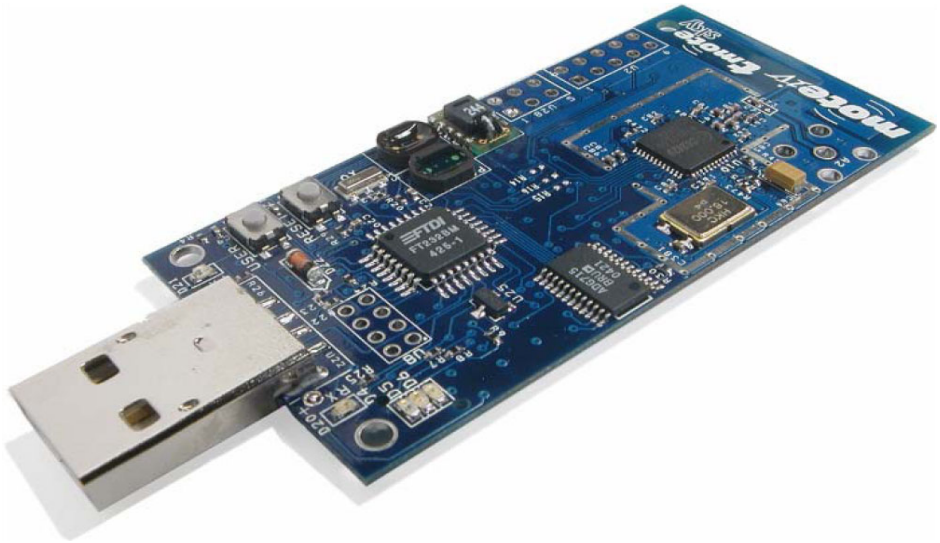


A Brief History of Sensor Networks

Muneeb Ali

Princeton University

Introduction: 2003

Mote maker: David Culler's "motes" monitor the environment and send reports wirelessly. (Photograph by Angela Wyant)

Image: MIT TechReview

Introduction: 2005

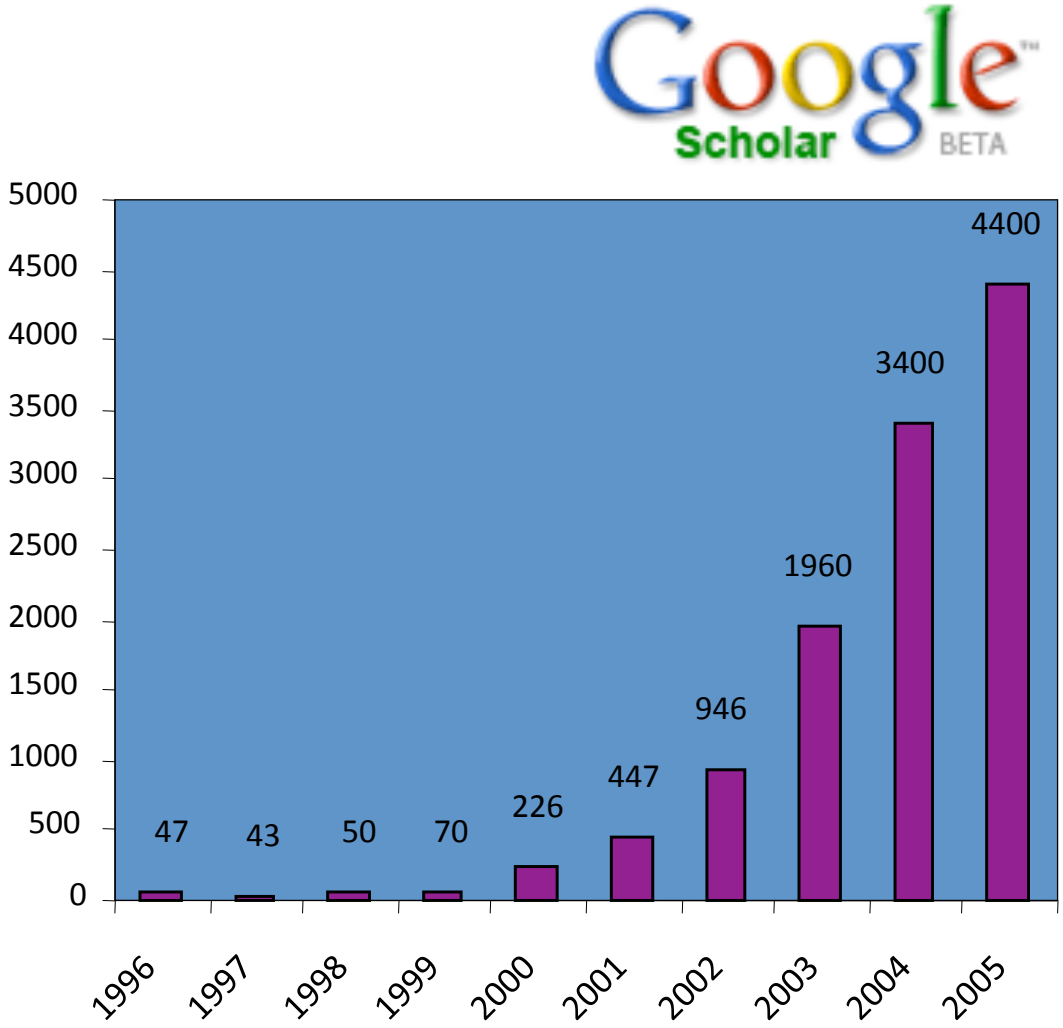
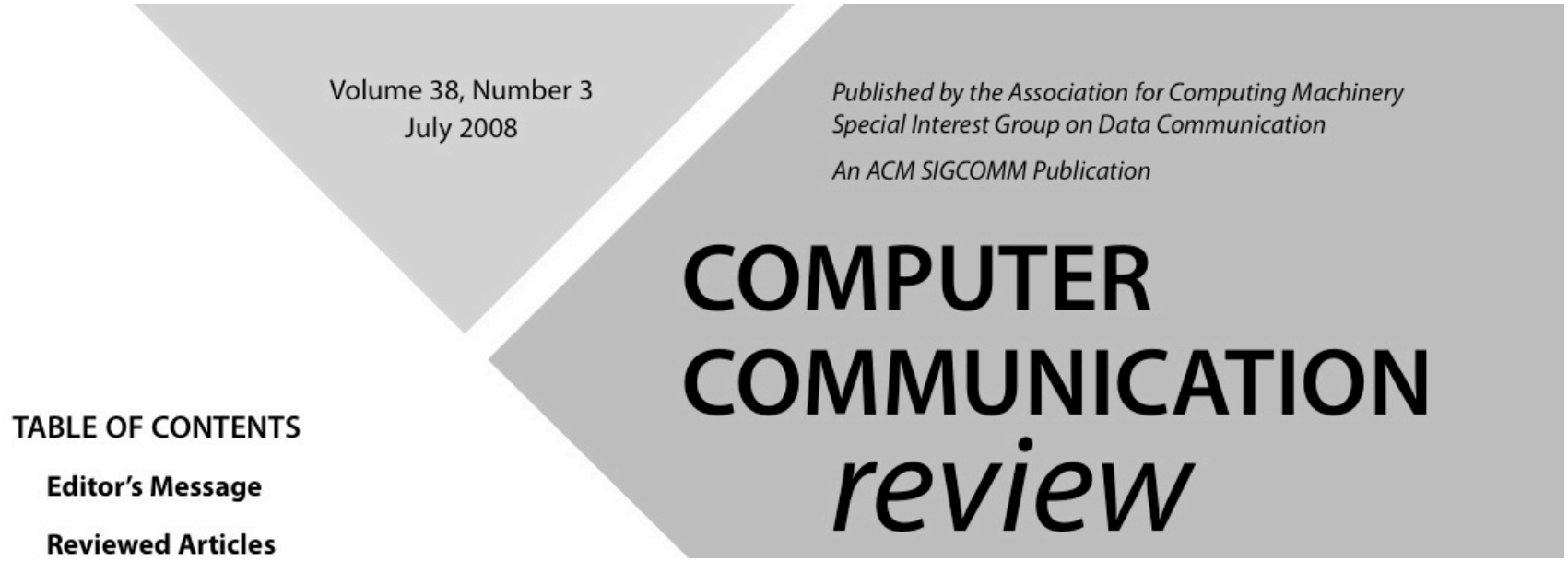


Image: Koen Langendoen

Introduction: 2008



Censor Networks: A Critique of "Sensor Networks" from a Systems Perspective
B. Raman, K. Chebrolu (IIT Bombay)

Introduction

This talk:

- A brief history of the last 5 years of research (2003-2008)

- Important problems, solutions, and lessons

- Future directions

A Brief History

Gordon Moore
Intel Co-Founder

A Brief History

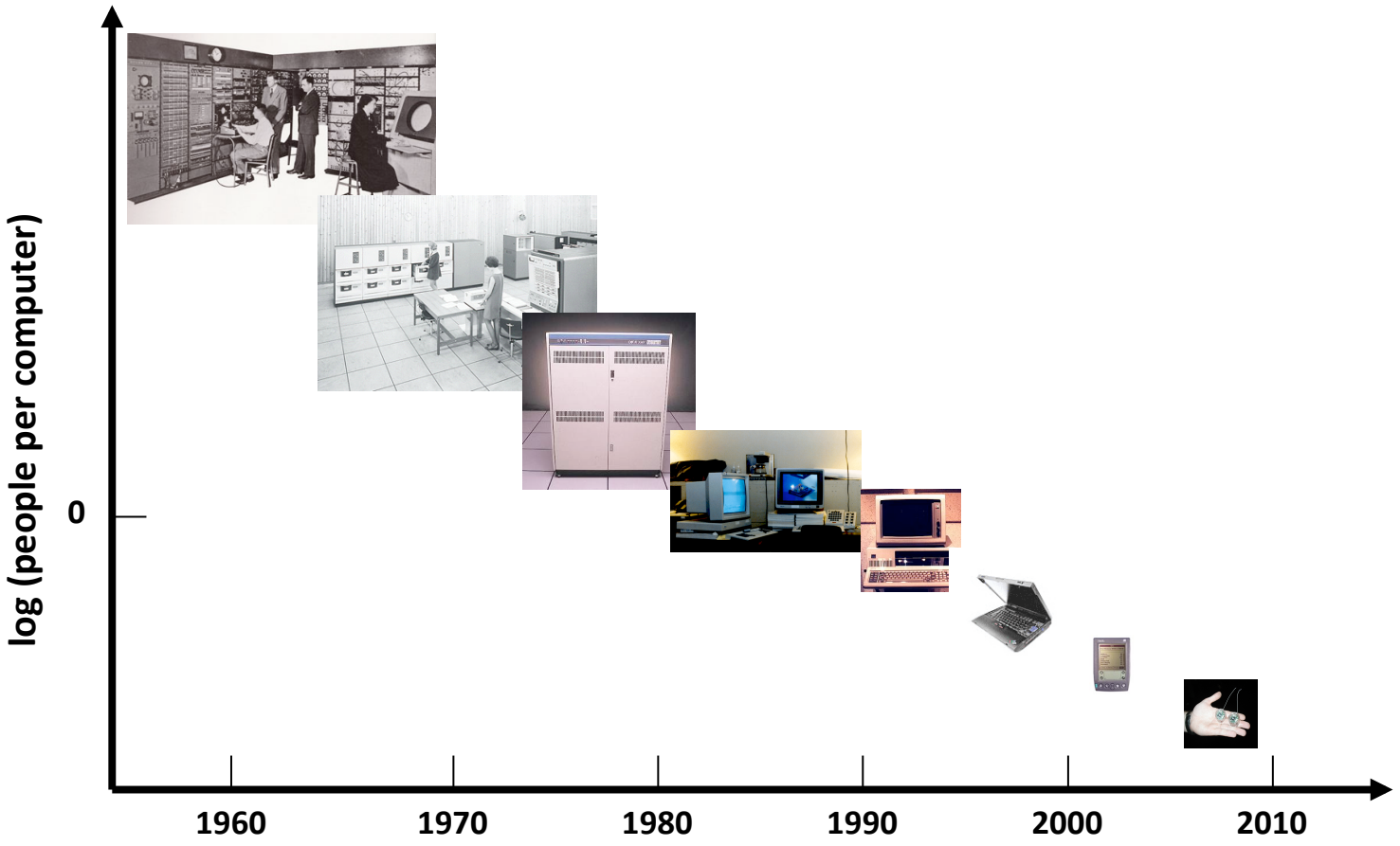
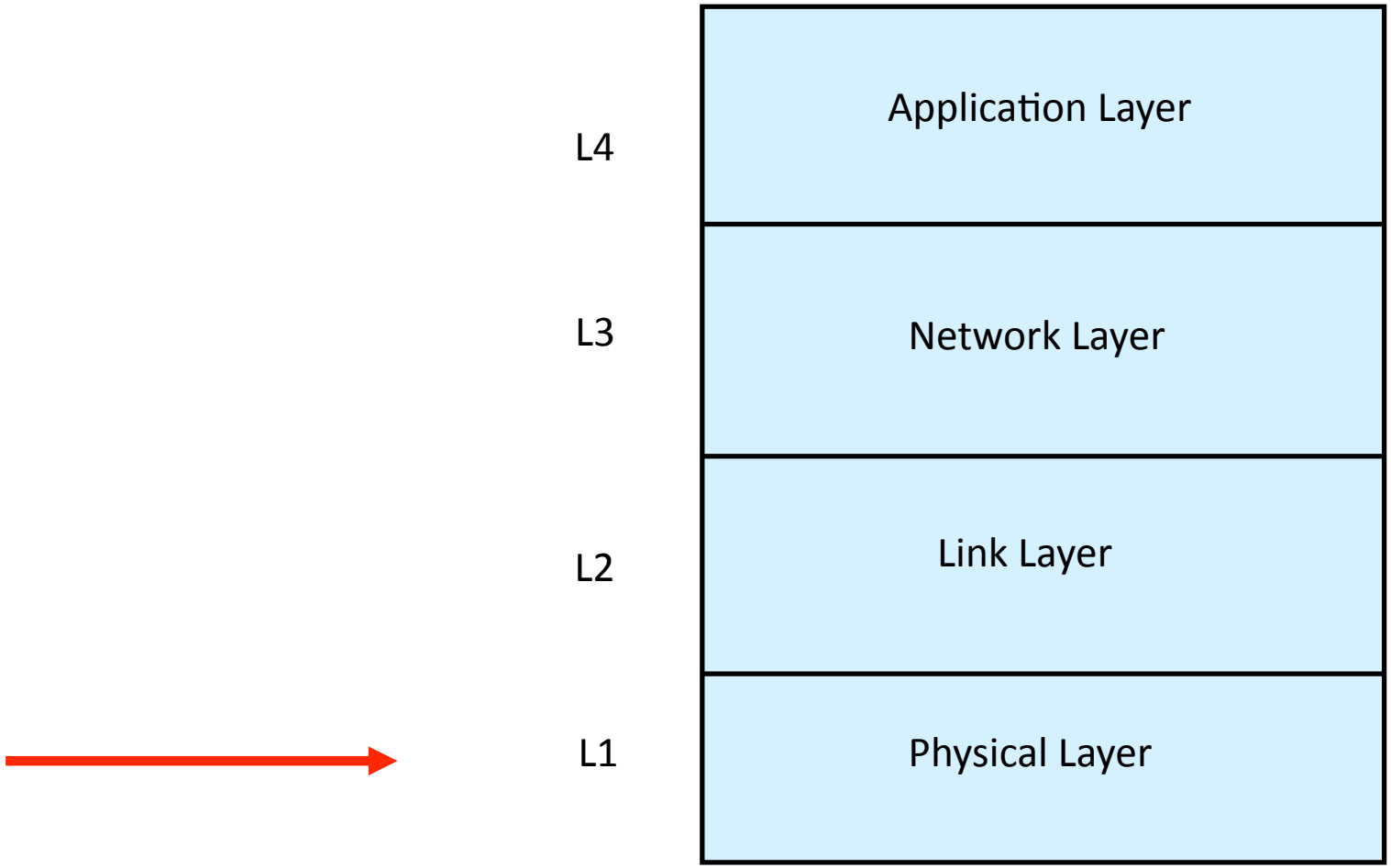


