A Brand New Wireless Day

What does it mean for design technology?

ASPDAC'08, Seoul

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Acknowledgments

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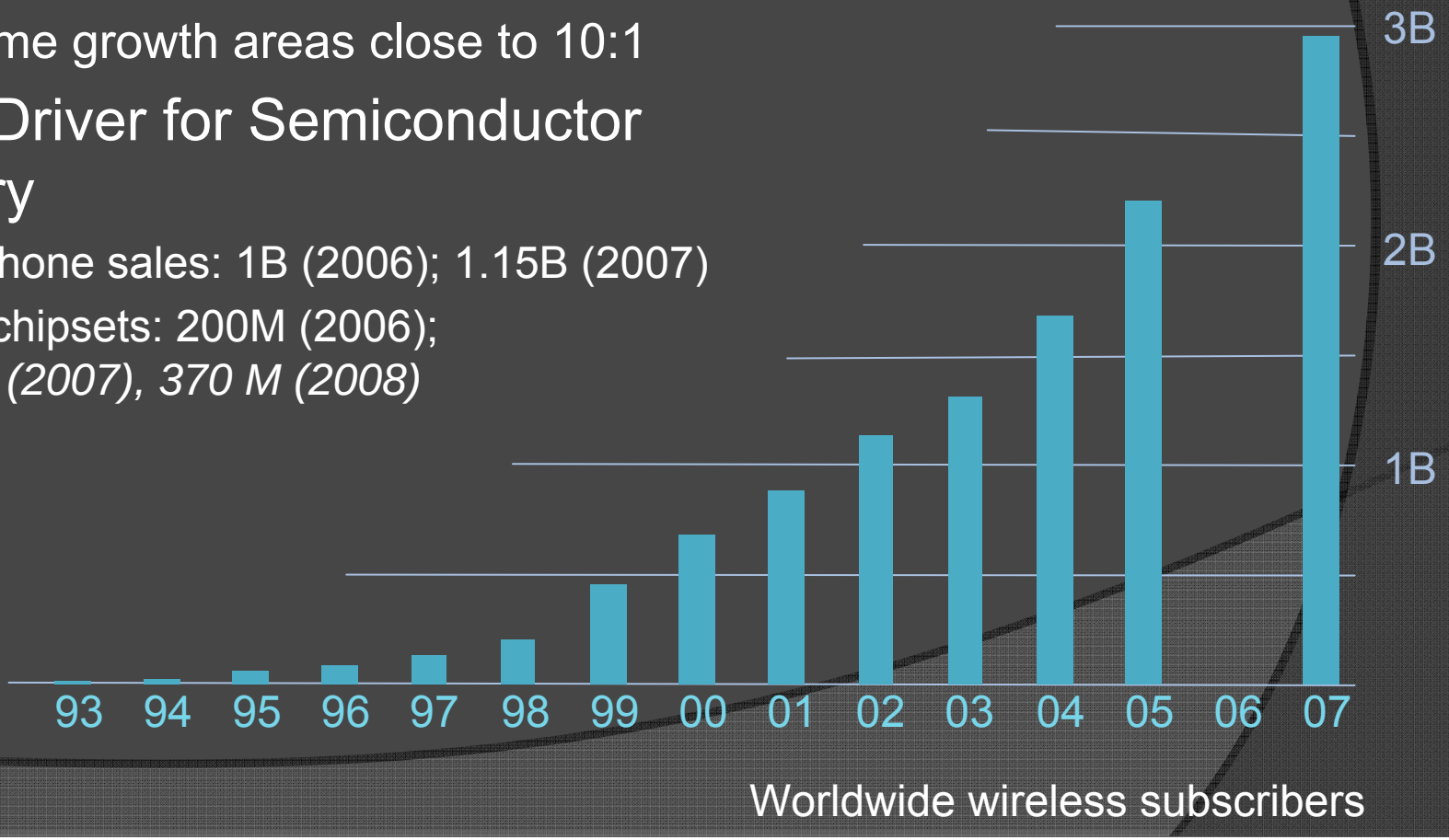
The Era of True Mobility is Here

- Wireless subscribers expected to top 3 Billion in 2008! (40% penetration)
- Mobile devices outnumber PCs 5:1
  - In some growth areas close to 10:1
- Major Driver for Semiconductor Industry
  - Cell phone sales: 1B (2006); 1.15B (2007)
  - WIFI chipsets: 200M (2006); *280M (2007), 370 M (2008)*



Exponentials Bound to Continue

EE Times: Latest News

Wireless is everywhere; ignore it at your peril

Bolaji Ojo

Page 1 of 2

EE Times

(01/07/2008 9:00 AM EST)

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REPRINTS

The search is over for the next killer app. It is wireless, it is all around you, and it will leave no sector of the global economy untouched.

EE Times, January 07, 2008

- 5 Billion people to be connected by 2015 (Source: NSN)
- The emergence of Web2.0
  - The “always connected” community network
- 7 trillion wireless devices serving 7 billion people in 2017 (Source: WWRF)
  - 1000 wireless devices per person?

[Courtesy: Niko Kiukkonen, Nokia]

A 1000 Radios per Person?

Multi-modal cellphones

WAN

WIFI

FM

GPS

DVBS

Bluetooth

Health and Medical

Smart homes

The early days

Intelligent cars

RF-ID Explosion

Information-Technology in Turmoil

From Batch

Over Interactive

To Immersion

The Emerging IT Scene

Infrastructional core

Sensory swarm

Mobile access

The Technology Gradient: Computation

Driven by Moore's Law

Driven by "More Than Moore" and "Beyond Moore"

The Technology Gradient: Communication

Mostly wired

Almost uniquely wireless

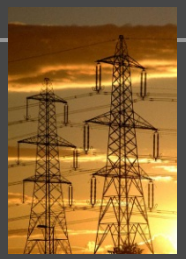
The Birth of “Societal IT Systems (SiS)”

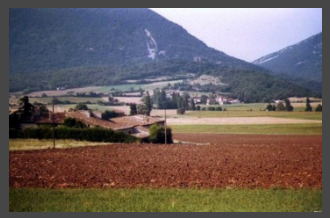
“A complex collection of sensors, controllers, compute nodes, and actuators that work together to improve our daily lives”

- The Emerging Service Models
  - Intelligent data access and extraction
  - Immersion-based work and play
  - Environmental control, energy management and safety in “high-performance” homes
  - Automotive and avionic safety and control
  - Management of metropolitan traffic flows
  - Distributed health monitoring
  - Power distribution with decentralized energy generation

The Opportunities are Just Humongous

- Emergency Preparedness & Defense against Terror
- Education
- Energy Efficiency
- Environmental Monitoring
- Health Care
- Transportation
- Service to the Third World Using IT



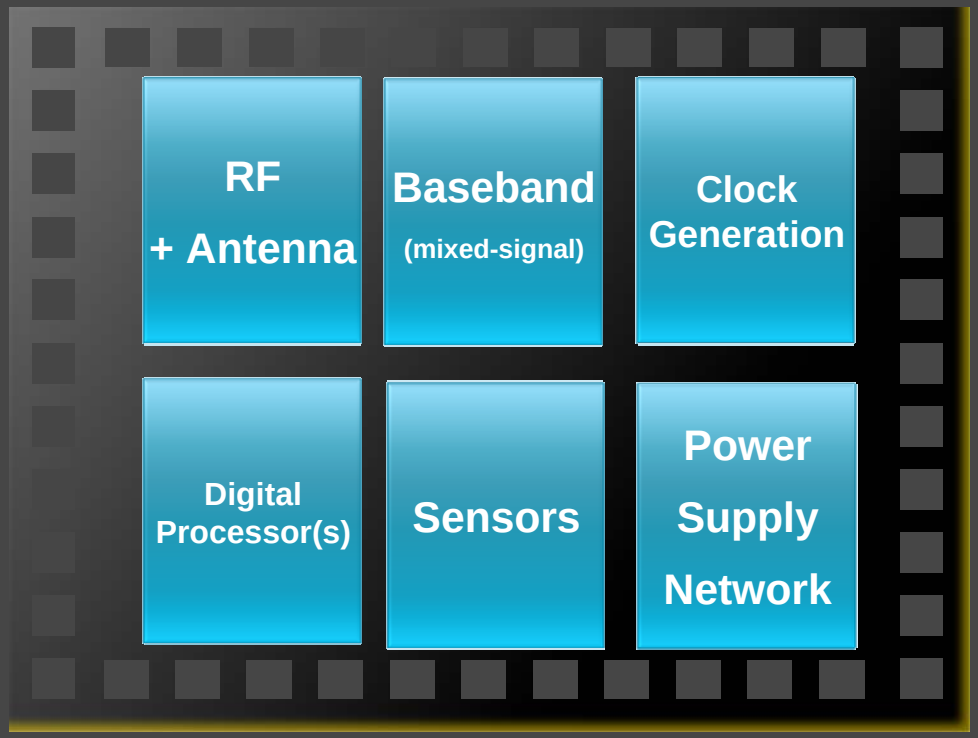


iTRIS
Center for Information Technology Research in the Interest of Society

Societal IT Systems – What it means for Wireless

- From the Very Small
  - Ubiquitous, Pervasive
  - Disappearing
  - Perceptive, Ambient
- To the Very Large
  - Always connectable – whatever happens
  - Absolutely reliable
  - Scalable, Adaptive, Flexible

