

# **Introduction to Wireless Sensor Networks**

Marco Zennaro  
T/ICT4D Laboratory  
ICTP-Italy

# 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!

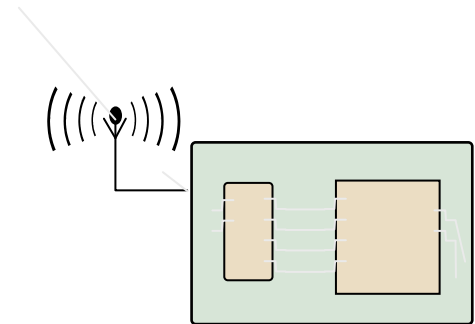
Problems are due to

- 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**.



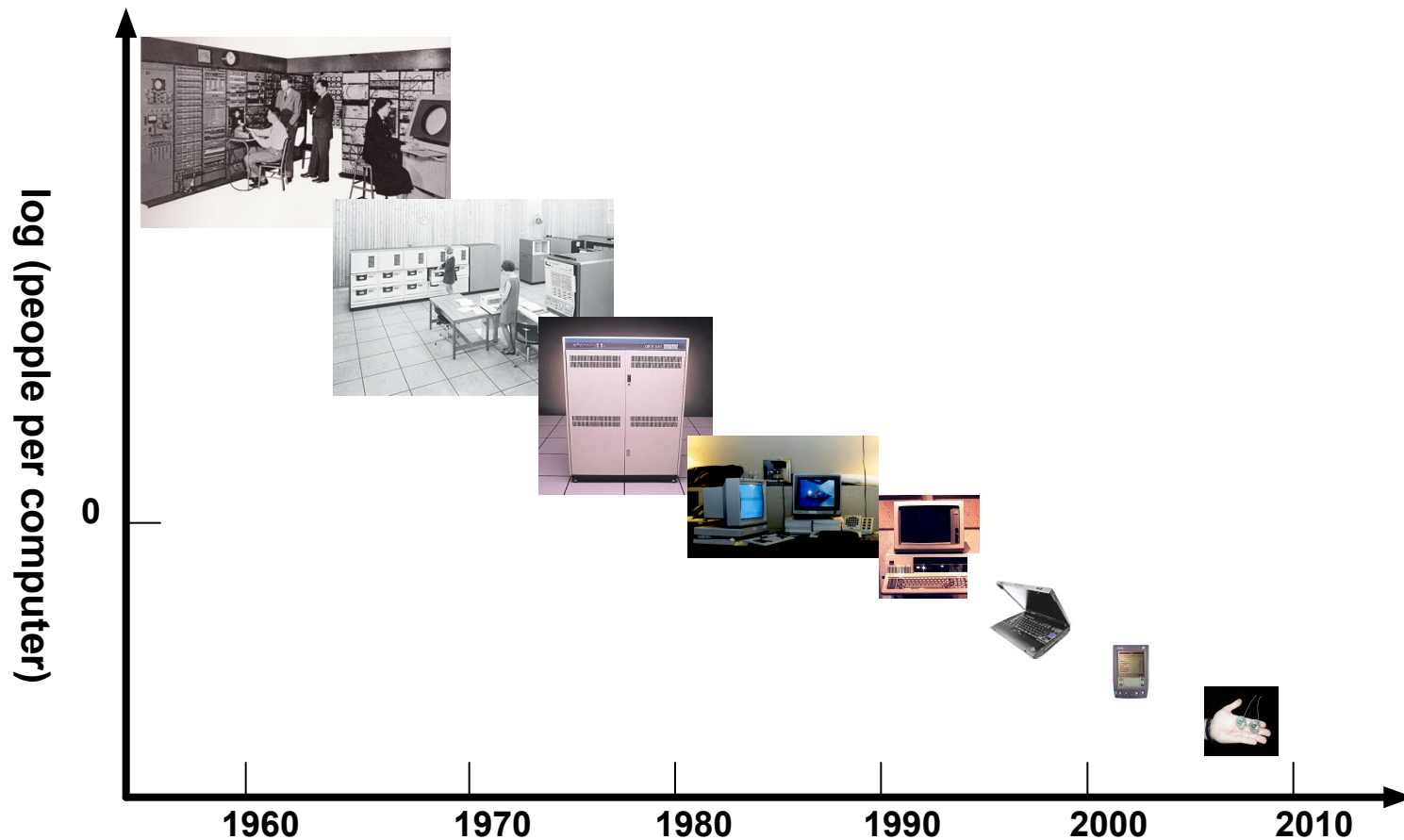
# Wireless sensor networks

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.

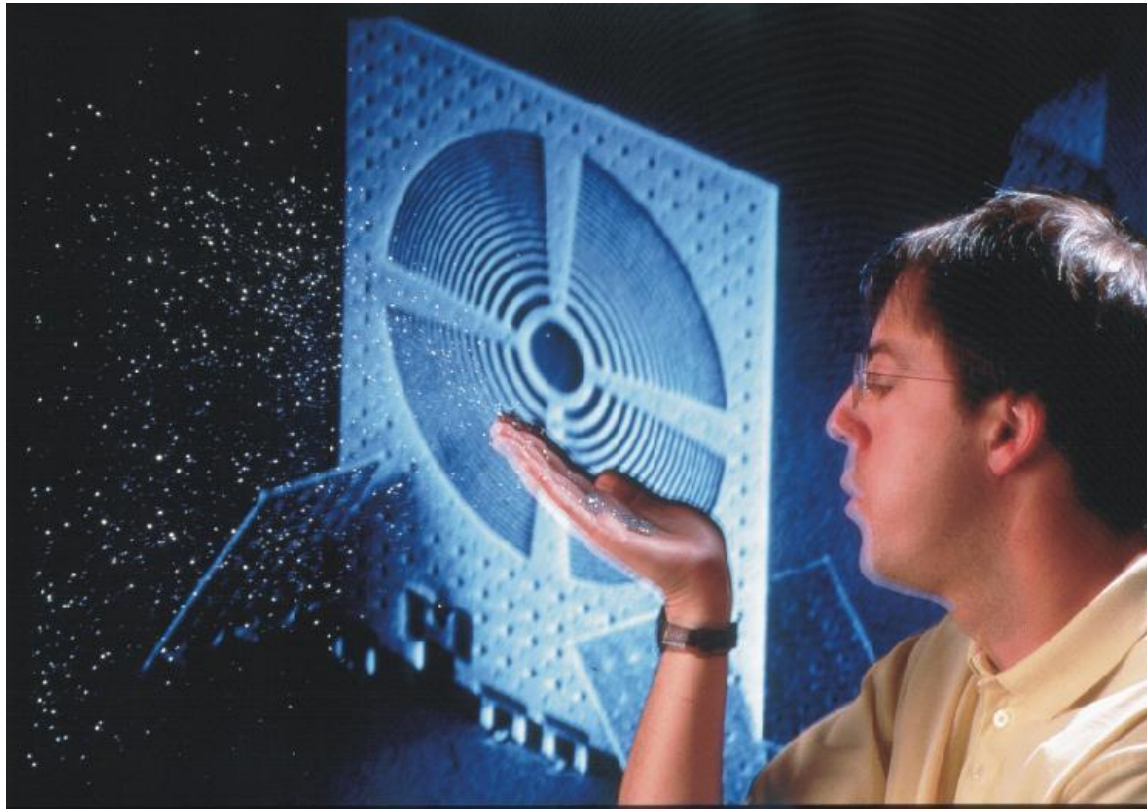
# Wireless sensor networks



[Culler:2004]