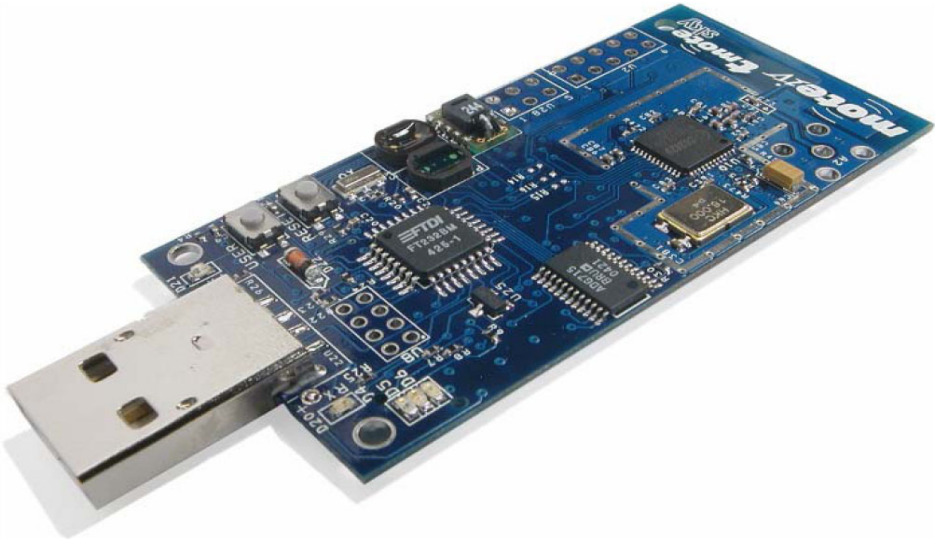
Image: Culler:2004

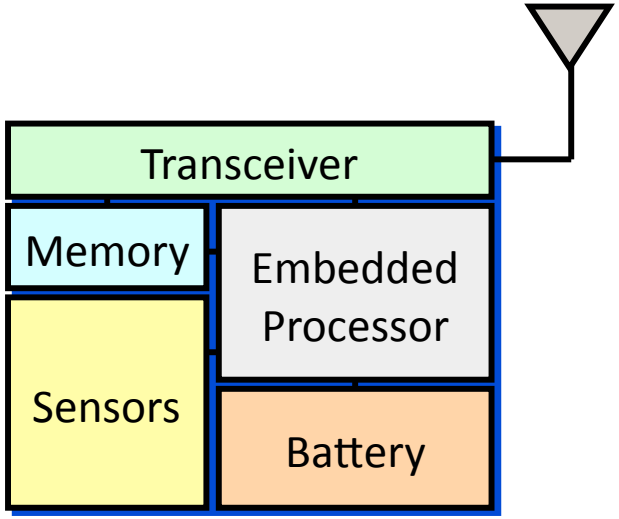
Network Stack



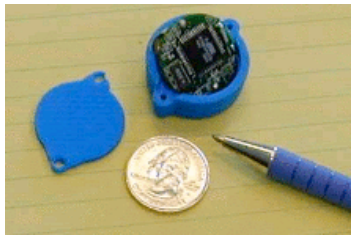
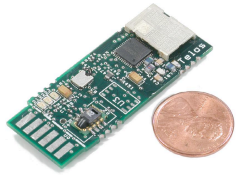
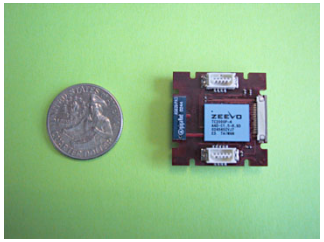
L1: Physical

- Memory: 10 KB
- Radio: CC2420 (250 Kbps)
- Processor: MSP430 (16-bit)





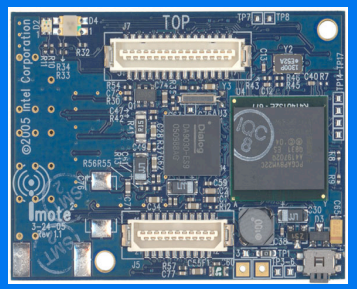
L1: Physical

	René 1999	Mica-2 2002	Tmote Sky 2005	Imote2 2007
CPU	**ATMEL 8535**	**ATmega128L**	**TI MSP430**	**Intel PXA271**
	8-bit, 4 MHz	8-bit, 8 MHz	16-bit, 8 MHz	32-bit, 13-416 MHz
	36 μW sleep	36 μW sleep	15 μW sleep	390 μW sleep
	60 mW active	60 mW active	5.4 mW active	$\geq$ 31 mW active
Memory	512 B RAM	4 KB RAM	10 KB RAM	32 MB RAM
	8 KB Flash	128 KB Flash	48 KB Flash	32 MB Flash
Radio	**RFM TR1000**	**CC1000**	**CC2420**	
	10 Kbps	76 Kbps	250 Kbps	
	2 μW sleep	100 μW sleep	60 μW sleep	
	12 mW receive	36 mW receive	63 mW receive	
	36 mW xmit	75 mW xmit	57 mW xmit	
	0.5 ms setup	2 ms setup	1 ms setup	

L1: Physical

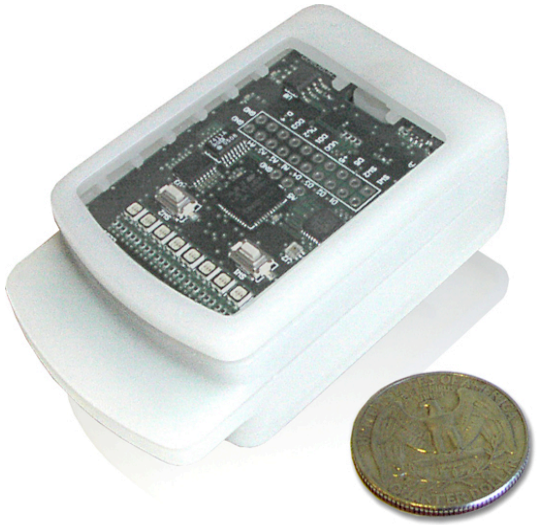
Intel Imote 2



- 320/416/520MHz PXA271 XScale Processor
  - 32MB SDRAM on-board
  - 32MB Flash on-board
- [802.15.4] Radio (ChipCon CC2420)

Image courtesy intel

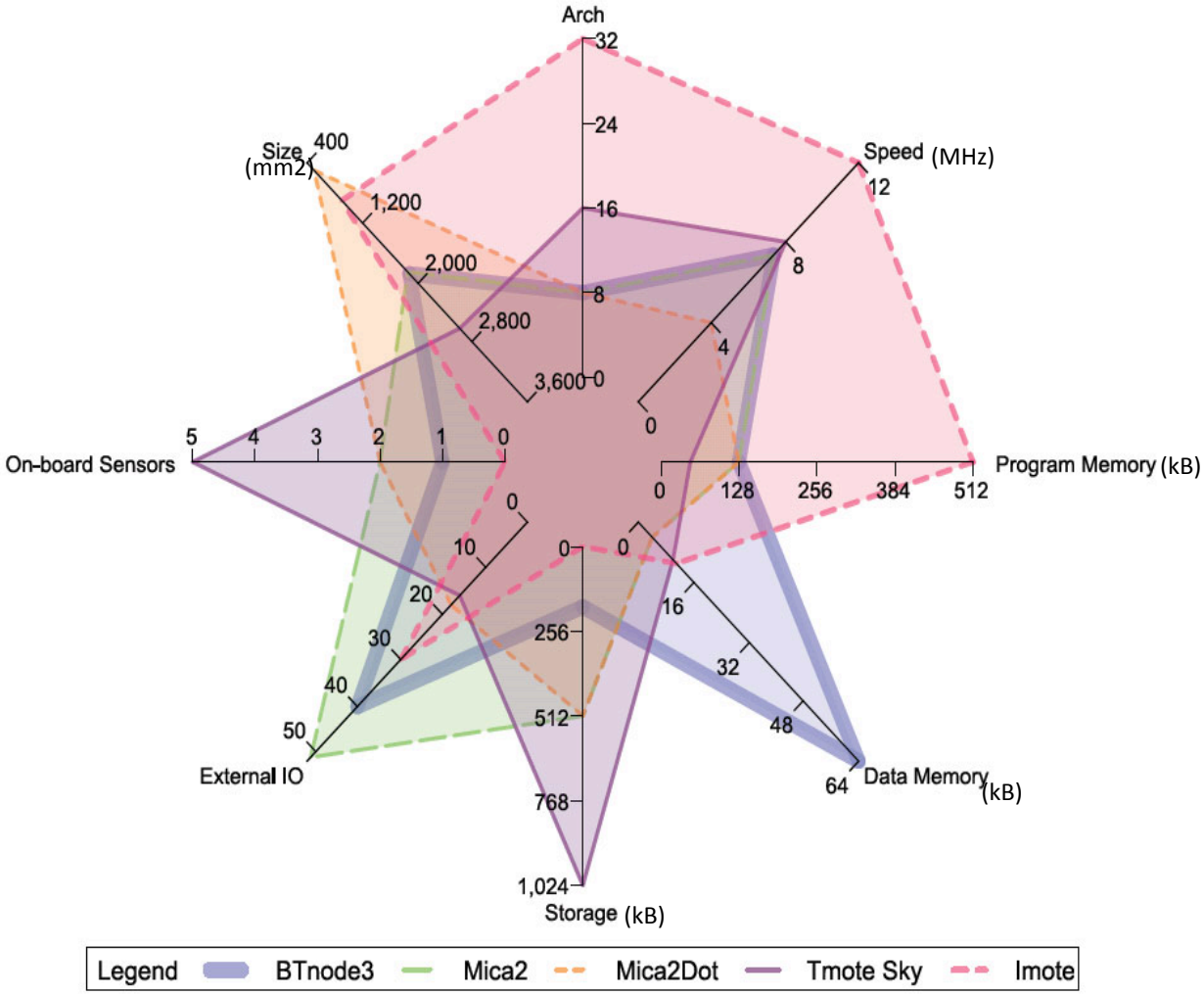
Sun Spot



- 32 bit ARM7 core
  - 256K RAM
  - 2M Flash
- [802.15.4] Radio (ChipCon CC2420)

