THE SWARM
AT THE EDGE OF THE CLOUD
– A NEW FACE OF WIRELESS

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NEWS EUROPE

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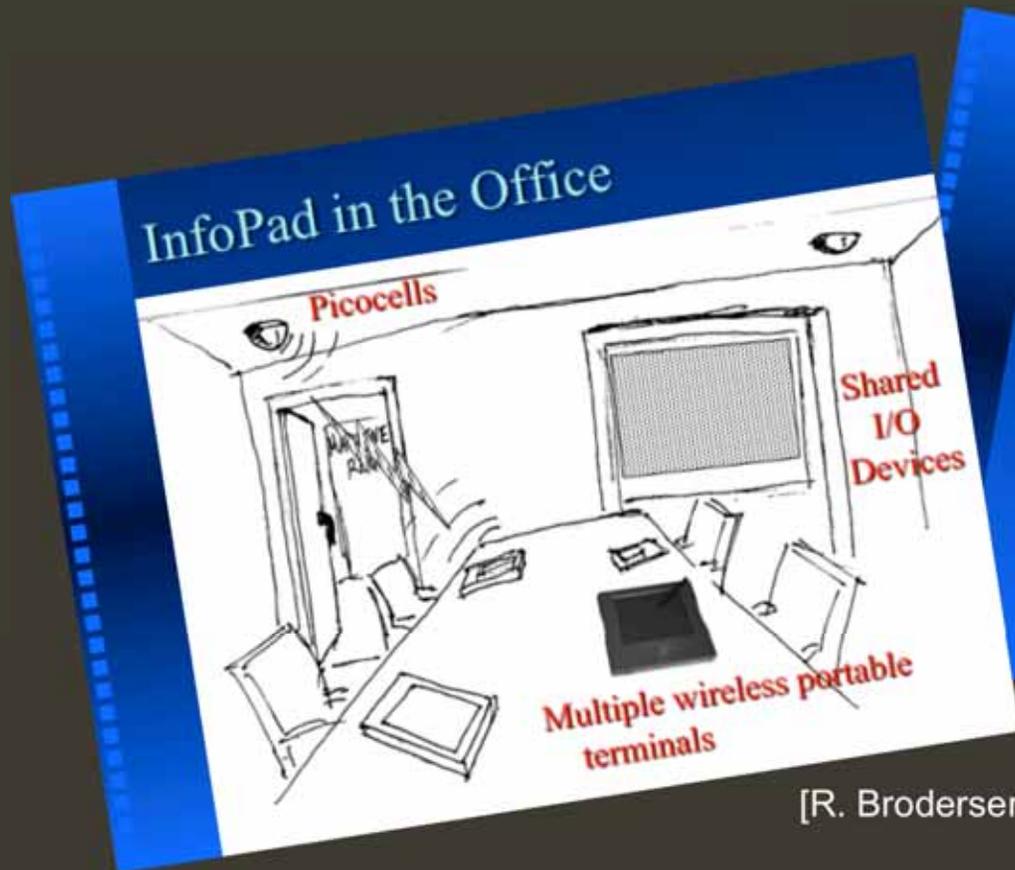# Drunk Swedish moose found in apple tree

REUTERS

The moose was apparently searching for fermenting apples when she got stuck

A homeowner in southern Sweden got a shock when he found a drunken moose stuck in his neighbour's apple tree.

Related Stories

1990 Question: What Happens to Computers if Wireless Connectivity Becomes Ubiquitous?

InfoPad in the Office

Picocells

Shared I/O Devices

Multiple wireless portable terminals

InfoPad

- Goal is to provide information access of multimedia data in a device that is as simple, low cost and small size as possible
  - Network support, high bandwidth connectivity and ease of use - like a network computer
  - Wireless connectivity and portability - like a phone
  - User interface and form factor - like a PDA

[R. Brodersen, ISSCC keynote 1997]

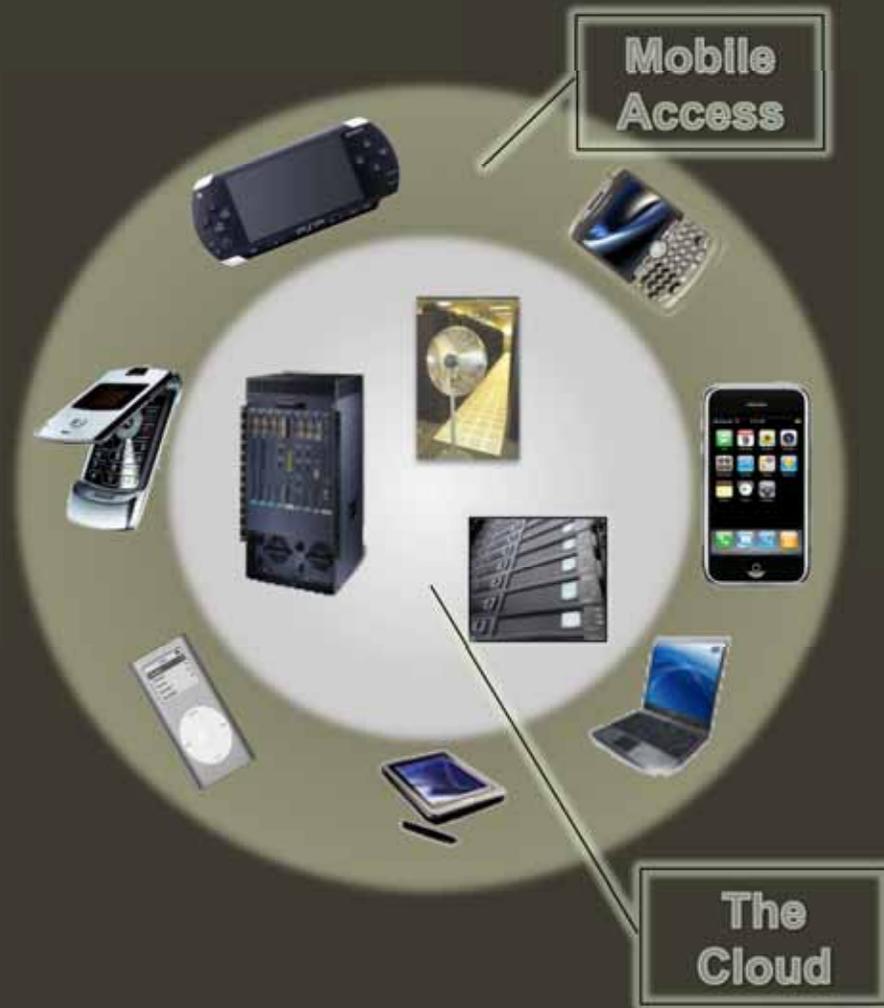## The Birth of the Wireless Tablet
The UCB Infopad Project (1992-1996)

2010 Outcome: The Tablet as Gateway to the Cloud
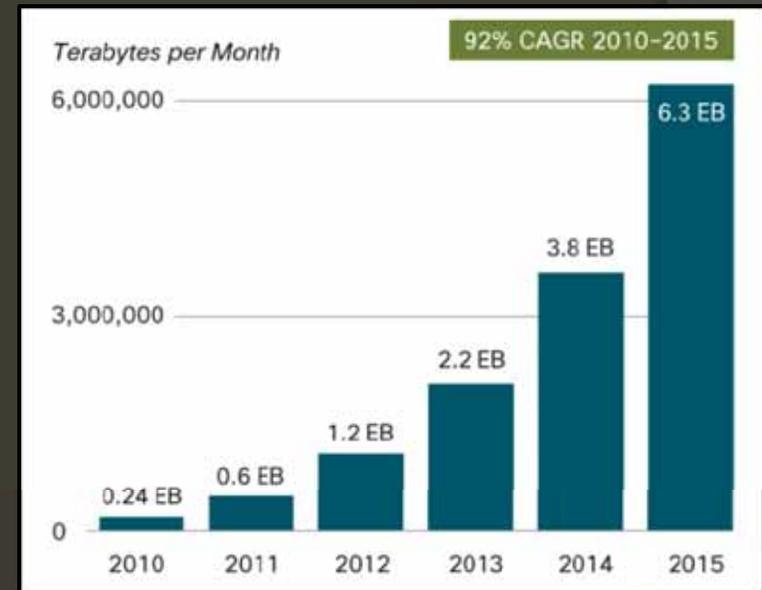
- Primary intent: interact with the Internet