# Wireless sensor networks

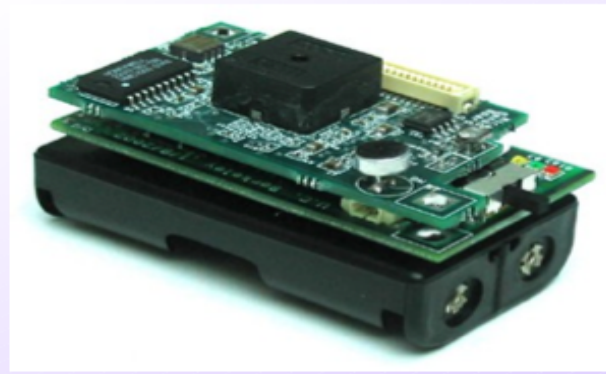
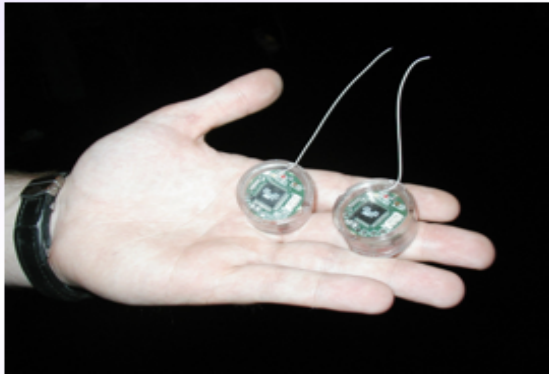
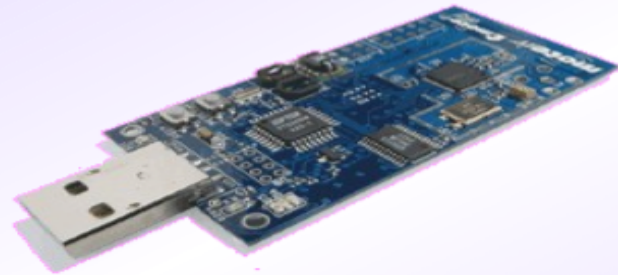
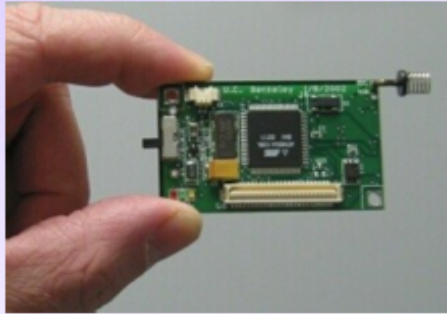


Next Century  
Challenges: Mobile  
Networking for  
**“Smart Dust”**

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)

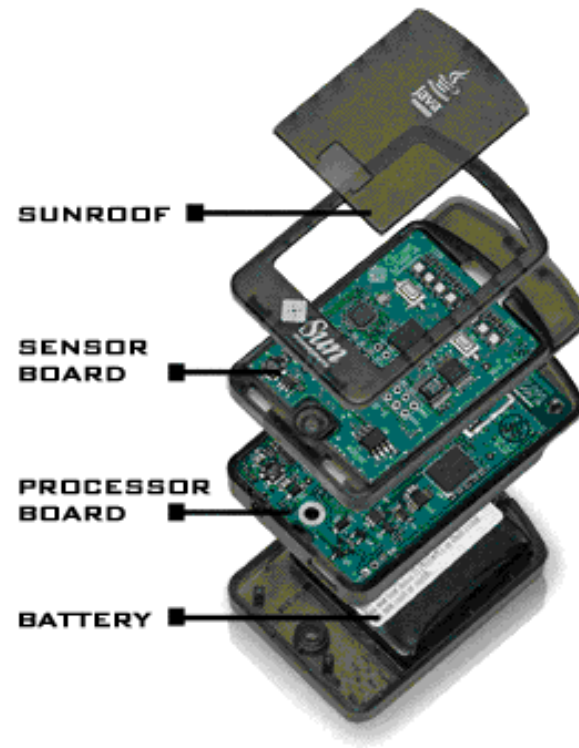
**Memory** used for the program code and for in-memory buffering

**Radio** used for transmitting the acquired data to some storage site

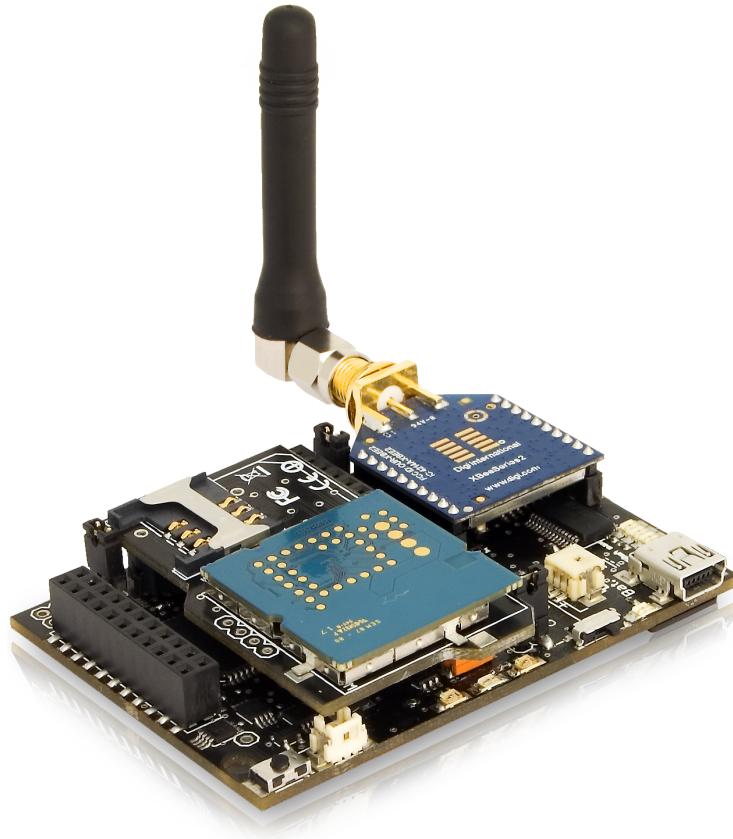
**Sensors** for temperature, humidity, light, etc