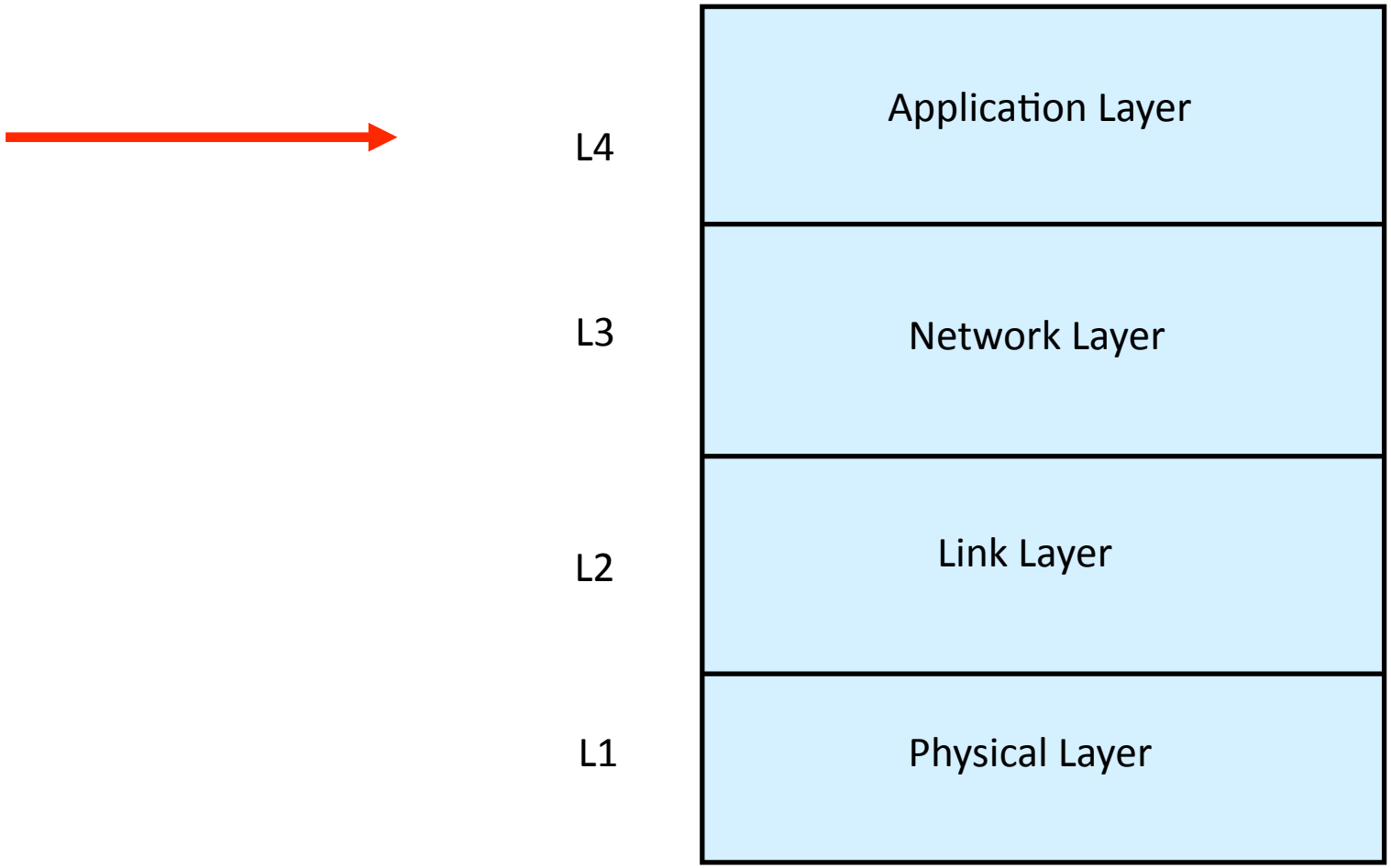
Image courtesy Sun microsystems

L1: Physical



Reference: Jan Beutel, Metrics for Sensor Network Platforms, ACM RealWSN June 2006

Network Stack



L4: Applications

[Berkeley, 2002]

L4: Applications

[Vanderbilt, 2003]

L4: Applications

[Princeton, 2004]

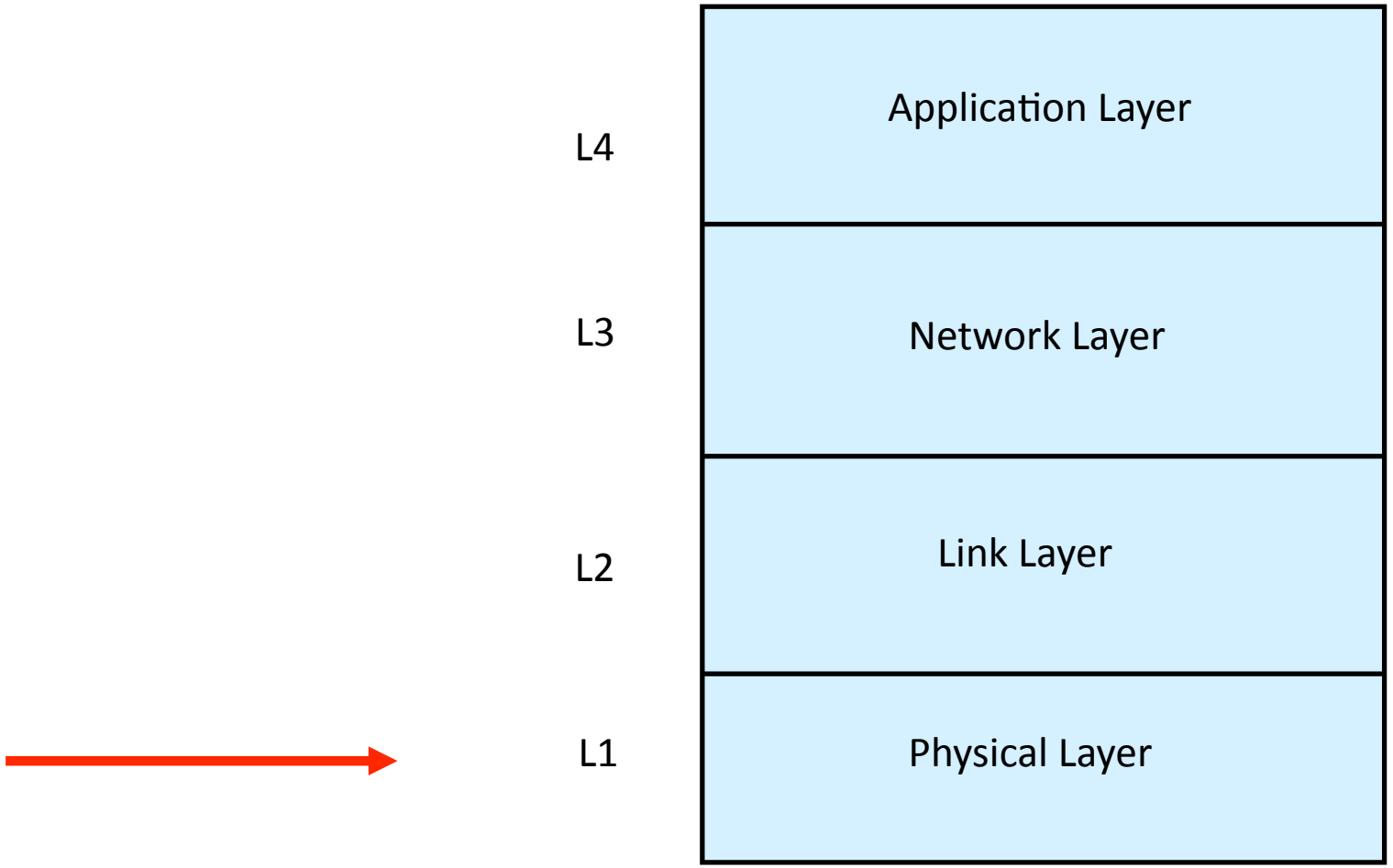
L4: Applications

[Delft, 2006]

L4: Applications

[Harvard, 2007]

Network Stack: Challenges



Challenges: Energy

~2 kcal (per battery)

<<<

~2

(Quarte

Without cheese!!!

Image: Koen Langendoen

Challenges: Wireless

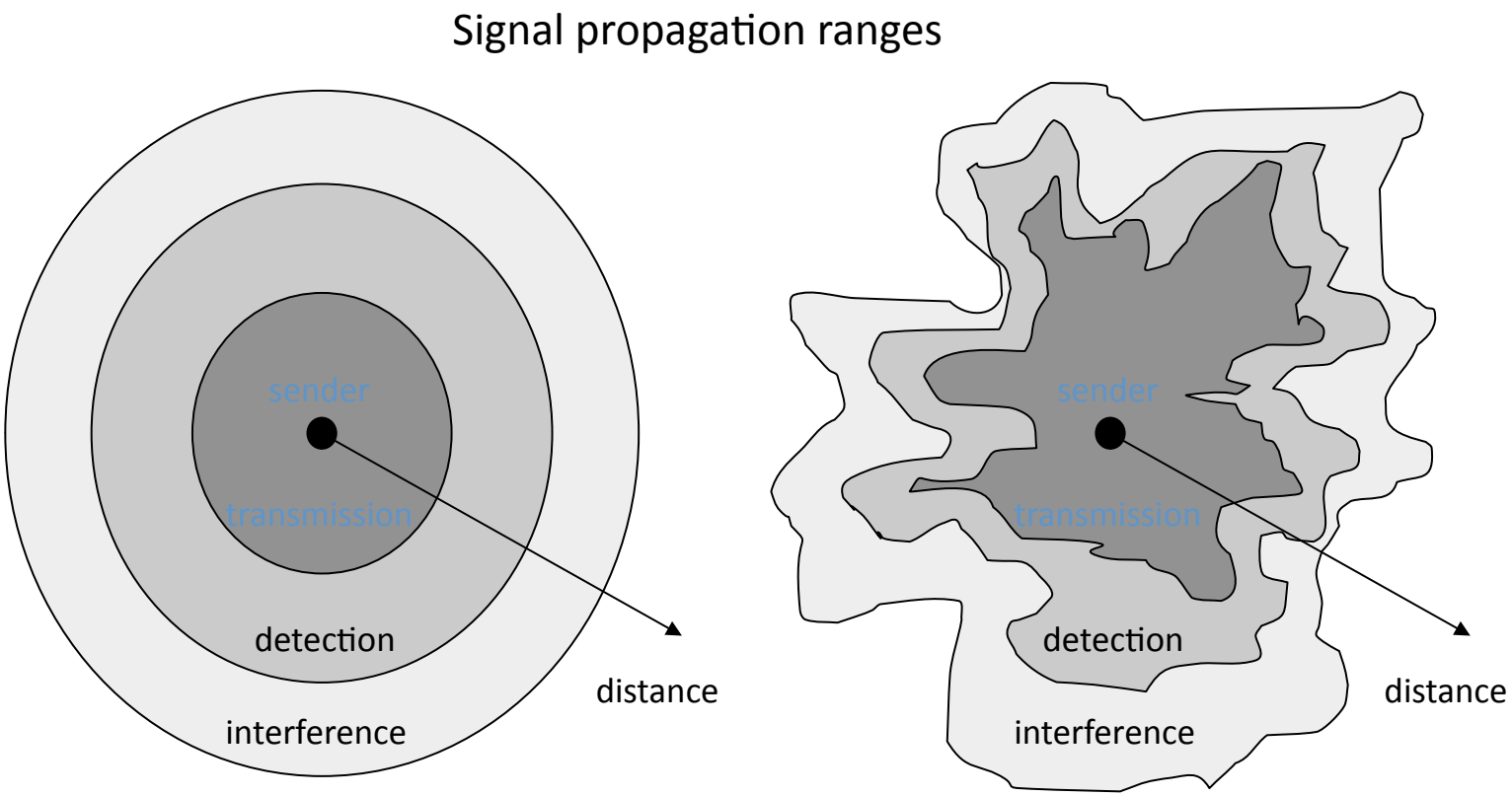
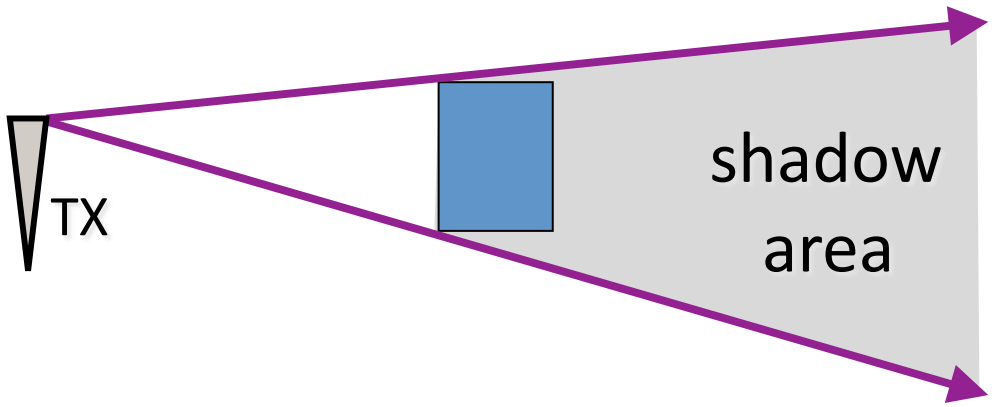