The IT Platform of Today:
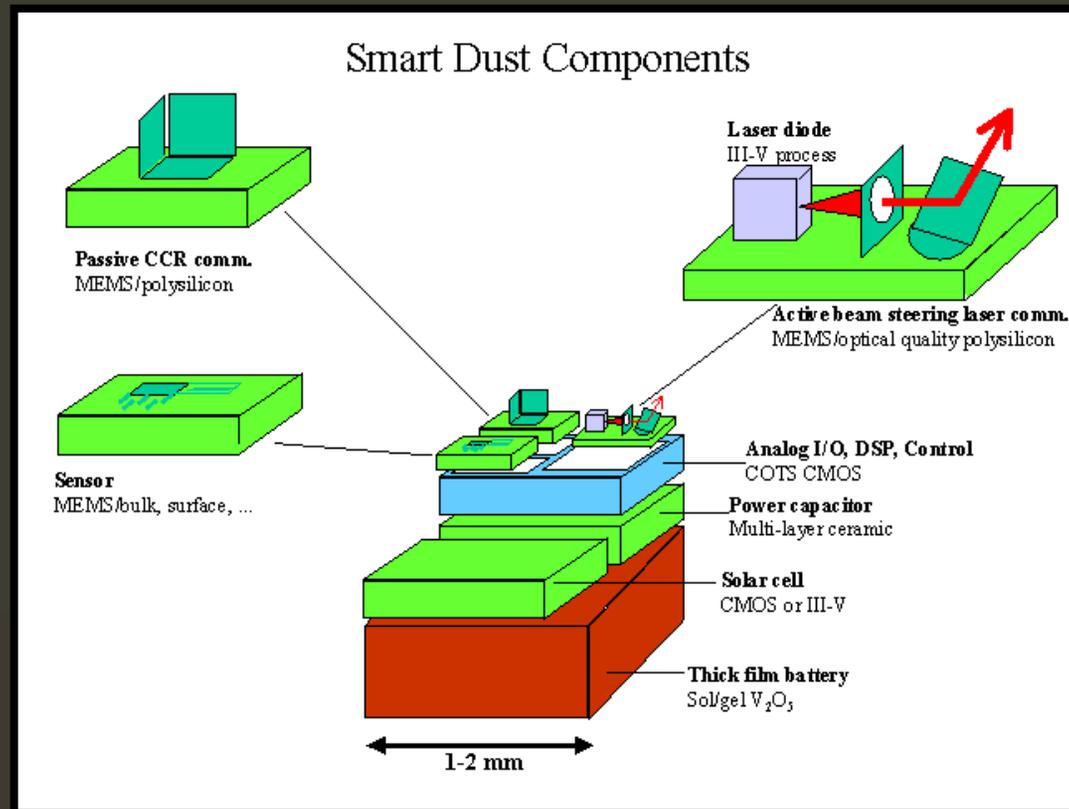# Mobiles at the Edge of the Cloud

Mobile Access

The Cloud

Mobile data growth
[Source: Cisco VNI Mobile, 2011]

Mobile traffic grew 2.6x in 2010
(nearly tripling for 3rd year)
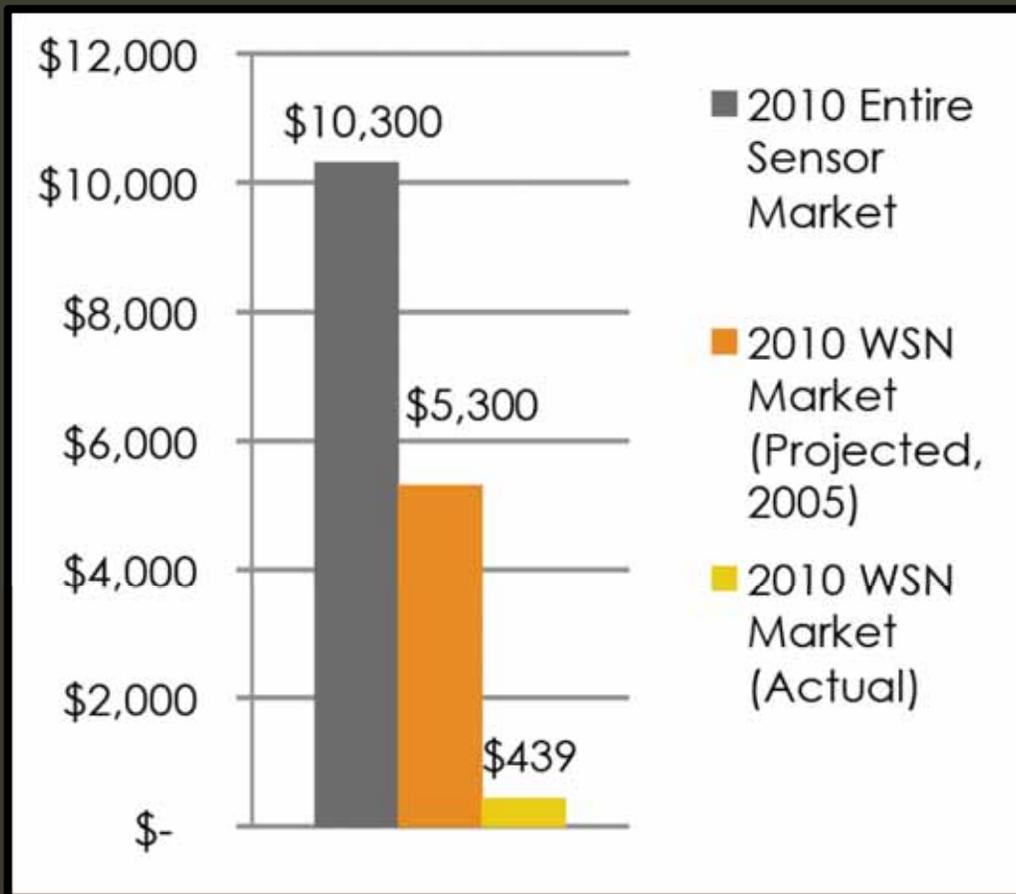**Driven by Tablets**

[J. Rabaey, ASPDAC'08]

1995 Question: What happens if sensors become tiny, wireless, and self-contained?

Smart Dust Components

... Wireless Sensor Networks

2010 Outcome: The Unfullfilled Promise of Wireless Sensor Nets

Source: On World

What slowed them down?
(Source: On World)

- Cost savings not yet disruptive
- Reliability
- Energy (battery life)
- Ease of use

Wireless Sensor Nets
What REALLY slows them down:
NO Economy of Scale

Stovepipes, Fragmentation, Non-interoperability, Lack of Virtualization

Industrial automation, smart buildings, renewable energy, data centers, …

TinyOS, eCOS, LiteOS, Contiki, Arch Rock

802.11x (WiFi), 802.15.4x (Zigbee), 802.15.1 (Bluetooth(LE)), 802.15.6 (WPANs), NFC, …

Vision 2025

- Integrated components will be approaching molecular limits and/or may cover complete walls

- Every object will have a wireless connection, hence leading to trillions of connected devices,

- Collaborating to present unifying experiences or to fulfill common goals

What will it Enable?
The Birth of the Swarm

The Swarm at The Edge of the Cloud

Mobile Access & Relay

The Swarm

The Cloud

[J. Rabaey, ASPDAC'08]

The Futuristic Swarm

"Tiny devices, chirping their impulse codes at one another, using time of flight and distributed algorithms to accurately locate each participating device. Several thousands of them form the positioning grid … Together they were a form of low-level network, providing information on the orientation, positioning and the relative positioning of the electronic jets… It is quite self-sufficient. Just pulse them with microwaves, maybe a dozen times a second …"

