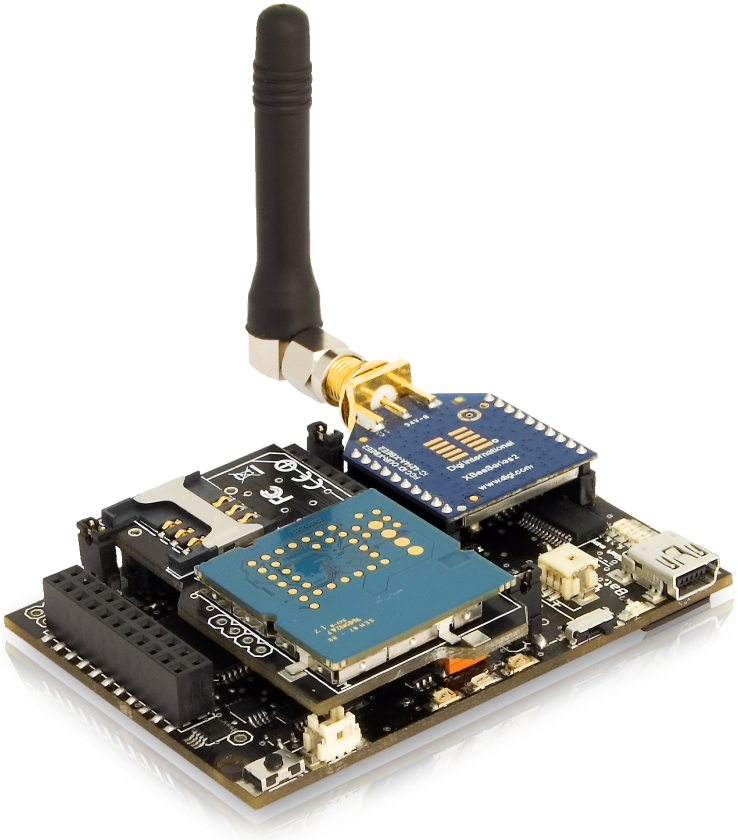
Radio used for transmitting the acquired data to some storage site

Sensors for temperature, humidity, light, etc

Mote Anatomy



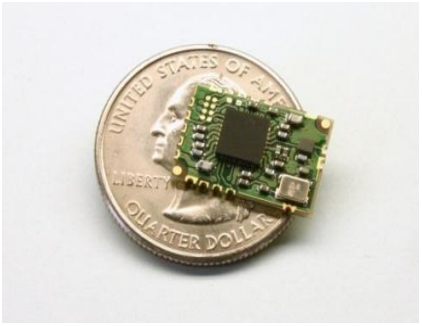
Mote Anatomy



Mote Anatomy

These motes are highly constrained in terms of

- Physical size
- CPU power
- Memory (few tens of kilobytes)
- Bandwidth (Maximum of 250 KB/s)



Power consumption is critical

- If battery powered then energy efficiency is paramount

May operate in harsh environments

- Challenging physical environment (heat, dust, moisture, interference)

Potential of WSN

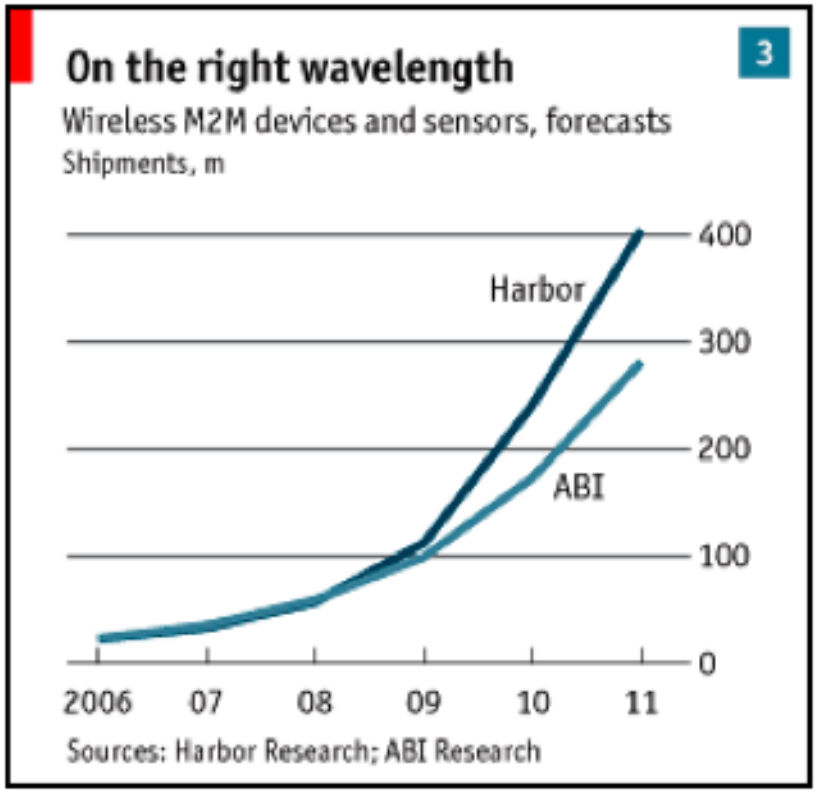
US National Research Council report ("Embedded Everywhere"): the use of wireless sensor networks (WSN) could well dwarf previous milestones in the information revolution.

MIT's Technology Review in February 2003 predicted: WSN will be one of the most important technologies in the near future.

