Towards the Internet of Everything…

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CS162 – Operating Systems and Systems Programming

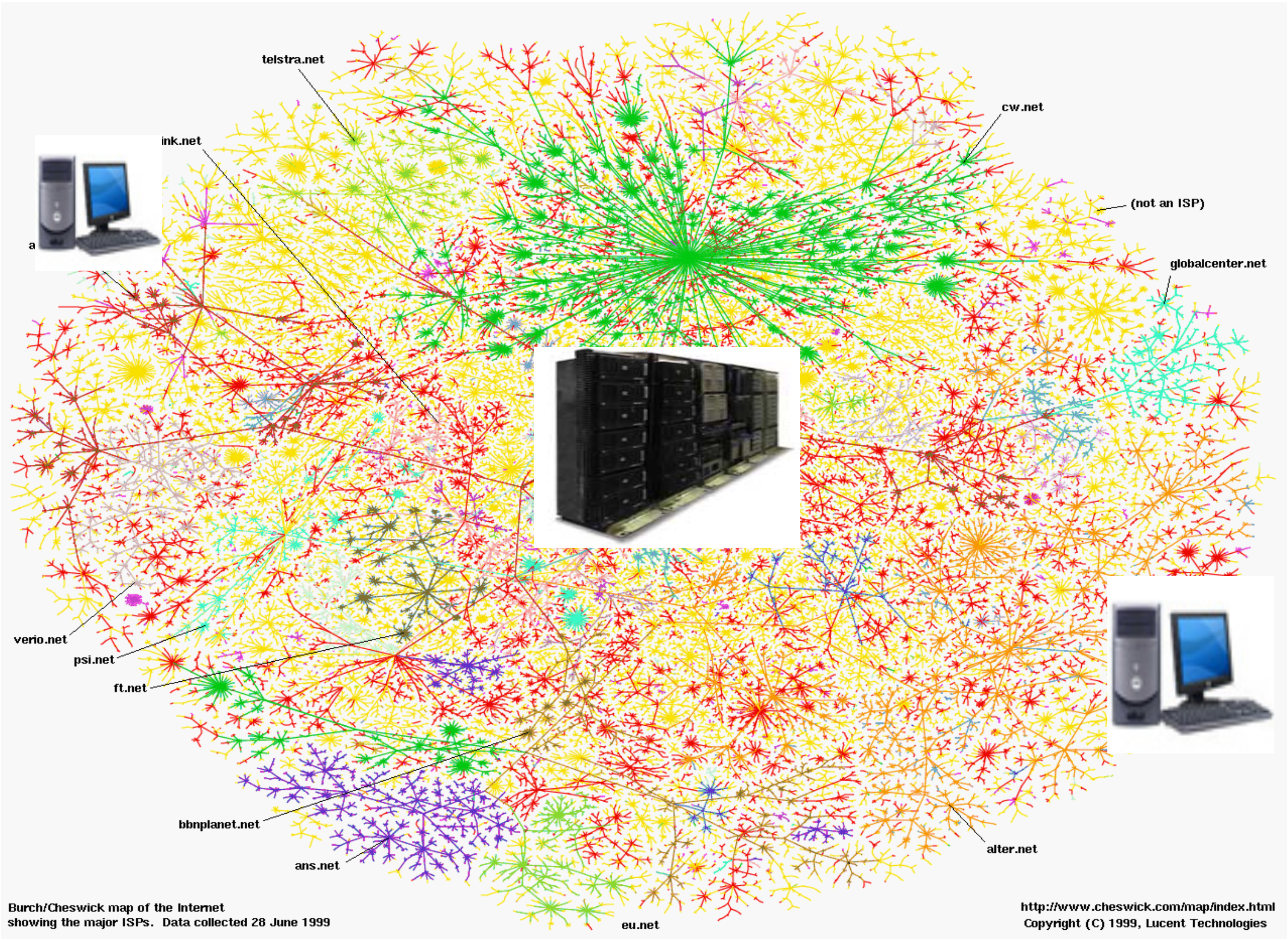
http://cs162.eecs.berkeley.edu/

Lecture 41

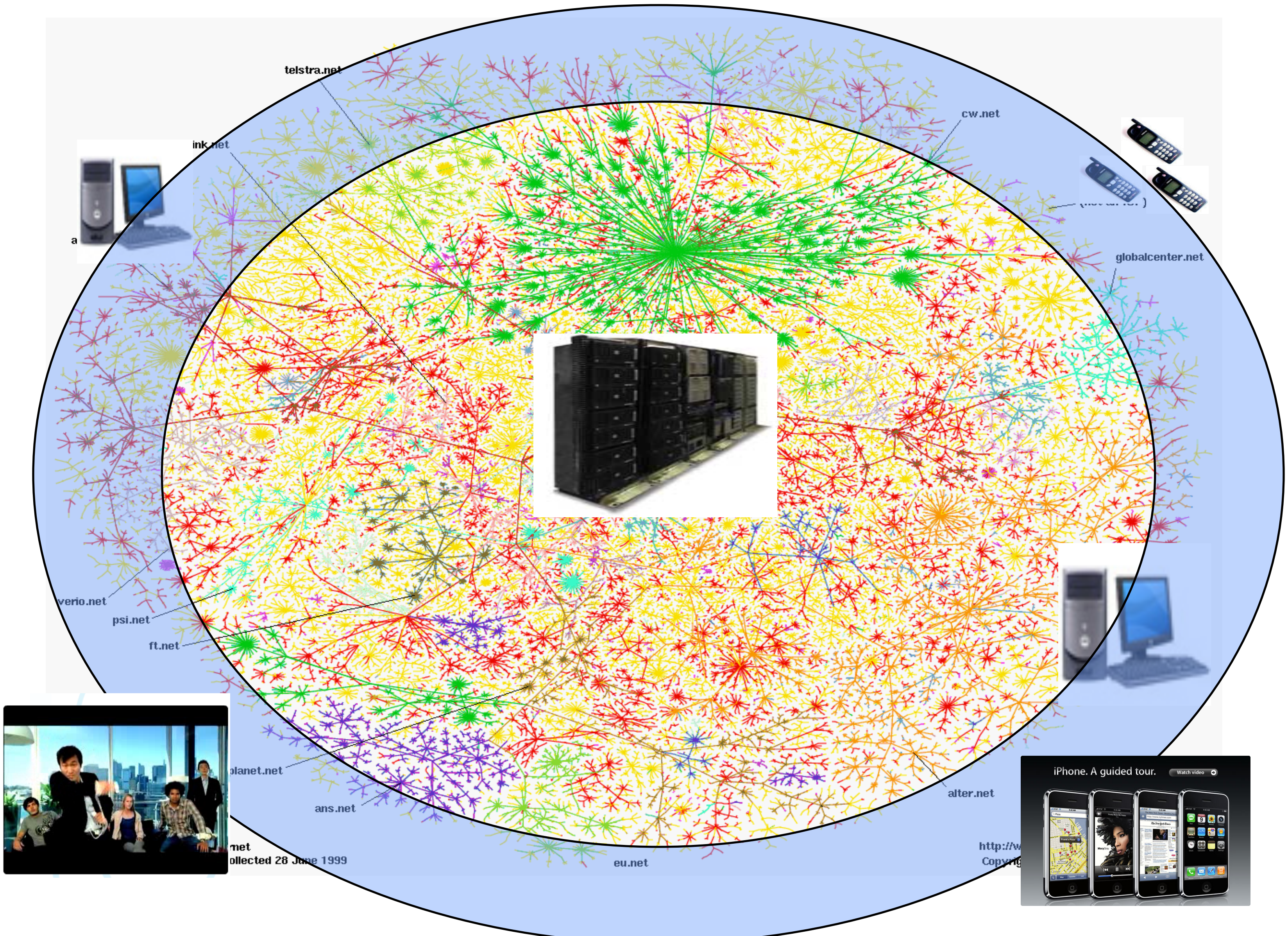
December 5, 2014

8

1997 - The Internet of Every Computer

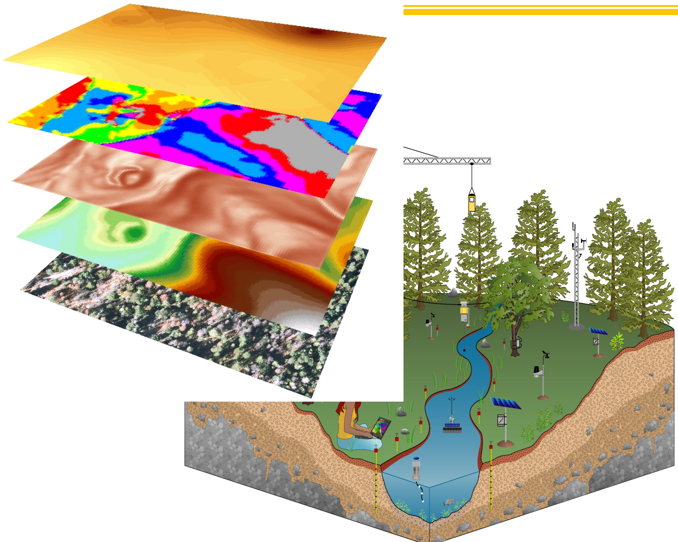


2007 - The Internet of Every Body



2017 - The Internet of Everyday Things

Why "Real" Information is so Important



Enable New Knowledge

Save Resources

Improve Productivity

