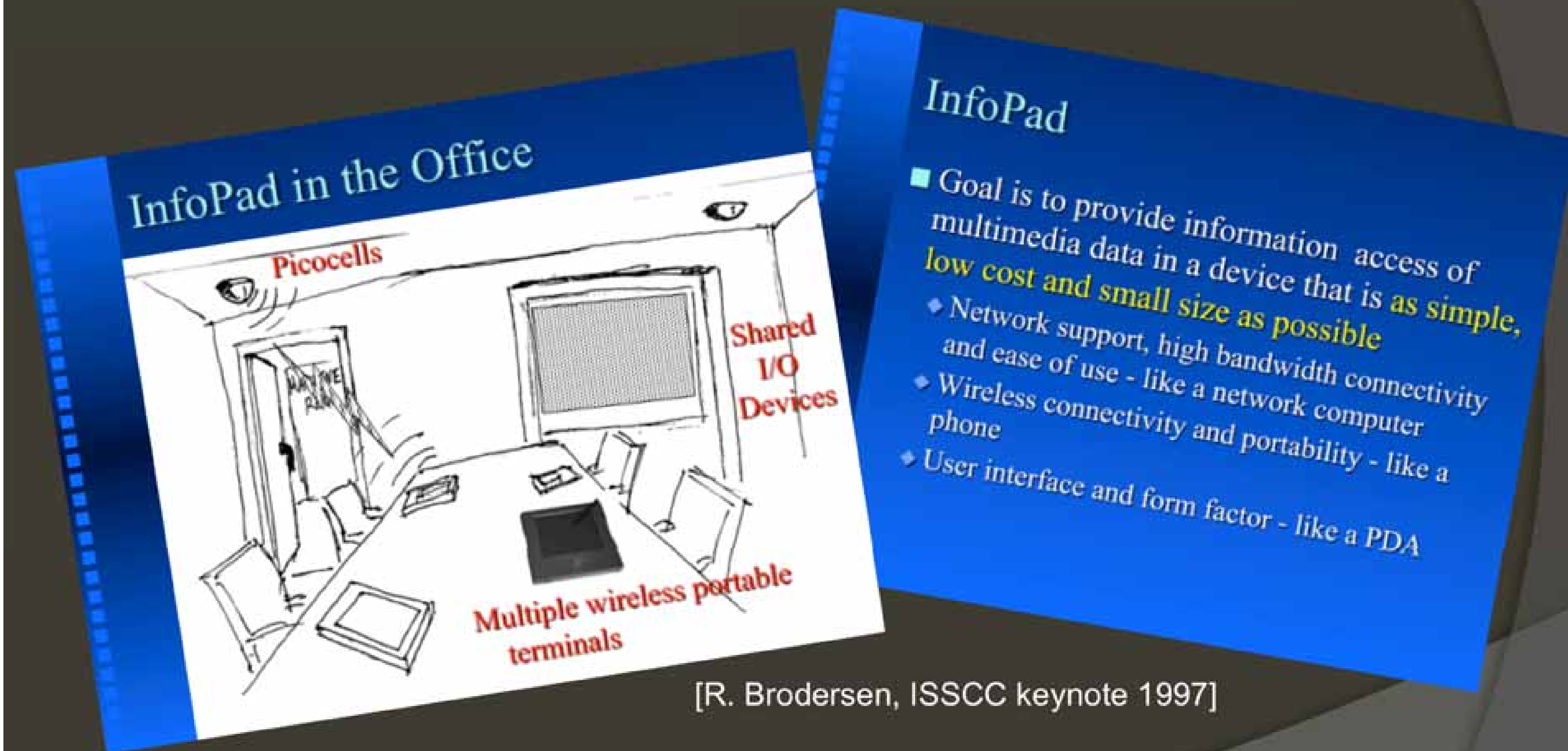
THE SWARM AT THE EDGE OF THE CLOUD – A NEW FACE OF WIRELESS

Jan M. Rabaey
Berkeley Wireless Research Center (BWRC)
Multiscale Systems Research Center (MuSyC)
EECS, University of California at Berkeley

DREAM SEMINAR UCB, OCT. 24, 2011

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



[R. Brodersen, ISSCC keynote 1997]

The Birth of the Wireless Tablet

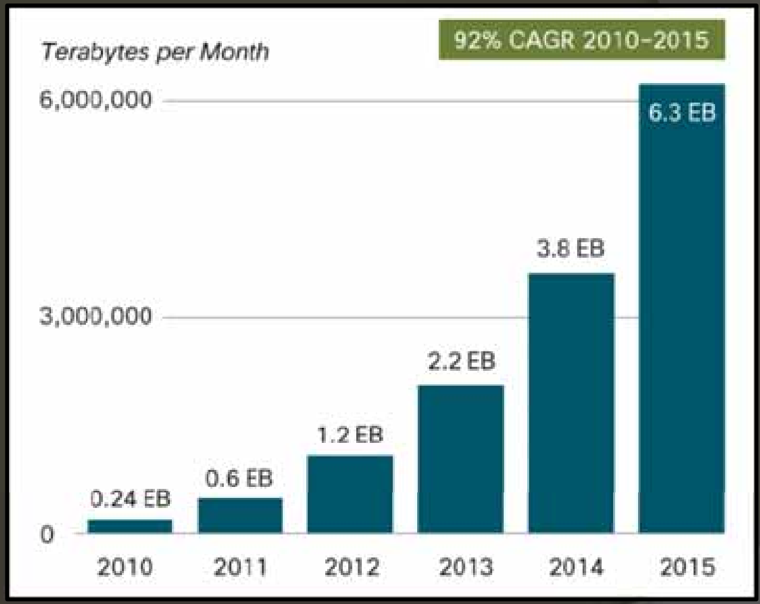
The UCB Infopad Project (1992-1996)

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

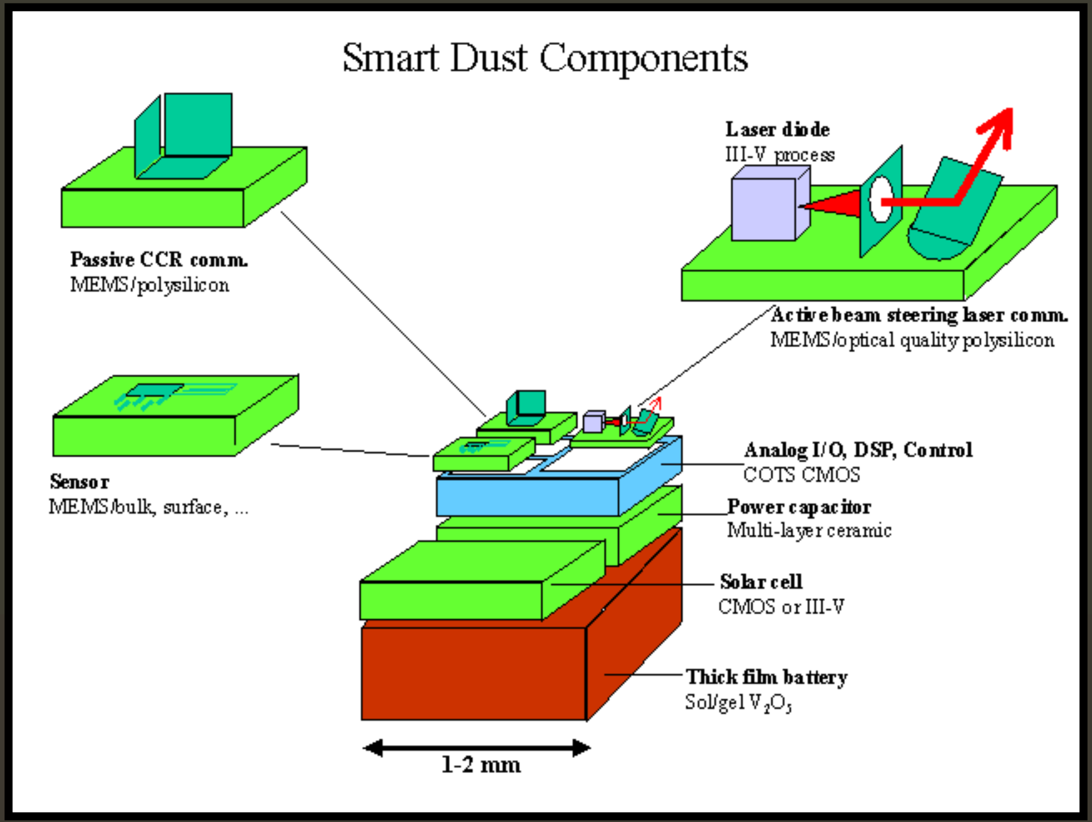
Mobile data growth
[Source: Cisco VNI Mobile, 2011]