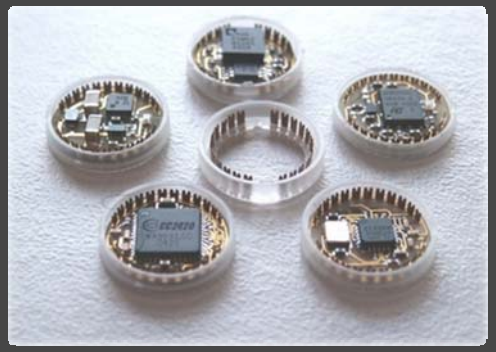
SiS Wireless– The Very Small



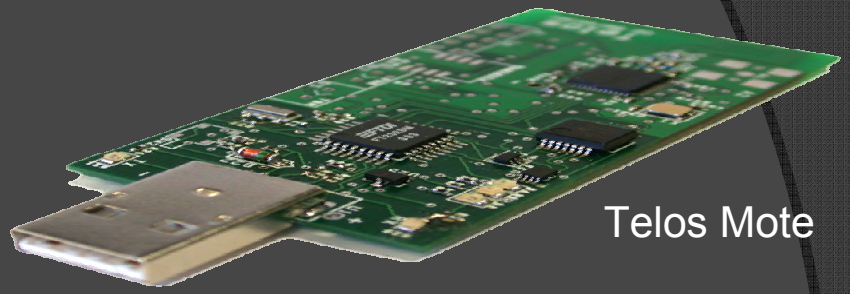
"Disappearing electronics"

- Low-cost
- Miniature size
- Self-contained from energy perspective

Major Progress Over Past Years

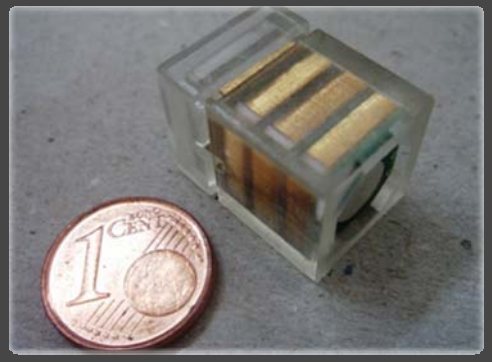


Philips Sand module

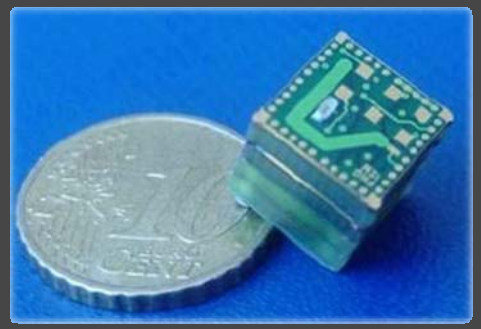


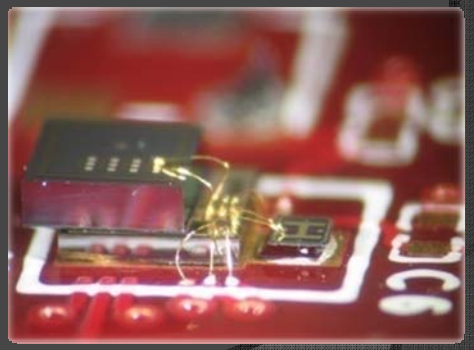
Telos Mote

UCB PicoCube



IIMEC e-Cube



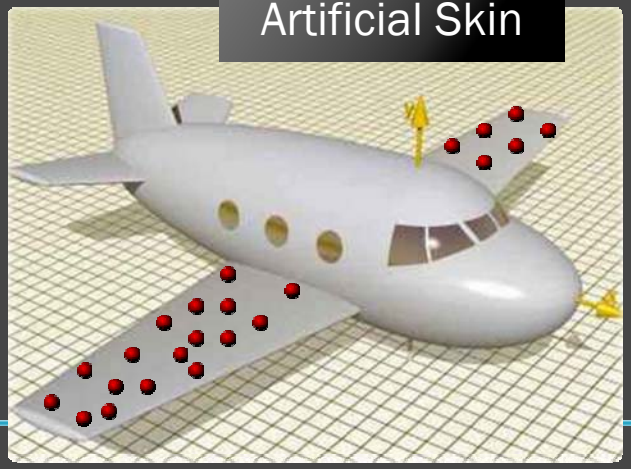


UCB mm^3 radio

[Ref: Ambient Intelligence, W. Weber Ed., 2005]

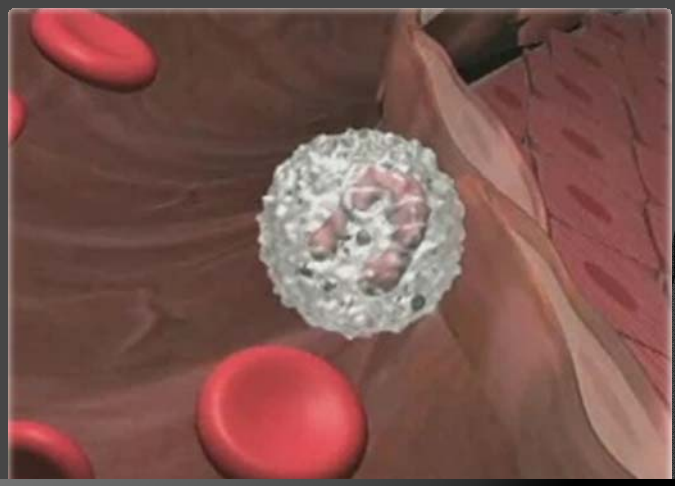
Yet … True Immersion Still Out of Reach

Artificial Skin



Interactive Surfaces

Smart Objects



“Microscopic” Health Monitoring

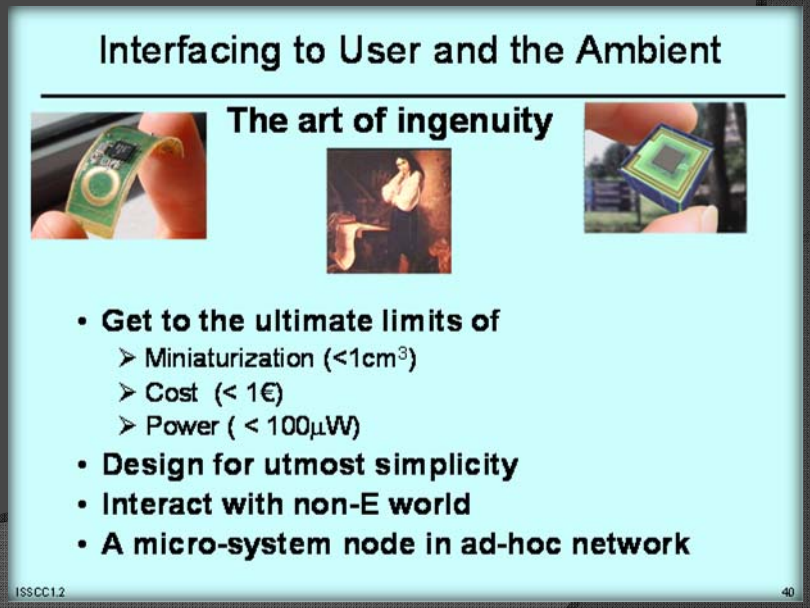
Another leap in size, cost and energy reduction

Rethinking the Meaning of Scaling

- Traditional technology scaling continues to drive advances in infrastructure backbone (data and compute servers, routers, base stations, …)
- Not so for the "Mobile and Sensory Swarm"…
  - Exponentially increasing number of (ultra-)small components
- Driven by heterogeneous integration of innovative technologies

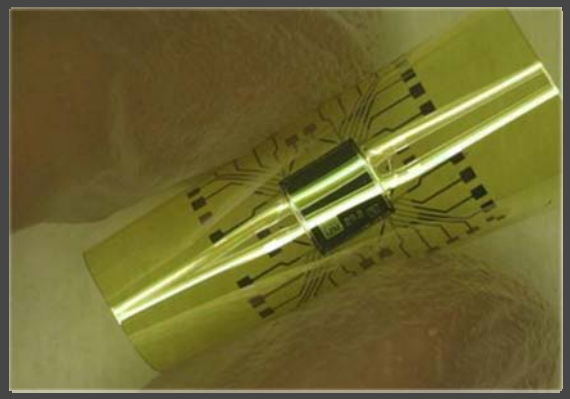
"More Than Moore"

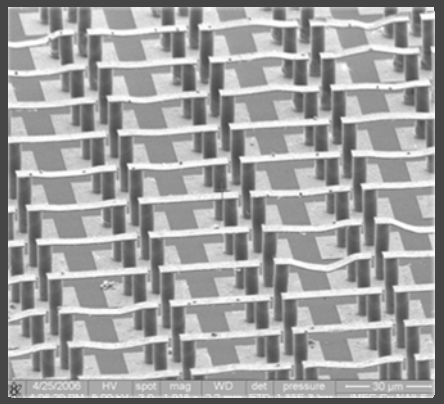
[H. De Man, Keynote Address, ISSCC 2005].