# Mote Anatomy

## ANATOMY OF A SUNSPOT



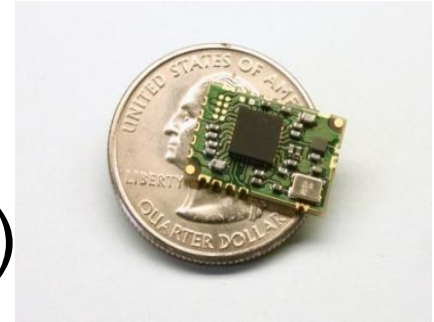
# Mote Anatomy



# 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

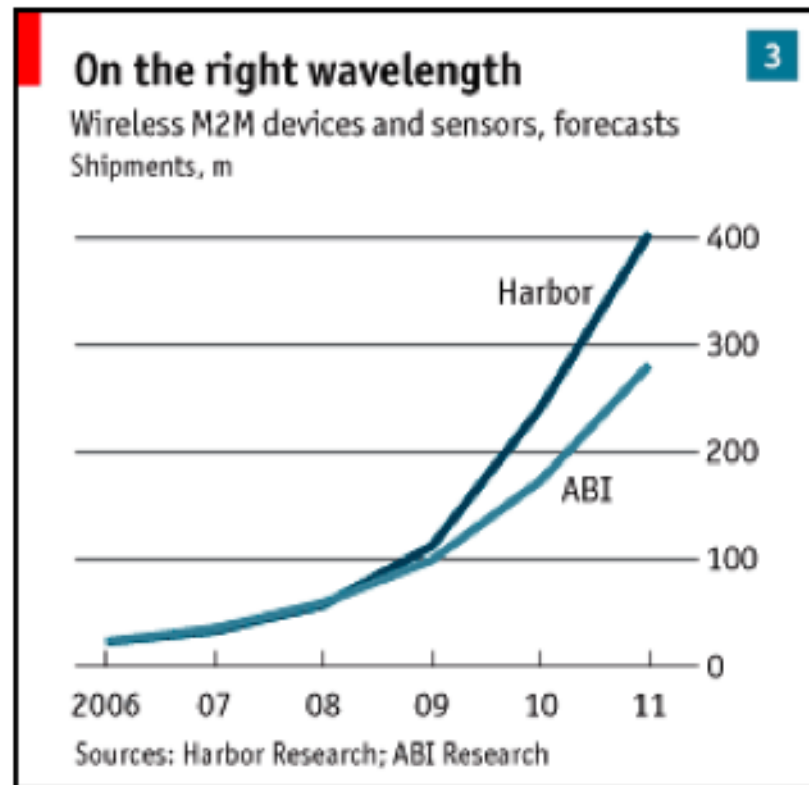
US National Research Council report ("Embedded Everywhere"): the use of wireless sensor networks (WSN) could well dwarf previous milestones in the information revolution.

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

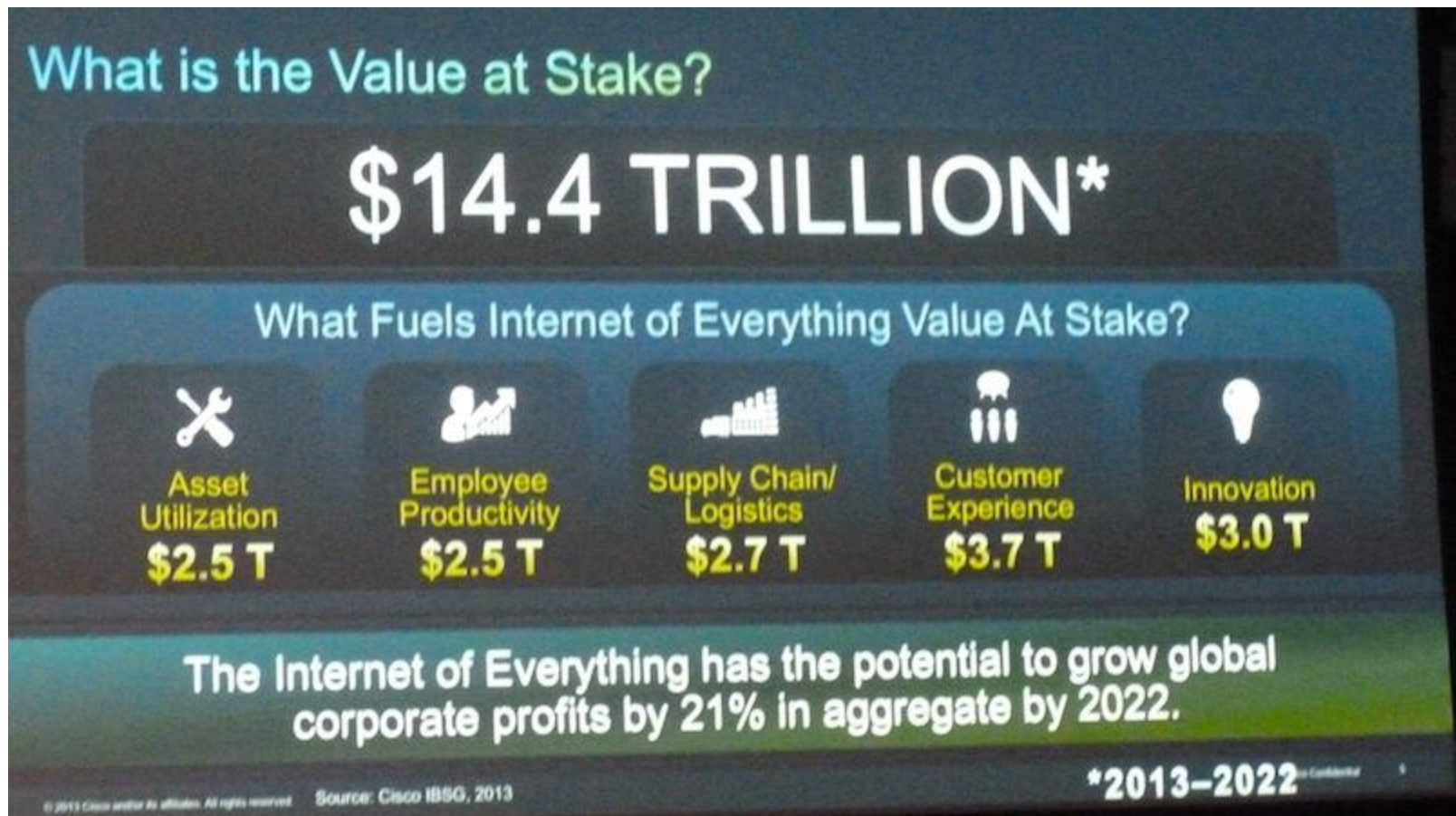
The Economist, in April 2007, had an issue called “When everything connects”.