Nature, in the "2020 computing: Everything, everywhere" report, said that WSN are going to be one of the most interesting technologies!

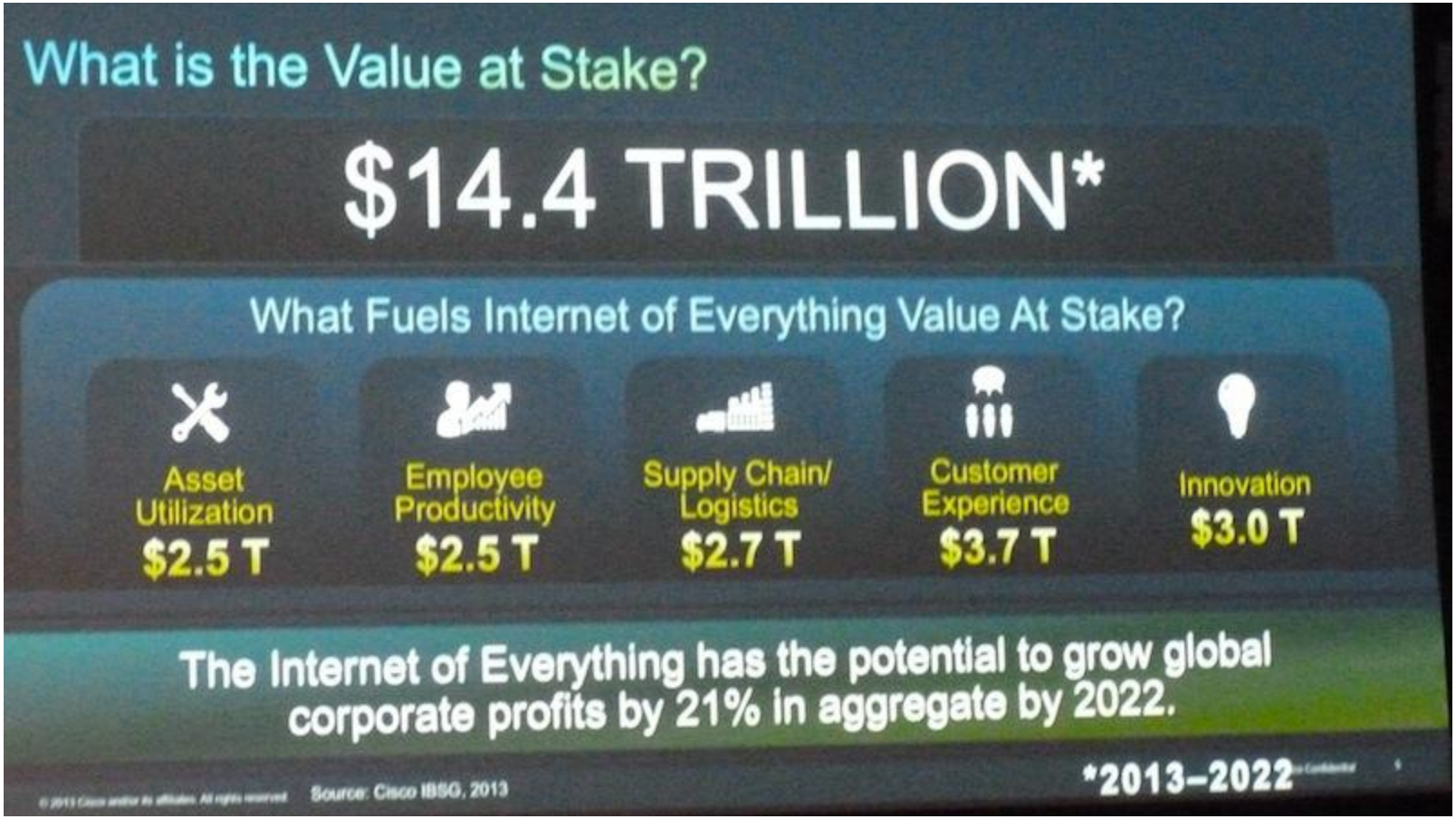
Potential of WSN - 2007

The Economist, in April 2007, had an issue called “When everything connects”.