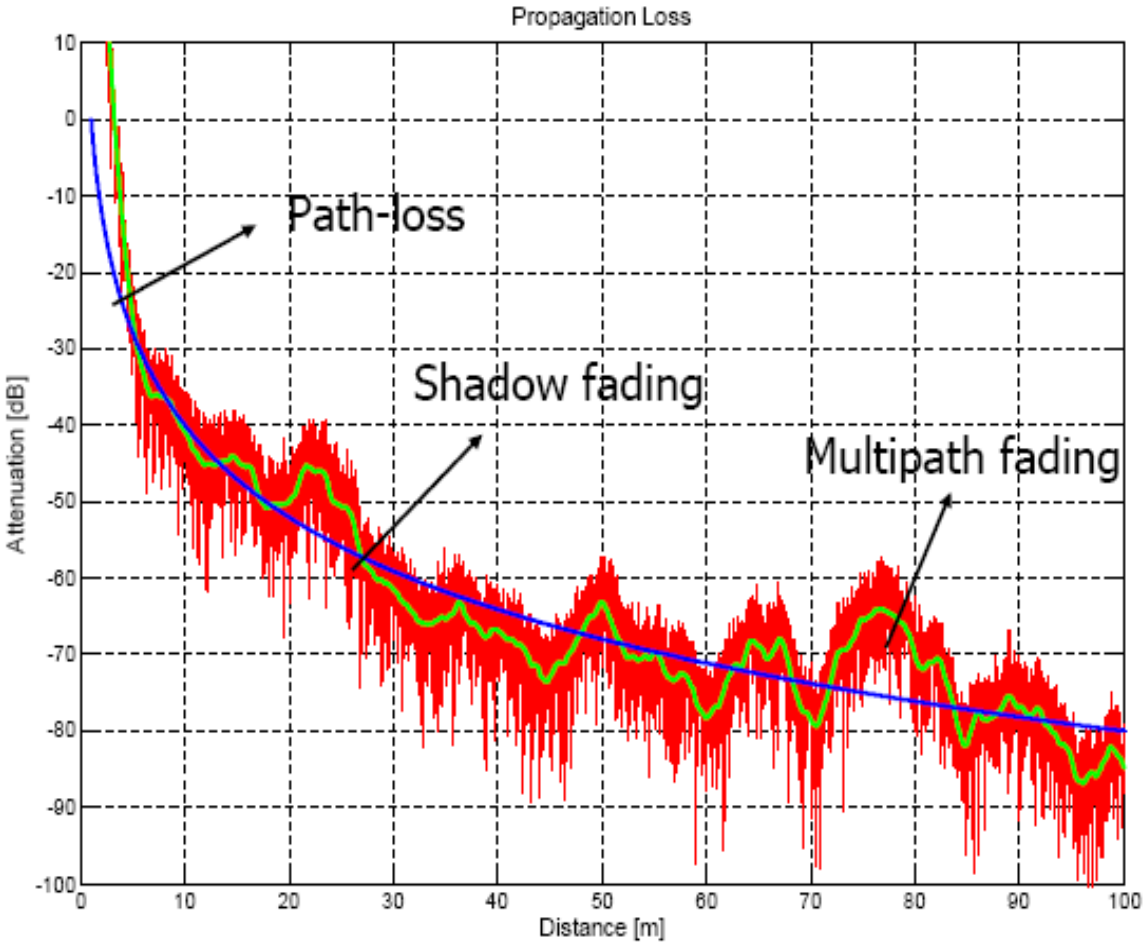
Image: Koen Langendoen

Challenges: Wireless



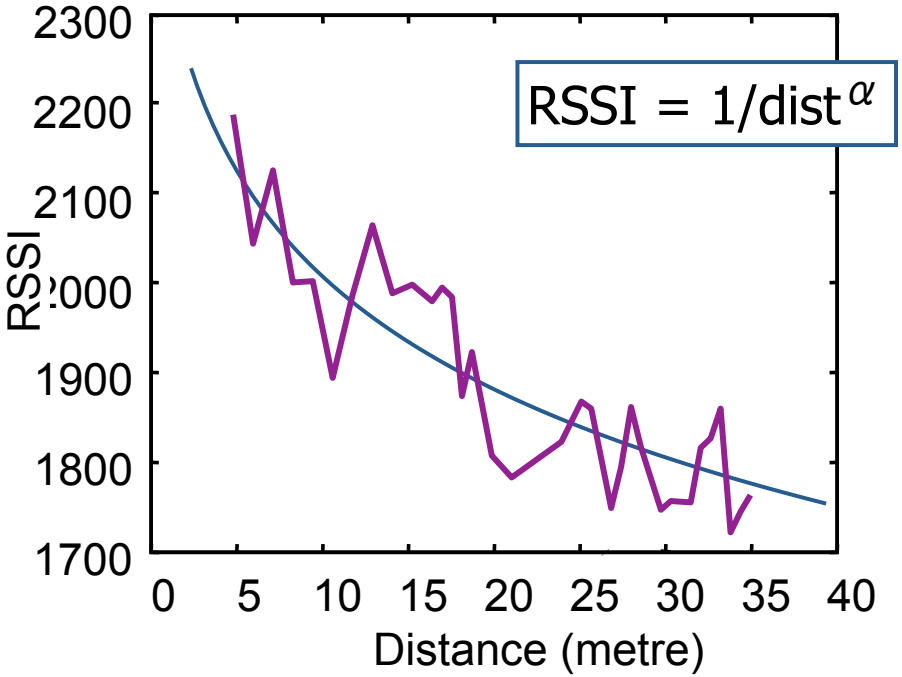
Reflections / Shadowing

Challenges: Wireless



[G. Janssen, ET4358]

Challenges: Wireless

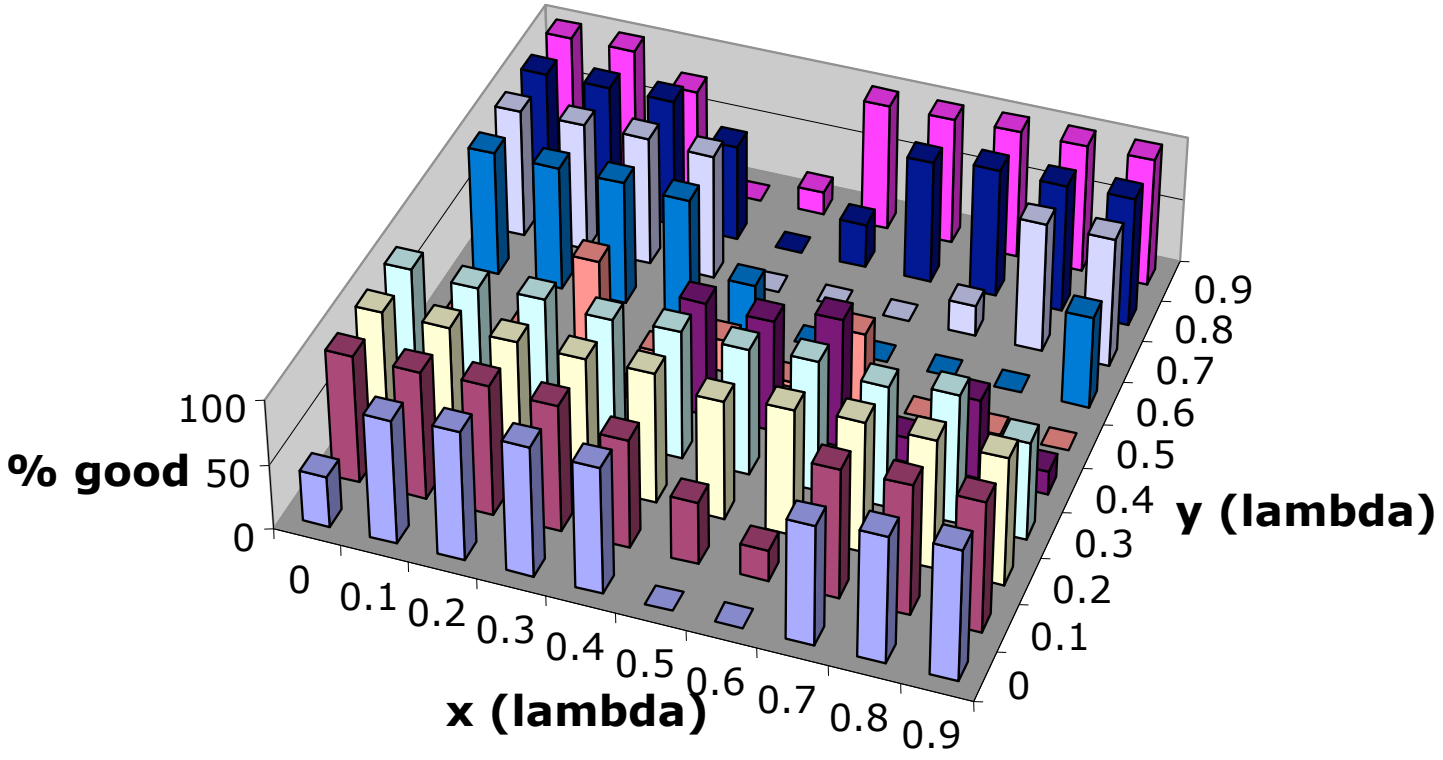


Grey Area Effect

Challenges: Wireless

Link layer & multipath fading

CC2420 @ 2.4 GHz, power = -1dBm, 2am



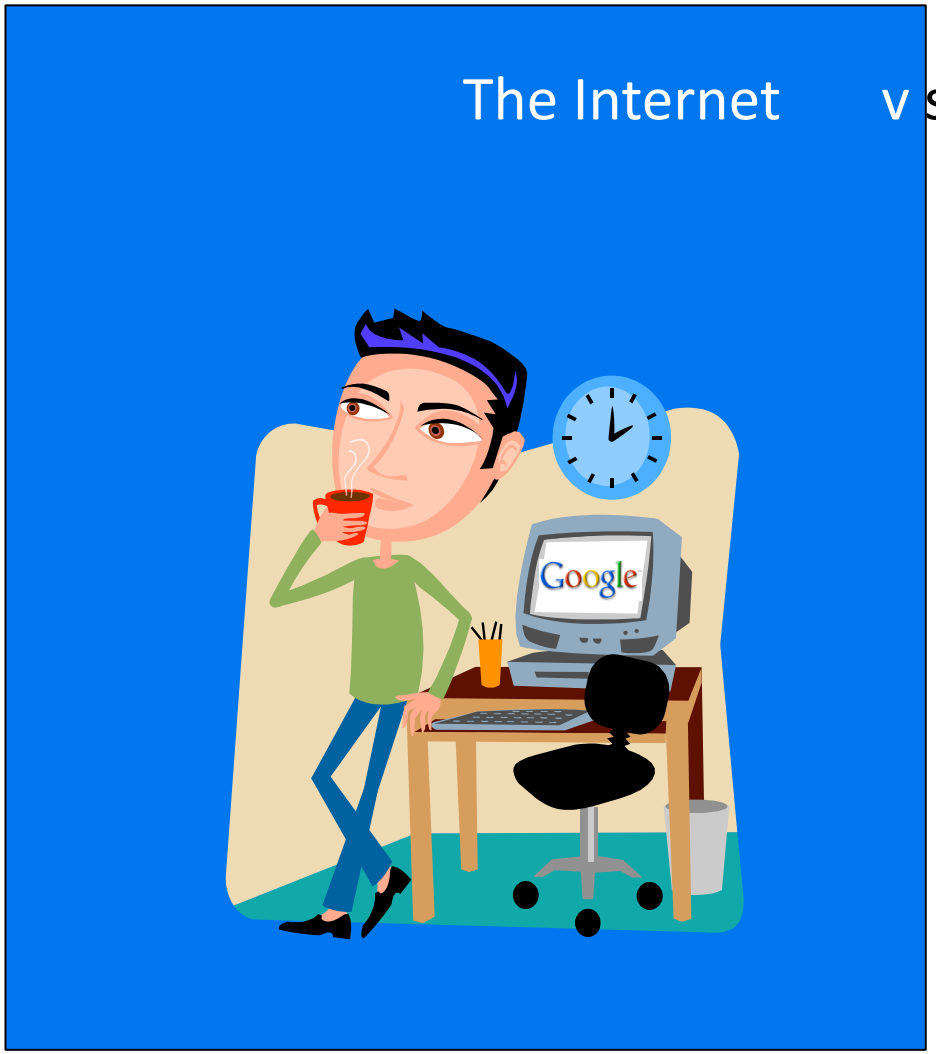
[Robert Poor, Ember corp.]

Challenges: RAM

- Scalability
- Limited RAM is fundamental
- Effects power
- O(N) state infeasible

Challenges: Applications

The Internet v s. Sensor-Nets



Challenges: Summary

The Internet

- Independent hosts
- End to end flows
- Infrastructure
- Wired (generally)
- Latency, throughput
- Bandwidth is relatively cheap

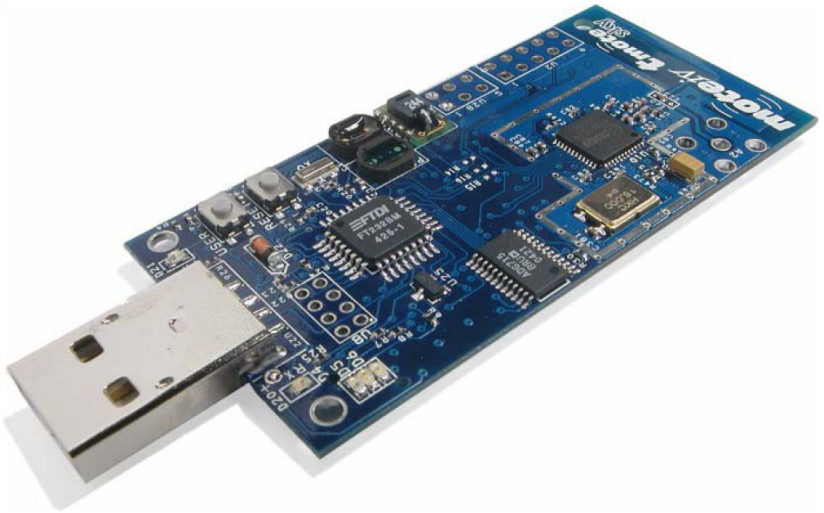
v s. Sensor-Nets

- Collaborative use
- Collect, disseminate, ...
- Ad-hoc
- Wireless
- Energy
- Bandwidth is expensive