More Than Moore — Driven by Technology Innovation

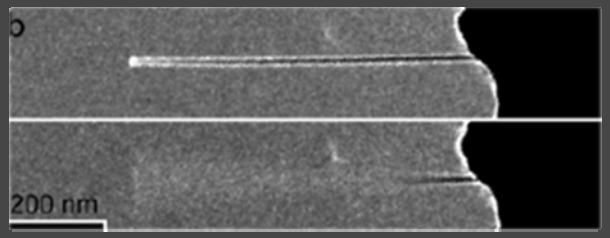
Chips in Flexible PCB
[Courtesy: E. Beyne, IMEC]

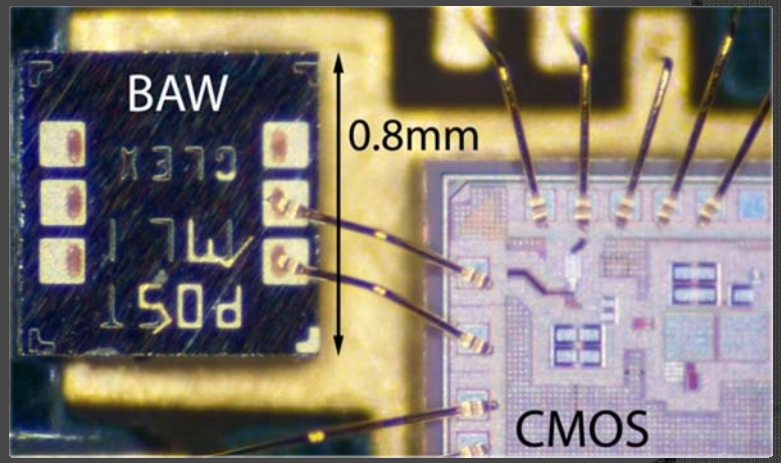




3D-SiC – Cu-Nail
[Courtesy: E. Beyne, IMEC]

Nanowire-based AM Radio
[Courtesy: Jensen, UCB]



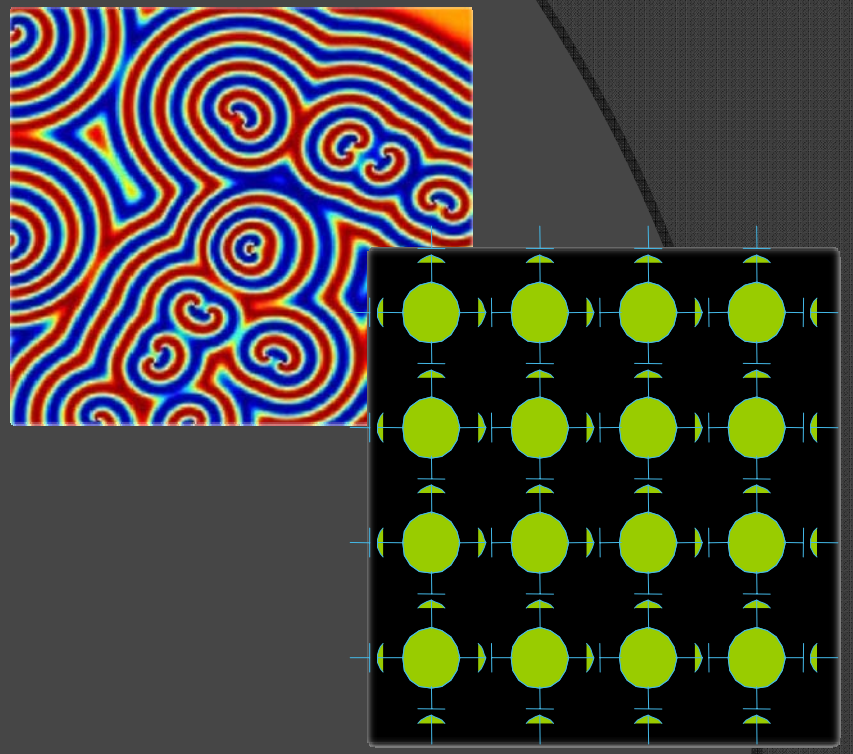


Passive MEMS Components Provide Selectivity at ULP
[Courtesy: N. Pletcher, UCB]

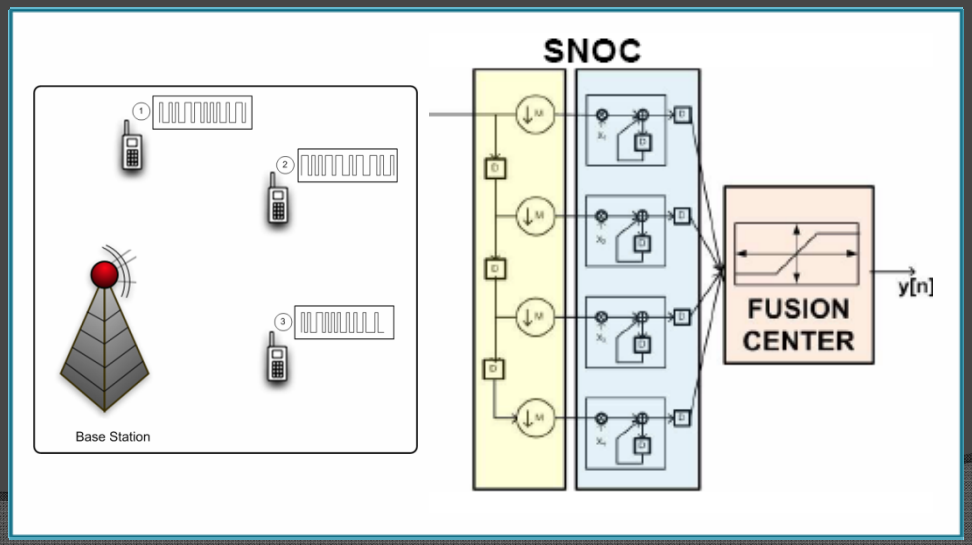
Mechanical Computing [Courtesy: C. Nguyen, UCB]

Beyond Moore ...

- True immersion means broadening of the senses as well as "perceptional processing"
- "Bio-inspired" and "Bio-based" computing may be better choice to dramatically improve "user experience"



Coupled non-linear oscillator arrays display emergent behavior
[Courtesy: J. Roychowdhuri, UMN]



Sensor-network on a chip
[Courtesy: N. Shanbhag, UIUC]

SiS Wireless– The Very Large

- Reliable universal coverage at all times!?
  - 7 trillion radios will quickly run out of spectrum …
  - Wireless is notoriously unreliable
    - Fading, interference, blocking
  - Mobility requires dynamic reconfiguration
  - Heterogeneity causes incompatibilities
    - Large number of standards to co-exist
    - Devices vary in form-factor, size and energy source


TOP STORY

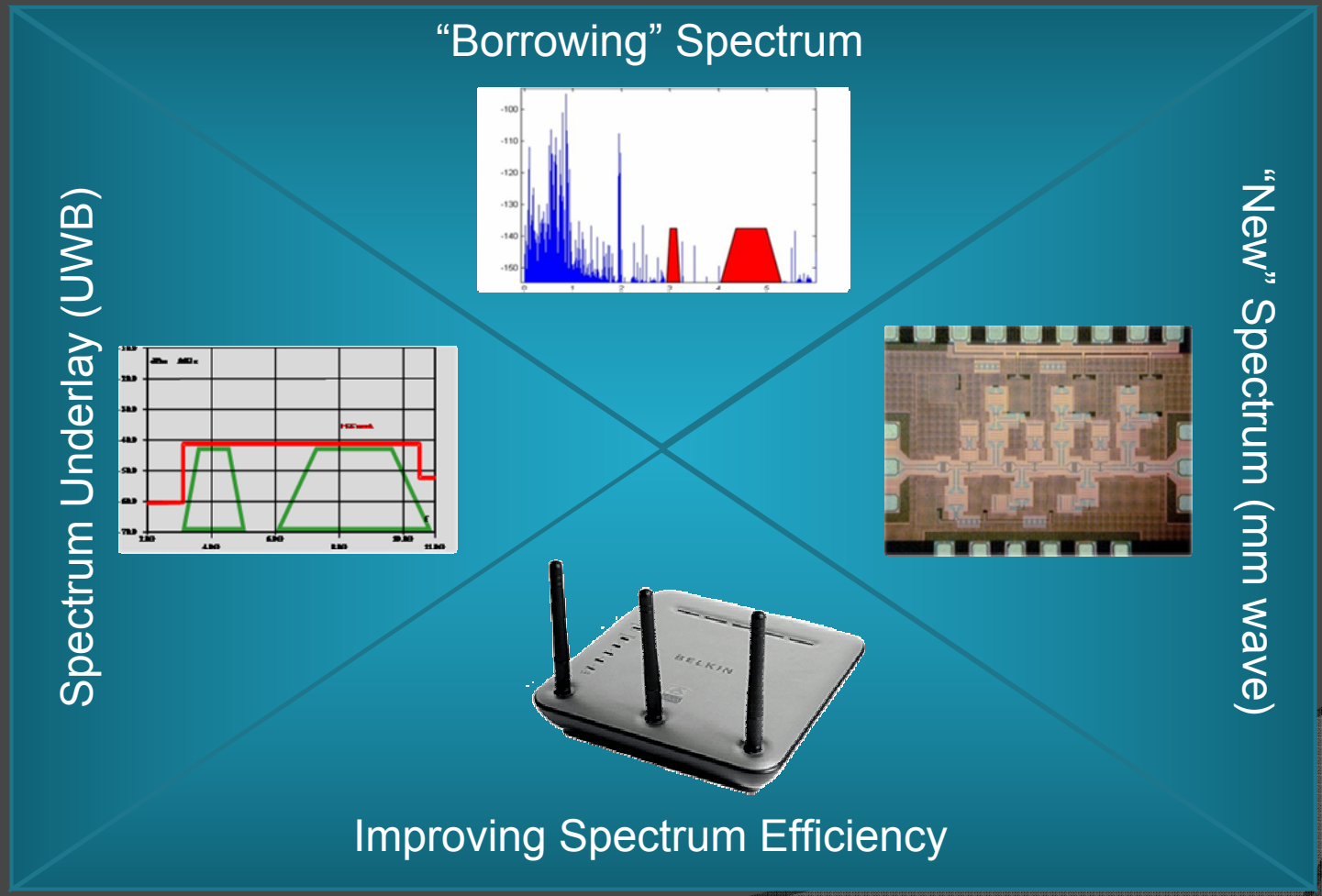
Updated Mon, 14 Jan 2008 01:03:01 PM EST

CE's wireless Babel: Connectivity strategies are all over the map

Now that consumer electronics companies are delivering a full suite of product to the digital living room, they are working out how to connect them.