Increase Comfort

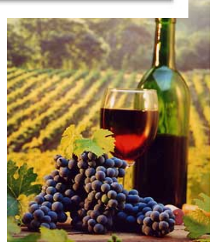
Enhance Safety & Security

Preventing Failures

High-Confidence Transport

Protect Health

Improve Food & H20



2013

telstra.net
sprintlink.net
att.net
bbnplanet.net
ans.net
eu.net
alter.net
other ISPs
Burch/Cheswick map of the Internet
showing the major ISPs. Data collected 28 June 1999
http://www.cheswick.com/map/index.html
Copyright (C) 1999, Lucent Technologies
PHILIPS
I WANT / JE VEUX
hue
PERSONAL WIRELESS LIGHTING
My Lights

2014

COOPER Wiring Devices

Enjoy Wireless Plug-In Lighting or Appliance Control

Cooper Wiring Devices RF9505-TDS ASPIRE RF 15A Split Control Duplex Receptacle - Desert Sand

Add Z-Wave Control to Your Incandescent or Fluorescent Appliances

GE 45605 Z-Wave Wireless Lighting Control Duplex Receptacle

2013

2014


Honeywell
Gemeten
Instelling
20.5
19.0
14:38


12:15
70
62
TARGET TEMP
HEAT
MENU
PROG


70
Solidyne


70
COOL
NETWORK
thermostat


ROOM TEMPERATURE
67
70
ON/OFF
AUTO MODE
AUTO FAN
F/C


AKE
25.0℃


55°
65°
72
85°
95°
72°
Current
Cool
Fan Auto
Weather
Quick Save
Details
Program
More
ecobee