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

[J. Rabaey, ASPDAC'08]

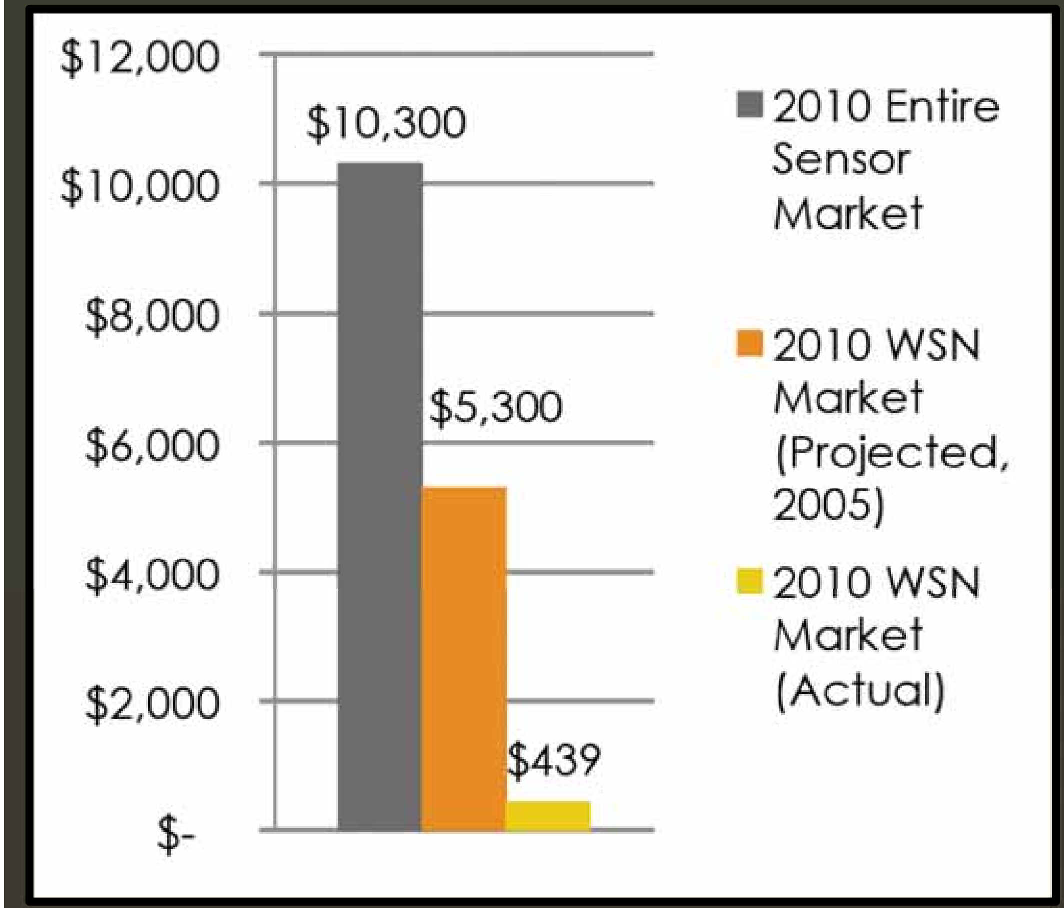
1995 Question: What happens if sensors become tiny, wireless, and self-contained?



… Wireless Sensor Networks

[Courtesy: K. Pister, UC Berkeley]

2010 Outcome: The Unfullfilled Promise of Wireless Sensor Nets



Source: On World

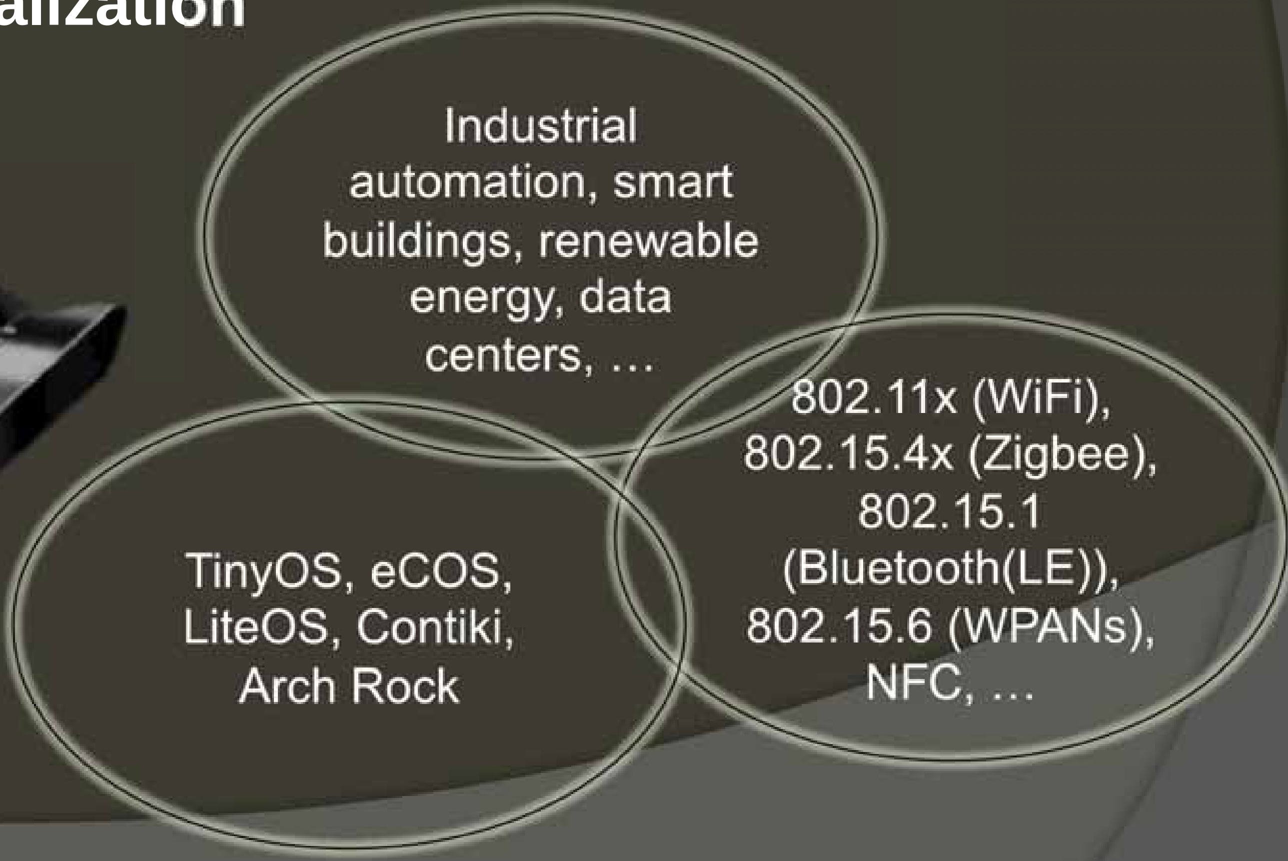
What slowed them down?
(Source: On World)