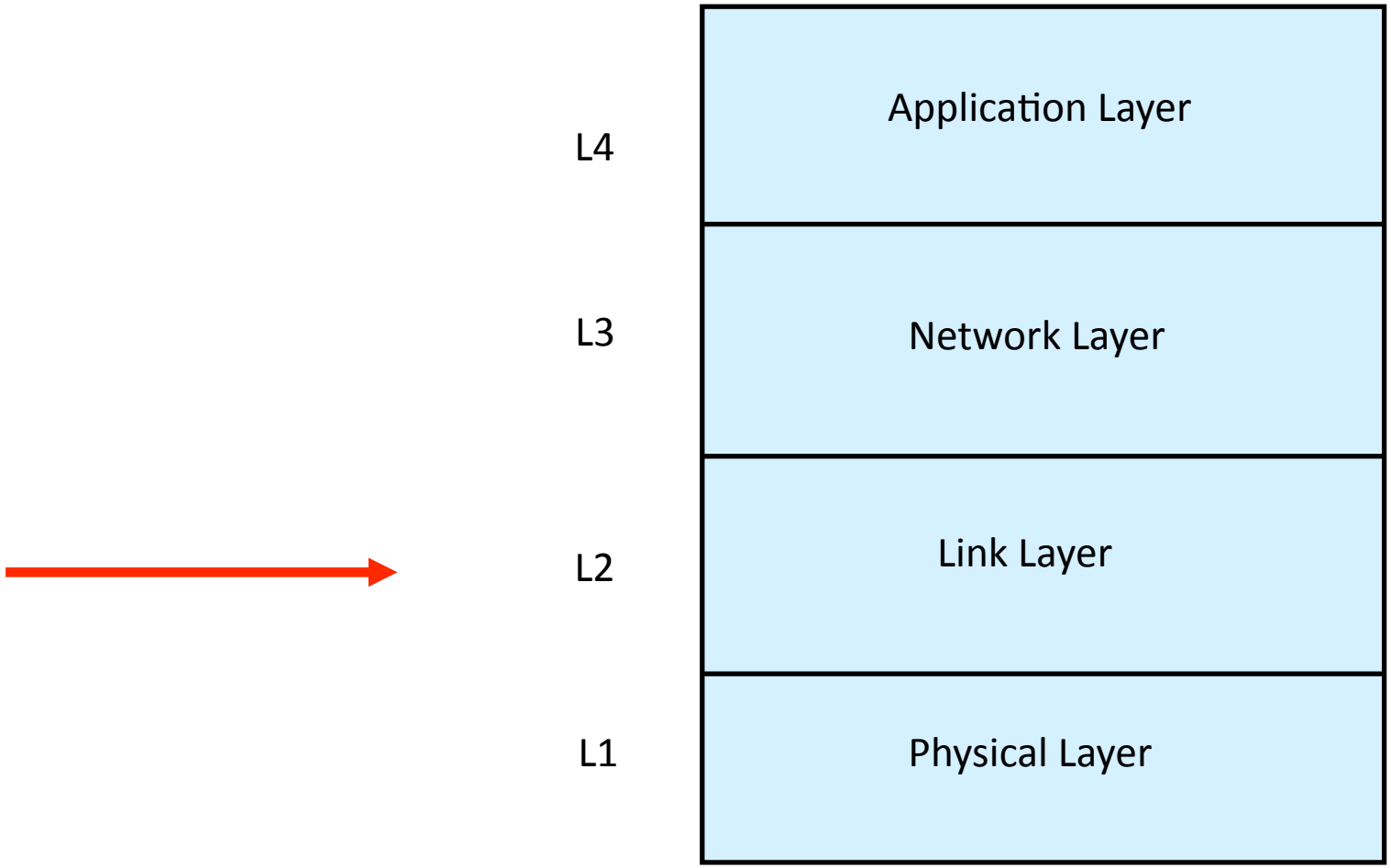
Reference: Philip Lewis, ICSI Talk, May 2004

Research Problems

- Medium Access Control
- Routing
- Localization
- Operating Systems
- Security
- Programming Abstractions
- Query Processing



Network Stack



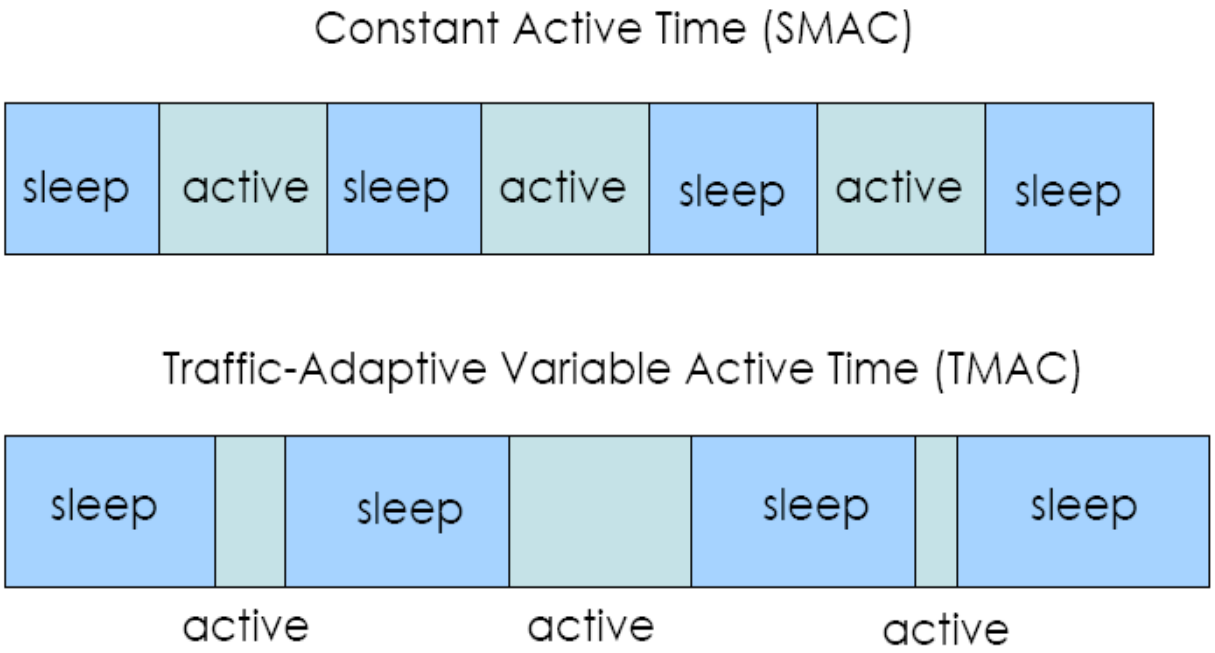
L2: MAC

The MAC Alphabet Soup
served in Wireless Sensor Networks

Acronym	Full name
µ-MAC	micro-MAC
AI-LMAC	Adaptive Information-centric and Lightweight MAC
B-MAC	Berkeley MAC
BitMAC	BitMAC
BMA	Bit-Map-Assisted
CMAC	Convergent MAC
Crankshaft	Crankshaft
CSMA-MPS	CSMA with Mimimum Preamble Sampling
CSMA/ARC	Randomized CSMA with Adaptive Rate Control
DMAC	Data gathering MAC
E2-MAC	Energy Efficiency-MAC
EMACs	EYES MAC
f-MAC	framelet-MAC
FLAMA	FLow-Aware Medium Access
Funneling-MAC	Funneling MAC

Contact person: Koen Langendoen

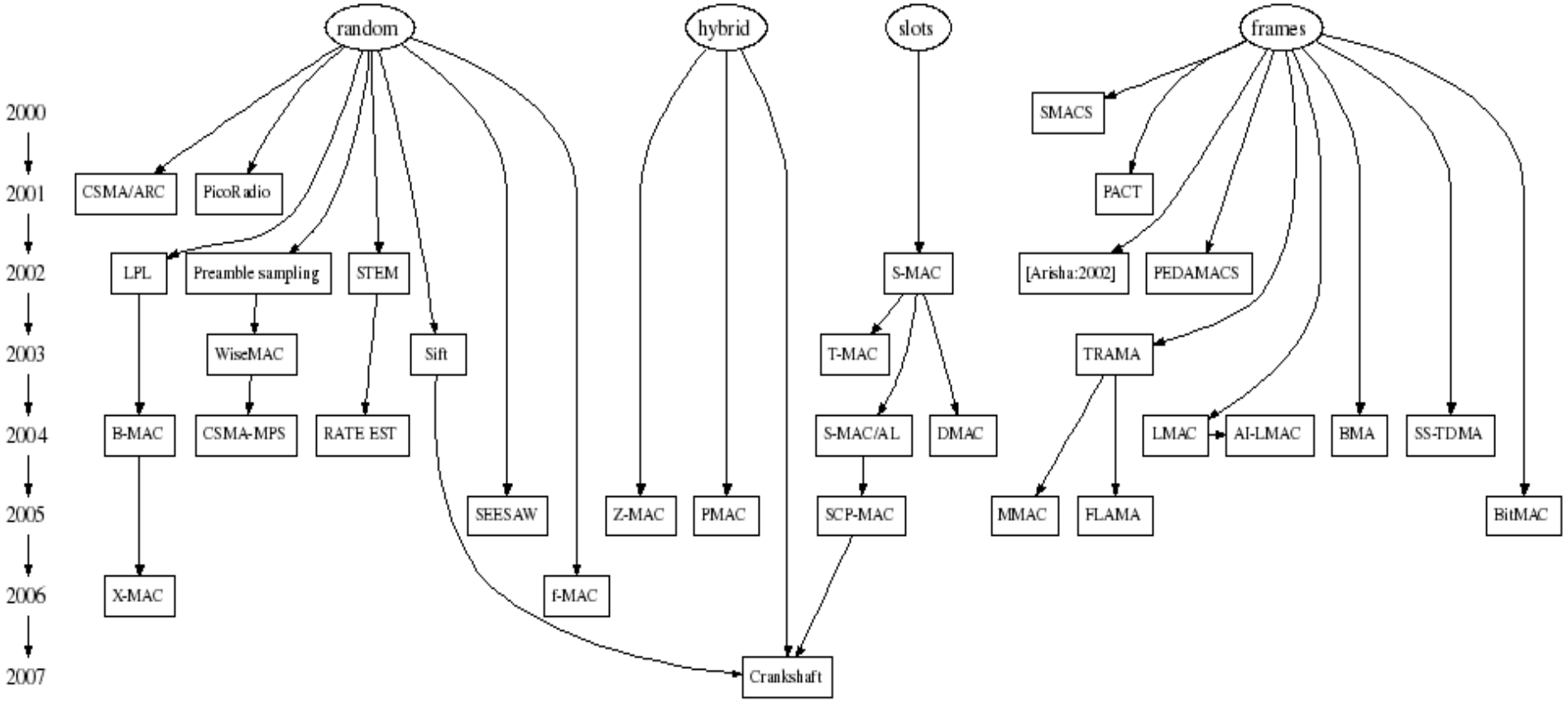
L2: MAC



Constant active-time (SMAC) vs Traffic-Adaptive dynamic active time (TMAC)

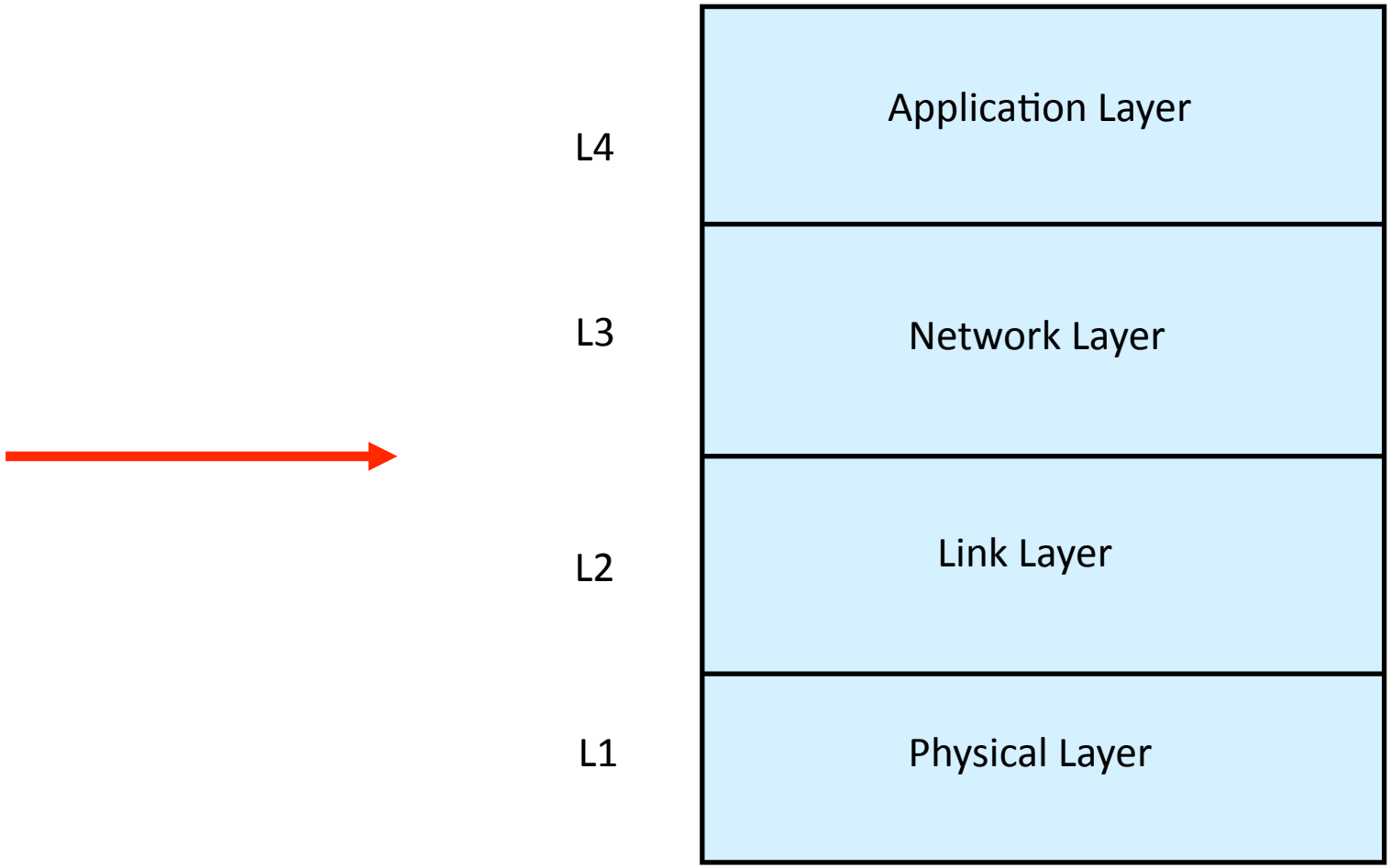
Classic Paper: S-MAC (UCLA)