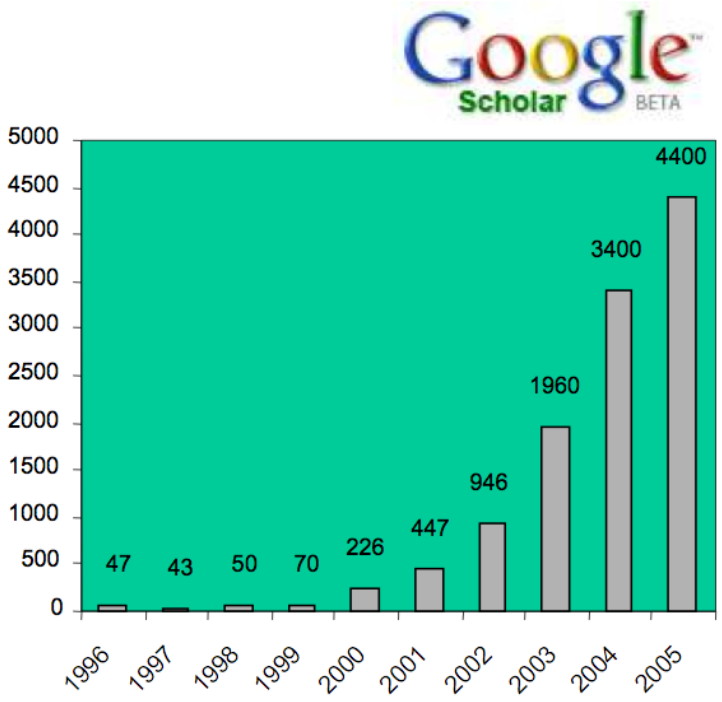


Potential of WSN - 2013

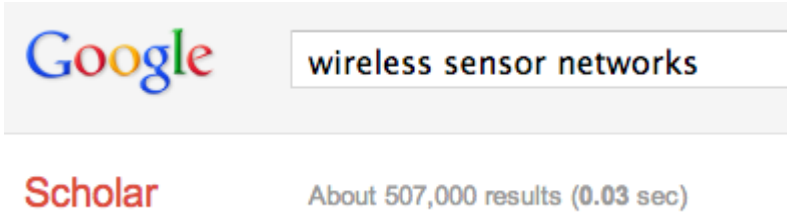
Cisco Says its “Internet of Everything” is worth $14.4 Trillion.



Potential of WSN - research



2005



2013

A World of Sensors

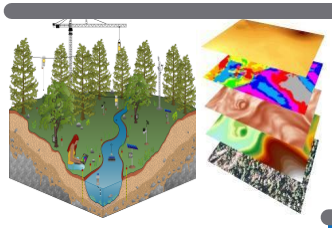
Predictive Maintenance

Energy Saving Smart Grid

High-Confidence Transport and Asset Tracking

Improve Productivity

Intelligent Buildings



Enable New Knowledge

Enhanced Safety & Security

Improve Food and H_2O

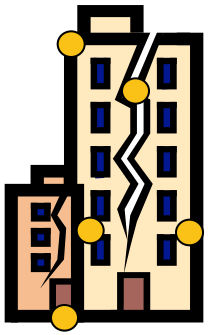
Healthcare

Smart Home

WSN application examples

Intelligent buildings

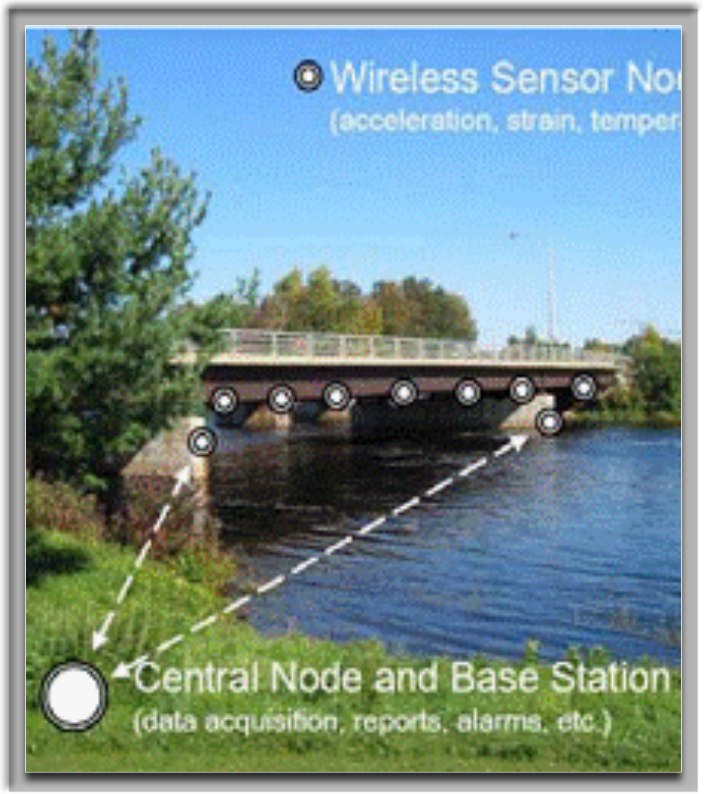
- Reduce energy wastage by proper humidity, ventilation, air conditioning (HVAC) control
- Needs measurements about room occupancy, temperature, air flow, …
- Monitor mechanical stress after earthquakes



WSN application examples

Bridge Monitoring

- In California, 13% of the 23,000 bridges have been deemed structurally deficient, while 12% of the nation's 600,000 bridges share the same rating.
- New York may be the first state with a 24/7 wireless bridge monitoring system.



WSN application examples

Keeping an eye on Cathedral of L'Aquila

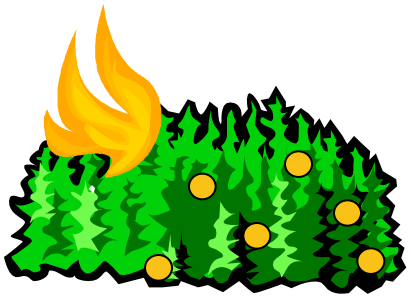
Structural monitoring of a noted Italian cathedral seriously damaged in a devastating earthquake in April 2009 is carried out wirelessly.

Inside the severely damaged Cathedral of L'Aqila, which needs constant monitoring.