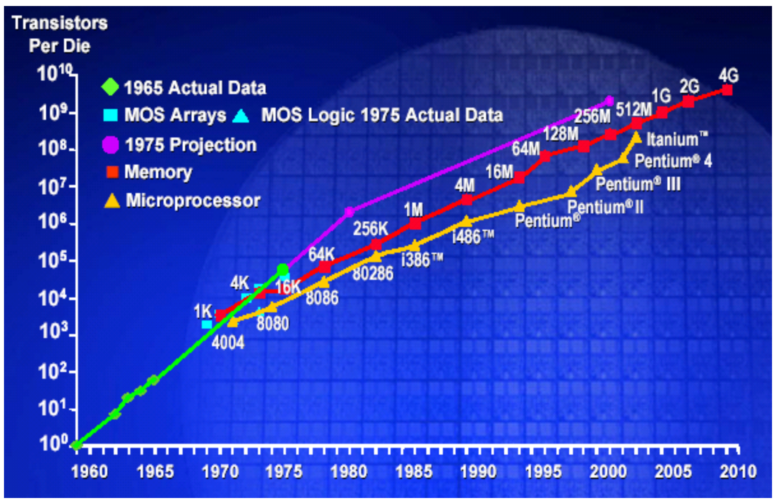

72

2014

2014 Will Be The Year Of Wearable Technology

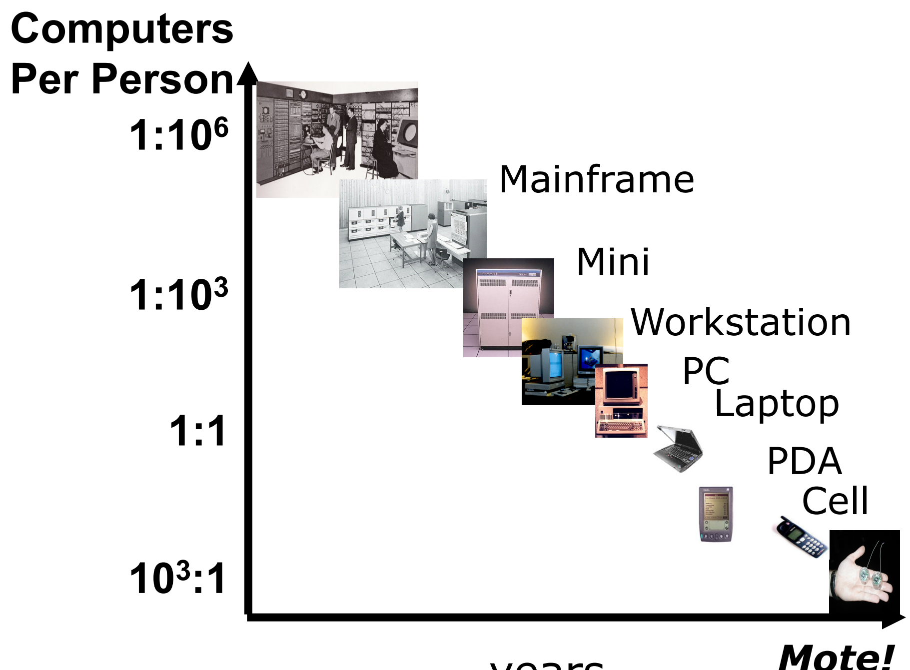
Broad Technology Trends

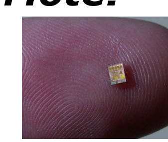
Moore's Law: # transistors on cost-effective chip doubles every 18 months



Today: 1 million transistors per $

Bell's Law: a new computer class emerges every 10 years





Same fabrication technology provides CMOS radios for communication and micro-sensors