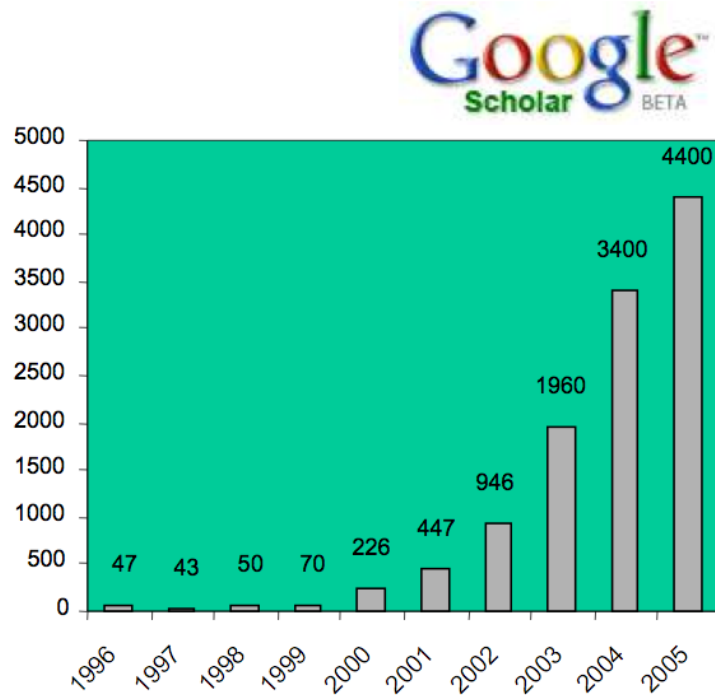


# Potential of WSN - 2013

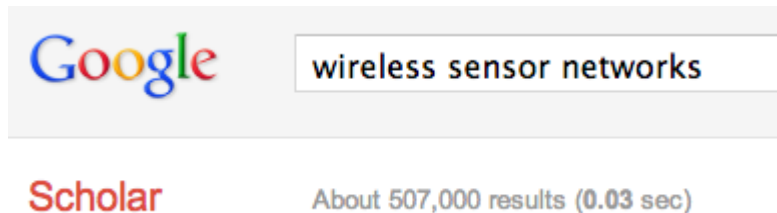
Cisco Says its “Internet of Everything” is worth \$14.4 Trillion.



# Potential of WSN - research



2005



2013

# A World of Sensors



**Predictive Maintenance**



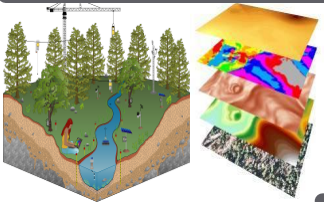
**Energy Saving Smart Grid**



**High-Confidence Transport and Asset Tracking**



**Improve Productivity**



**Enable New Knowledge**



**Intelligent Buildings**



**Enhanced Safety & Security**



**Improve Food and H<sub>2</sub>O**



**Smart Home**



**Healthcare**

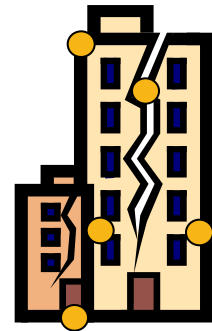
# WSN application examples

## 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

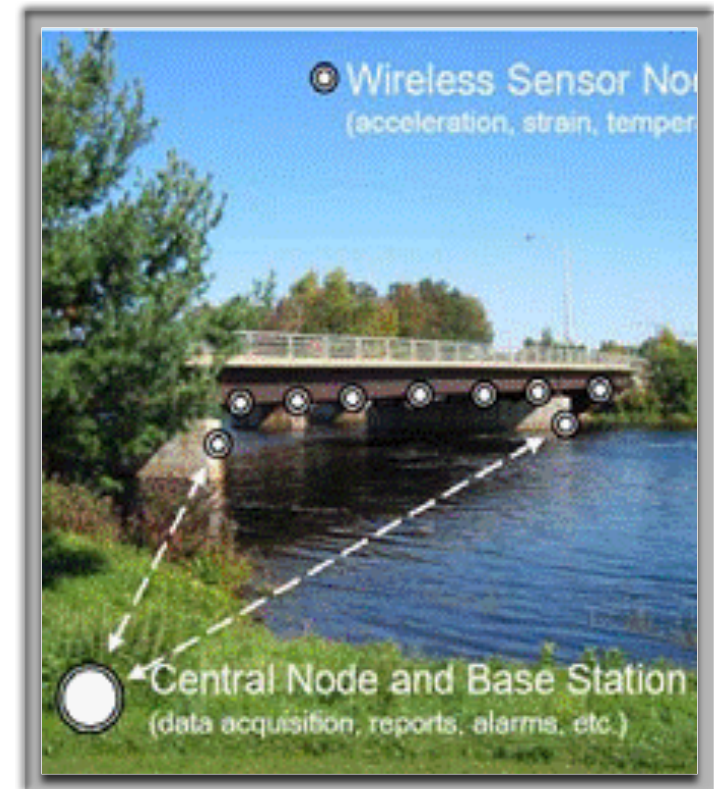


# WSN application examples

## 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'Aquila, which needs constant monitoring.*

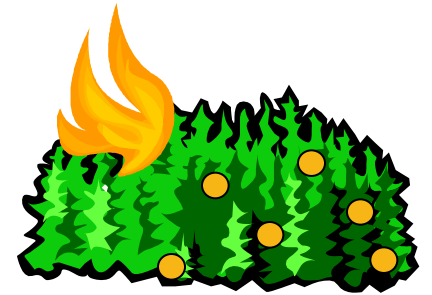
# WSN application examples

## Disaster relief operations

Drop sensor nodes from an aircraft over a wildfire

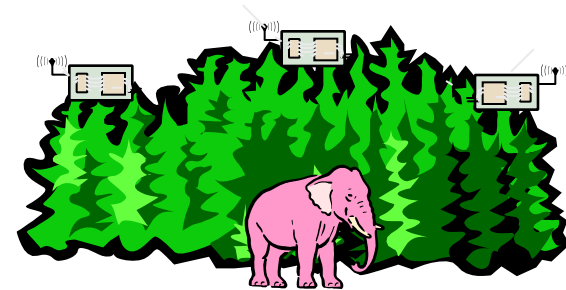
Each node measures temperature

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?