WSN application examples

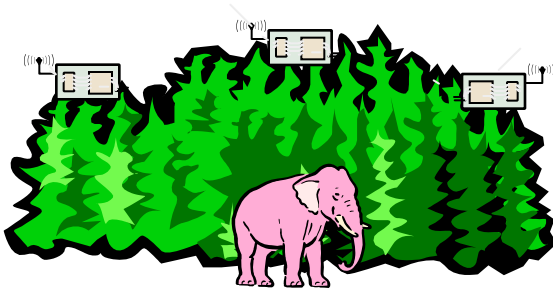
Disaster relief operations

- Drop sensor nodes from an aircraft over a wildfire
- Each node measures temperature
- Derive a “temperature map”



Biodiversity mapping

- Use sensor nodes to observe wildlife



WSN application - Zebranet

ZebraNet: an application to track zebras on the field

The objective of the application is to gather dynamic data about zebra positions in order to understand their mobility patterns.
What are the motivations for the zebras to move? water? food? weather?
How do they interact?
The sensors are deployed in collars that are carried by the animals.
The users are the biologists.

WSN application - Zebranet

WSN application - Zebranet

[Princeton, 2004]

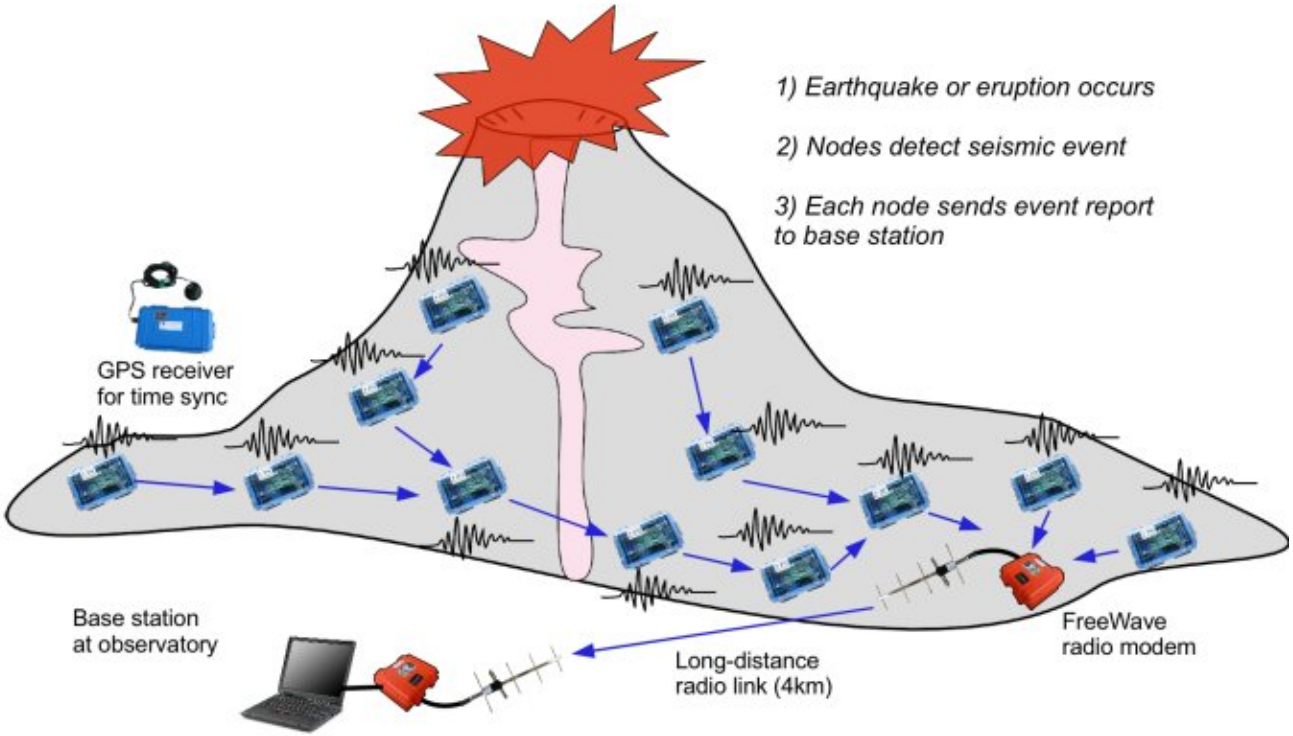
WSN application - Zebranet

Zebras don't like collars! Well... who likes collars?

The zebras rip off the solar cells from the collar in less than one week!

After that, the batteries died...