- 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



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

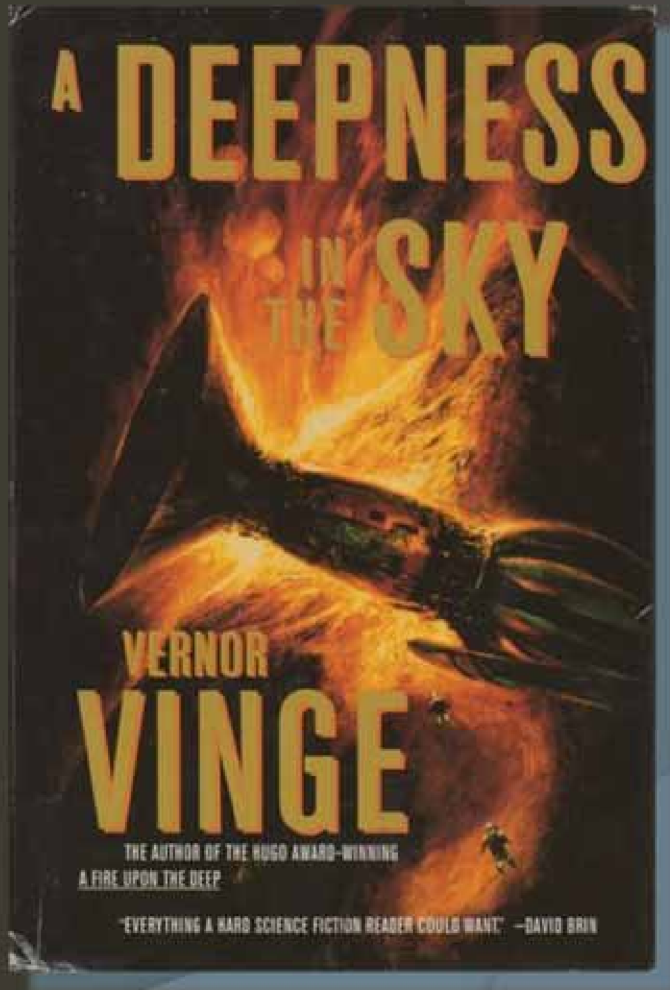
[J. Rabaey, ASPDAC'08]

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

[H. Gill, NSF 2008]

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 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

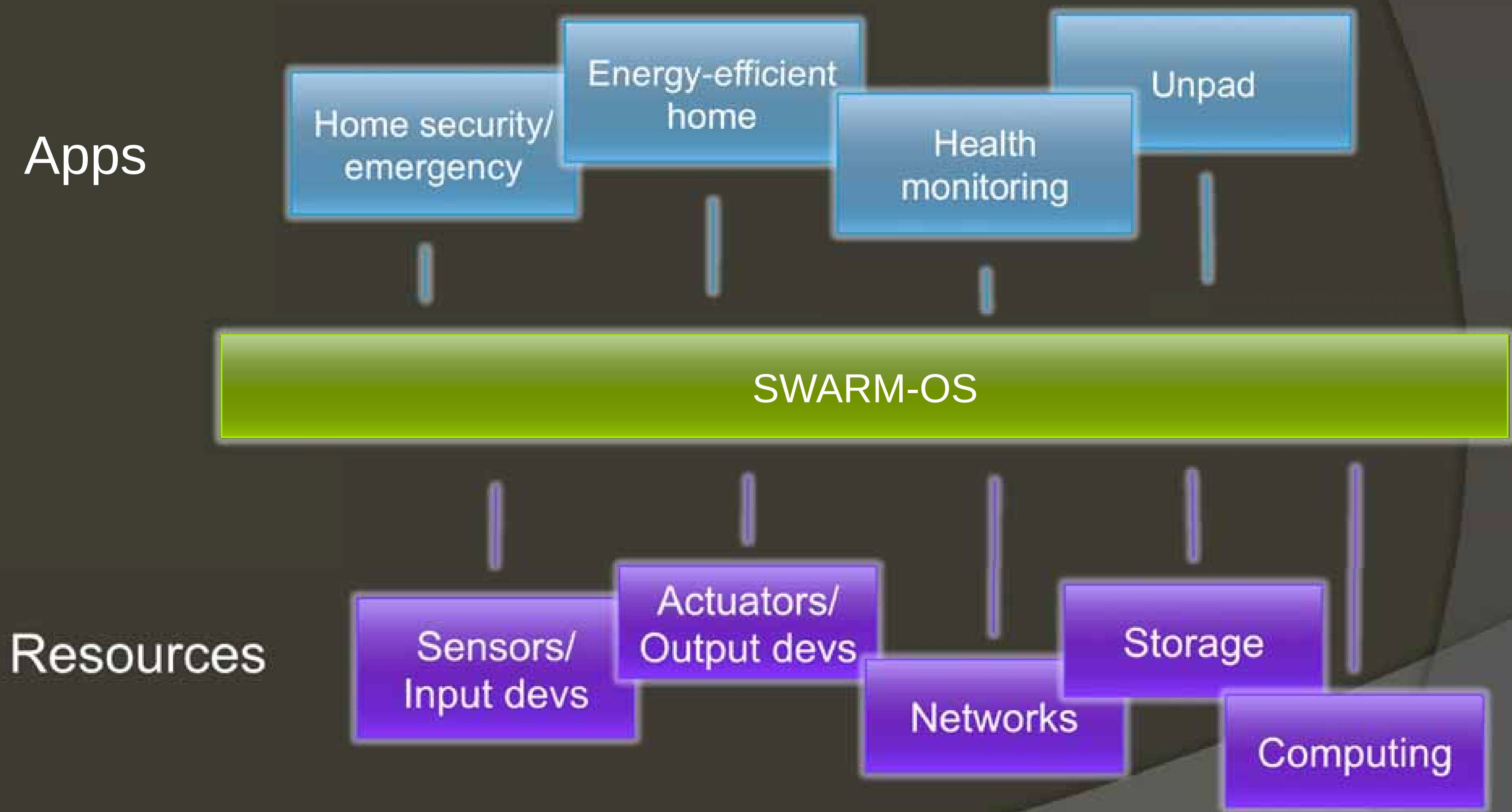
* Term originally coined by BWRC Directors

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



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

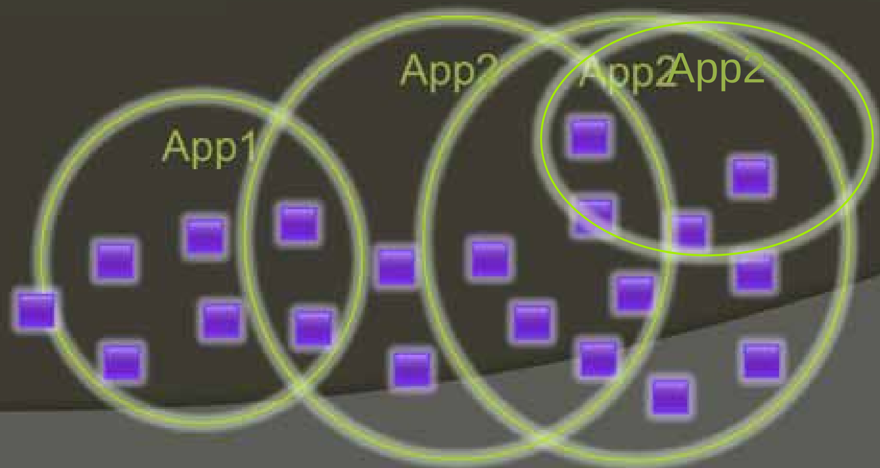
The Swarm as a Platform

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, …



How to Deal with Dynamics
Structured versus ad-hoc?

BOTH OF THE ABOVE!