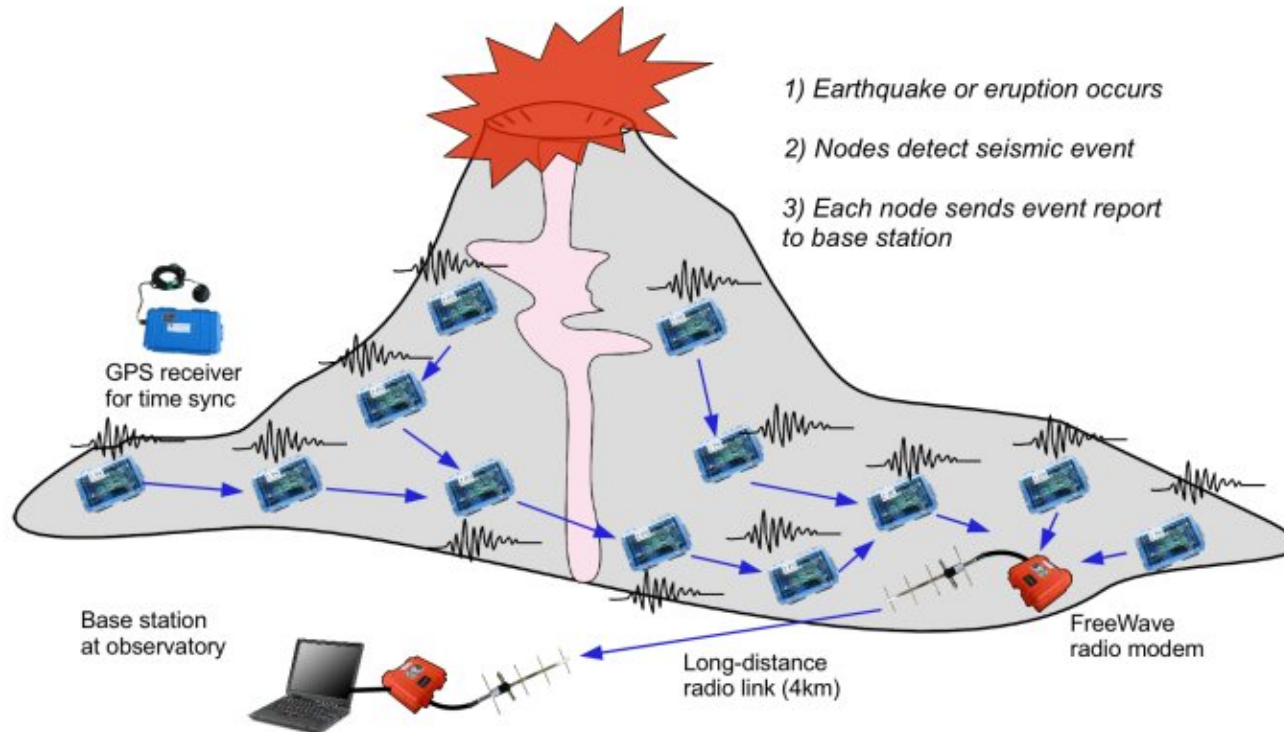
The zebras rip off the solar cells from the collar in less than one week!

After that, the batteries died...