WSN application - Volcano

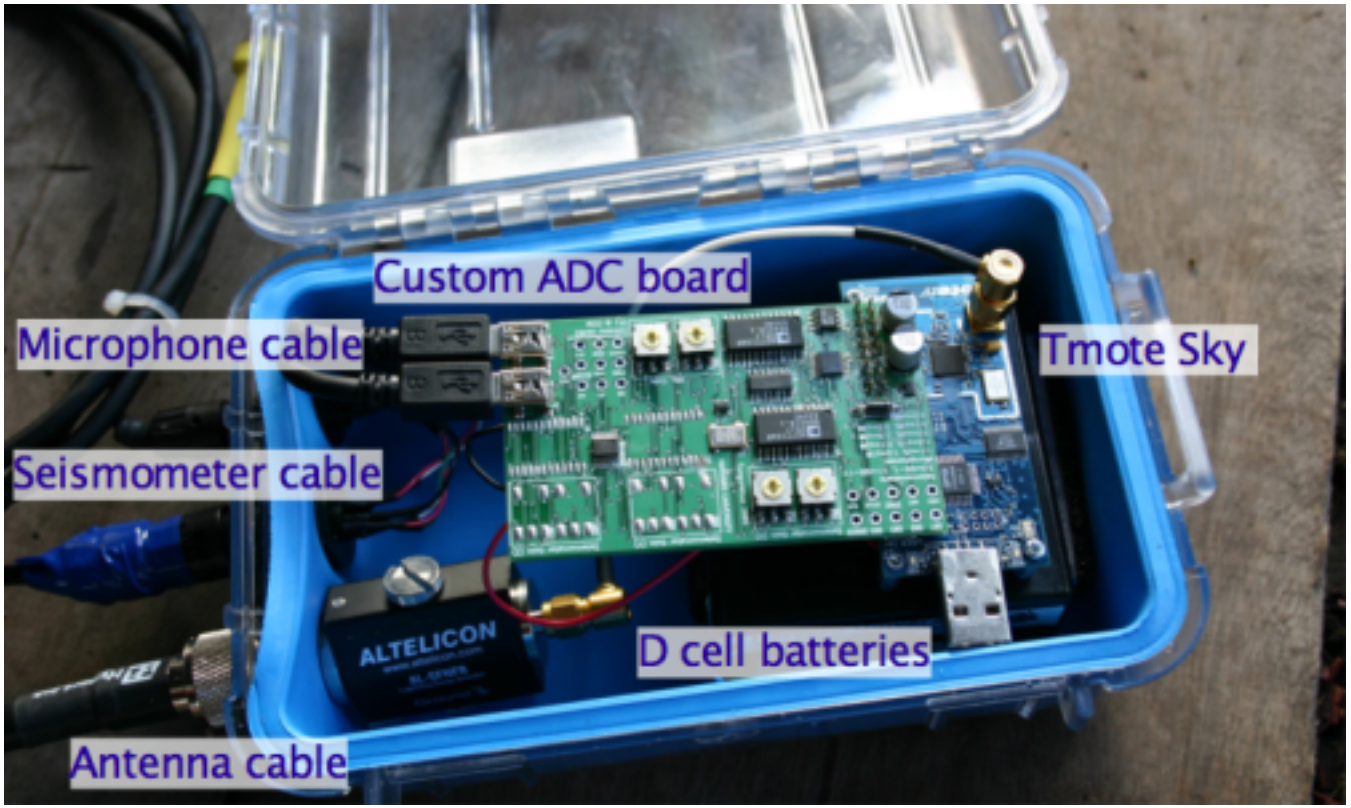


WSN application - Volcano

Reference: “Deploying a Wireless Sensor Network on an Active Volcano”, Geoffrey Werner-Allen, Konrad Lorincz, Matt Welsh, Omar Marcillo, Jeff Johnson, Mario Ruiz, Jonathan Lees, IEEE Internet Computing, Mar/Apr 2006

Tungurahua, Ecuador

WSN application - Volcano



WSN application - Volcano

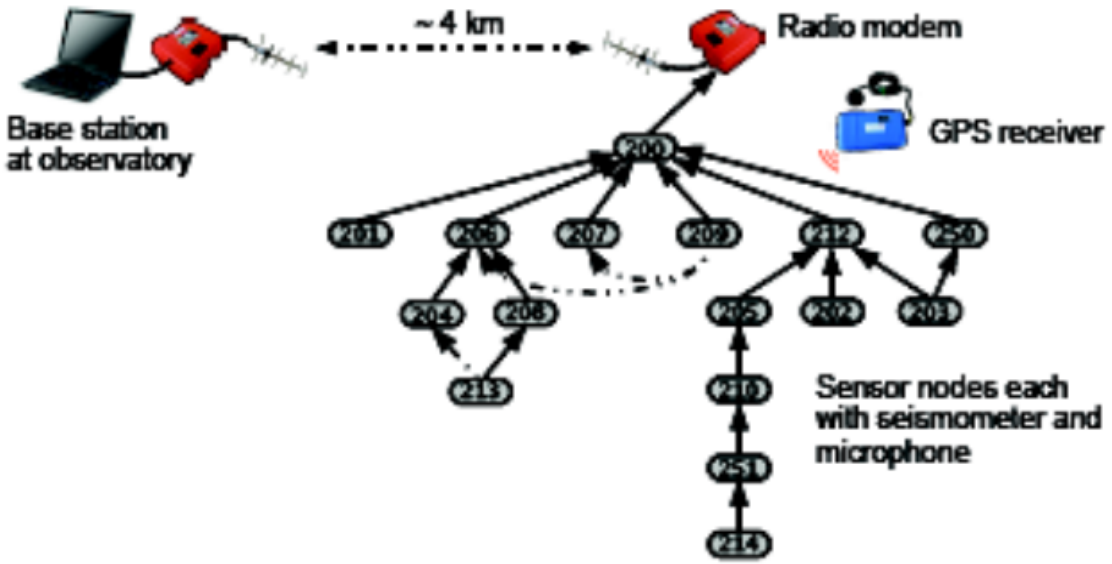


Figure 2: **Sensor network architecture.** *Nodes form a multihop routing topology, relaying data via a long-distance radio modem to the observatory. A GPS receiver is used to establish a global timebase. The network topology shown here was used during our deployment at Reventador.*

WSN application - Volcano

Challenges Encountered

Event detection: when to start collecting data?
High data rate sampling
Spatial separation between nodes
Data transfer performance: reliable transfer required
Time synchronization: data has to be time-aligned for analysis by seismologists