Pham Trinli, thousands of years from now

Vernor Vinge,
"A Deepness in the Sky," 1999
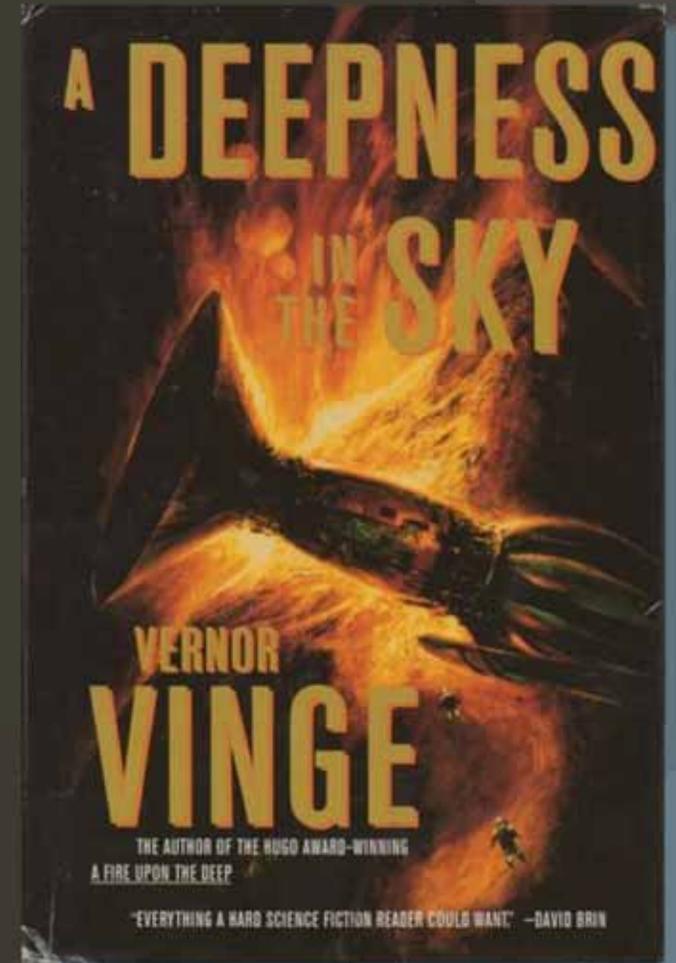
CyberPhysical Systems
Linking the Cyber and Physical Words

Aka: The Internet of Things, Societal IT Systems, …

CyberBiological Systems (BioCyber)
Linking the Cyber and Biological Worlds

Examples: Telesurgery, Body-area networks, health diagnostics, drug delivery, brain-machine interfaces, ...

The Age of the "UnPad" (or $\overline{\text{Pad}}$) *

Computers and mobiles to completely disappear!

The Immersed Human

Real-life interaction between humans and cyberspace, enabled by enriched input and output devices on and in the body and in the surrounding environment

* Term originally coined by BWRC Directors

A Glimpse at the "Unpad"

Courtesy: Corning Glass
"A World Made of Glass"

(http://www.youtube.com/watch?v=iY1Q0bNwXuI)

The Swarm as a Platform

A mediation layer

Apps

SWARM-OS

Resources
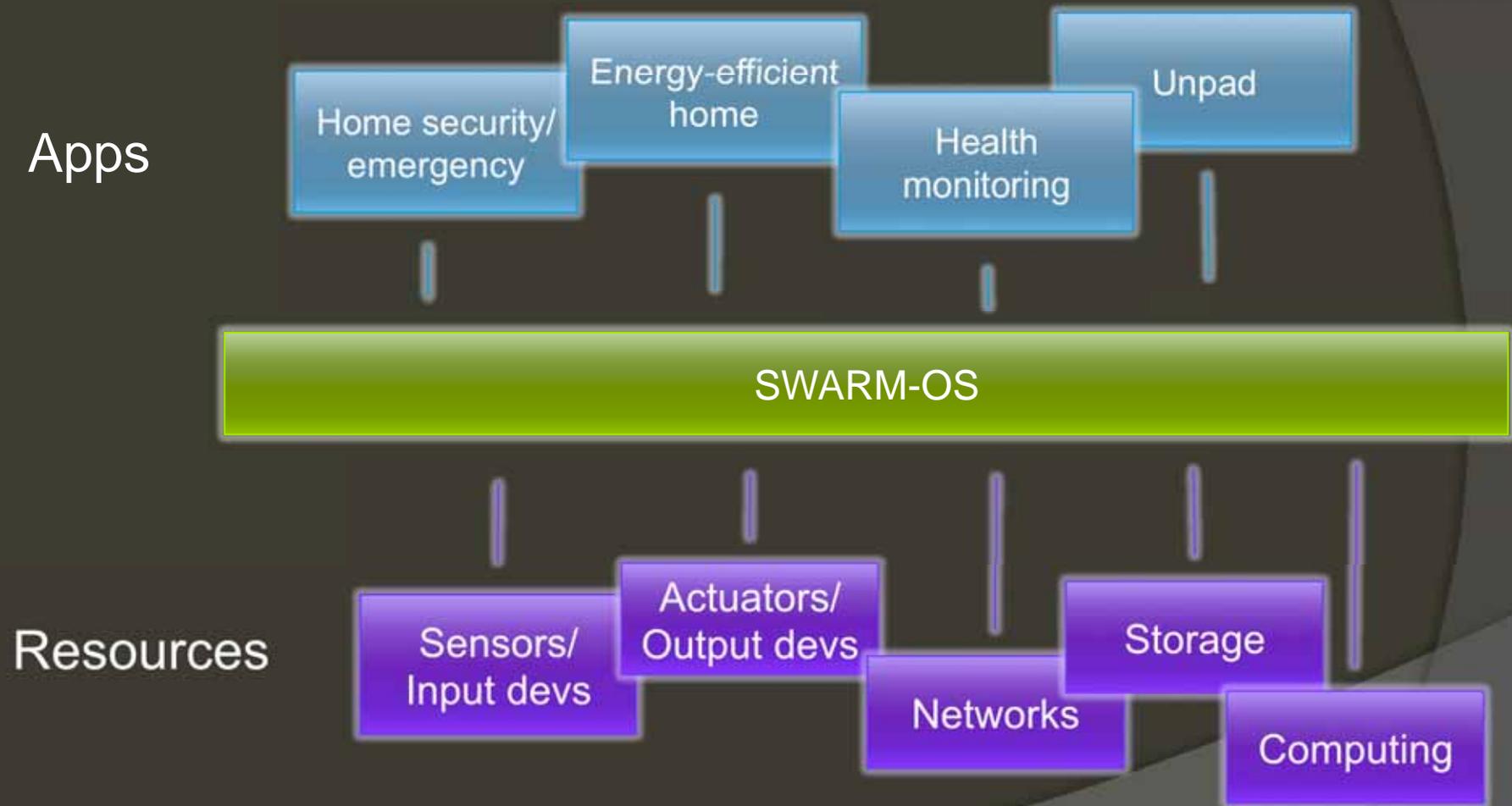
Presenting a uniform API to Apps Developers (similar to trends in the Cloud)

The Swarm as a Platform

Operating System (Broad Sense): Environment that
- Presents abstracted vision of hardware to applications
- Dynamically balances application needs versus available resources under time and energy constraints

What makes SWARM-OS different (and hard)?

- Distributed
- Space/context-aware
- Heterogeneous shared (and sparse) resources
- Dynamic
  - Mobility, scope, resources, connectivity, …

App2   App2 App2

App1
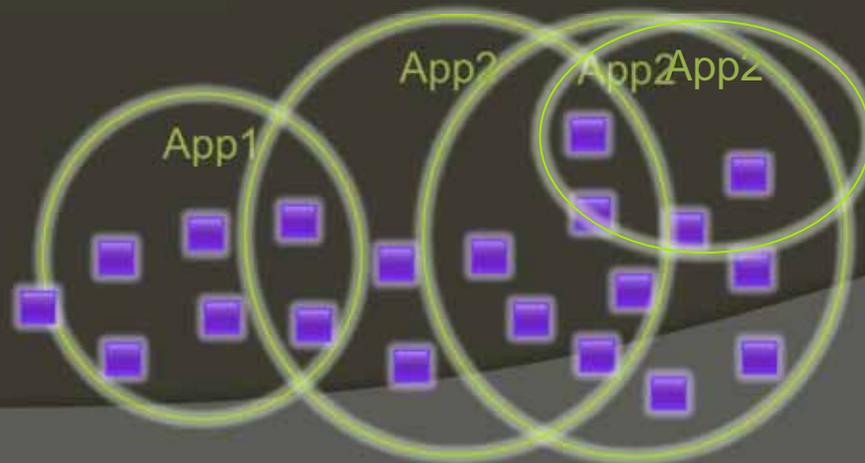
How to Deal with Dynamics
Structured versus ad-hoc?

BOTH OF THE ABOVE!