Exploiting the Edge of the Cloud (or The Fog*)

Packs plenty of computation, communication, storage and energy resources

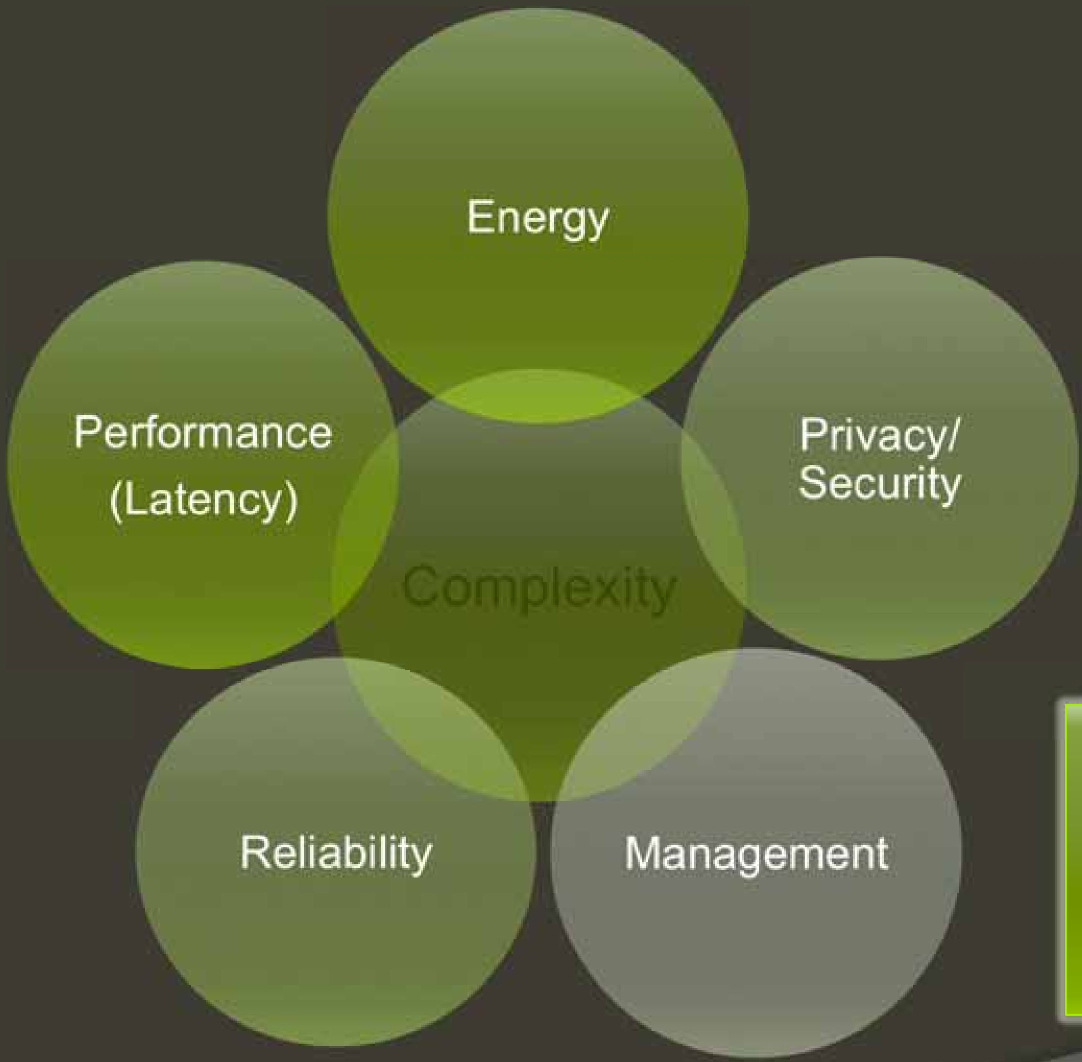
Avoids the overhead of the Cloud

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)

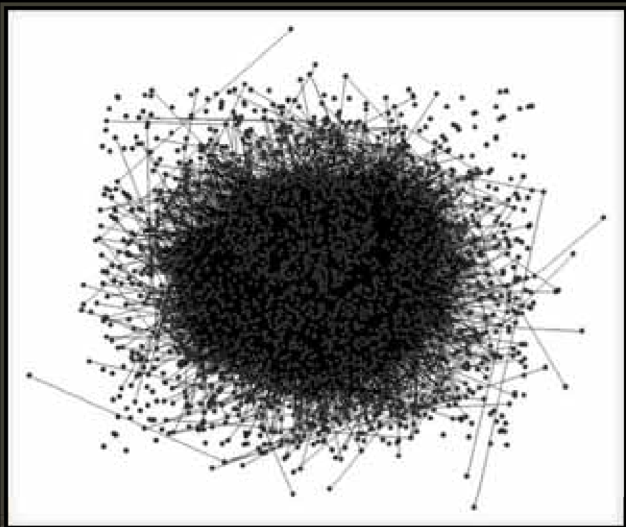


Complex distributed control systems combining heterogeneous components under dynamically varying conditions

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

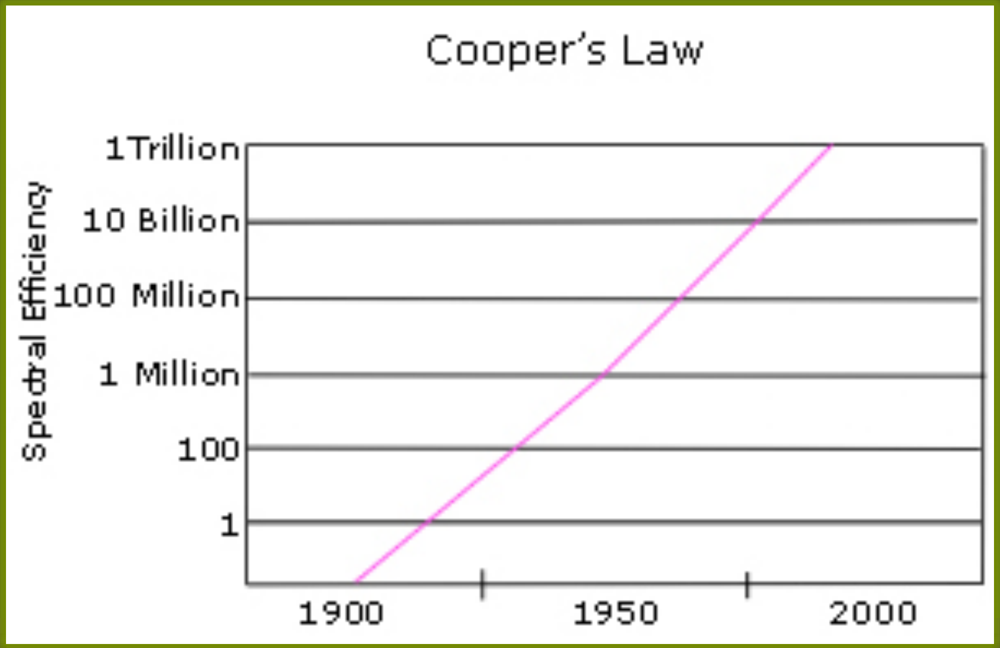
Need connectivity strategies that get better with increasing numbers!

- Exploit locality/proximity
- Exploit density
- Collaborate!
- Ensure reliability and safety
- Enable Energy-Proportionality

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

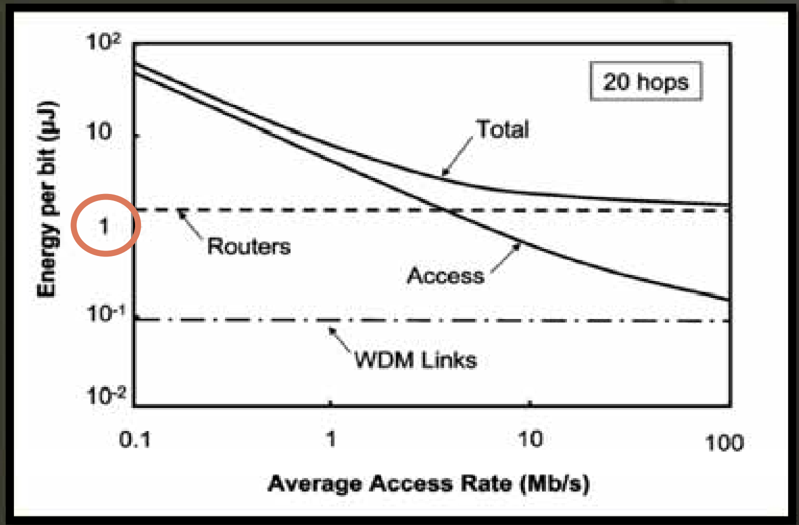
Message: The Swarm offers an unique opportunity

[M. Cooper, www.arraycom.com]