EE Times, Jan. 14 2008

A World with Unlimited Wireless Bandwidth and Always-On Coverage?



Some exciting technology developments

A World with Unlimited Wireless Bandwidth and Always-On Coverage?

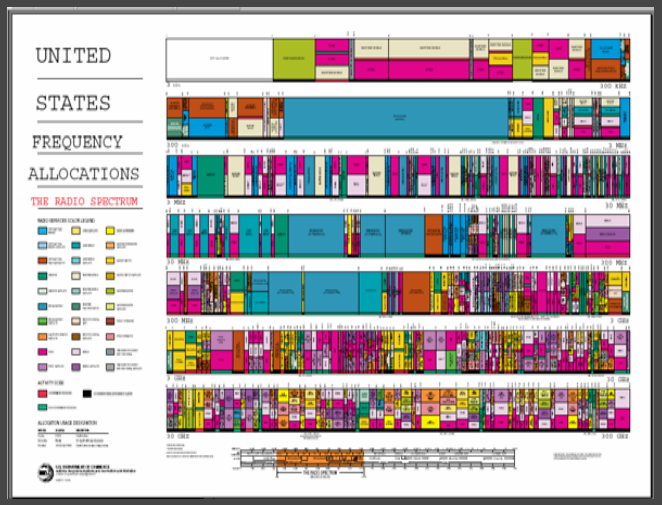
- Cognitive capabilities of terminals offer prospect of dramatic increase in attainable wireless data-rates
- Collaboration among terminals and infrastructure essential to accomplish cognitive promises, while providing reliability
  - Enables multi-modal operation (e.g. in emergencies)
  - Opens door for collaboration between heterogeneous services or standards
- Connectivity Brokerage as the new operational (as well as business) paradigm

A Fundamentally Disruptive Technology

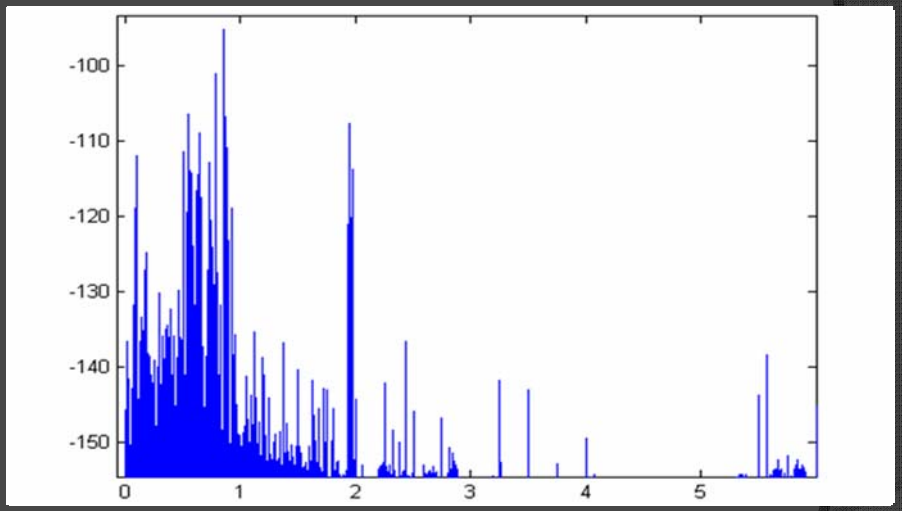
Spectrum Shortage?

- Existing spectrum policy has full allocation but poor utilization

Allocation

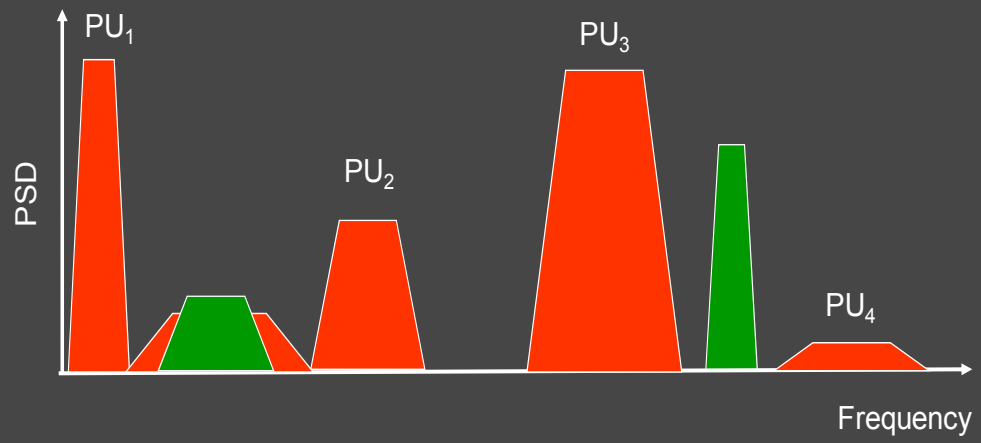


Utilization



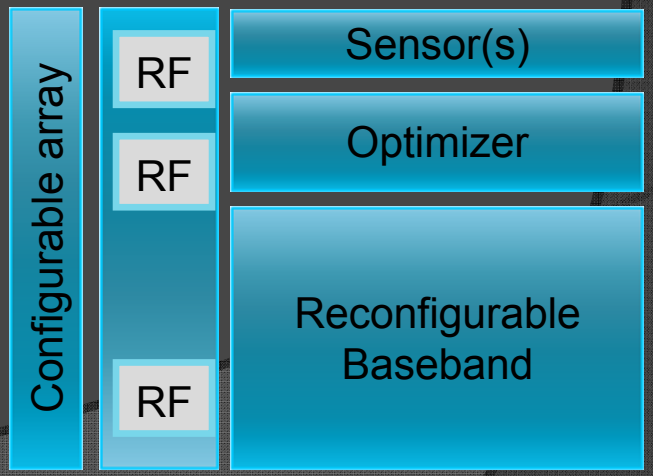
The cognitive radio strategy is to sense the spectrum and to only transmit if there will be no interference

Cognitive Radio to Enable Dynamic Spectrum Allocation



First Experiment in Cognitive: TV Bands @ 700 MHz (IEEE 802.22)

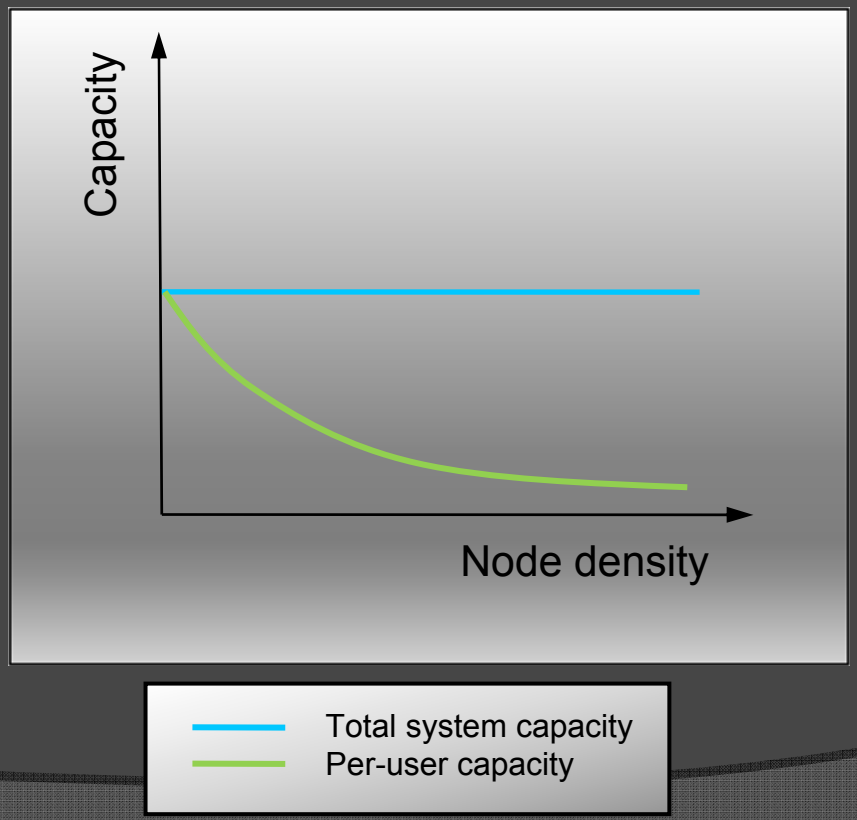
- **Sense** the spectral environment over a wide bandwidth
- Reliably **detect** presence/absence of primary users and/or interferers
- **Rules** of sharing the available resources (time, frequency, space)
- **Flexibility** to adjust to changing circumstances (power, freq. band)