# WSN application - Volcano

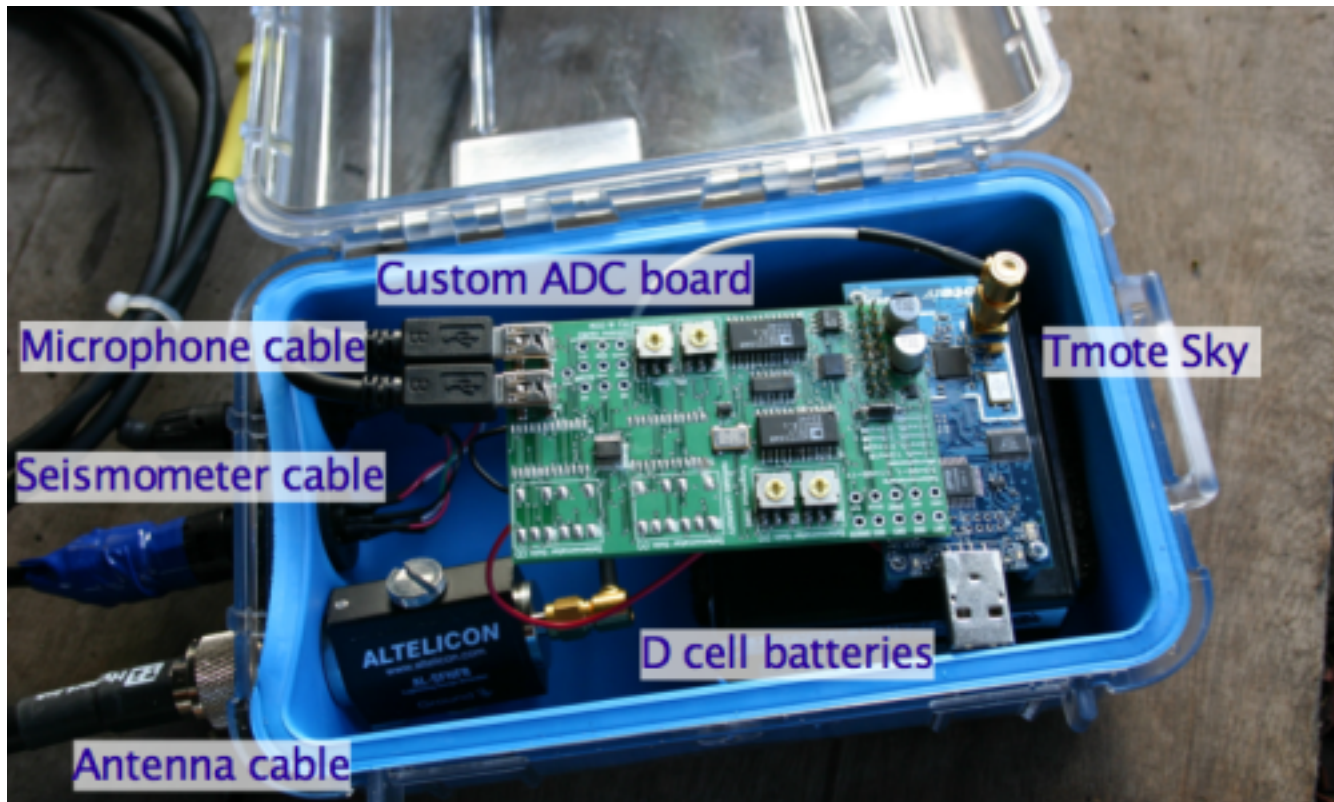


# WSN application - Volcano

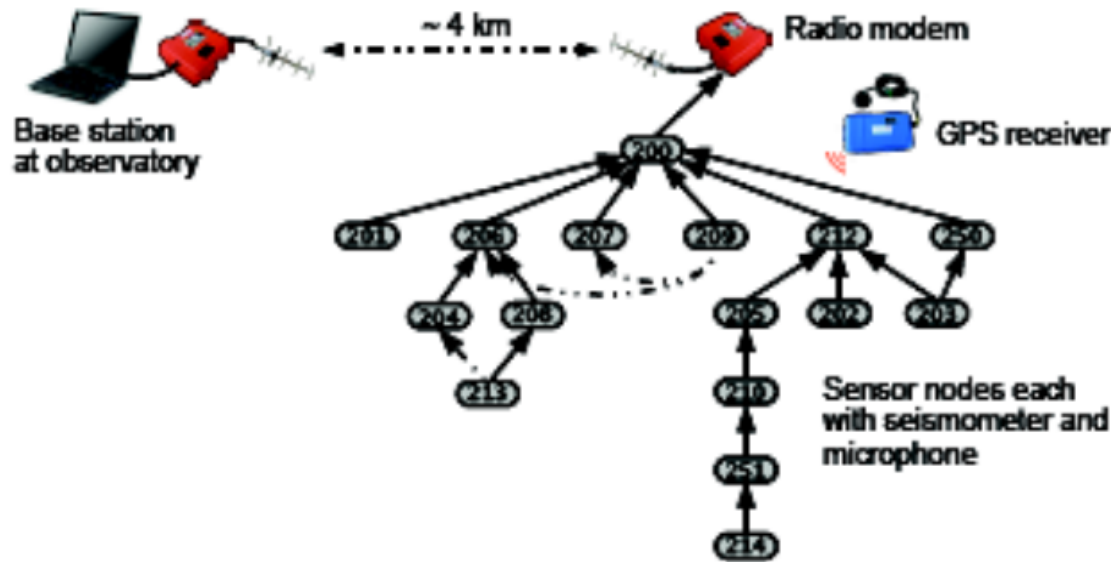
Reference: “Deploying a Wireless Sensor Network on an Active Volcano”, Geoffrey Werner-Allen, Konrad Lorincz, Matt Welsh, Omar Marcillo, Jeff Johnson, Mario Ruiz, Jonathan Lees, IEEE Internet Computing, Mar/Apr 2006

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**

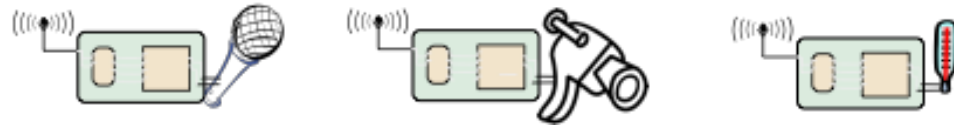
# WSN application - Medicine



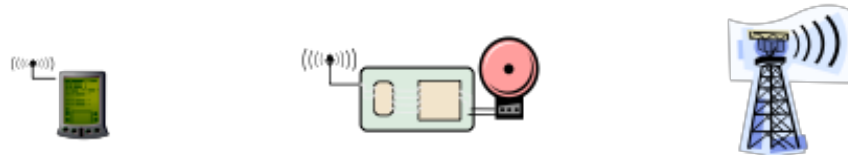
[CodeBlue: Harvard]

# WSN application - roles

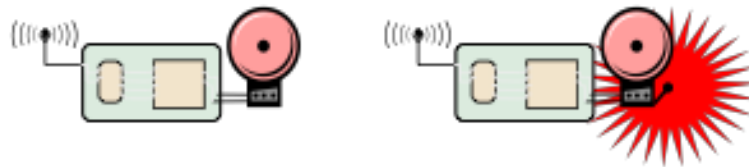
**Sources** of data: measure data, report them “somewhere”