Exploiting Locality/Proximity

The peer-to-peer opportunity

[R. Tucker, 2009]



Internet energy/bit

Wireless peer-to-peer

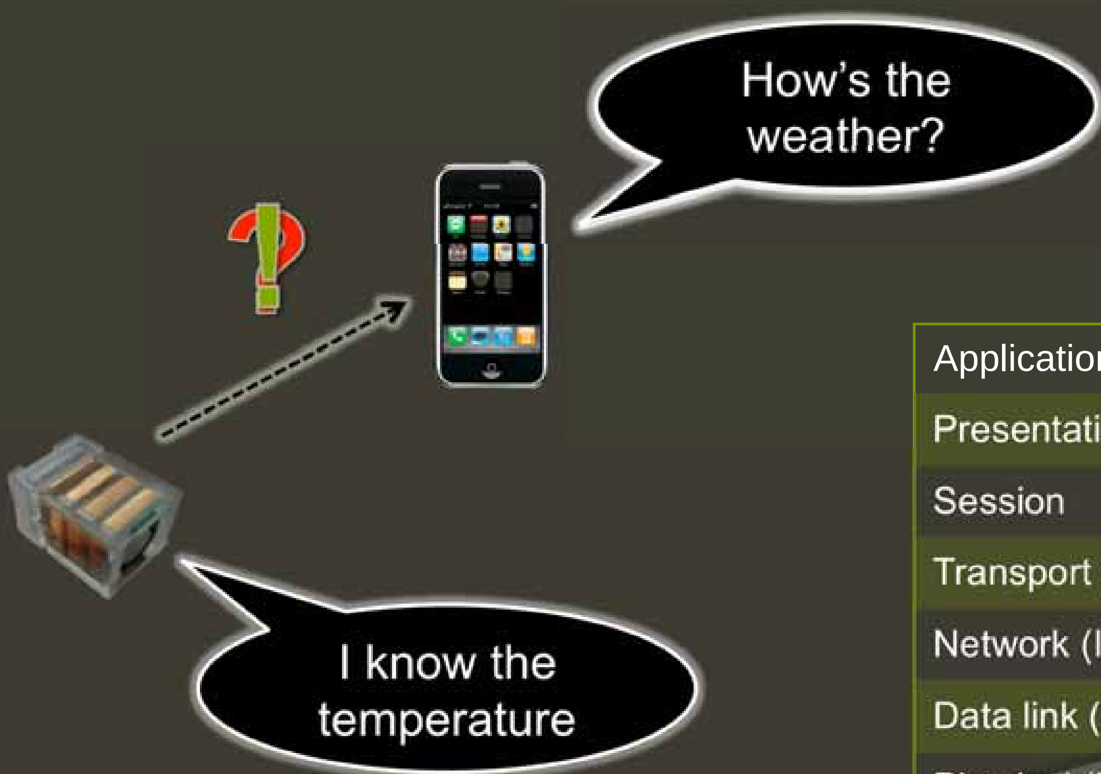
Radio	TX (nJ/bit)	RX (nJ/bit)
Zigbee	185	135
BT LE	55	40
Nordic	10	13
BAN	3	1
60 GHz	0.1	0.1

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

Exploiting Locality/Proximity

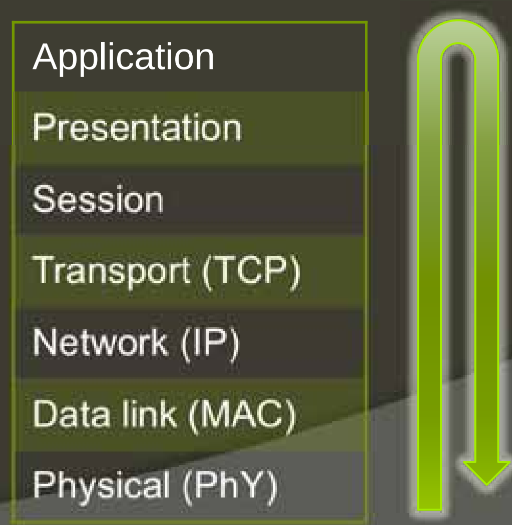
The peer-to-peer challenge

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



Current approach:

- Establish connection
- Register device
- Application detects device
- Application queries

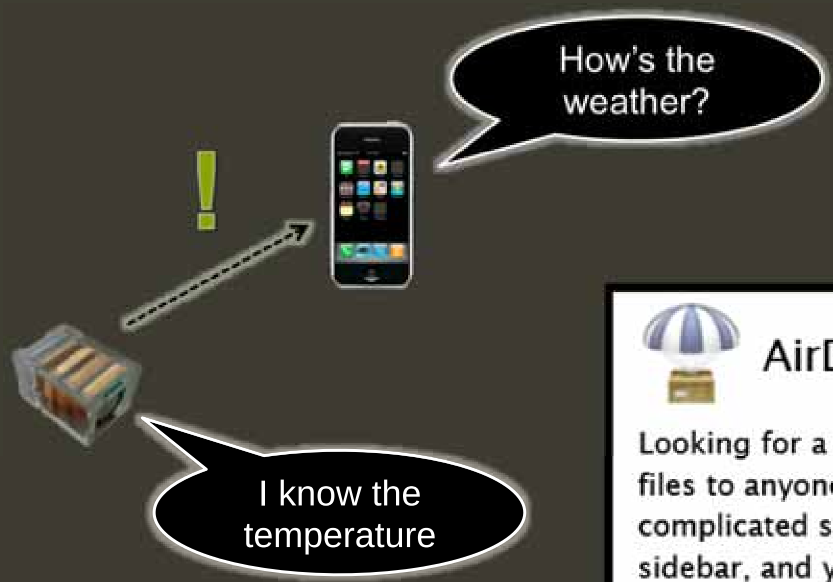


Latency
Energy
Capacity
Overhead

Exploiting Locality/Proximity

The peer-to-peer challenge

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



Dedicated "stovepipe" solutions

AirDrop

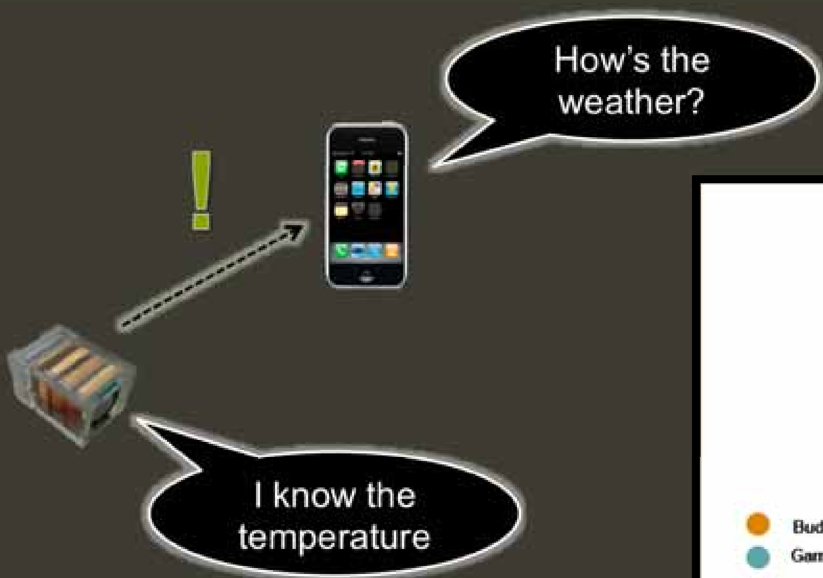
Looking for a fast way to share files with people nearby? With AirDrop, you can send files to anyone around you wirelessly — no Wi-Fi network required. And no complicated setup or special settings. Just click the AirDrop icon in the Finder sidebar, and your Mac automatically discovers other AirDrop users 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