THE CLOUD

THE EDGE

THE SWARM

Exploiting the Edge of the Cloud (or The Fog*)
Packs plenty of computation, communication, storage and energy resources
Avoids the overhead of the Cloud

Not an "OS as usual"
Reactive or opportunistic emergence of capabilities desirable

[F. Bonomi, Cisco, "Cloud and Fog Computing"– EON June 11]

The Swarm Challenge(s)

Energy

Privacy/Security

Performance (Latency)

Complexity

Reliability

Management
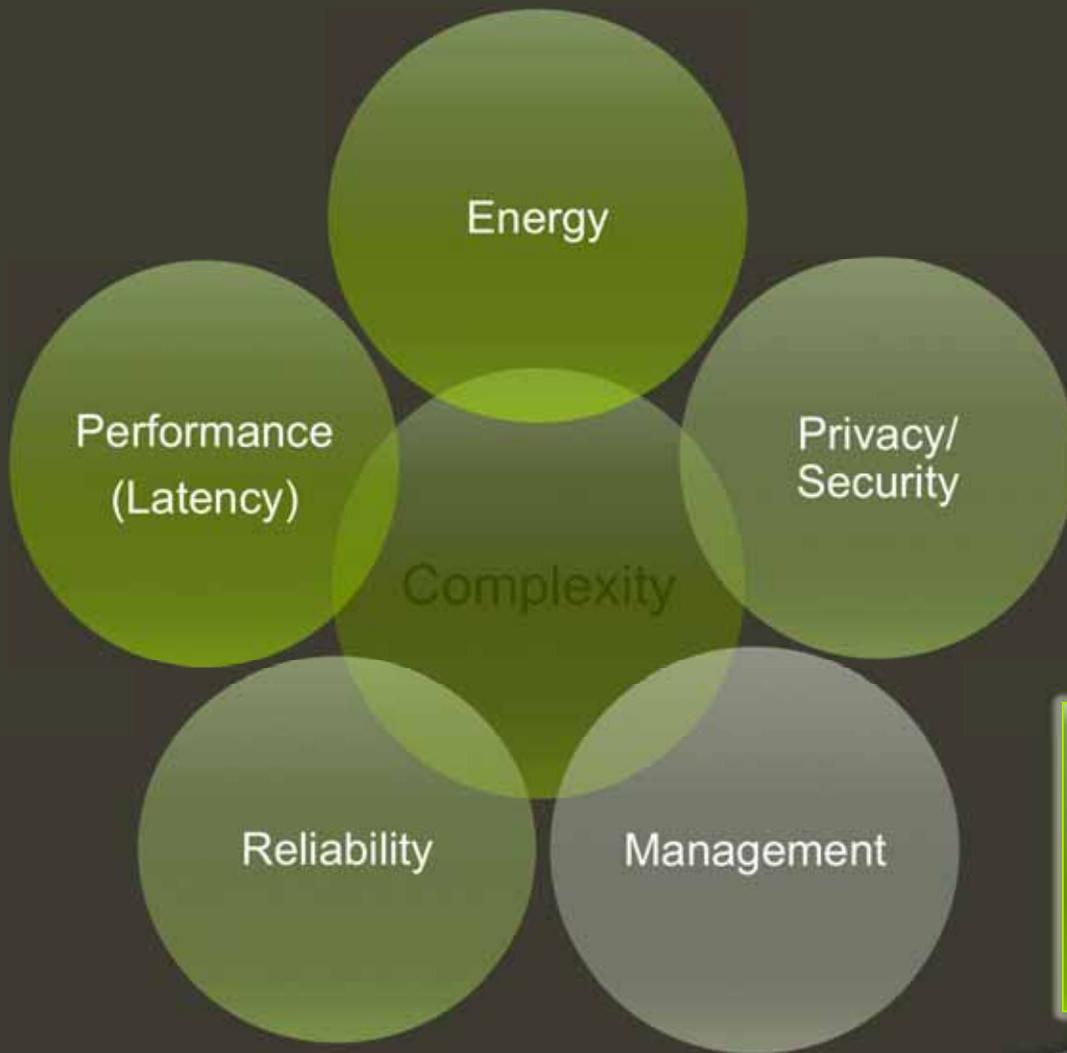
Complex distributed control systems combining heterogeneous components under dynamically varying conditions

The Swarm Opportunity

It's A Connected World
Time to Abandon the "Component"-Oriented Vision
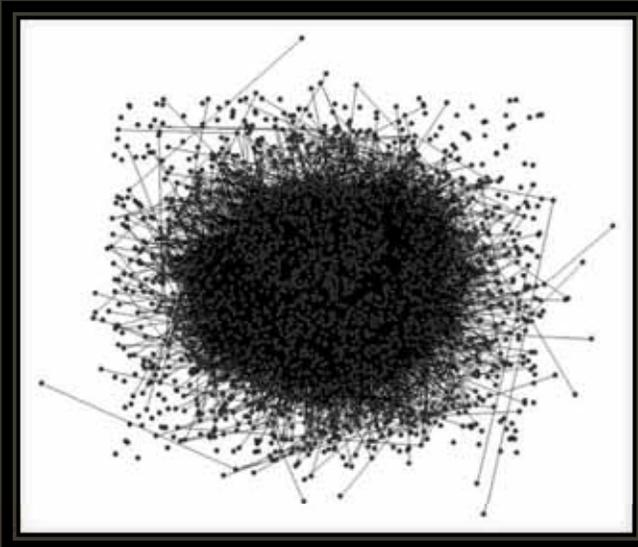
The functionality is in the swarm!
- There is power in numbers
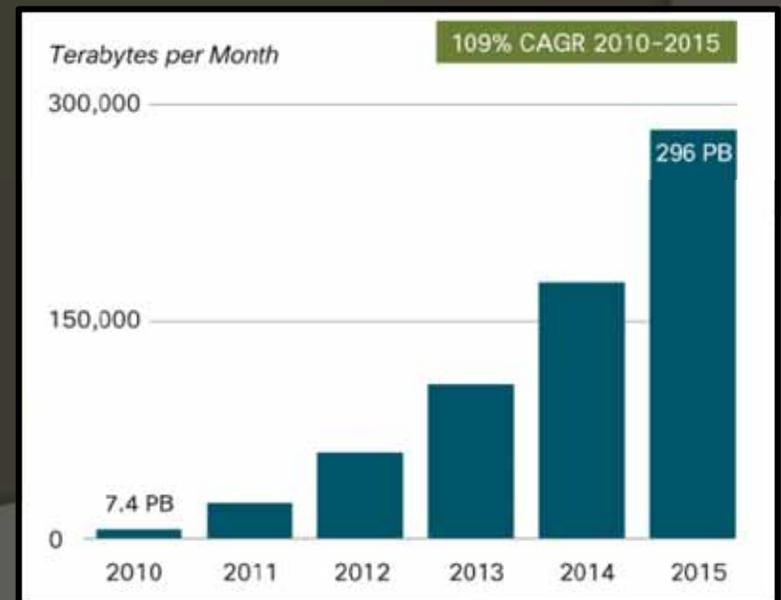- Resources can be dynamically provided based on availability

Moore's Law morphs into Metcalfe's Law:
Scaling is in number of connected devices,
no longer in number of transistors/chip

[J. Rabaey, MuSyC 2009]

A New Face for Wireless

Need connectivity strategies that get better with increasing numbers!

- Exploit locality/proximity

- Exploit density

- Collaborate!

- Ensure reliability and safety

Machine-to-machine (M2M) traffic:
40x between 2010 and 2015

Terabytes per Month | 109% CAGR 2010-2015

300,000

150,000

296 PB

7.4 PB

0

2010 2011 2012 2013 2014 2015

Get Better with Large Numbers

Wireless Capacity Doubled Every 30 Months Since 1900 *
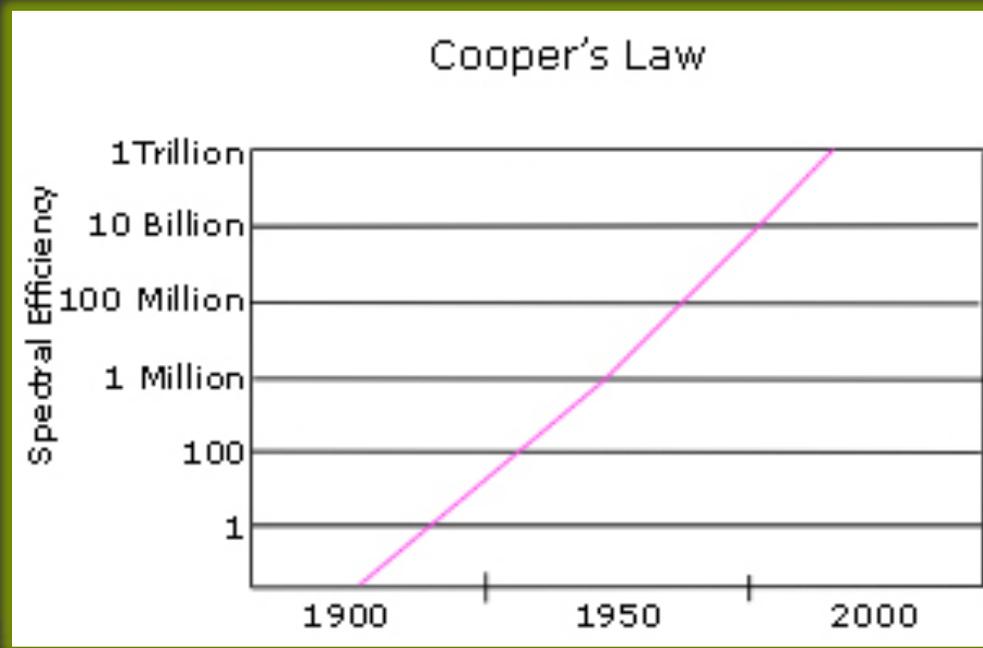
Million-fold capacity increase since 1957