WSN application - Agriculture

Agriculture

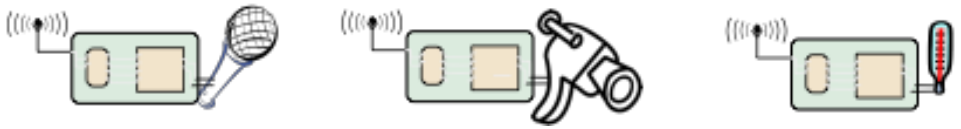
e.g., TU Delft Deployment

WSN application - Medicine

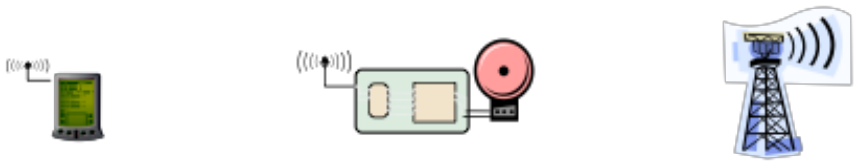
[CodeBlue: Harvard]

WSN application - roles

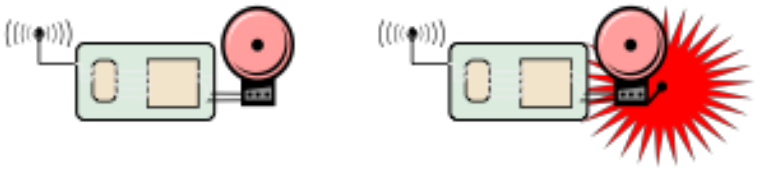
Sources of data: measure data, report them "somewhere"



Sinks of data: interested in receiving data from WSN



Actuators: control some device based on data, usually also a sink



WSN application - patterns

Interaction patterns between sources and sinks classify application types:

Event detection: Nodes locally detect events (maybe jointly with nearby neighbors), report these events to interested sinks

Periodic measurement

Function approximation: Use sensor network to approximate a function of space and/or time (e.g., temperature map)

WSN application - patterns

Interaction patterns between sources and sinks classify application types:

Edge detection: Find edges (or other structures) in such a function (e.g., where is the zero degree border line?)

Tracking: Report (or at least, know) position of an observed intruder (“pink elephant”)

WSN application - deployment

How are sensor nodes deployed in their environment?

Dropped from aircraft: **Random** deployment
Usually uniform random distribution for nodes over finite area is assumed
Is that a likely proposition?

Well planned, fixed: **Regular** deployment
E.g., in preventive maintenance or similar
Not necessarily geometric structure, but that is often a convenient assumption

WSN application - deployment

How are sensor nodes deployed in their environment?

Mobile sensor nodes

Can move to compensate for deployment shortcomings

Can be passively moved around by some external force (wind, water)