‘Low-Tech’ Enabling Technology

Microcontroller

Flash Storage

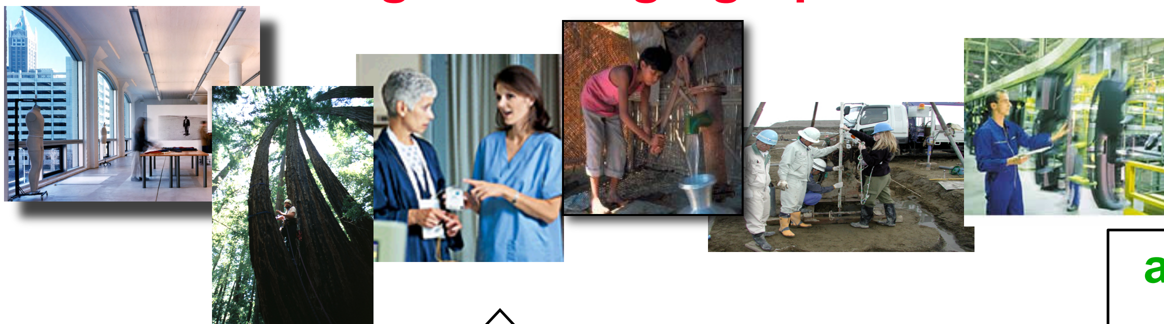
Radio Communication

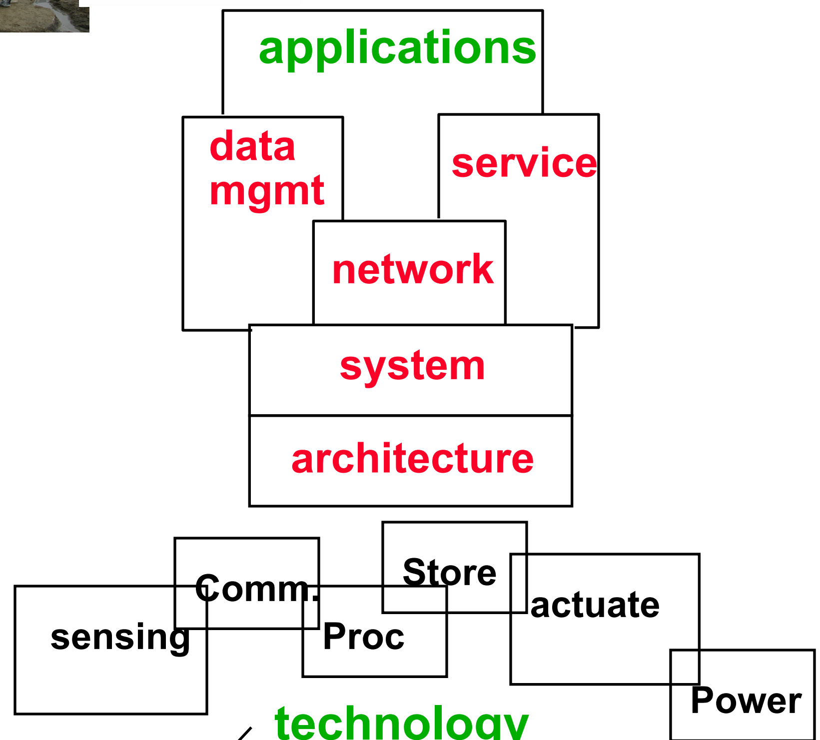
Sensors

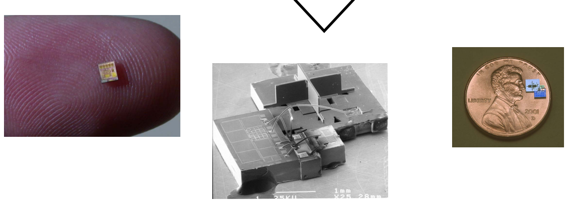
IEEE 802.15.4

The Systems Challenge

Monitoring & Managing Spaces and Things







Miniature, low-power connections to the physical world

Leading Internet Research Perspective ~ 1999

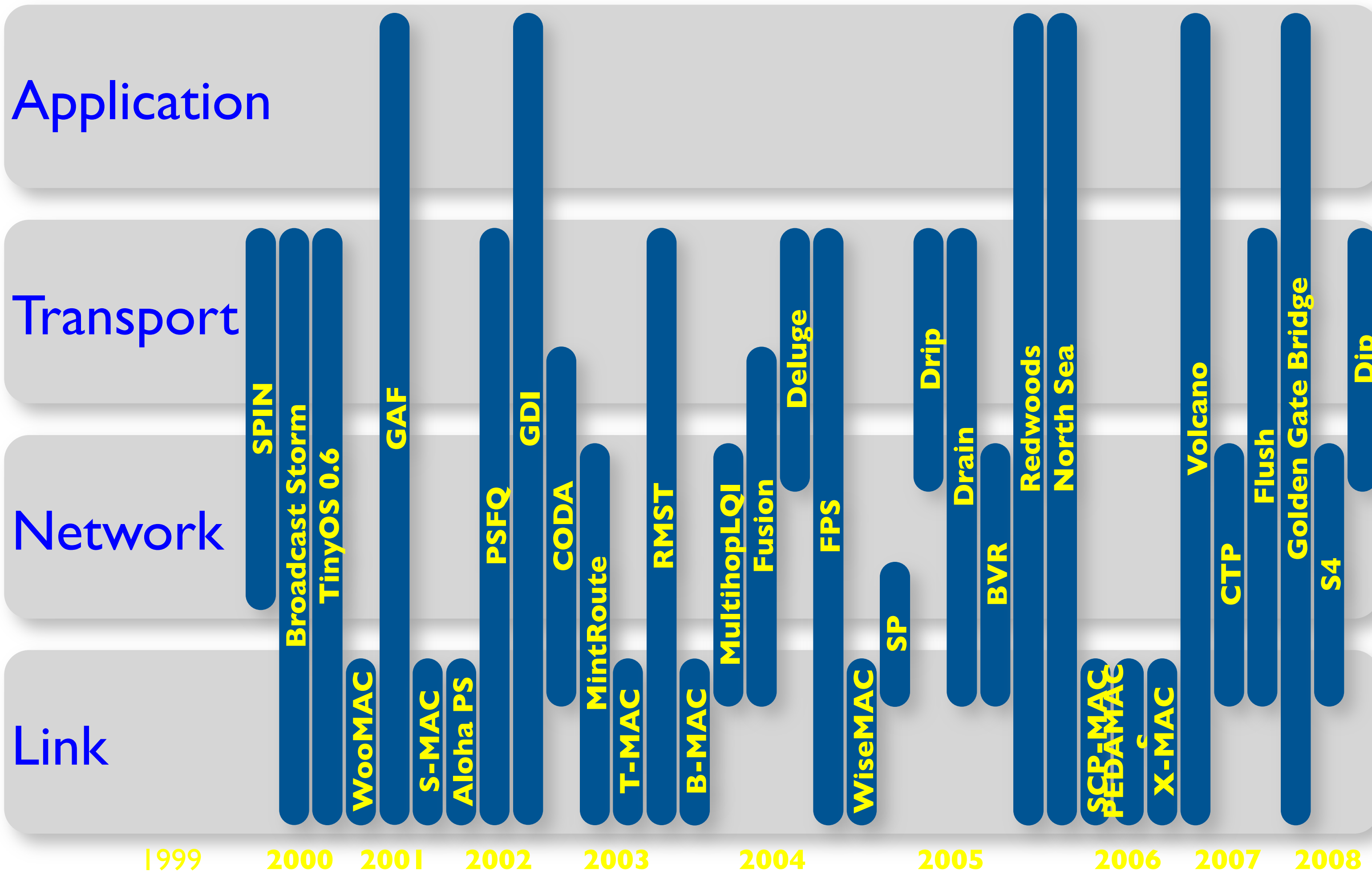
- "Resource constraints may cause us to give up the layered architecture."
- "Sheer numbers of devices, and their unattended deployment, will preclude reliance on broadcast communication or the configuration currently needed to deploy and operate networked devices."
- "There are significant robustness and scalability advantages to designing applications using localized algorithms."
- "Unlike traditional networks, a sensor node may not need an identity (e.g. address)."
- "It is reasonable to assume that sensor networks can be tailored to the application at hand."