The Power of Collaboration

Conventional wireless mindset:

- Services compete!
  - Example: Bluetooth, WIFI and Zigbee
- Adding terminals degrades user capacity

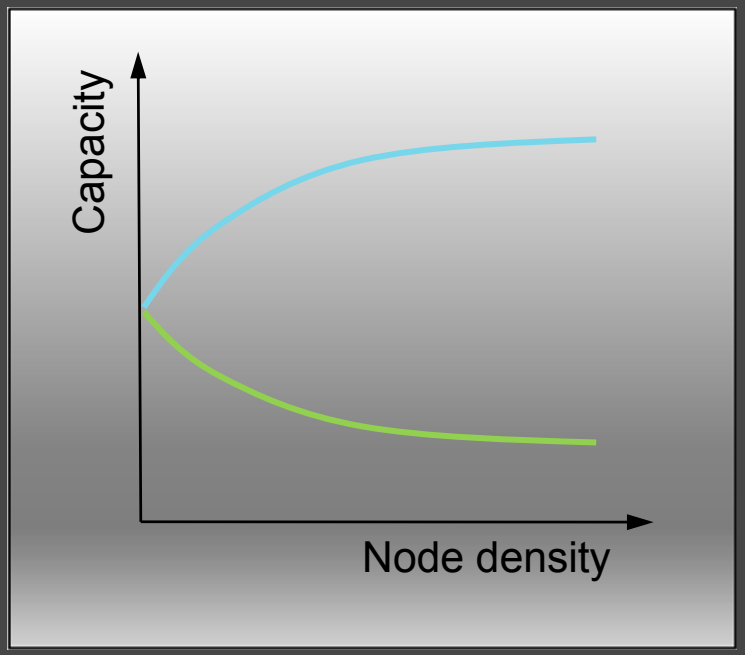


Collaboration is essential for better spectrum utilization

- A single terminal or base-station has only limited perspective
- Working together leads to better capacity, coverage and/or reliability

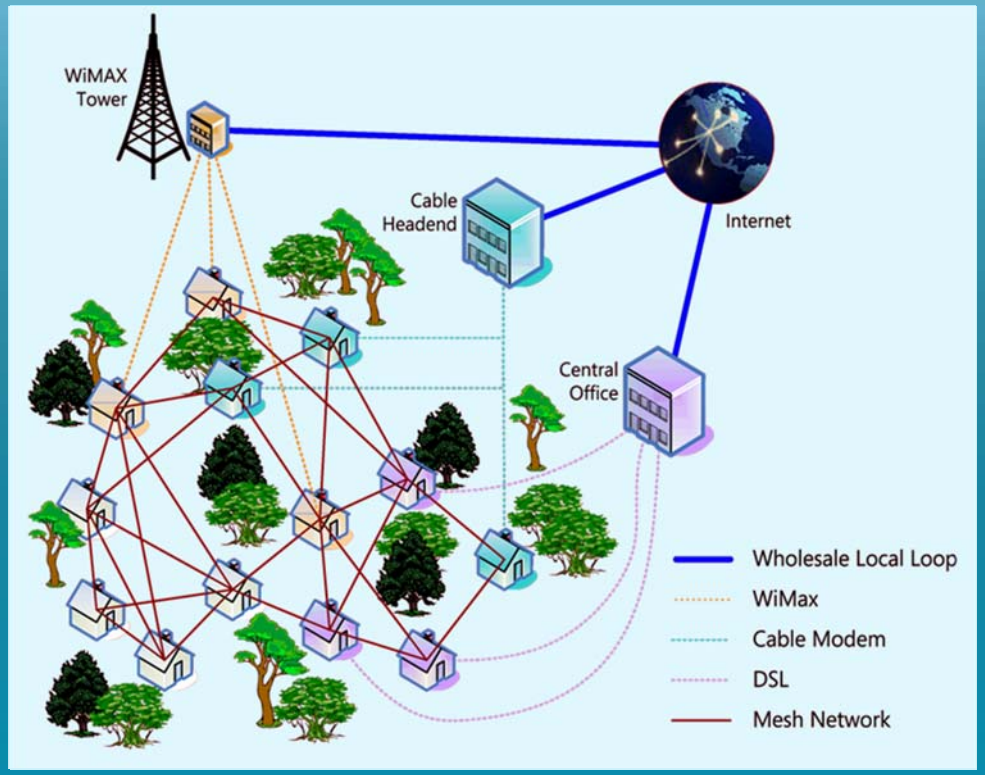
The Power of Collaboration

Packet Multi-hop



[Ref: Gupta/Kumar'00]

Wireless Meshes

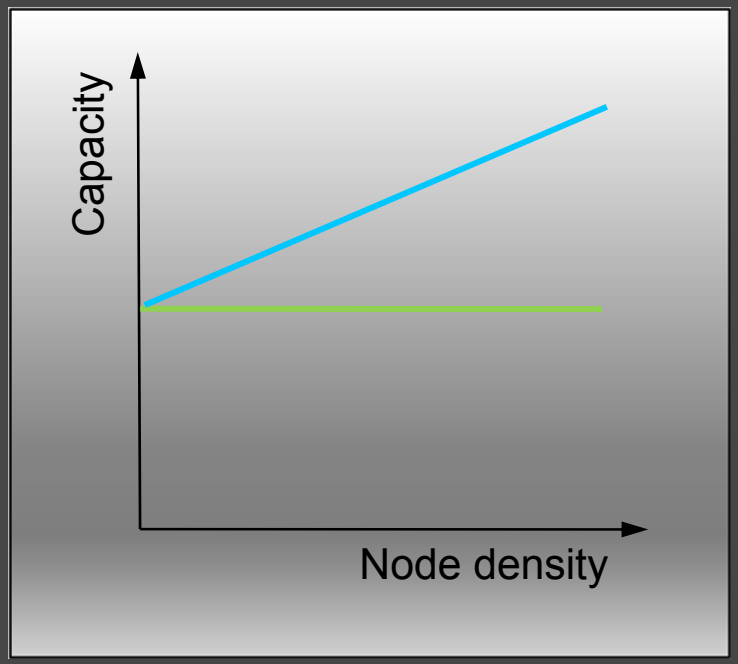


- Connect the unconnected
- Increase "perceived user value"
- Provide reliability in case of failure

[Courtesy: R. Chandra, Microsoft Research]

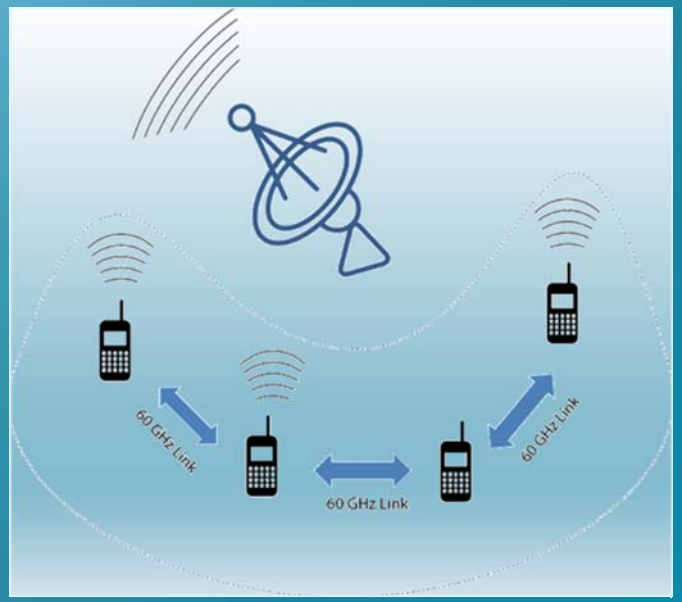
The Power of Collaboration

Collaborative Diversity



[Ref: Ozgur/Leveque/Tse'07]

Collaborative MIMO



- Construct large effective-aperture antenna array by combining many terminals, increasing throughput or coverage
- Local ad-hoc network between terminals

Cognitive-Collaborative Networks: The Challenges

- How to manage degrees of freedom?
  - Frequency/spatial utilization, collaboration, topology
- So that some global and user goals are met
  - Cost, User experience, Life time
- While …
  - Providing absolute reliability
  - Hiding complexity
  - Providing security and access control
  - Dealing with legacy systems