25x from wider spectrum,

5x by dividing spectrum into smaller slices,

5x by designing better modulation schemes,

1600x from reduced cell sizes and transmit distance.

Biggest gain in next decade to come from smaller cells!

Message: The Swarm offers an unique opportunity

[M. Cooper, www.arraycom.com]

Exploiting Locality/Proximity

The peer-to-peer opportunity

[R. Tucker, 2009]
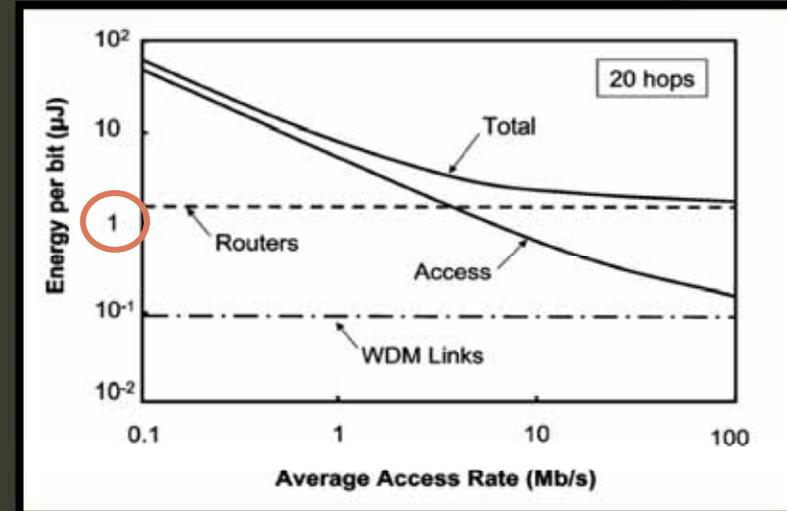
Internet energy/bit

Wireless peer-to-peer

Radio	TX (nJ/bit)	RX (nJ/bit)
Zigbee	185	135
BT LE	55	40
Nordic	10	13
BAN	3	1
60 GHz	0.1	0.1

[L. Vandeperre, B. Gyselinckx, IMEC-2011]

Exploiting Locality/Proximity

The peer-to-peer challenge

How to know if two nodes are even interested in talking?

Current approach:
- Establish connection
- Register device
- Application detects device
- Application queries
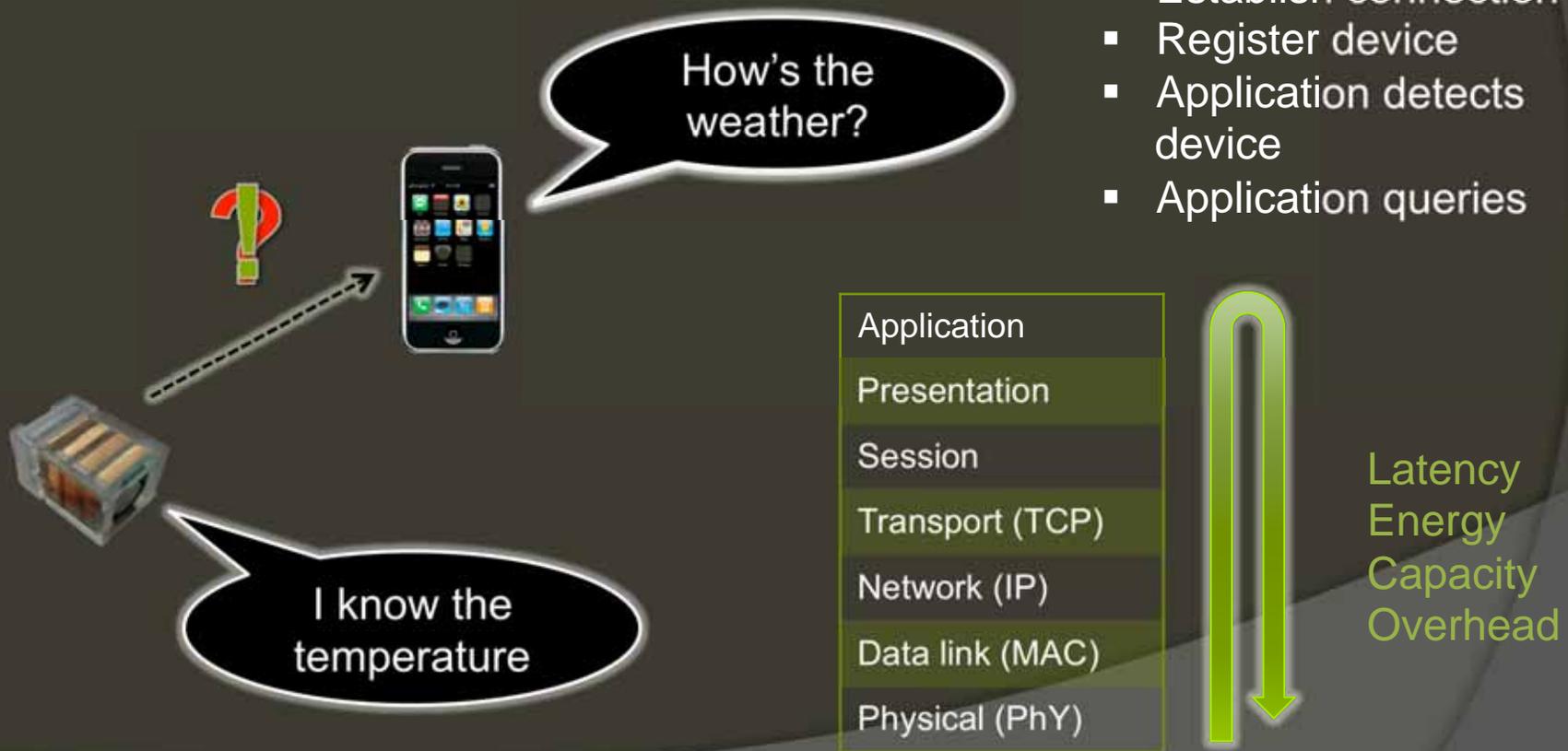
How's the weather?

I know the temperature

| Application |
| Presentation |
| Session |
| Transport (TCP) |
| Network (IP) |
| Data link (MAC) |
| Physical (PhY) |

Latency
Energy
Capacity
Overhead

Exploiting Locality/Proximity

The peer-to-peer challenge

How to know if two nodes are even interested in talking?

How's the weather?