L2: MAC

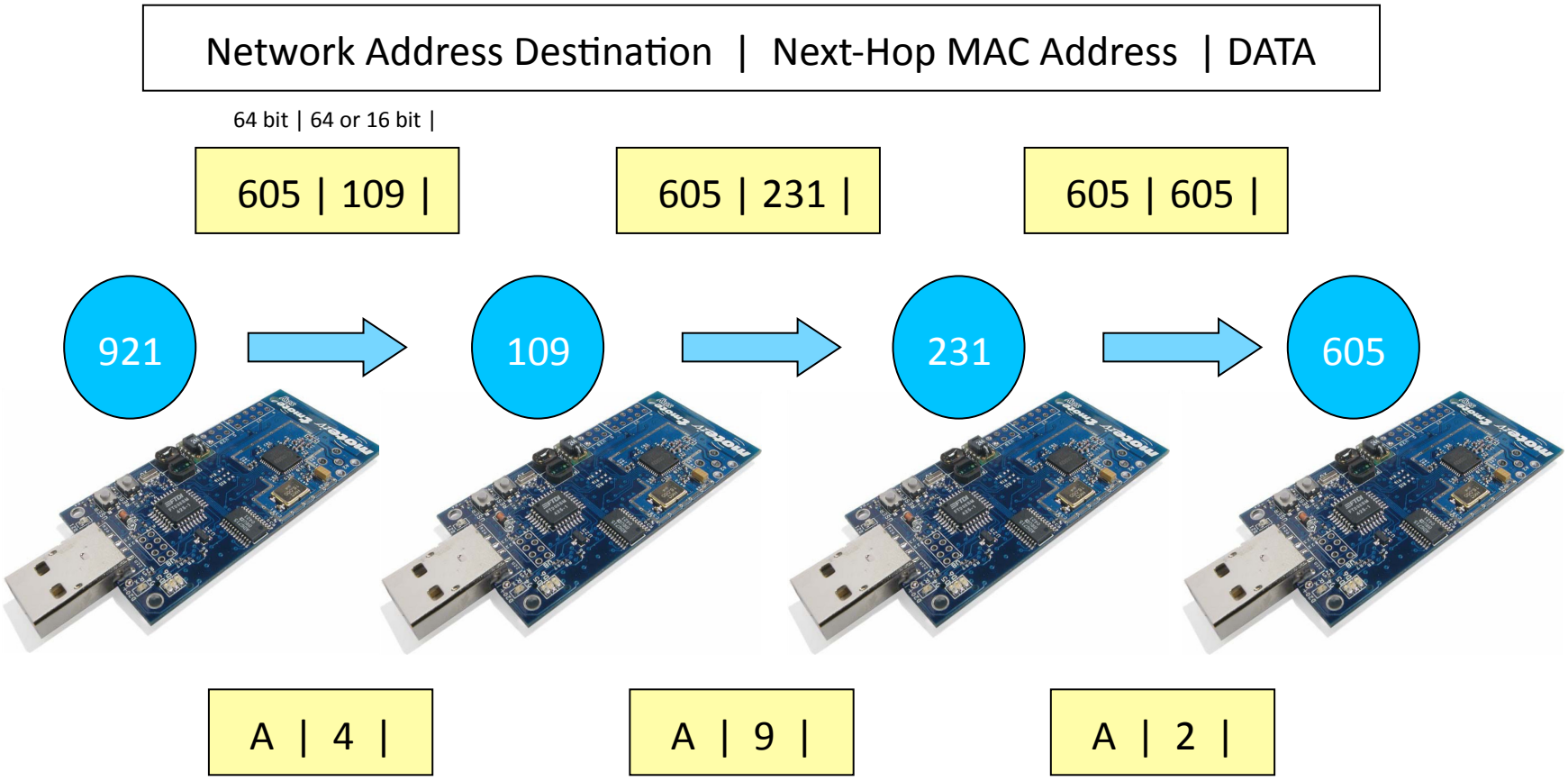


Read: MAC Survey by Koen Langendoen

Network Stack

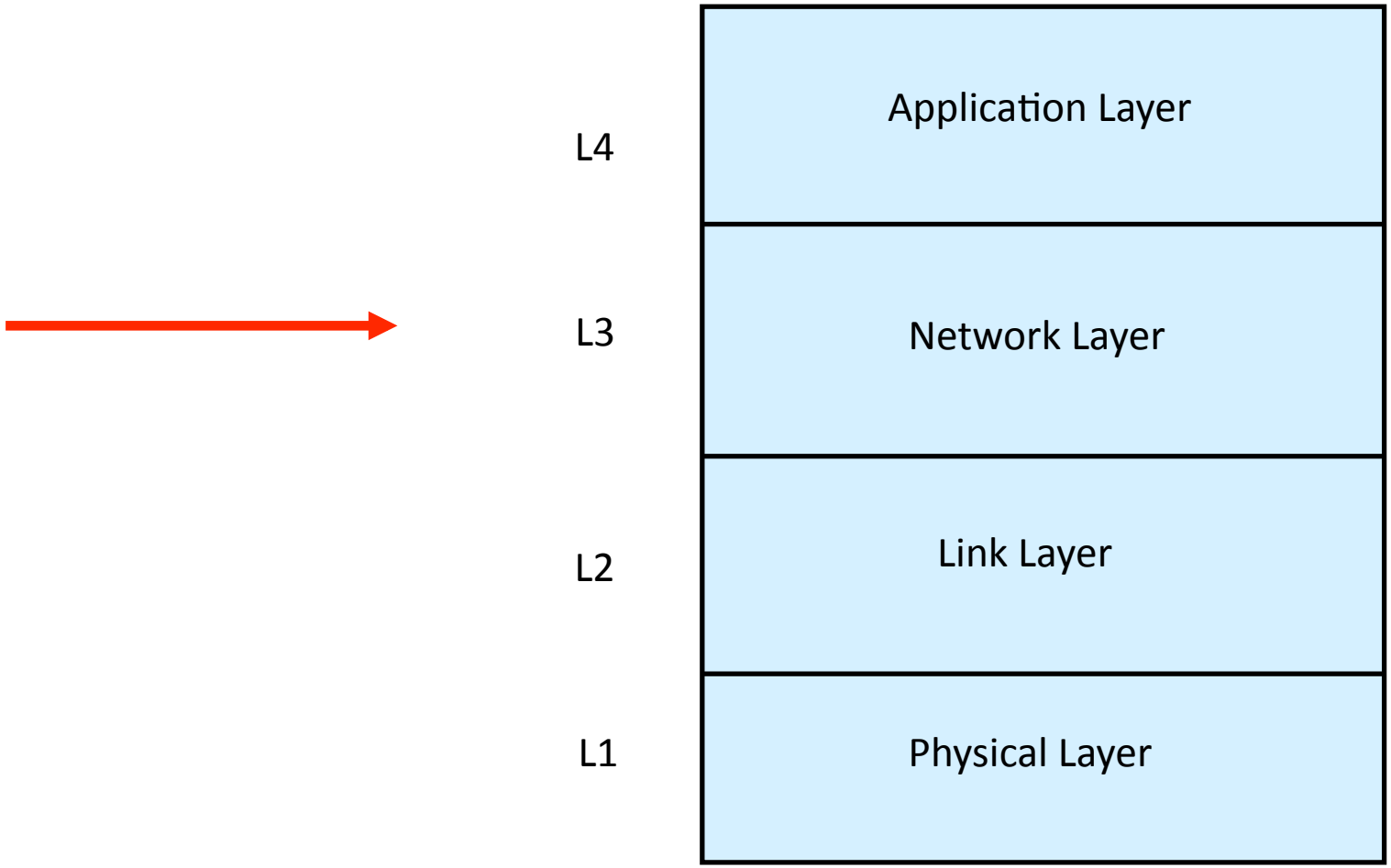


L2/L3: Naming and Addressing

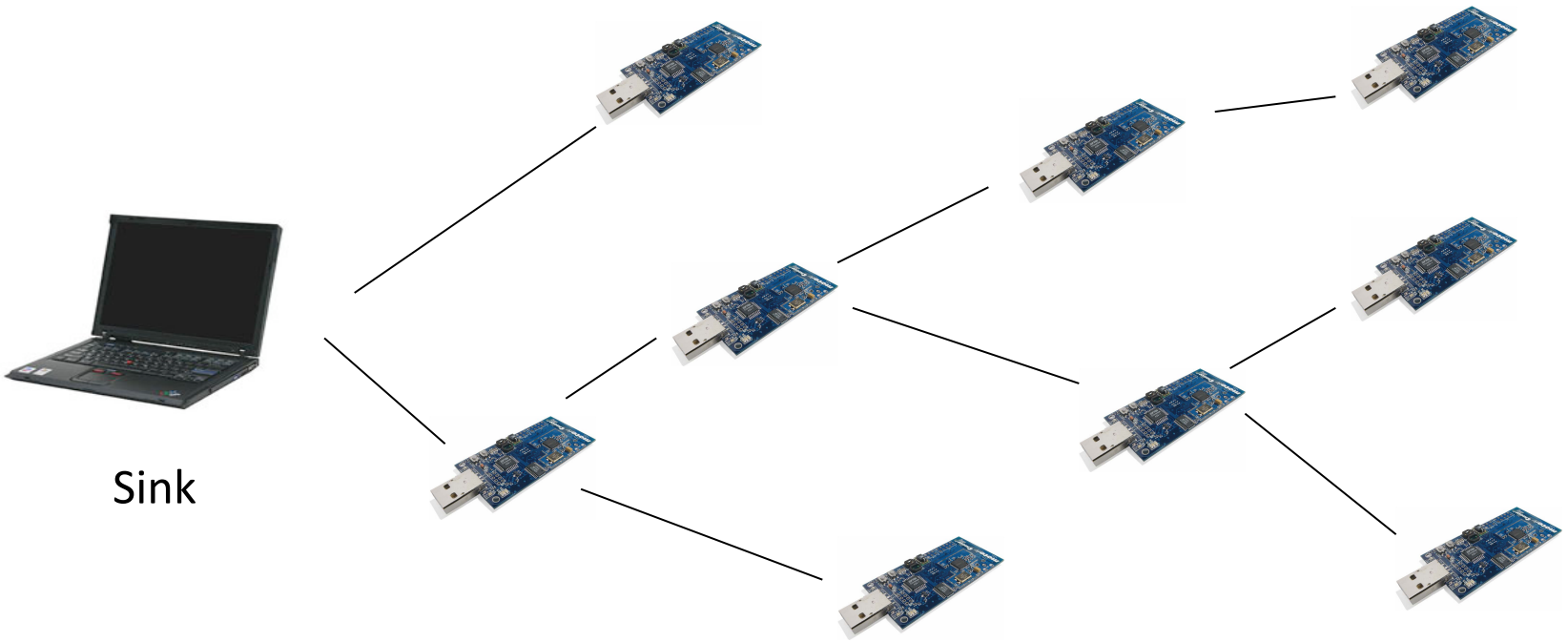


Read: 'Low-level Naming' paper (UCLA)