Can actively seek out “interesting” areas

WSN application - requirements

Scalability

- Support large number of nodes

Wide range of densities

- Vast or small number of nodes per unit area

Programmability

- Re-programming of nodes in the field might be necessary, improve flexibility

Maintainability

- WSN has to adapt to changes, self-monitoring, adapt operation

Internet of Things

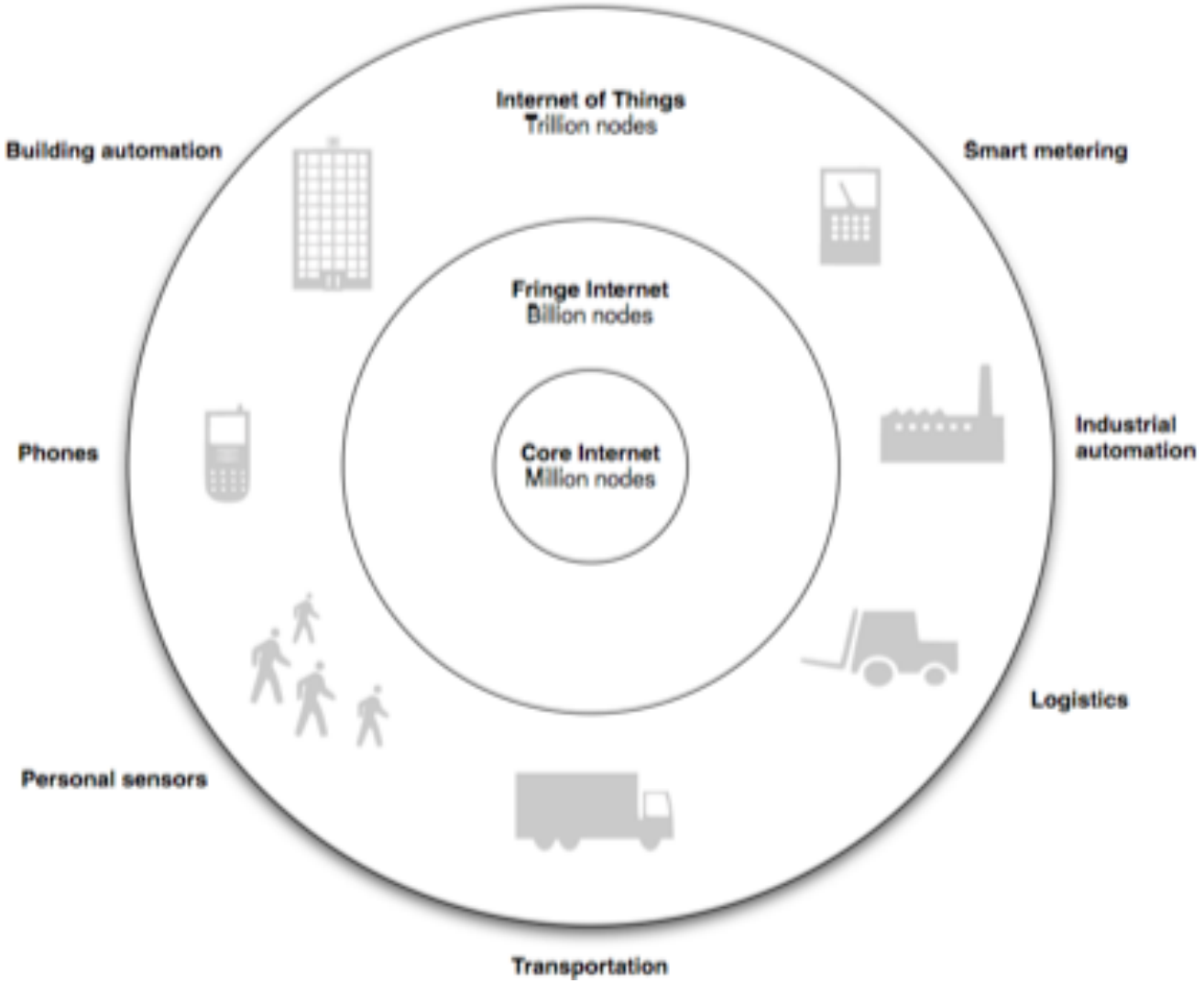
1980s: the PC revolution

1990s: the Internet revolution

2000s: the mobile revolution

2010s: the Internet of Things

Internet of Things



What is a Smart Object?

A tiny and low cost computer that may contain:

- A **sensor** that can measure physical data (e.g., temperature, vibration, pollution)
- An **actuator** capable of performing a task (e.g., change traffic lights, rotate a mirror)
- A **communication device** to receive instructions , send data or possibly route information

This device is embedded into objects

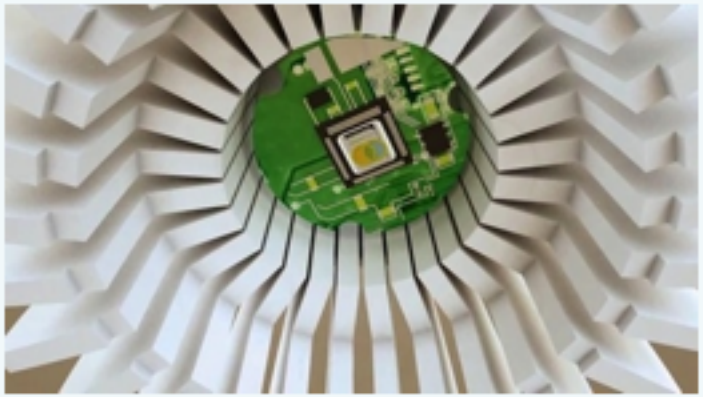
- For example, thermometers, car engines, light switches, gas meters

We now talk about **Internet of Things**

Internet of Things

All Our Lightbulbs Will Have IP Addresses

By Adrian Covert on May 20, 2011 at 12:00 PM



When we remarked that home automation technology was a reason we needed iPv6 technology, we weren't kidding. If Netherlands-based NXP has it their way, we'll all be using networked LED lightbulbs, each with their own IPv6 address.

According to Fast Company, this GreenChip technology operates on the 802.15.4 wireless protocol, which means it doesn't use the same bandwidth as 802.11 wi-fi gadgets. Cool.

But what do you do with networked bulbs? Automate your home, of course.

> "You'll also be able to control mood lighting "states" with a remote control, or via your iPad, as if you were a theatre lighting designer; you'll be able to quickly and easily incorporate movement sensing automated lighting, that could even turn on dimly if it detects you're stumbling to the bathroom at midnight; and you'll be able to download apps to hone and polish your home's lighting energy needs so that you end up with a smaller power bill.