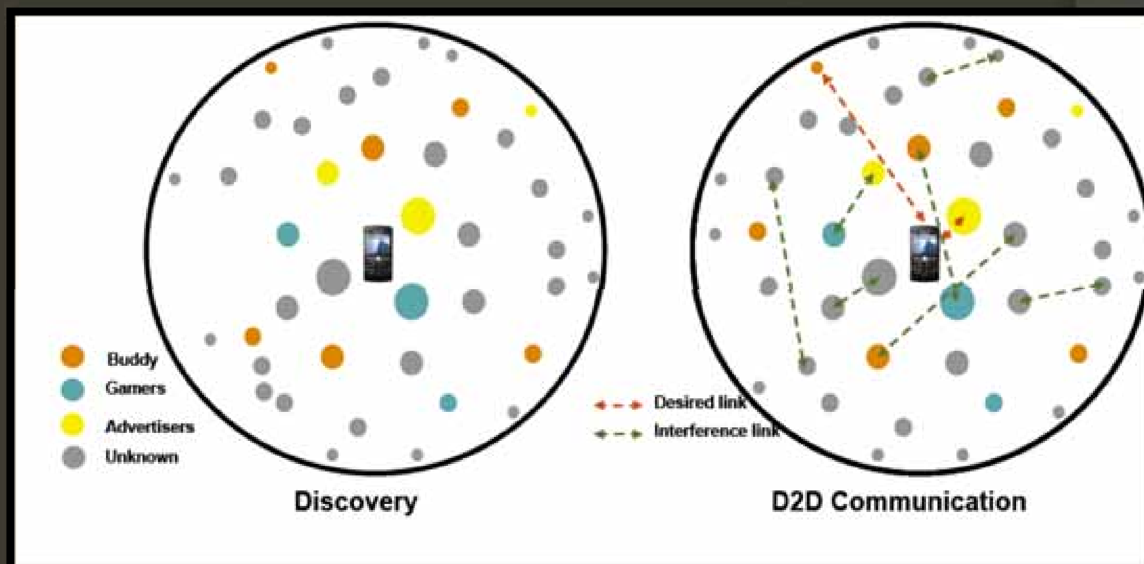
The peer-to-peer challenge

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



Alternative approach:

- Cut through the layers!



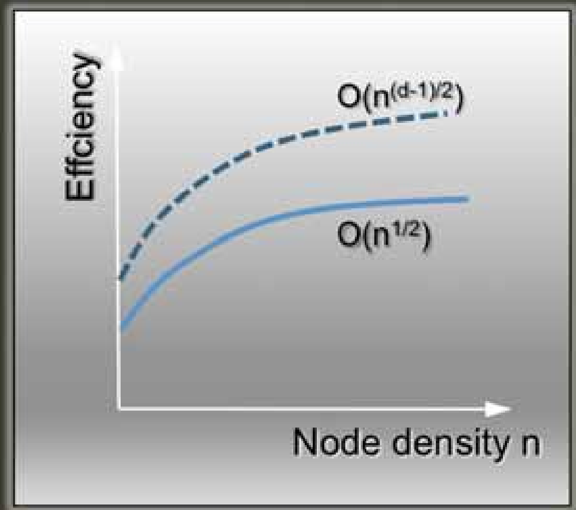
Example: Qualcomm FlashlinQ P2P protocol

Physical layer beaconing enables proximity and interest detection

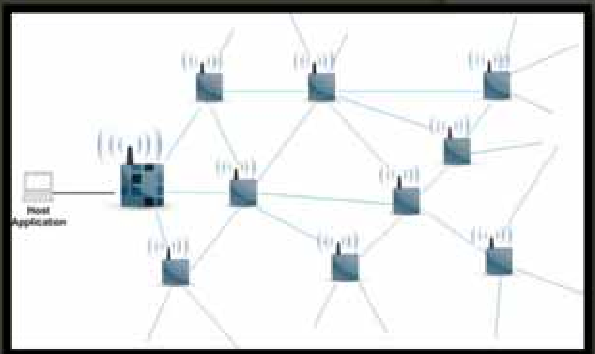
Exploiting Density

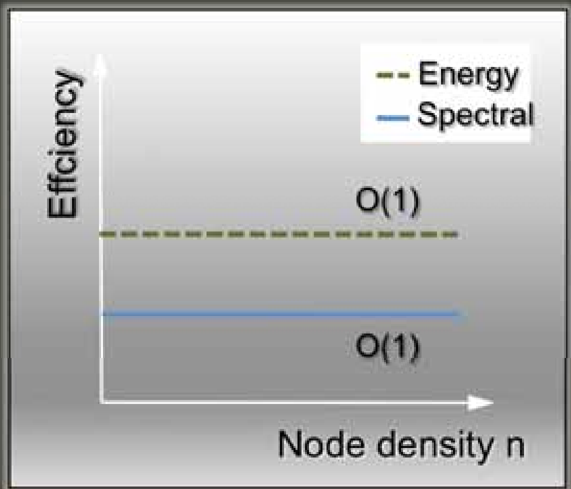
The power of collaboration

multi-hop [Gupta-Kumar00]

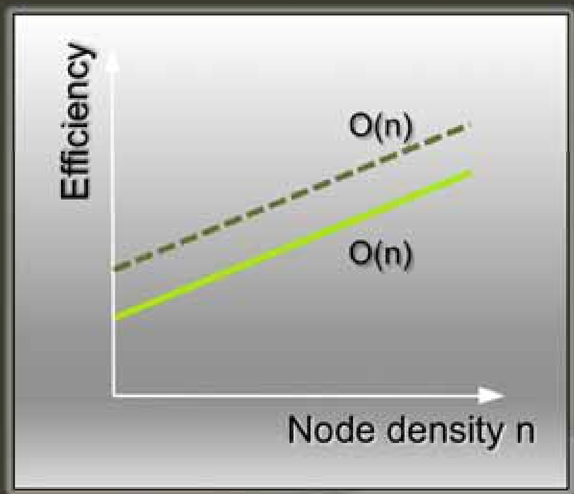


Example: mesh network

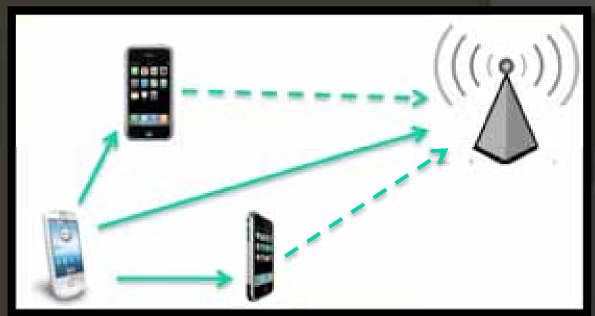




no-collaboration



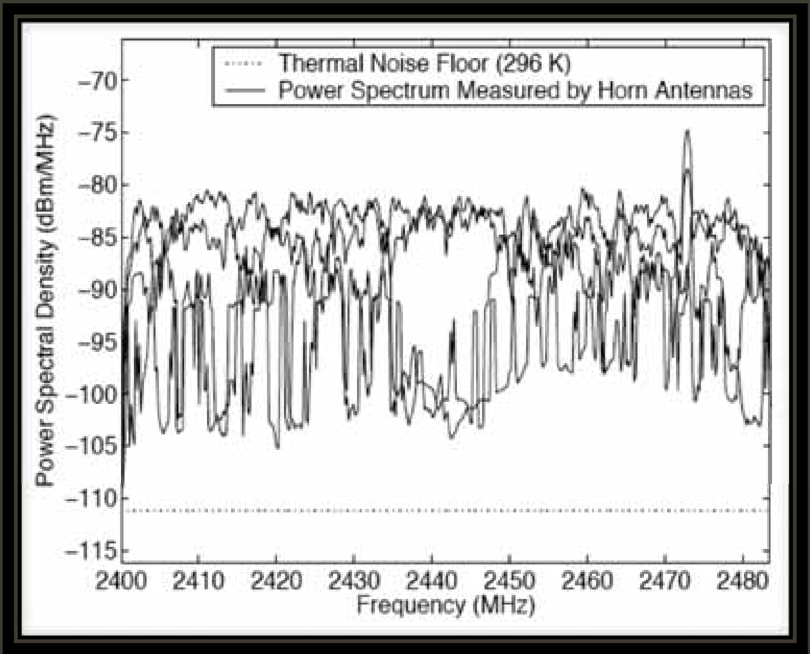
distributed MIMO [Tse07]