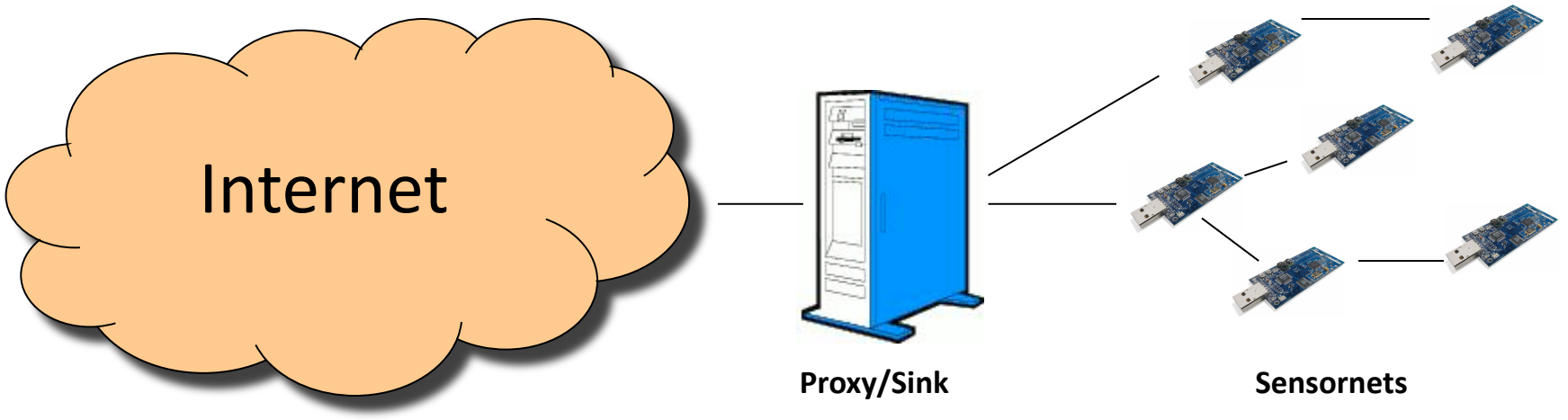
Network Stack



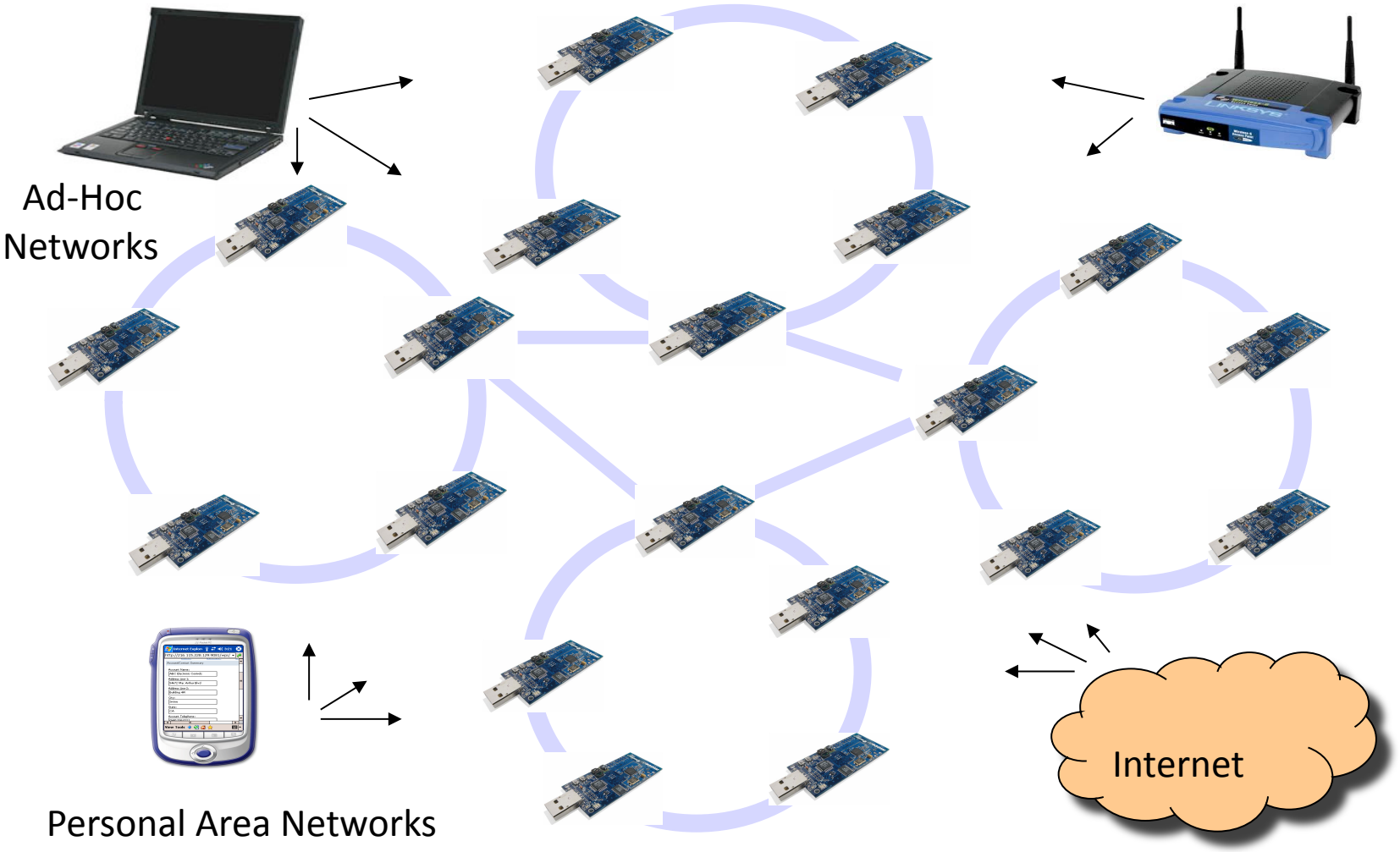
L3: Traditional View



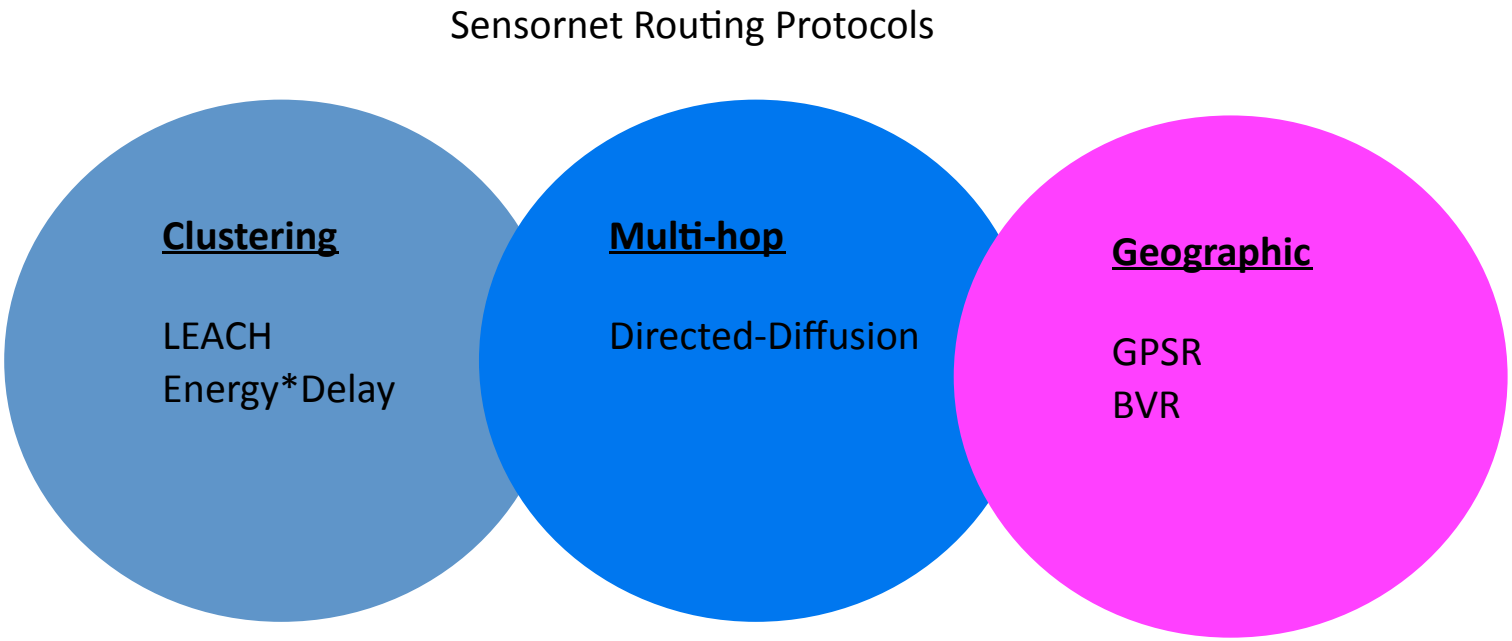
L3: Traditional View



L3: New View



L3: Routing


Sensornet Routing Protocols
Clustering
LEACH
Energy*Delay
Multi-hop
Directed-Diffusion
Geographic
GPSR
BVR

L3: Routing - LEACH

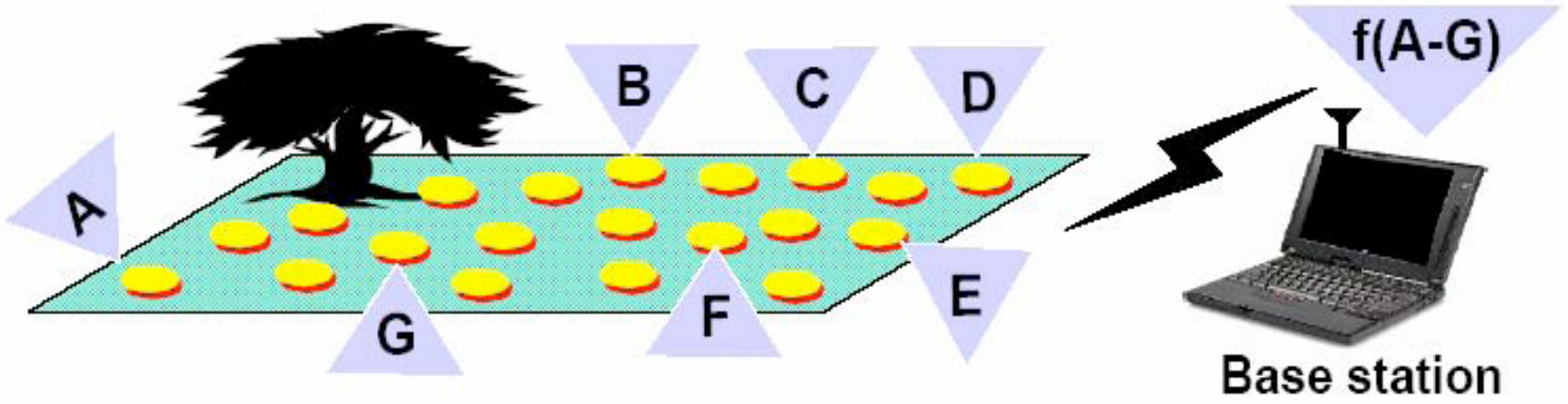
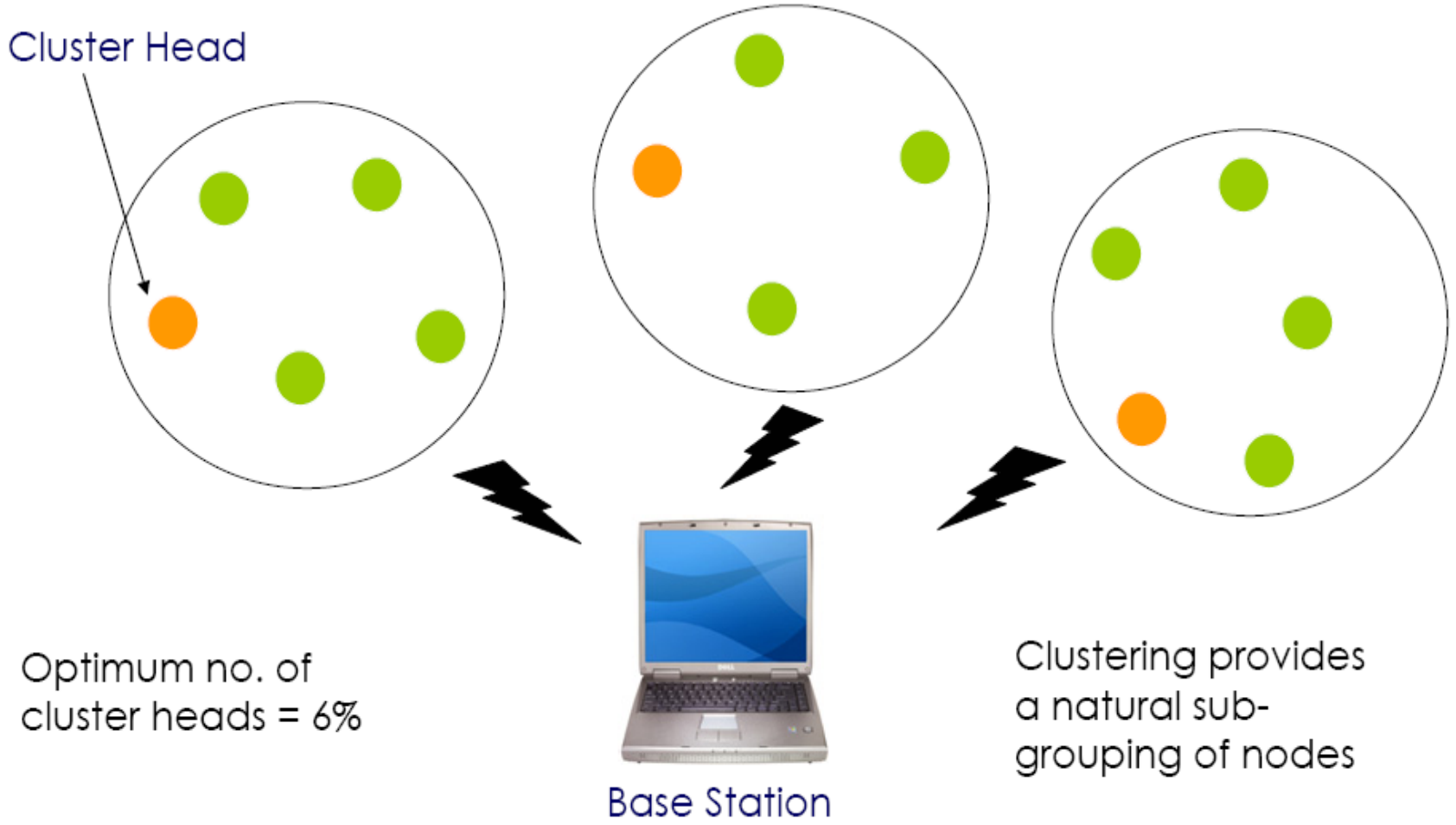