I know the temperature
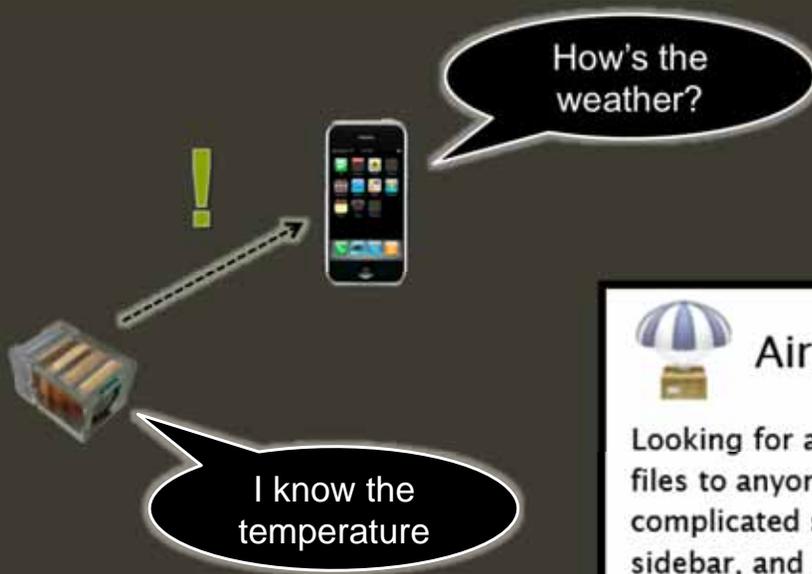
Dedicated "stovepipe" solutions

AirDrop

Looking for a fast way to share files with people nearby? With AirDrop, you can send files to anyone around you wirelessly — no Wi-Fi network required. And no complicated setup or special settings. Just click the AirDrop icon in the Finder sidebar, and your Mac automatically discovers other AirDrop users within about 30 feet of you. To share a file, simply drag it to someone's name. Once accepted, the fully encrypted file transfers directly to that person's Downloads folder.

Recently announced Mac OS X Lion

Exploiting Locality/Proximity

The peer-to-peer challenge

How to know if two nodes are even interested in talking?

Alternative approach:
- Cut through the layers!
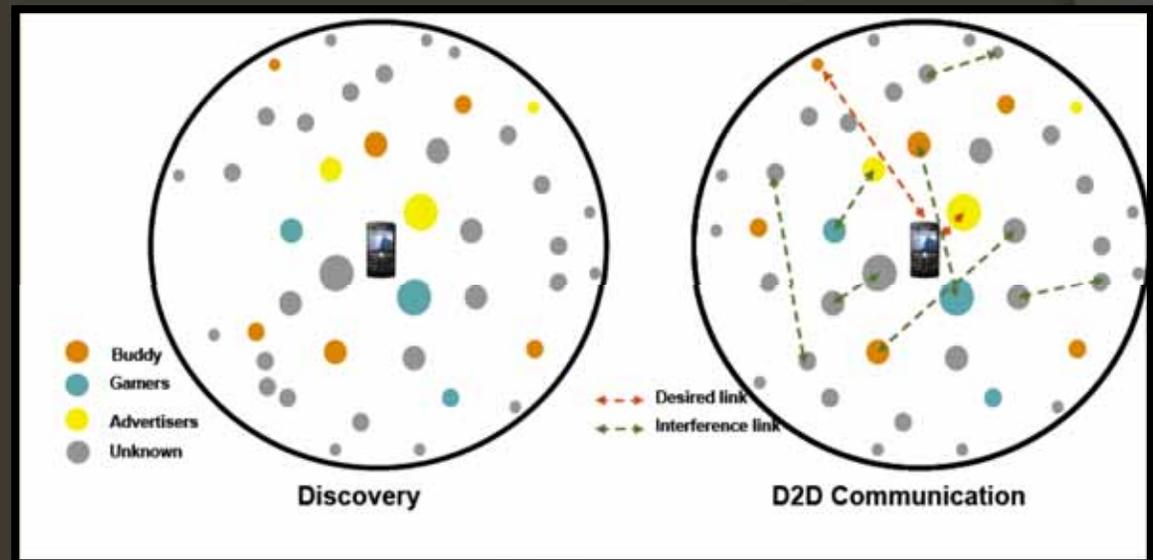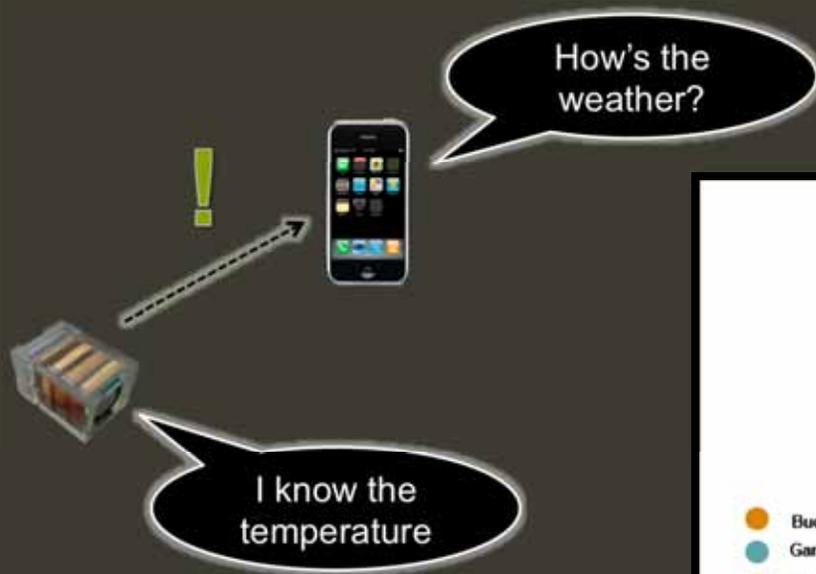
Example: Qualcomm FlashlinQ P2P protocol
Physical layer beaconing enables proximity and interest detection
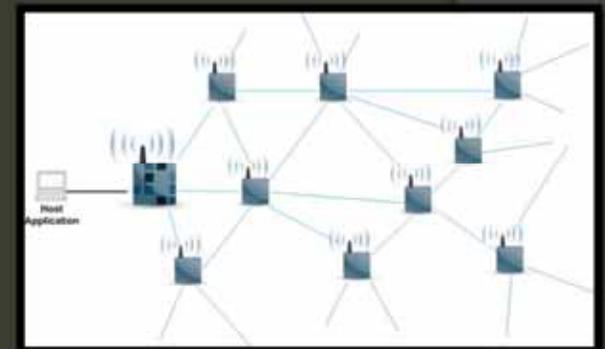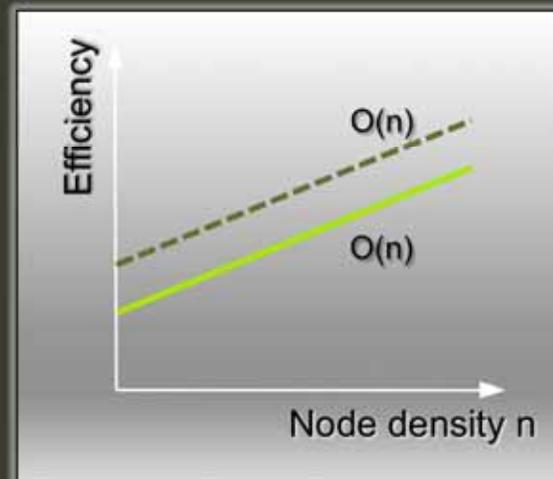
Exploiting Density

The power of collaboration

no-collaboration

multi-hop [Gupta-Kumar00]
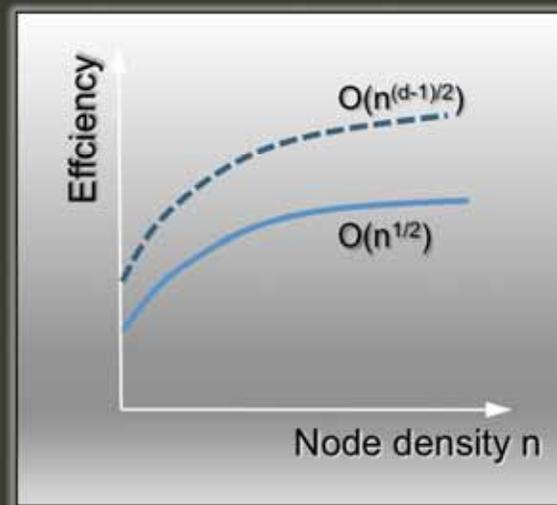
distributed MIMO [Tse07]

Example: mesh network
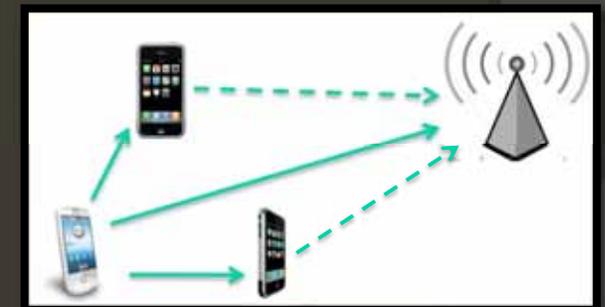
Example: relay network