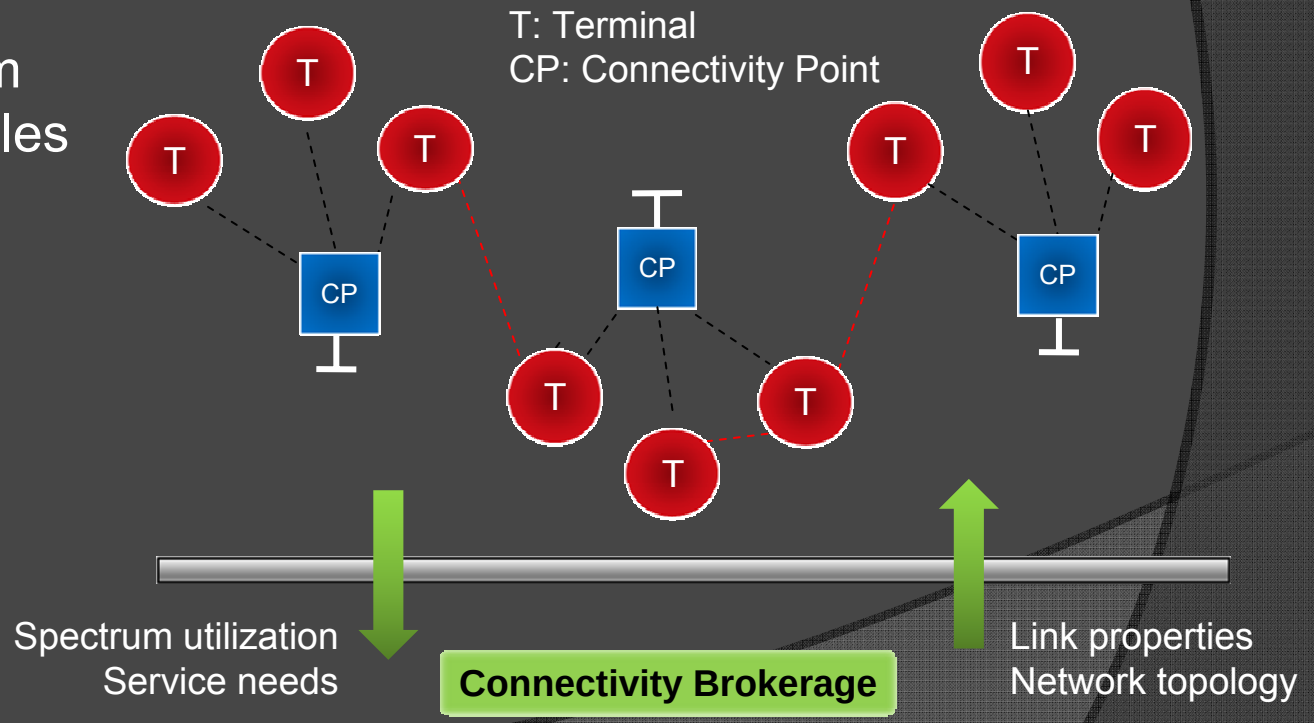
A Societal IT System on Its Own!

Making Cognitive/Collaborative Work

Connectivity Brokerage (*) as a Distributed OS

Functional entity that enables collection of terminals to transparently connect to backbone network or each other to perform set of services

While optimizing utilization of spectrum under policy rules, rules of engagement and security constraints.



(*) Term first coined by Adam Wolisz (TU Berlin)

A Technical as well as Economic Proposition

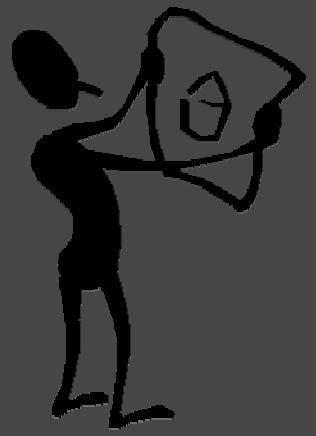
What Does This All Mean For the Design Community?

The moment for true System-Level Design (SLD) is finally here

Quo Vadis, SLD? Reasoning About the Trends and Challenges of System Level Design

Recognizing common requirements for co-design of hardware and software in diverse systems may lead to productivity gains, lower costs and first-pass design success.

By Alberto Sangiovanni-Vincentelli, *Fellow IEEE*



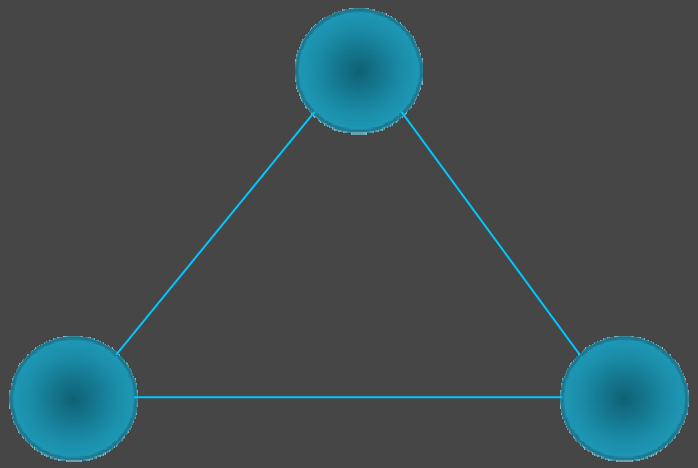
Proceedings of the IEEE, March 2007.

"… there is a common underlying basis that can be explored. This basis may yield a novel EDA industry and even a novel engineering field that could bring substantial productivity gains not only to the semiconductor industry but to all system industries including industrial and automotive, communication and computing, avionics and building automation, space and agriculture, and health and security, in short, a real technical renaissance." - ASV

A New Meaning to "System Design"

- Semiconductor and design automation industries focused on "component design"
- Need to address the whole system

Complexity and emergent behavior
of networked systems



System-level
Reliability

Power and latency
as driving metrics

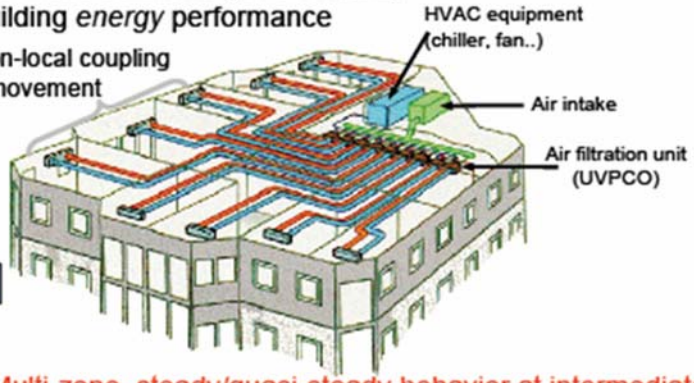
Addressing Complexity in SiS

Example: HVAC in High-Performance Buildings

Objectives: Efficient energy utilization and occupant comfort for normal building operation
Robust response to health and safety threats and events

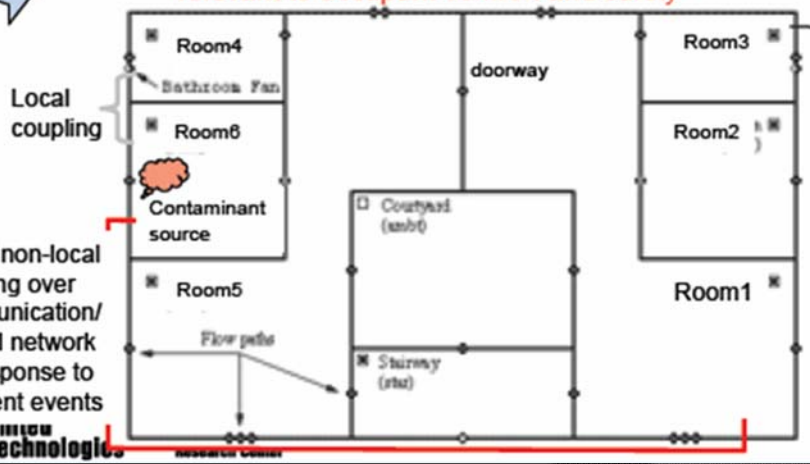
Energy & mass balances govern steady-state building *energy* performance

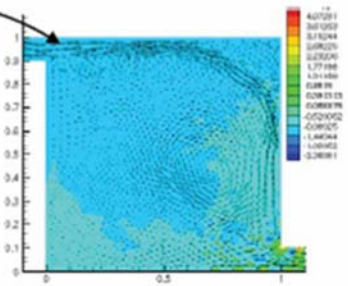
"Slow" non-local coupling from air movement system



- Large, spatially distributed system
- Interconnected system
  - Room neighborhood scale
  - Building floor scale
  - Whole building scale
- Multi-scale dynamic system & its control
  - Wide time scale separation
  - "Close" coupling leading to dynamic constraints between network and physical system

Multi-zone, steady/quasi-steady behavior at intermediate scales relevant to occupant *comfort* and *safety*



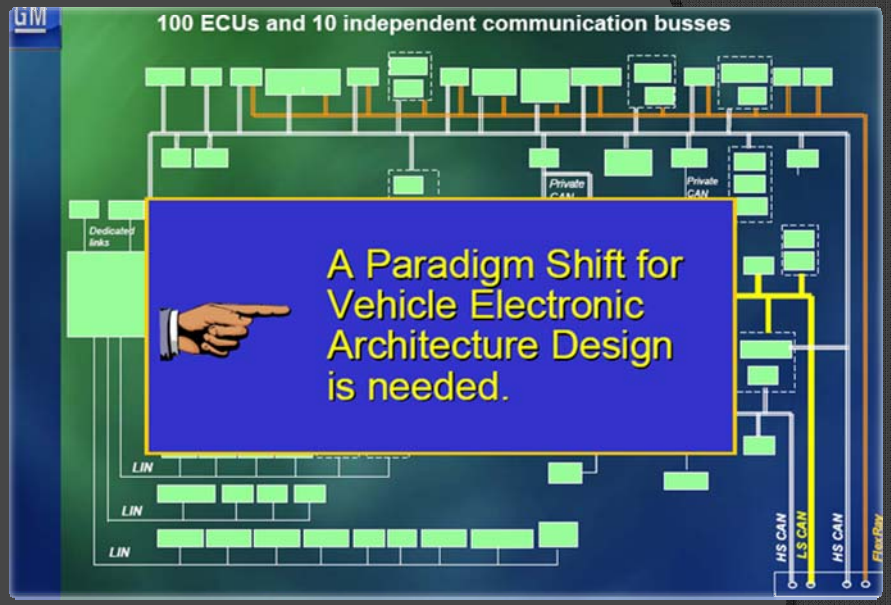


Spatiotemporal airflow dynamics at room scale relevant to *safe building environment*