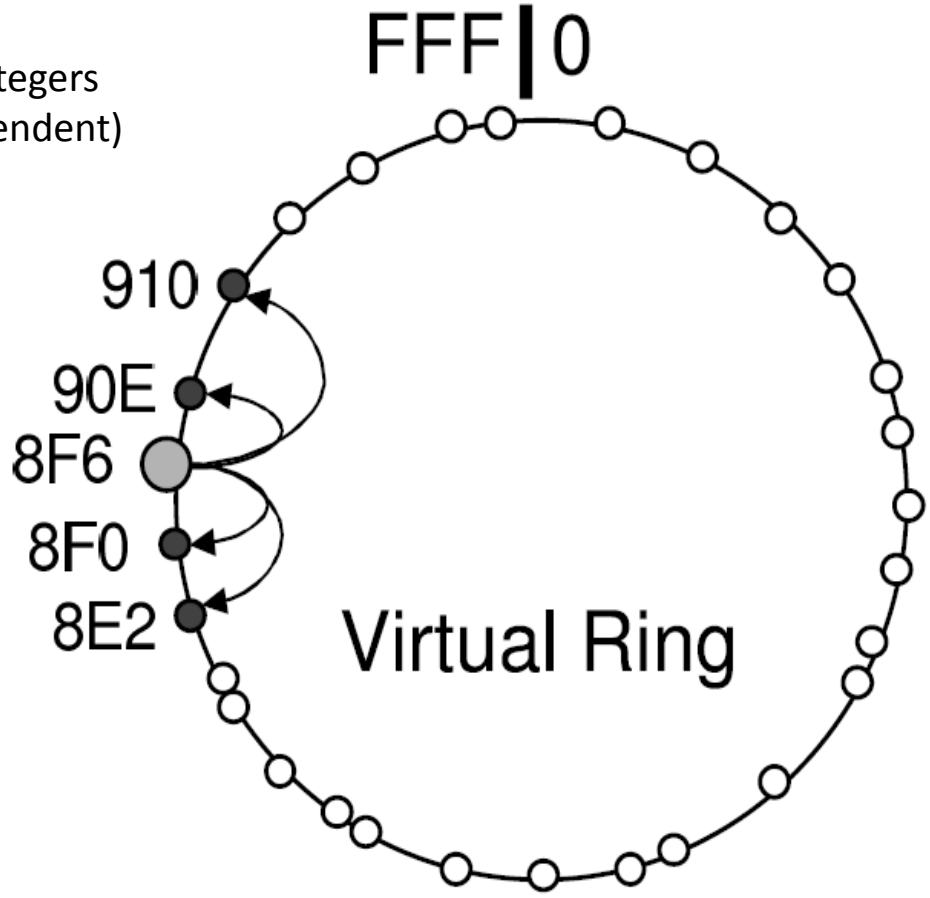
Image courtesy of Wendi Heinzelman

L3: Routing - LEACH

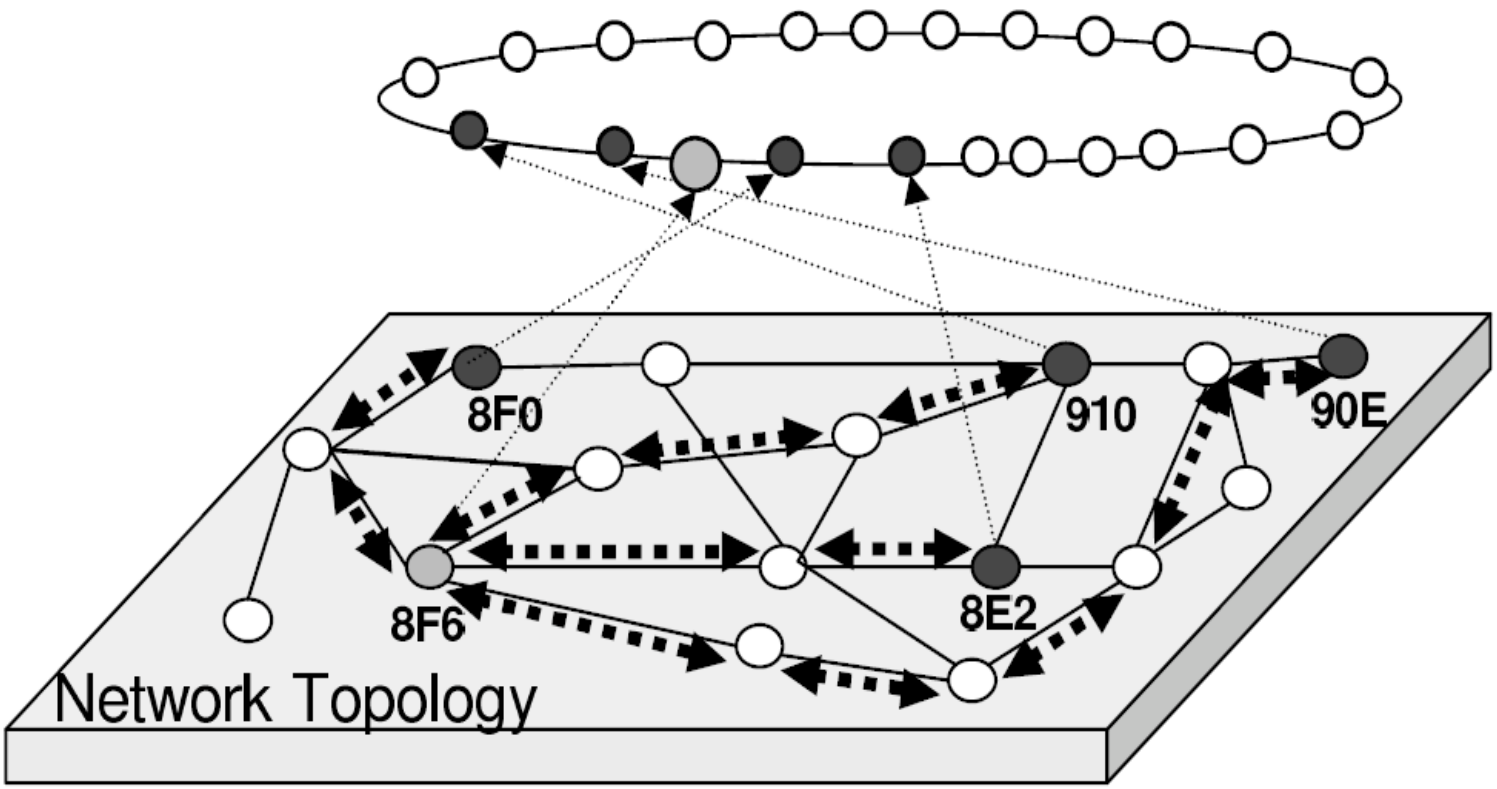


L3: Routing - VRR

Node IDs are Integers
(location independent)



L3: Routing - VRR



Operating Systems

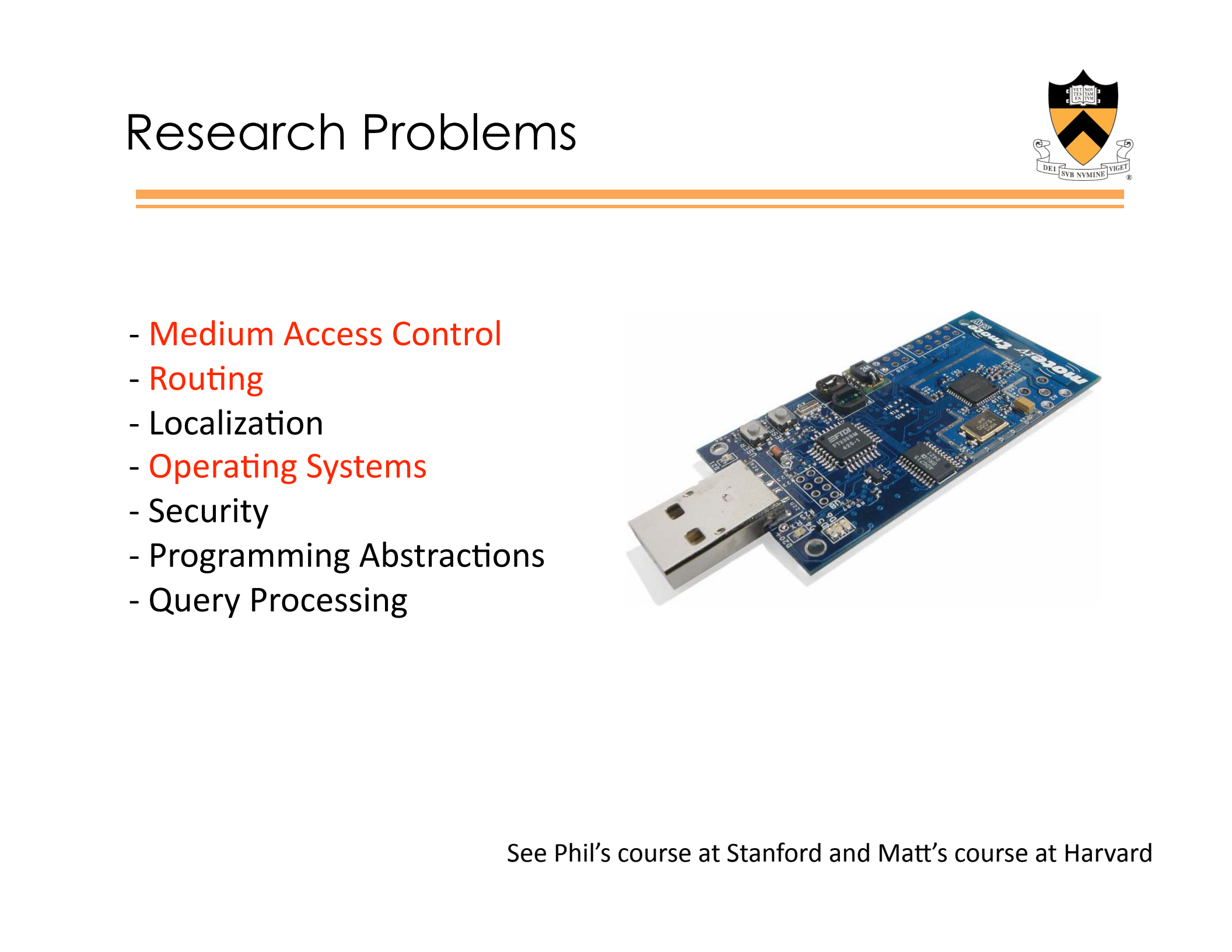
Contiki

MANTIS

SOS

Read: TinyOS book chapter by Phil Levis

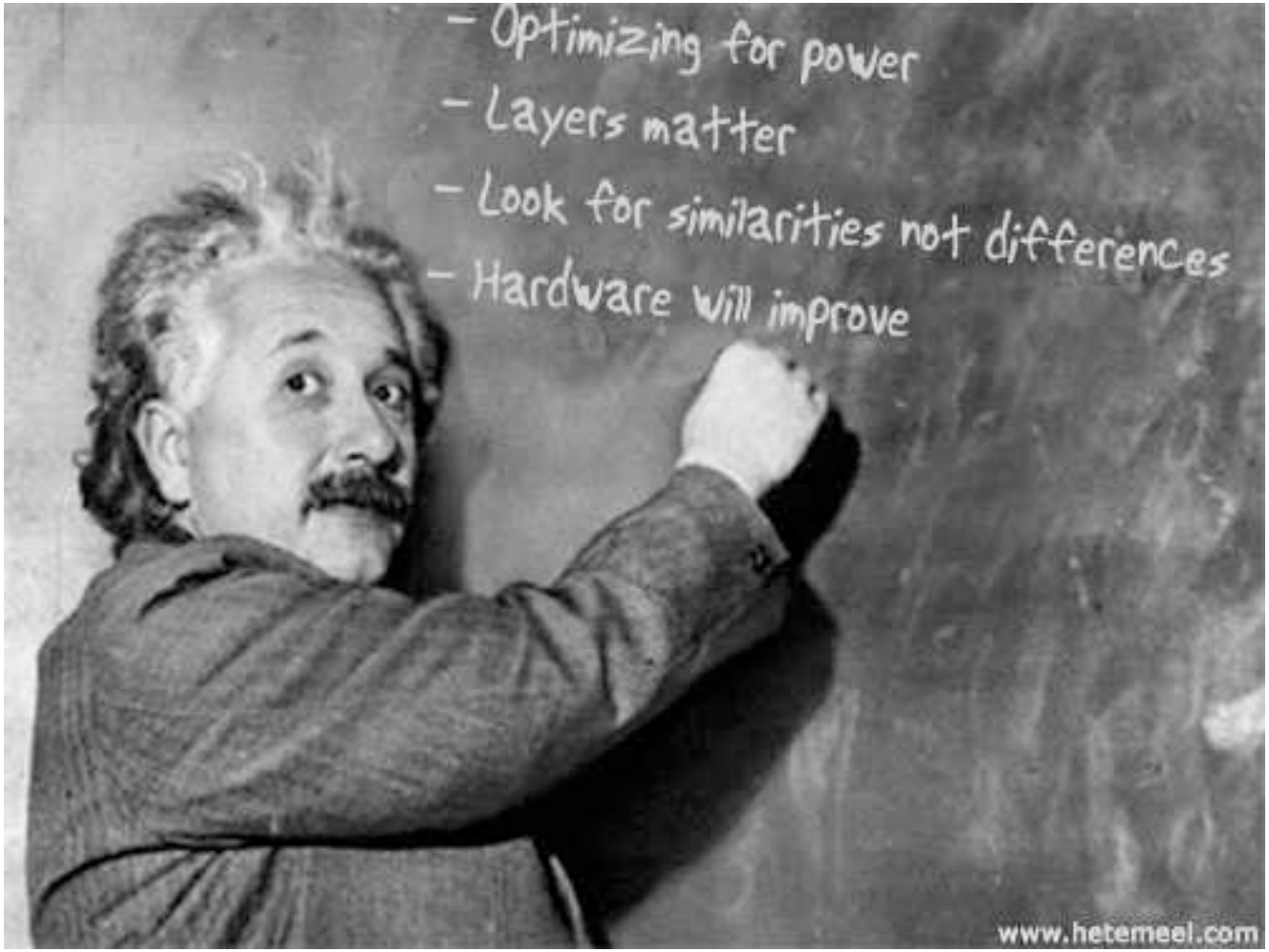
Research Problems



- Medium Access Control
- Routing
- Localization
- Operating Systems
- Security
- Programming Abstractions
- Query Processing

See Phil's course at Stanford and Matt's course at Harvard

What We Have Learned



Where Do We Go From Here

- RFID sensors (Moore's Law)

- Internet citizens (1st class)

- Urban Sensing

- Energy Management (Ember)

- Physical Sensing (Industry, Home)

- Startups

sentilla

Crossbow® TECHNOLOGY INC.

ember

Further Information

Muneeb Ali

http://muneeb.org

Thank You !