We were wrong…

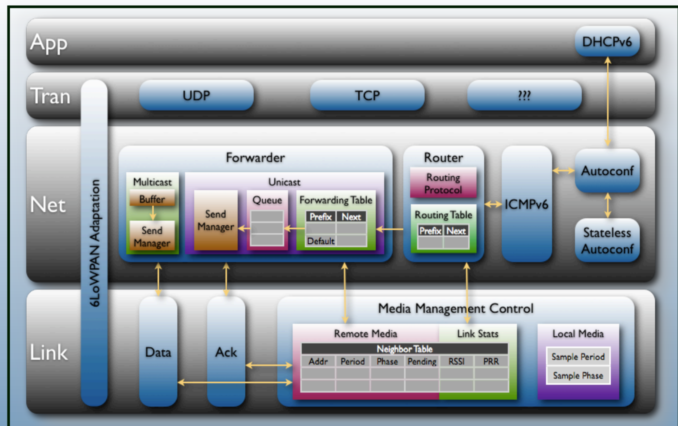
Key WSN Research Developments

- Event-Driven Component-Base Operating System
  – Framework for building System & Network abstractions
  – Low-Power Protocols
  – Hardware and Application Specific
- Idle listening
  – All the energy is consumed by listening for a packet to receive
  => Turn radio on only when there is something to hear
- Reliable routing on Low-Power & Lossy Links
  – Power, Range, Obstructions => multi-hop
  – Always at edge of SNR => loss is common
  => monitoring, retransmission, and local rerouting
- Trickle – don't flood (tx rate < 1/density, and < info change)
  – Connectivity is determined by physical points of interest, not network designer.
  – never naively respond to a broadcast
  – re-broadcast very very politely

Decade of Networking (sans Architecture)



Internet of Every Thing – Realized 2008



24038 ROM

3598 RAM

(including runtime)

* Production implementation on TI msp430/cc2420

- **Footprint, power, packet size, & bandwidth**
- **Open version 27k / 4.6k**

	ROM	RAM
CC2420 Driver	3149	272
802.15.4 Encryption	1194	101
Media Access Control	330	9
Media Management Control	1348	20
6LoWPAN + IPv6	2550	0
Checksums	134	0
SLAAC	216	32
DHCPv6 Client	212	3
DHCPv6 Proxy	104	2
ICMPv6	522	0
Unicast Forwarder	1158	451
Multicast Forwarder	352	4
Message Buffers	0	2048
Router	2050	106
UDP	450	6
TCP	1674	50

ArchRock

Internet of Every Thing – standardized 2010

ROLL — T. Winter, Ed.
Internet-Draft
Intended status: Standards Track — P. Thubert, Ed.
Expires: April 4, 2011 — Cisco Systems

A. Brandt
Sigma Designs
T. Clausen
LIX, Ecole Polytechnique
J. Hui
Arch Rock Corporation
R. Kelsey
Ember Corporation
P. Levis
Stanford University
K. Pister
Dust Networks
R. Struik

JP. Vasseur
Cisco Systems
October 1, 2010

RPL: IPv6 Routing Protocol for Low power and Lossy Networks
draft-ietf-roll-rpl-12

Abstract

Low power and Lossy Networks (LLNs) are a class of network in which both the routers and their interconnect are constrained. LLN routers

2008-02-15 charter

Routing Over Low power and Lossy networks (roll)