[Courtesy: Clas Jacobson, UTRC]

Addressing Complexity

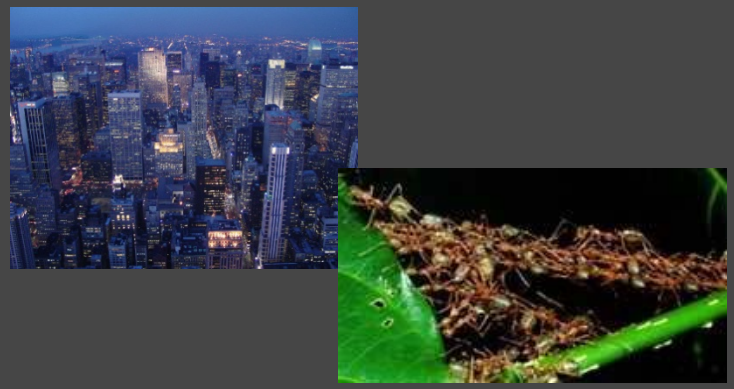
[Courtesy: M. Osella, GM]



- Directly caused by massive concurrency and heterogeneity in SiS systems
- What is needed:
  - Raising the abstraction model
    - Fundamental change in existing “bottom-up” (“up-integration”) business model
  - Enabling a “virtual engineering” design methodology
  - A system-level design science

Addressing Reliability

- Redundancy and resiliency at the core
  - Exploit the “swarm” component of SiS



Easier to make ants than humans
“Small, simple, swarm”

Measure, diagnose, and correct
Error-correcting codes

Measure and adapt
Cognitive radio

Intrinsic resiliency
Multi-hop networks
Playing the numbers game

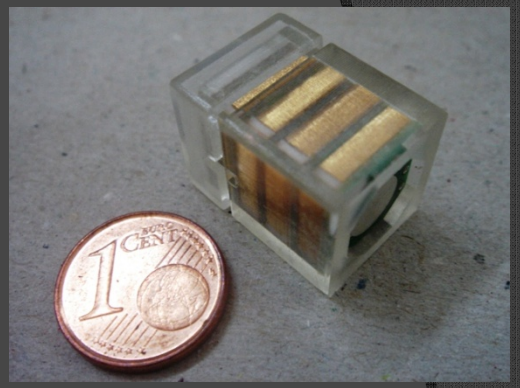
Addressing Reliability

- A system-level responsibility
  - Reliability can and should not be provided by components alone
    - Components can and will fail
    - Wireless links are unreliable by nature
    - “Physical layer” reliability too expensive
  - Correct system behavior does not require determinism at all levels
- Reliability modeling requires statistics
  - Models and abstractions that express reliability requirements and capabilities
  - Not-supported by current SLD environments

Addressing Power/Energy

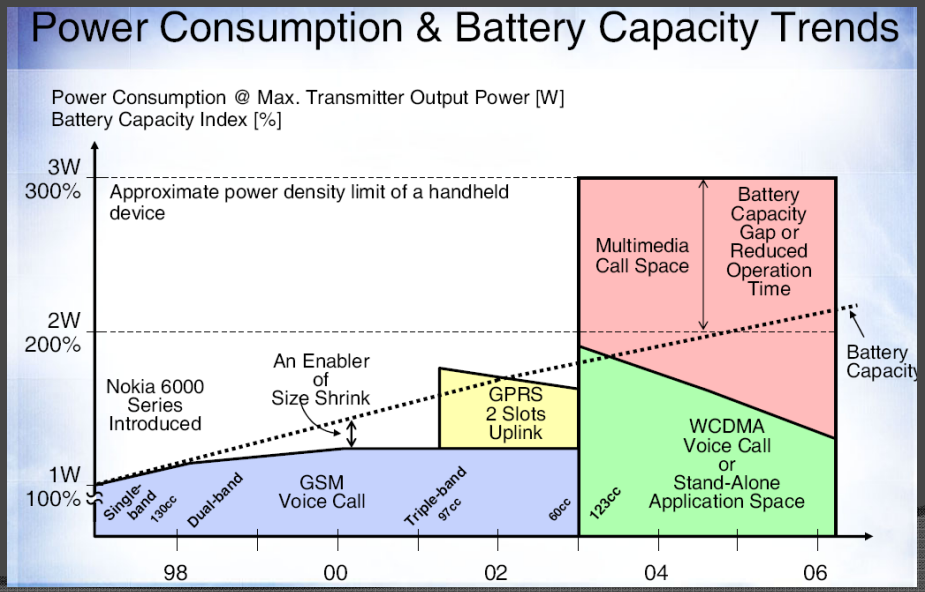
Google Data Center, The Dalles, Oregon

Infrastructure



Sensory swarm

Mobile



Y. Nuevo, ISSCC 04

Crucial at all levels of the systems hierarchy

Power and Latency

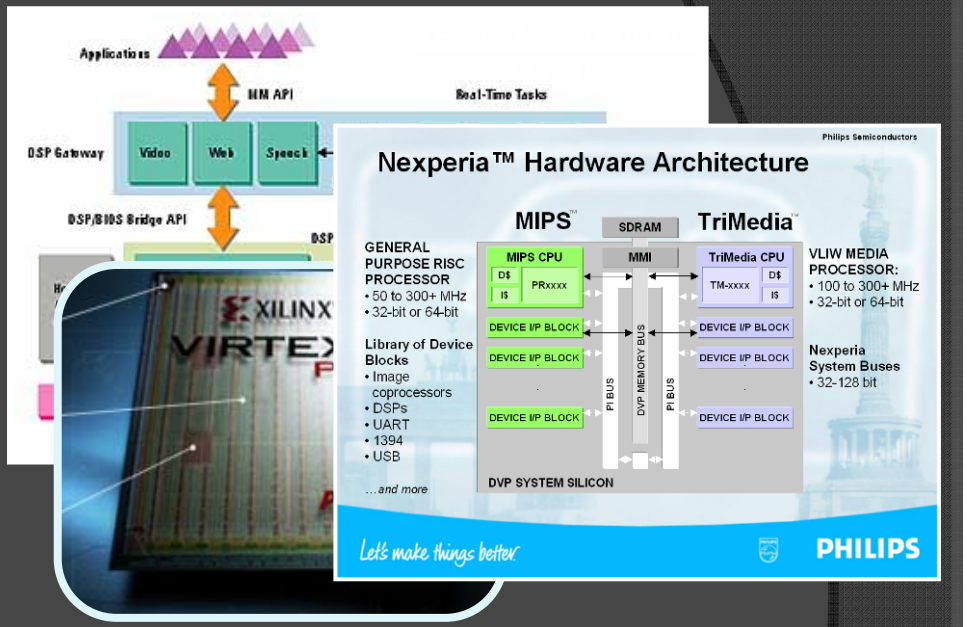
- In “always-connected” world, energy-intensive tasks can be performed in “power-rich” backbone
  - Use energy when and where available

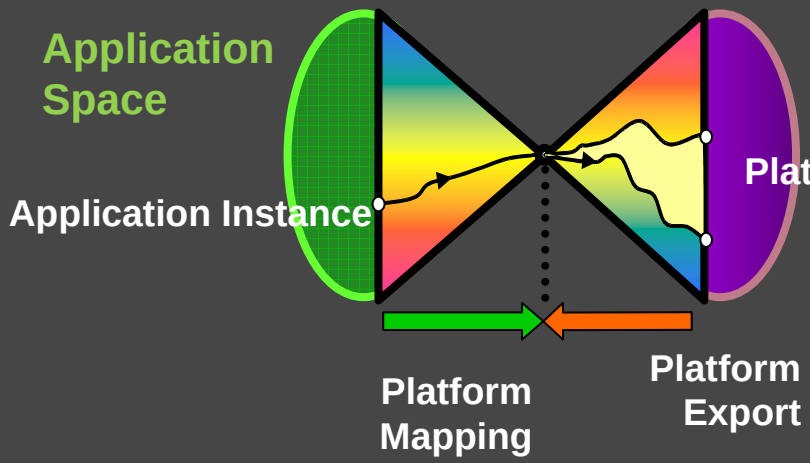
- What matters is “perceived user experience/unit energy” (*)
  - Requires trade-off between cost of computation and communication, as well as overcoming latency constraints
- System-level Modeling and Analysis Essential

(*) Term first coined by John Shen (Nokia NRC)

Platform-Based Design (PBD) to The Rescue

- Meet-in-the-Middle structured methodology that limits exploration space, yet achieves good results in limited time
- Formal mechanism for identifying most critical hand-off points in design chain
- A method for design re-use at all abstraction levels