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**

Ants

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

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

[D. Petrovic, UCB – Atheros]

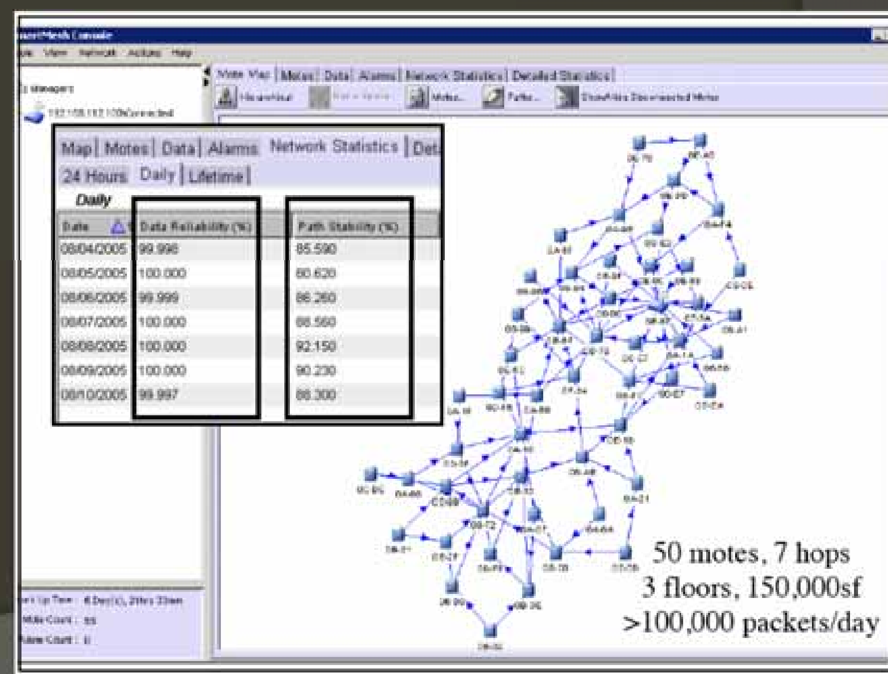
Wireless Less Reliable Than Wired?

Wired	**Wireless**
Point-to-point (wire as single point of failure)	Broadcast (redundancy & interference)

Wireless reliability with many 9's

- Exploit spatial diversity
- Exploit time diversity
- Exploit frequency diversity
- **Exploit redundancy**

When properly managed!

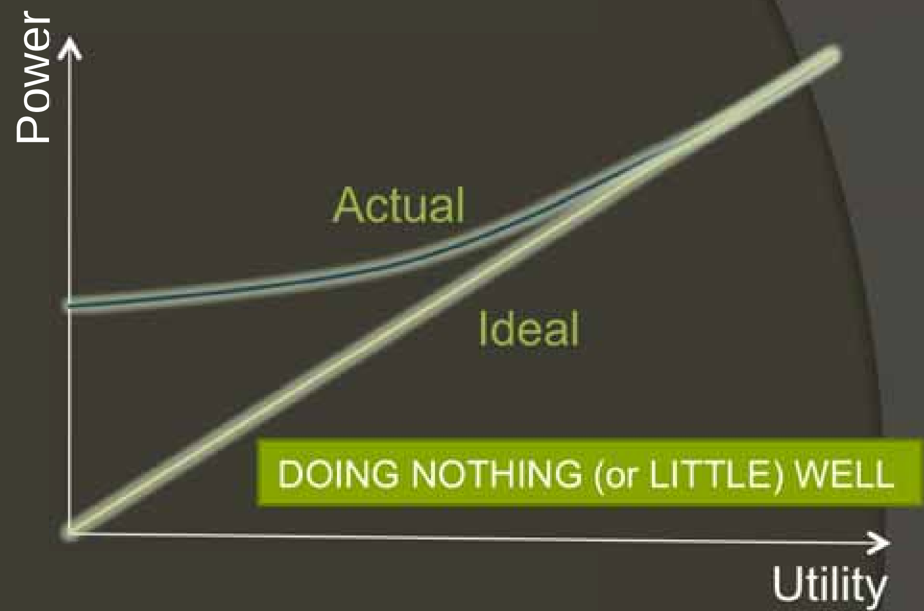


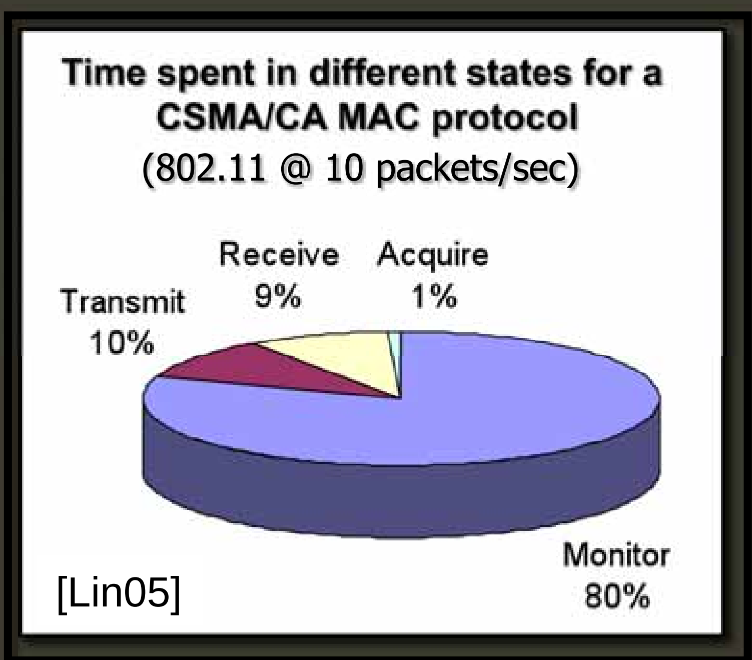
[Courtesy, Dust Networks]

Enabling True Energy-Proportionality*

Fundamental efficiency concept:

Energy Consumed ∝ Utility Delivered



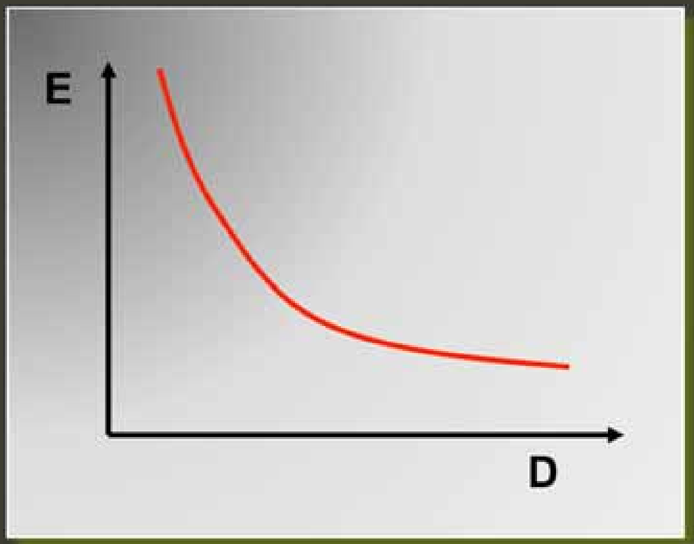


Not the case in ANY electronic system in use today (e.g. datacenter, computer, wireless LAN)

* Term originally coined by Luis Barroso (Google)

Enabling True Energy-Proportionality

A system responsibility!