**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

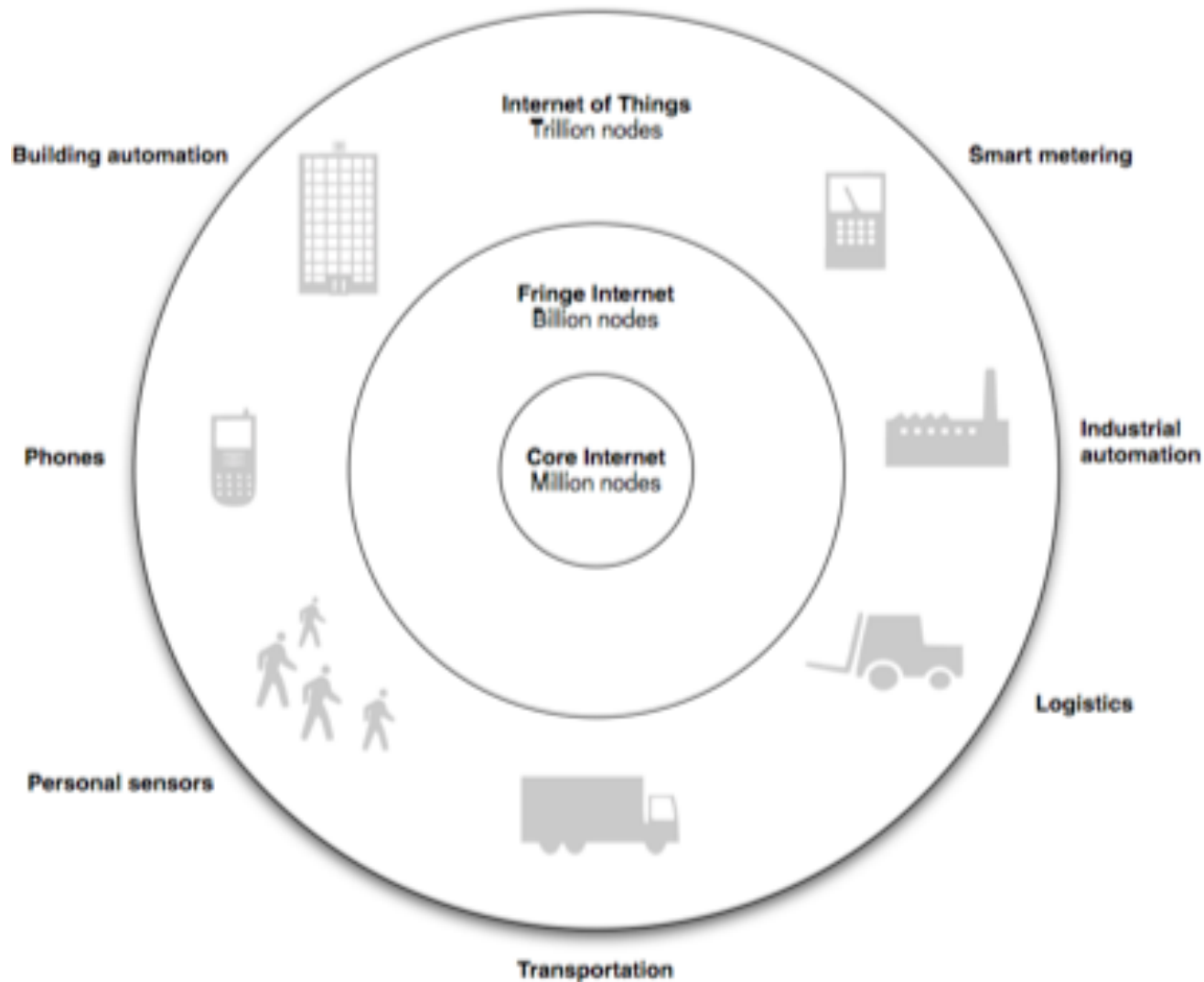
1980s: the PC revolution

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

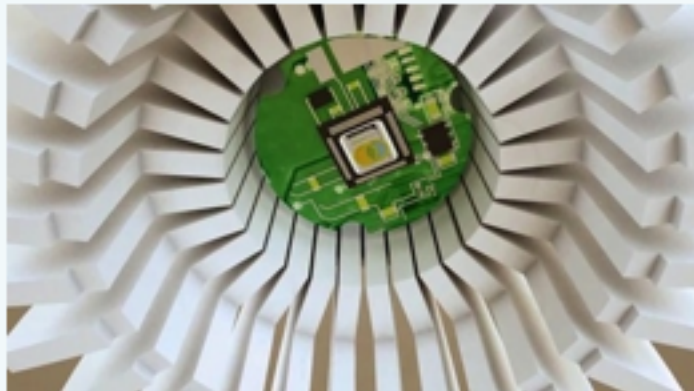
 Like

 Tweet

6

 +1

0



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

ambient™

## Ambient Umbrella

Glowing intelligence  
lets you know that there's  
rain in today's forecast.