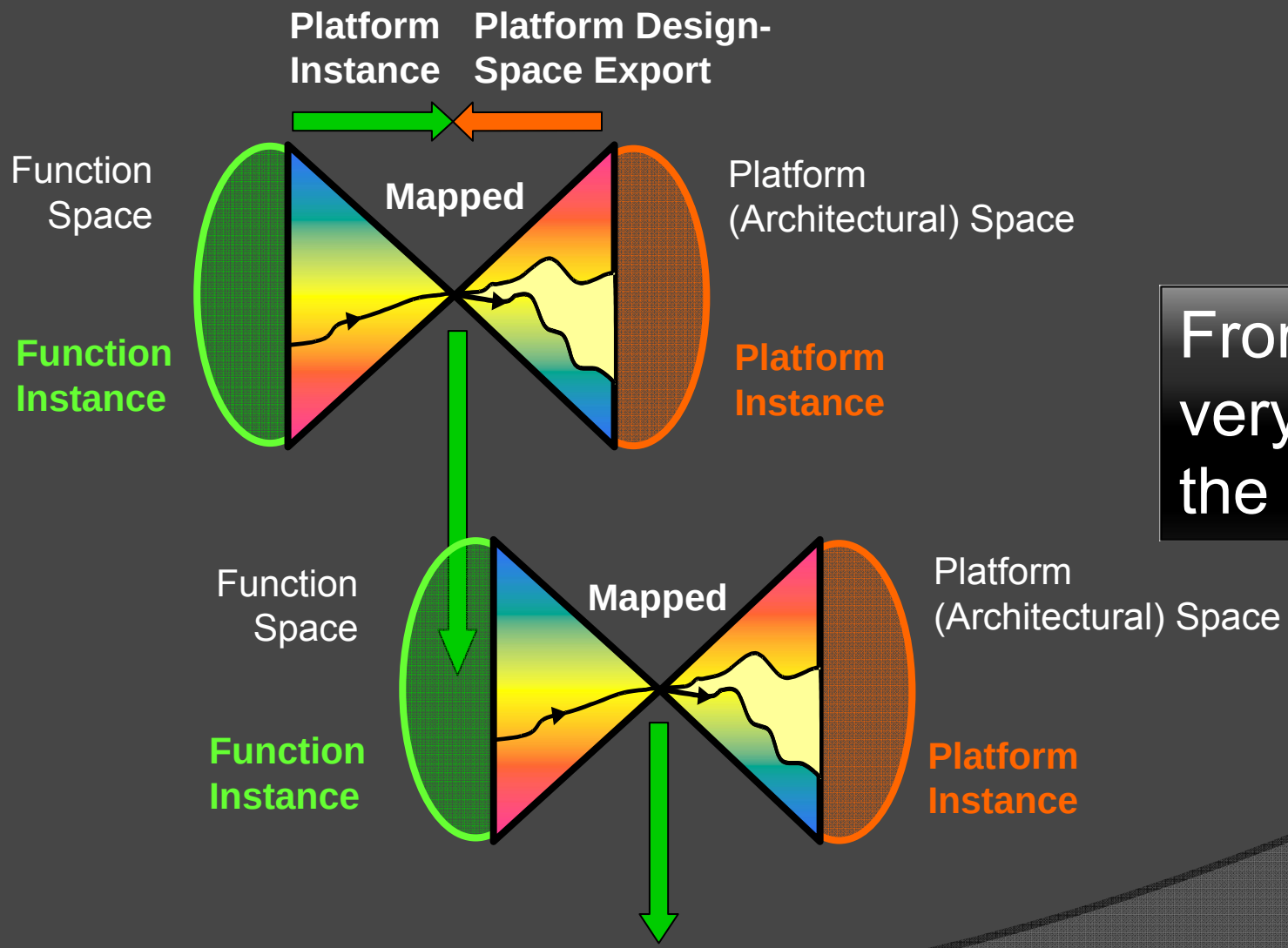




An intellectual framework for the complete electronic design process!

[Courtesy: A. Sangiovanni-Vincentelli]
See Keynote ASPDAC'06

Fractal Nature of Design

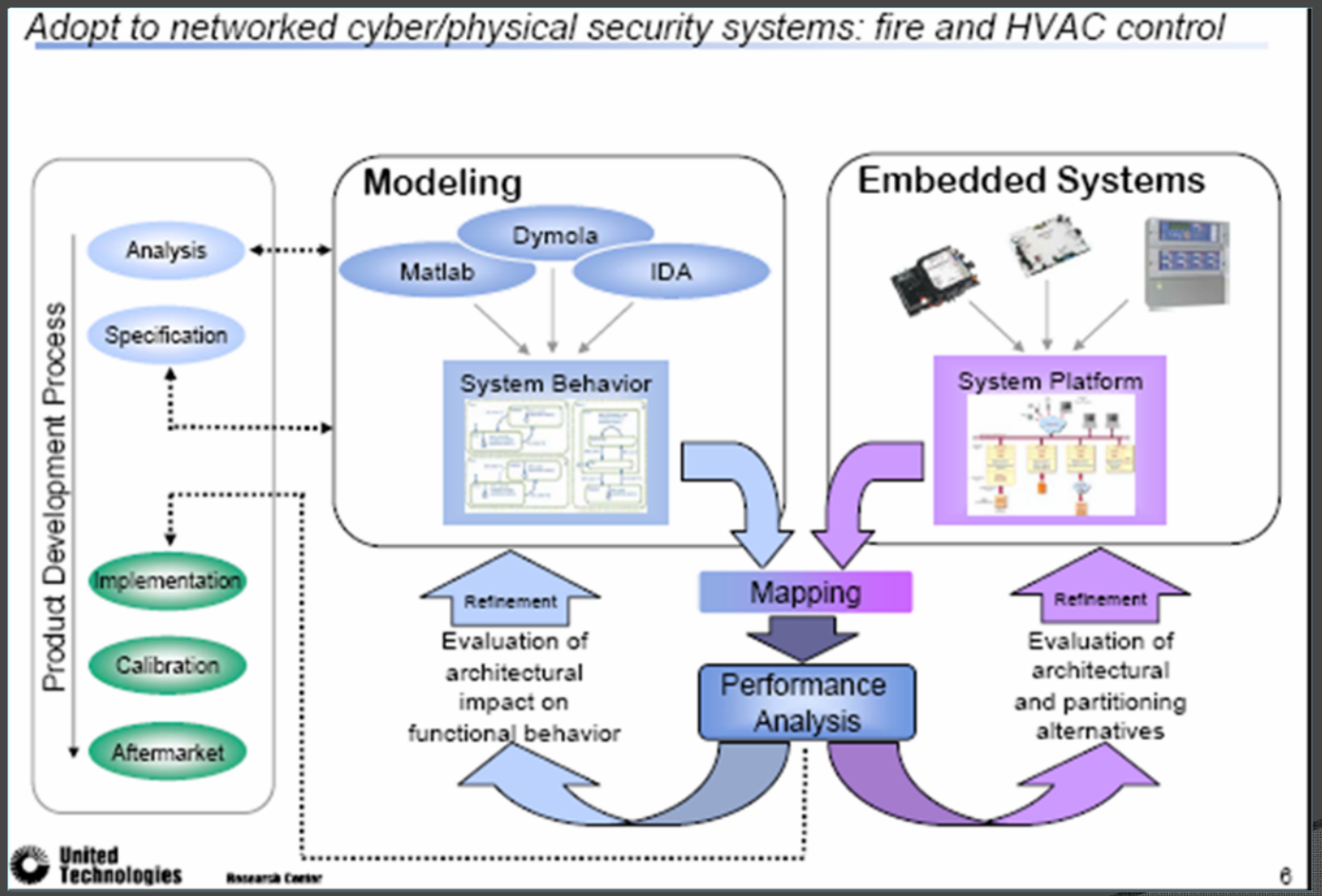


From the very large to the very small

[Courtesy: A. Sangiovanni-Vincentelli]

Extending PBD to the SiS Level

PBD for High-Performance Buildings



[Courtesy: C. Jacobson, UTC and A. Sangiovanni-Vincentelli, UCB]

A Call to Arms:
Benchmarks and Metrics of Old Won't Do

- Mostly based on "high-performance" or personal computer – style applications
  - SpecMarks, EEMBC, SSP, …
- Traditional quality metrics for design …
  - Performance (e.g. MIPS)
  - Energy efficiency (MIPS/W)
- are second-order or irrelevant in SiS Wireless Networks
  - Societal IT systems are rarely performance-constrained
  - Energy-efficiency is a function of where it is consumed and when

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The New Benchmarks and Metrics

- New Benchmarks Libraries Must Extend Beyond the Component
  - "Workloads of the Future"
- Relevant metrics for SiS Systems
  - "User experience per unit energy"
  - System Latency
  - Reliability/Liability
  - Complexity/composability

Needs Joint Effort By Industry and Academia

Concluding Reflections

- Ubiquitous always-connected wireless radically transforming the Information Technology Arena
  - Towards truly Immersive Systems
  - Cognitive Collaborative Wireless a powerful disruptive paradigm
- Complexity, heterogeneity, reliability and power present formidable challenges
- EDA has to extend itself from “component” to system oriented
  - Must subsume traditional design flows rather than replace them
- Broad collaboration between systems and semiconductor industries, as well as industry and academia needed
  - Need for new benchmark libraries
  - Need theory of system design

A call to action! These are exciting times again …

감사합니다!

“Technical skill is mastery of complexity while creativity is mastery of simplicity.” – E. Christopher Zeeman

“Other things being equal, complexity in a model indicates vacuousness rather than sophistication.” – J.M. Maciejowski

“I think complexity is mostly sort of crummy stuff that is there because it's too expensive to change the interface.” – Jaron Lanier

“Complexity is in the eye of the beholder.” – J. Rissanen