Internet of Things

IPv4 or IPv6

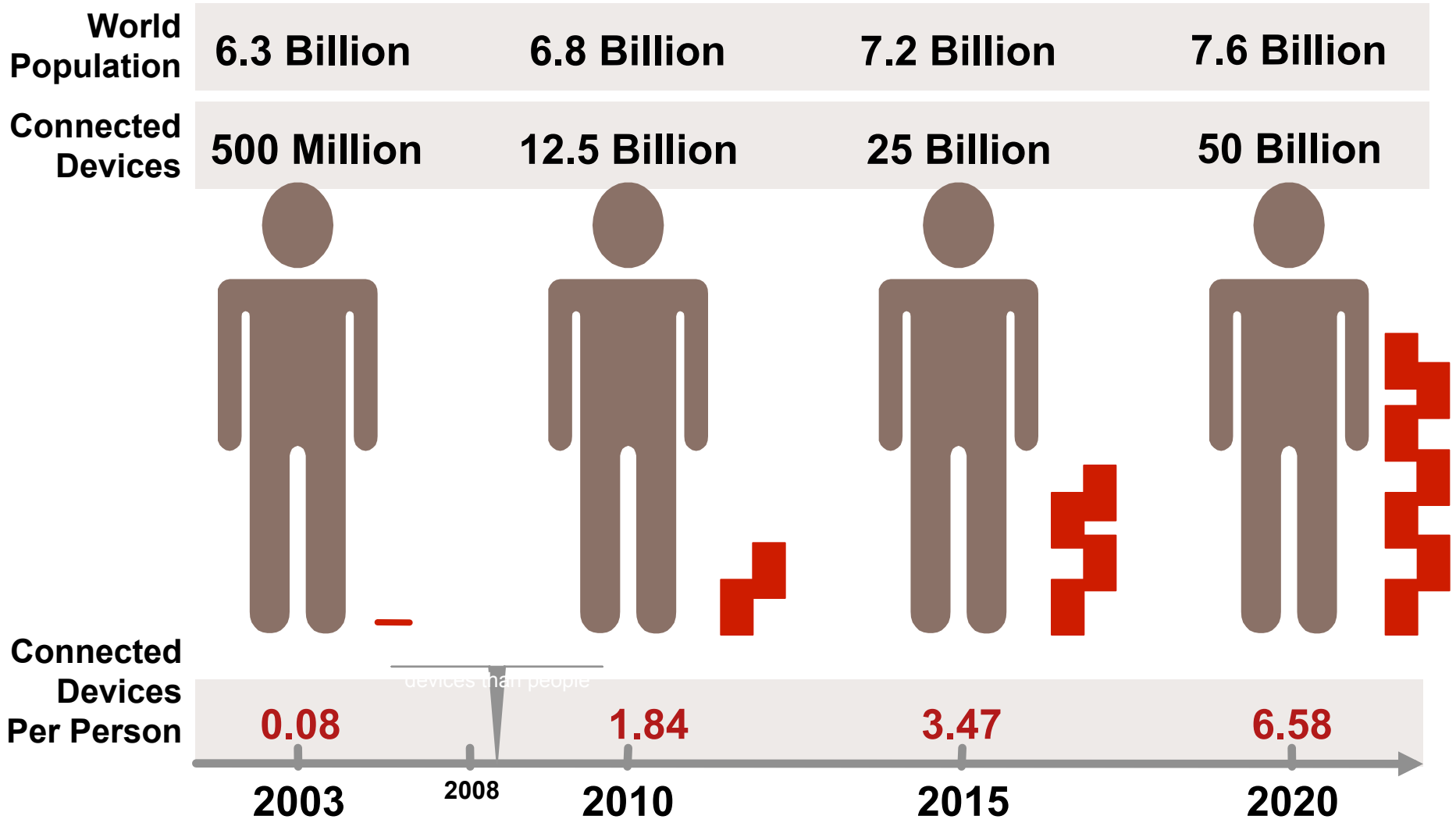
Smart Objects will add tens of billions of additional devices

There is no scope for IPv4 to support Smart Object Networks

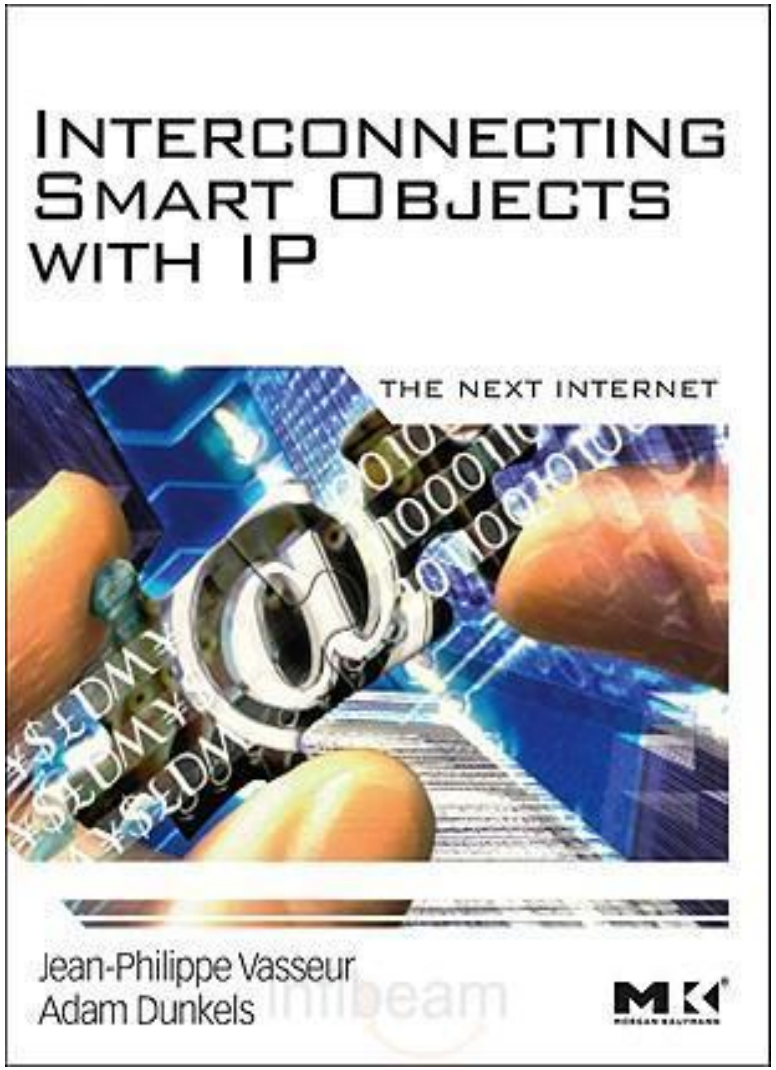
IPv6 is the only viable way forward

- Solution to address exhaustion
- Stateless Auto-configuration thanks to Neighbour Discovery Protocol
- Each embedded node can be individually addressed/accessed

Smart Objects



Recommended reading



- Covers the trends in Smart Objects
- Detailed application scenarios
- Written by
  - JP Vasseur (Cisco DE)
  - Adam Dunkels (Inventor of Contiki O/S, uIPv6)