Enabling Collaboration

Coexistence among legacy and more capable technologies
One of the 4 "Enduring Technical Wireless Challenges" *
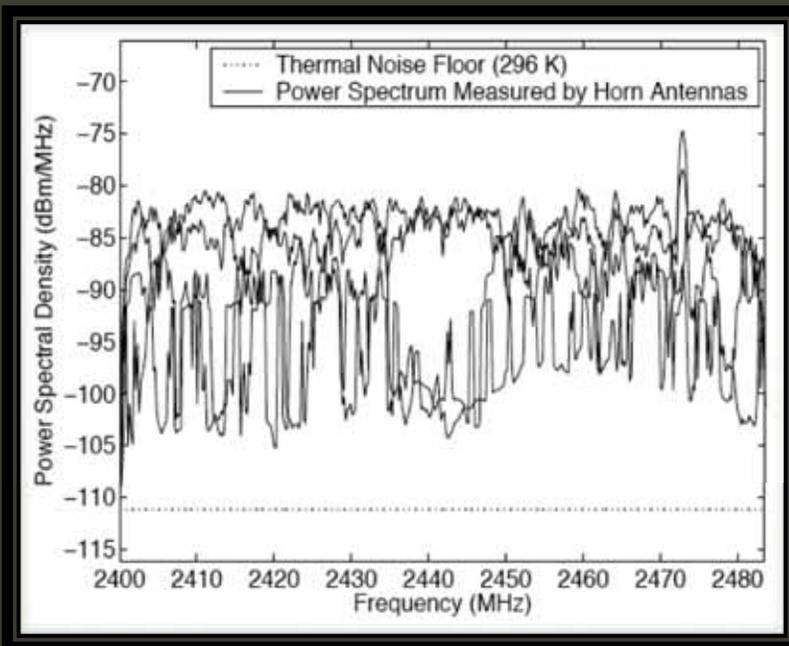
Spectral crowding in the ISM Band
(Bay Area, 2004)

What is needed:
A technology-agnostic ***mediation layer*** that enables information exchange and cooperation/ collaboration among heterogeneous wireless technologies and applications.**

- **Open**
- **Scalable**
- **Extensible**
- **Distributed**

Feels like … Swarm-OS!

*[NRC report on "Wireless Technology Prospects and Policy Options", 2011]
*[Rabaey et al, "Connectivity Brokerage", 2010]

Large Numbers and Reliability

Humans

- **10-15% of terrestrial animal biomass**
- **10^9 Neurons/"node"**
- **Since 10^5 years ago**

Easier to make ants than humans
"Small, simple, swarm"

Ants

- **10-15% of terrestrial animal biomass**
- **10^5 Neurons/"node"**
- **Since 10^8 years ago**

[D. Petrovic, UCB – Atheros]

Wireless Less Reliable Than Wired?

Wired

Point-to-point
(wire as single point of failure)

Wireless

Broadcast
(redundancy & interference)

Wireless reliability with many 9's
- Exploit spatial diversity
- Exploit time diversity
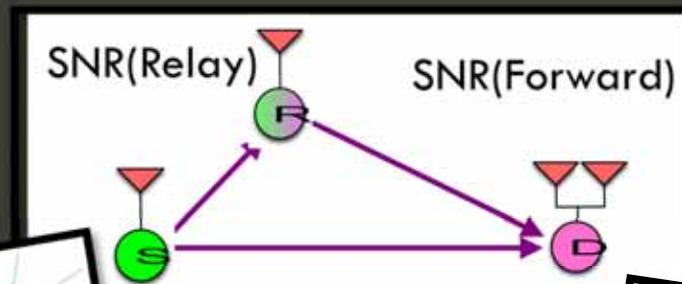- Exploit frequency diversity
- **Exploit redundancy**

When properly managed!

[Courtesy, Dust Networks]

50 motes, 7 hops
3 floors, 150,000sf
>100,000 packets/day
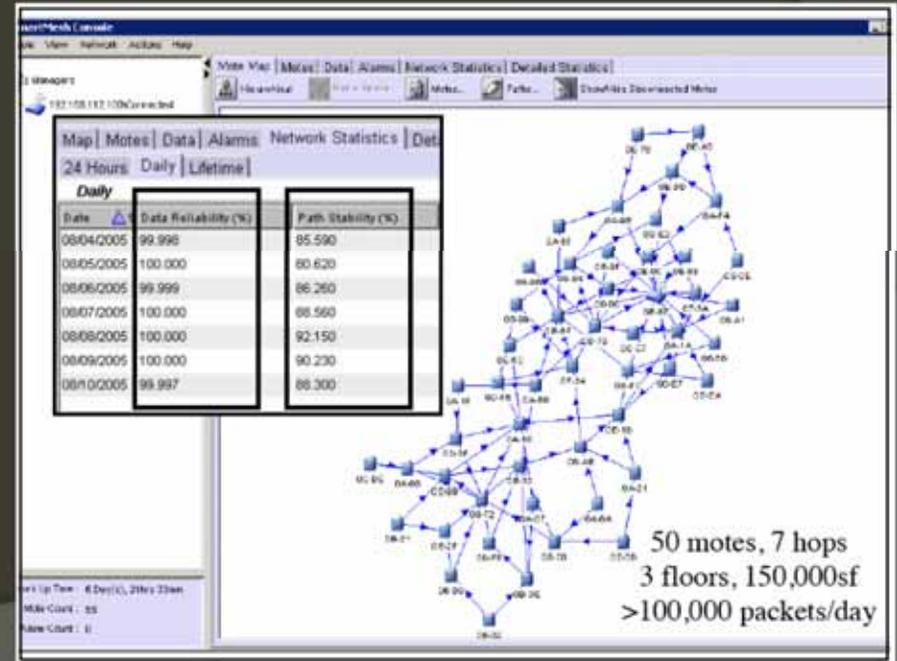
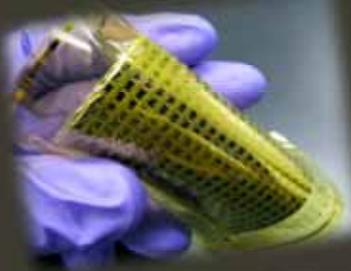# The New Face of Wireless ... What it Means for Semiconductor

Wireless platforms that embrace locality, collaboration, agility, reliability and energy-proportionality
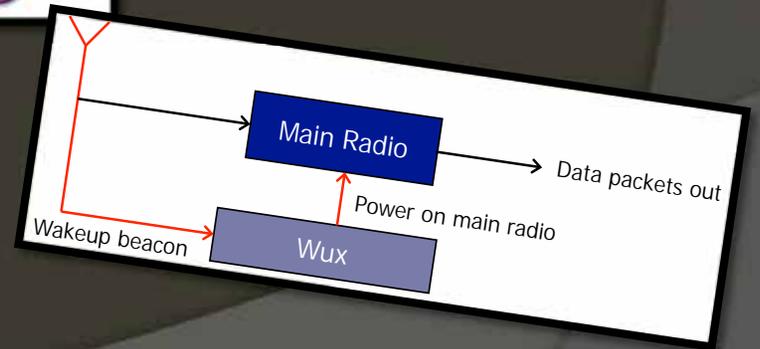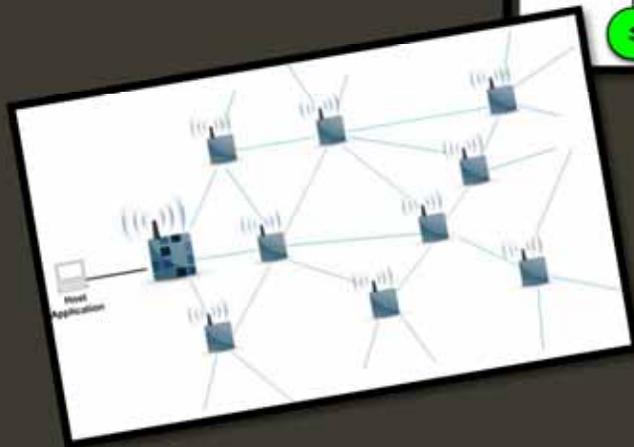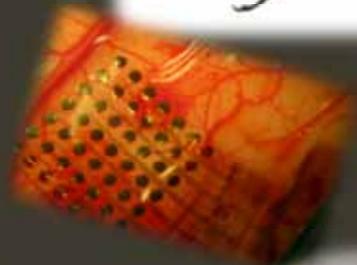
The Swarm ...
What it Means for Semiconductor