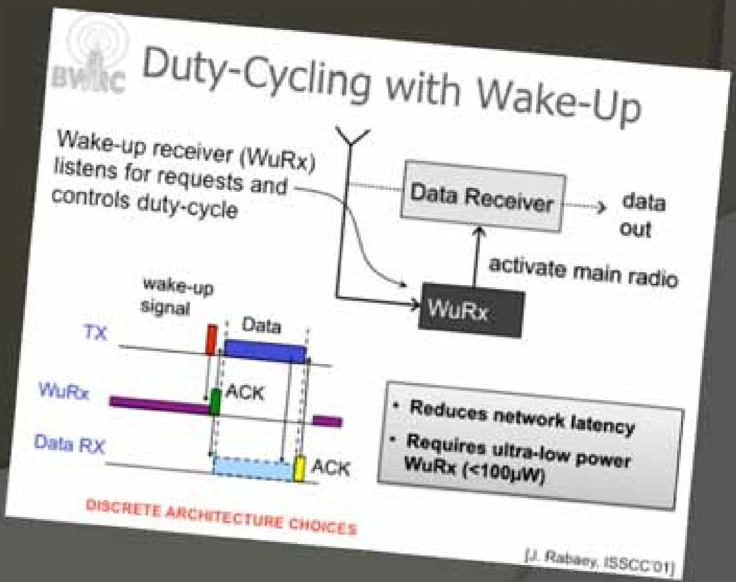
What a single node can do:
Change operation point by tweaking continuous or discrete design variables (supply, threshold voltages, power mode)

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

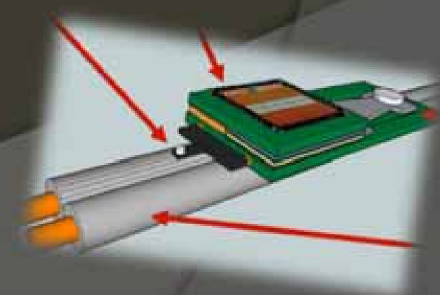


Enabling the Swarm …
"The Swarm Lab"

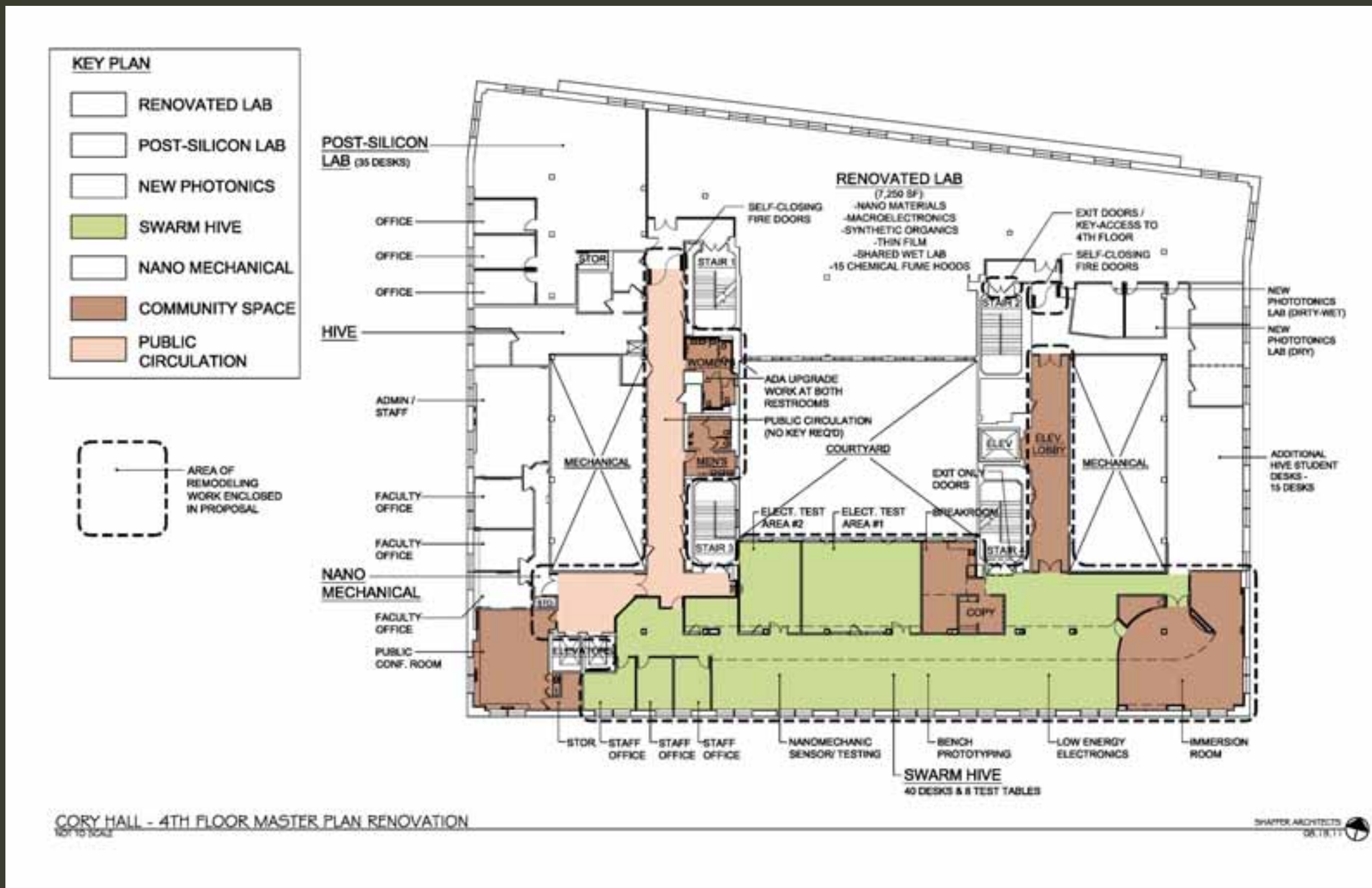
A vision for the 4th floor of Cory

"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



The Swarm Hive

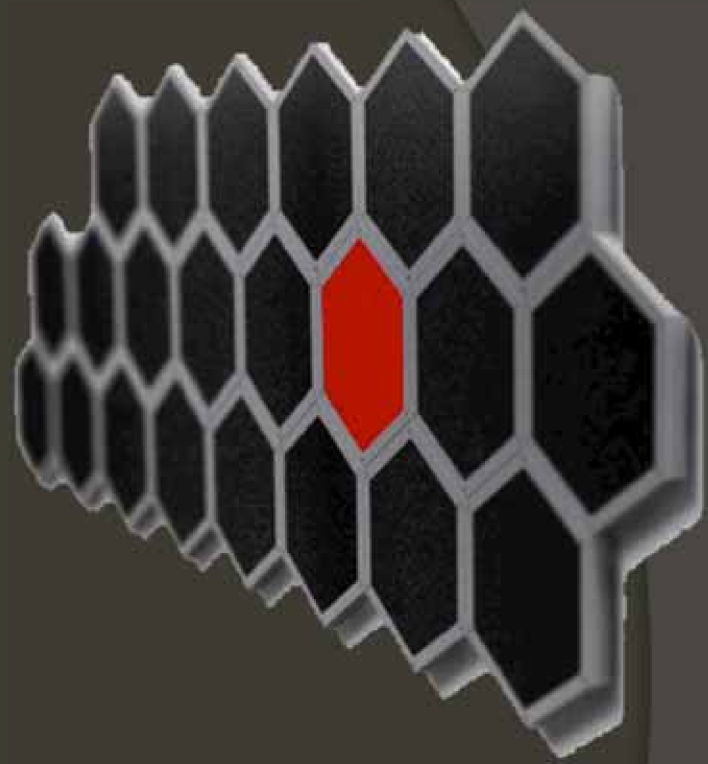


Swarm Hive Research Agenda

- Swarm Hive is ALL about integrative research - making swarms become a reality through the creation of an open platform vision
- Driven by a set of application drivers carefully selected based on research challenge, faculty and company interest, and potential global impact
  - The unPad, Universal and scalable interfaces for individuals with disabilities (WRERC), Personal swarms (BMI - but augmented with BAN), Smart Buildings
- Focus on integration necessitates collaboration with other Technology-focused Centers (BWRC, BSAC, Chess, Trust, PARLAB, Amp, BITS)

Mark Your Calendar!

- December 6 – Official opening of SWARM Lab



- Morning: Swarm Brain Storm – Banatao Auditorium
- Afternoon: Ribbon Cutting, Demo and Poster session in Swarm Hive
  - In presence of Paul Jacobs and entire Qualcomm Board of Directors

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!

Thank You!

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The Challenge of Large Numbers