# IPv4 or IPv6

Smart Objects will add tens of billions of additional devices

There is no scope for IPv4 to support Smart Object Networks

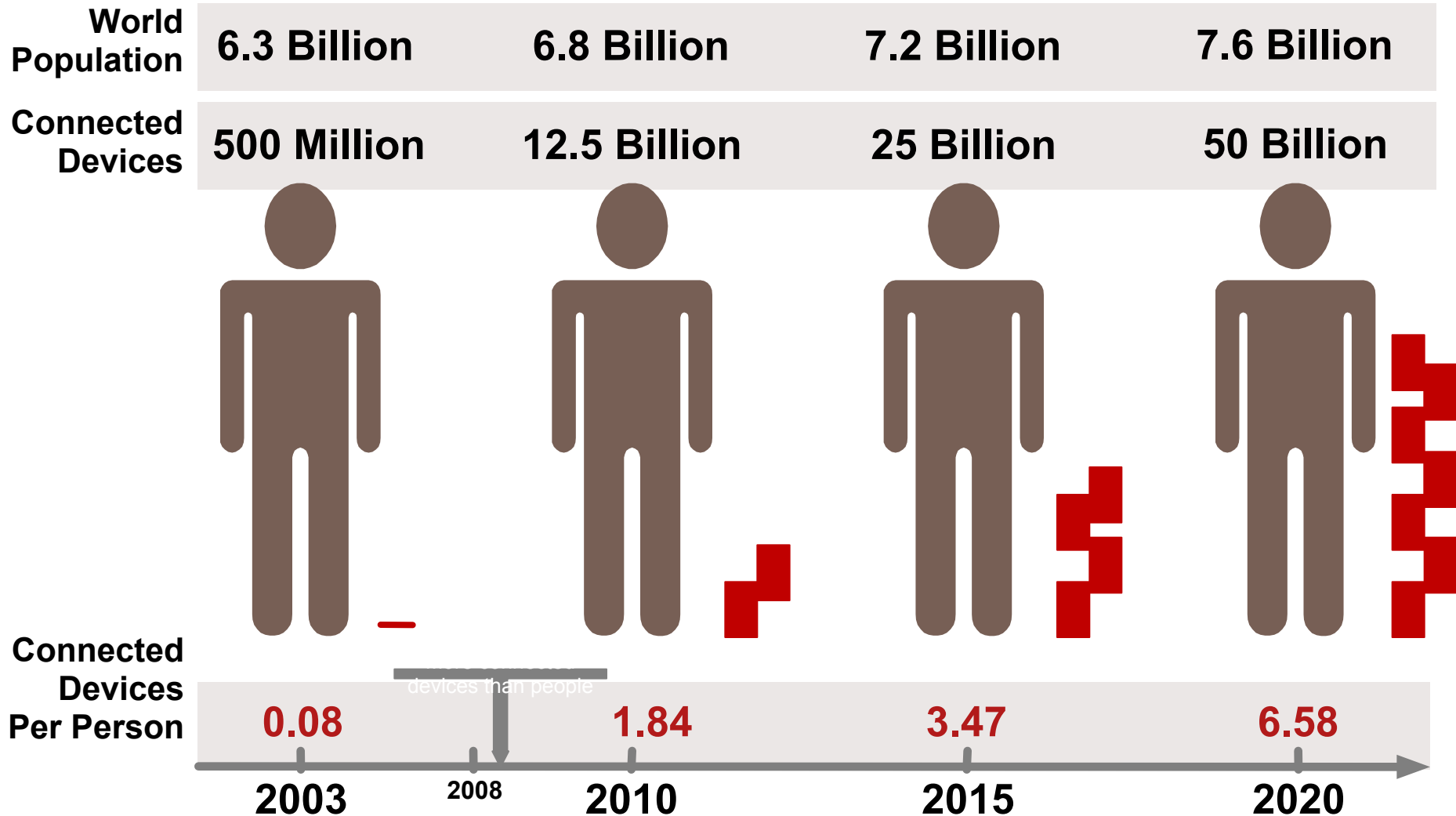
IPv6 is the only viable way forward

Solution to address exhaustion

Stateless Auto-configuration thanks to Neighbour Discovery Protocol

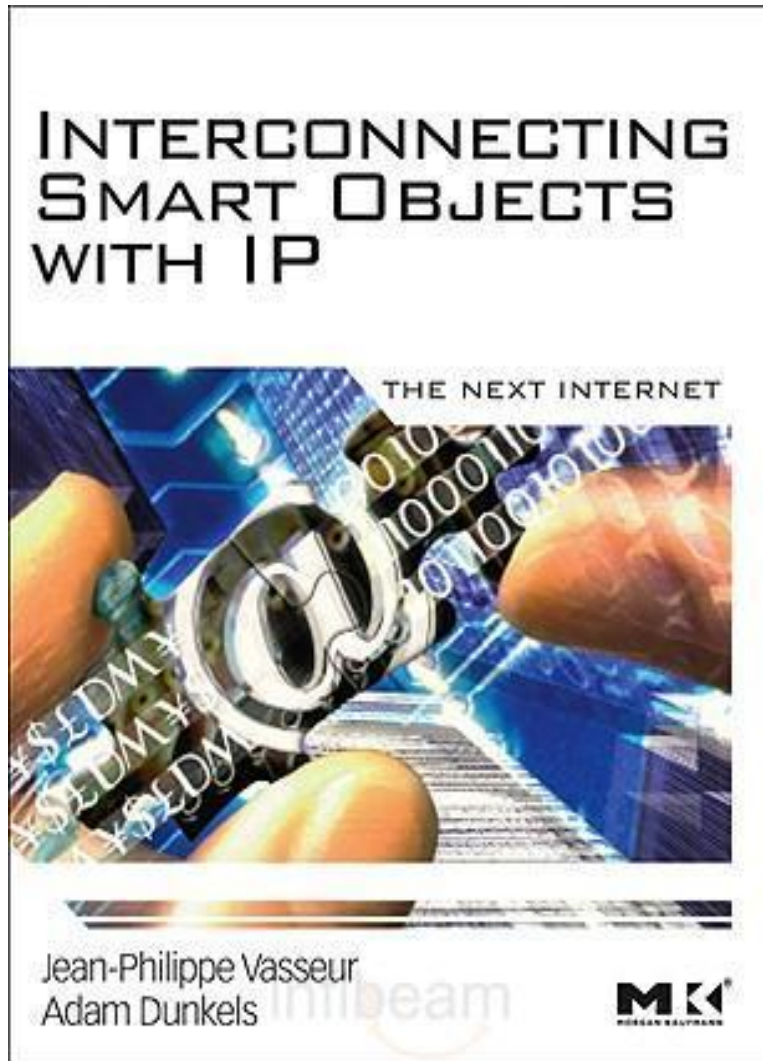
Each embedded node can be individually addressed/accessed

# Smart Objects





# Recommended reading



Covers the trends in Smart Objects

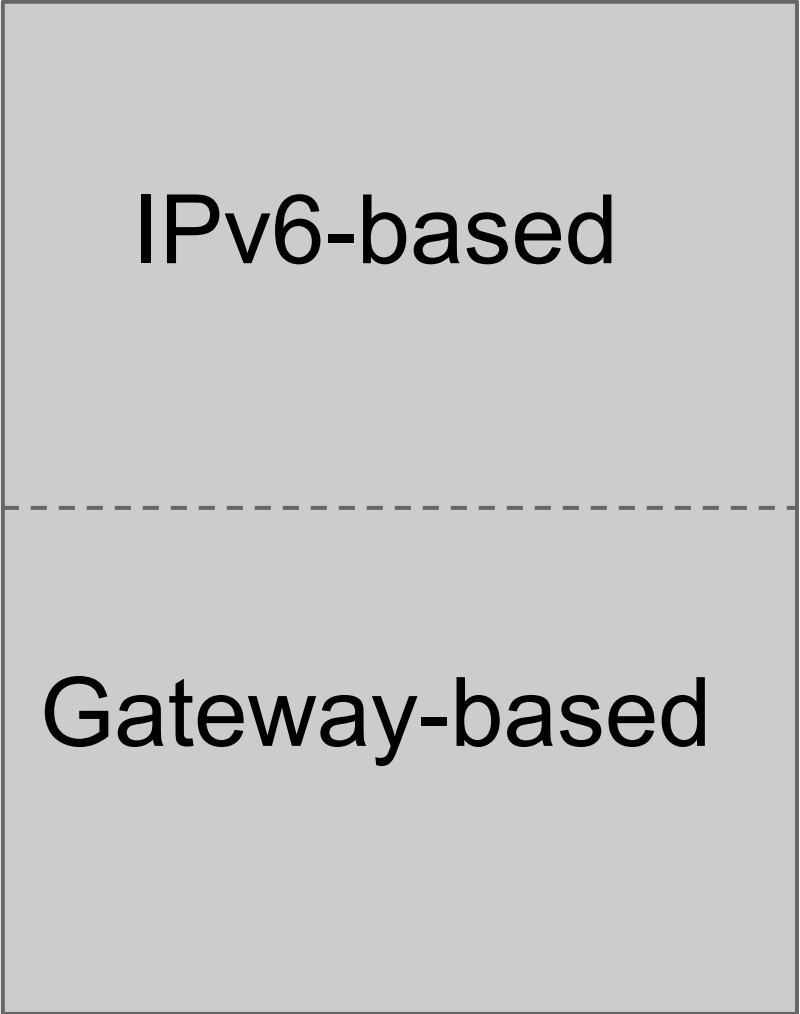
Detailed application scenarios

Written by

JP Vasseur (Cisco DE)

Adam Dunkels (Inventor of Contiki O/S, uIPv6)

# WSN options



IPv6-based

Gateway-based

# WSN options



Open WSN

Proprietary WSN

# WSN options

Open WSN  
IPv6-based

Open WSN  
Gateway-based

Proprietary WSN  
IPv6-based

Proprietary WSN  
Gateway-based

# WSN options

Open WSN IPv6-based	Open WSN Gateway-based
Proprietary WSN IPv6-based	Proprietary WSN Gateway-based

# Thanks

Marco Zennaro

[mzennaro@ictp.it](mailto:mzennaro@ictp.it)

[www.wsnblog.com](http://www.wsnblog.com)