A continuing quest of providing more function for less {energy, cost} - Embracing "More Then Moore" and "Beyond Moore"
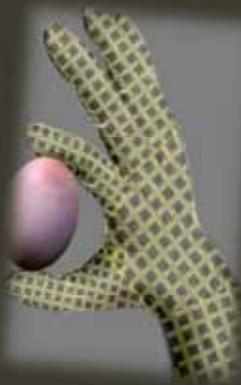
Nano-optics and mechanics

10 cm

Novel materials and substrates

Bioelectronics

An integrative vision – the Berkeley "Swarm Lab"

Enabling the Swarm ...
"The Swarm Lab"
A vision for the 4th floor of Cory

Create an open and universal platform to foster the creation and distribution of a broad range of innovative swarm applications

- ◉ The swarm hive
  - An incubator for swarm applications
- ◉ The "x-on-y" lab
  - Post-silicon electronics manufacturing
- ◉ The "nano-mechanical" lab
  - Exploring the opportunities of NEMS for sensing, computing, communication and energy harvesting
- ◉ The new photonics lab
  - Integrated photonics for sensing, communication and power generation

10 cm
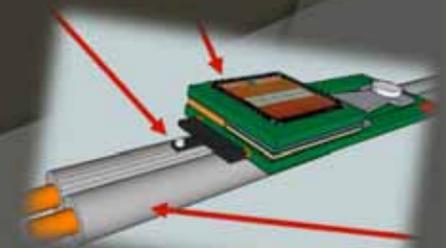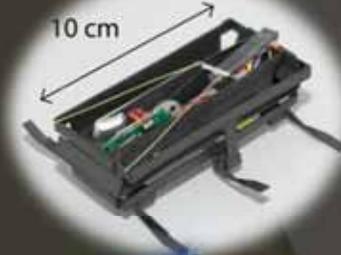
In Summary ... The Laws of the Swarm

- In a connected world, functionality arises from connections of many devices.
- A platform vision is essential to enable economy of scale.
- The dynamic nature of the environment, the needs and the resources dictate adaptive solutions.
- Largest efficiency gain obtained by dynamically balancing available resources: computation, storage, spectrum and energy.
- No one wins by being selfish. Cooperation and collaboration are a must.

A truly new face of wireless!

Postscript:
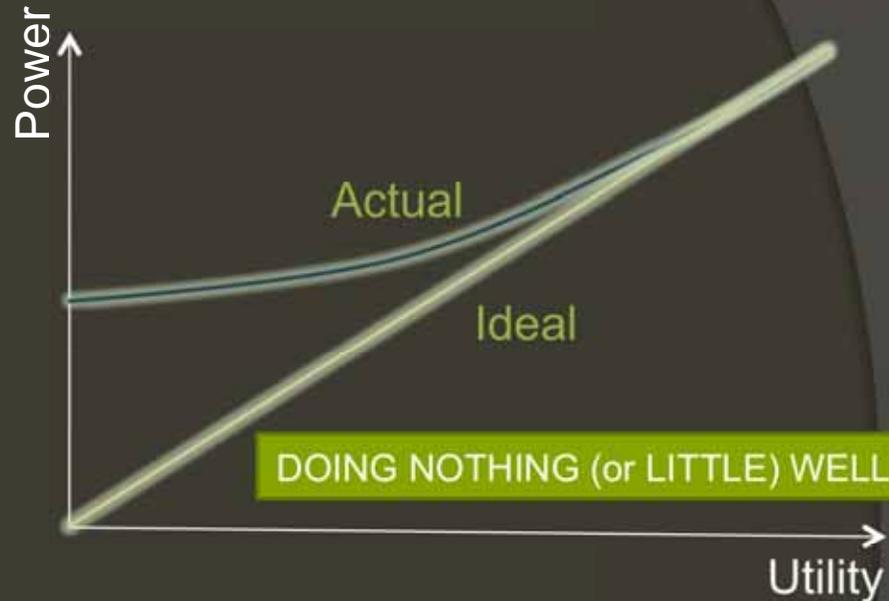## Failure is not an Option!

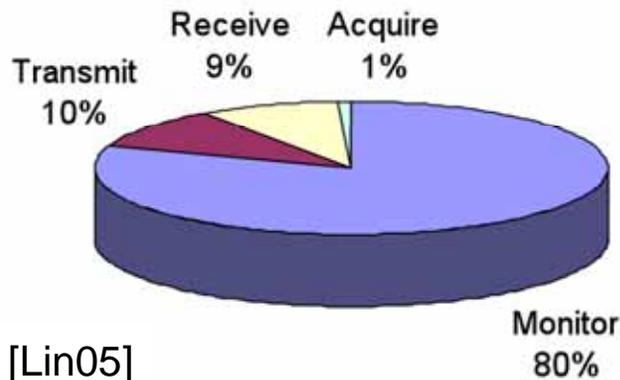**What an unruly swarm can do …**

Thank You!

Enabling True Energy-Proportionality*

Fundamental efficiency concept:

Energy Consumed $\propto$ Utility Delivered

Time spent in different states for a
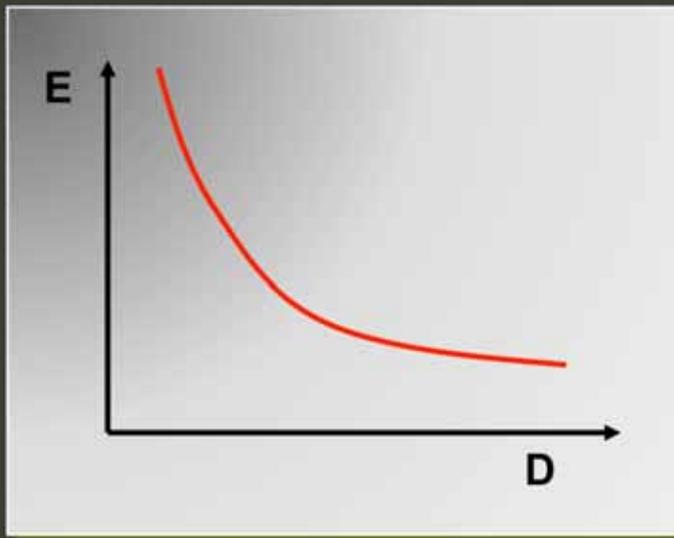CSMA/CA MAC protocol
(802.11 @ 10 packets/sec)

Transmit 10%
Receive 9%
Acquire 1%
Monitor 80%

[Lin05]

Power

Actual

Ideal

DOING NOTHING (or LITTLE) WELL

Utility

Not the case in ANY electronic system
in use today (e.g. datacenter,
computer, wireless LAN)

* Term originally coined by Luis Barroso (Google)

Enabling True Energy-Proportionality
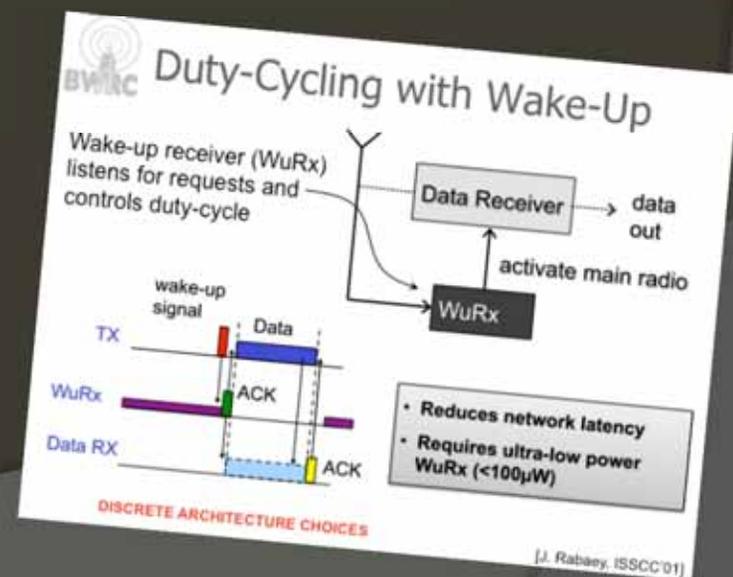
A system responsibility!

What a single node can do:
Change operation point by tweaking continuous or discrete design variables (supply, threshold voltages, power mode)

Limited by operating boundaries (e.g. leakage, max voltage)

What a system can do:
- Trade computation, storage and communication
- Perform remote caching (proxy)
- Enable "true" sleep modes
- …

A new form of collaboration

The Challenge of Large Numbers