Charter

Current Status: Active Working Group

Chair(s):
JP Vasseur <jpv@cisco.com>
David Culler <culler@eecs.berkeley.edu>

IPSO Alliance
Enabling the INTERNET OF THINGS

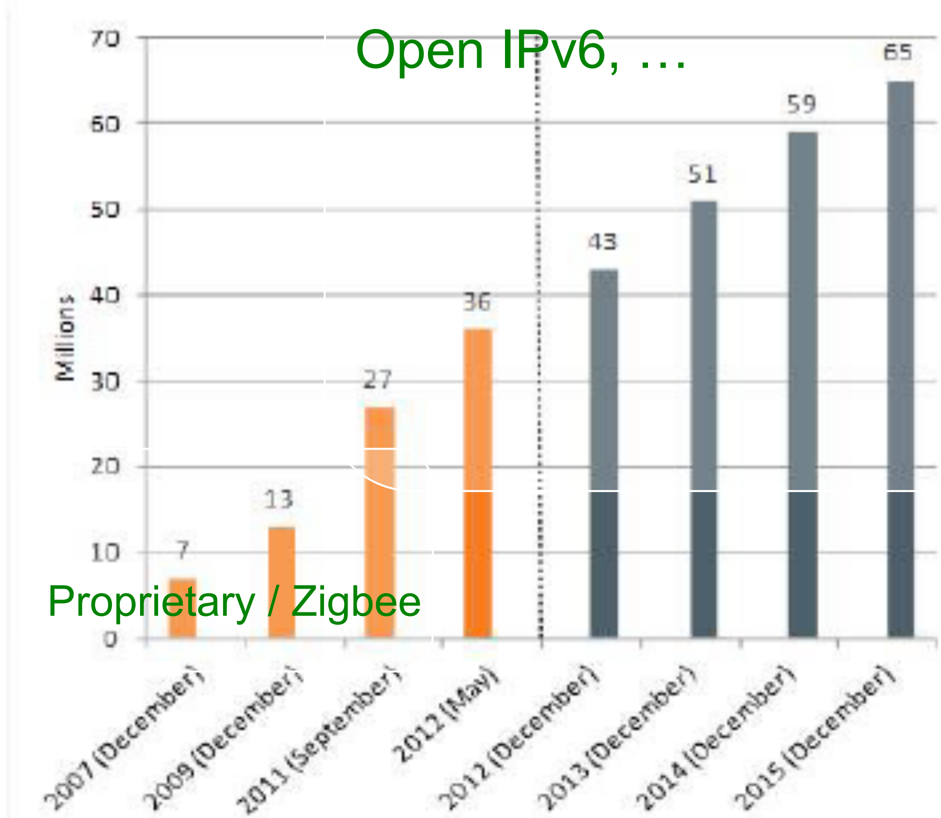
ZigBee® Alliance

ZigBee Smart Energy Version 2.0 Documents

ZigBee Smart Energy version 2.0 will be IP-based and offer a variety of new features.

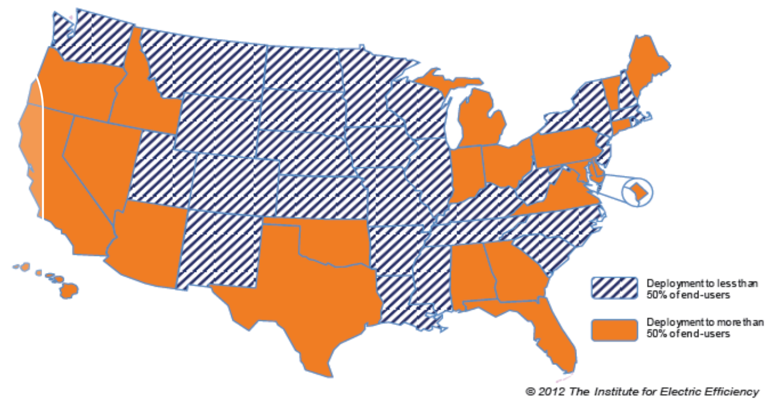
ISA

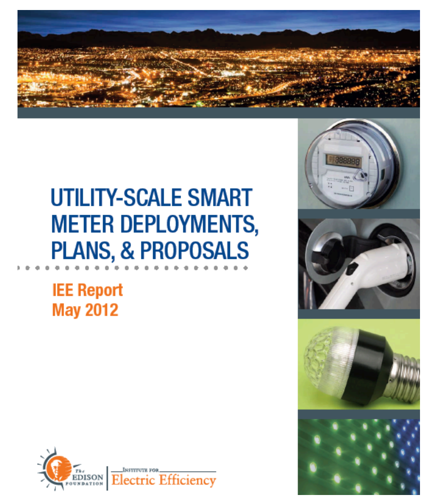
Smart meter rollouts



Source: Institute for Electric Efficiency, Federal Energy Regulatory Commission[2]

Figure 2. Expected Smart Meter Deployments by State by 2015



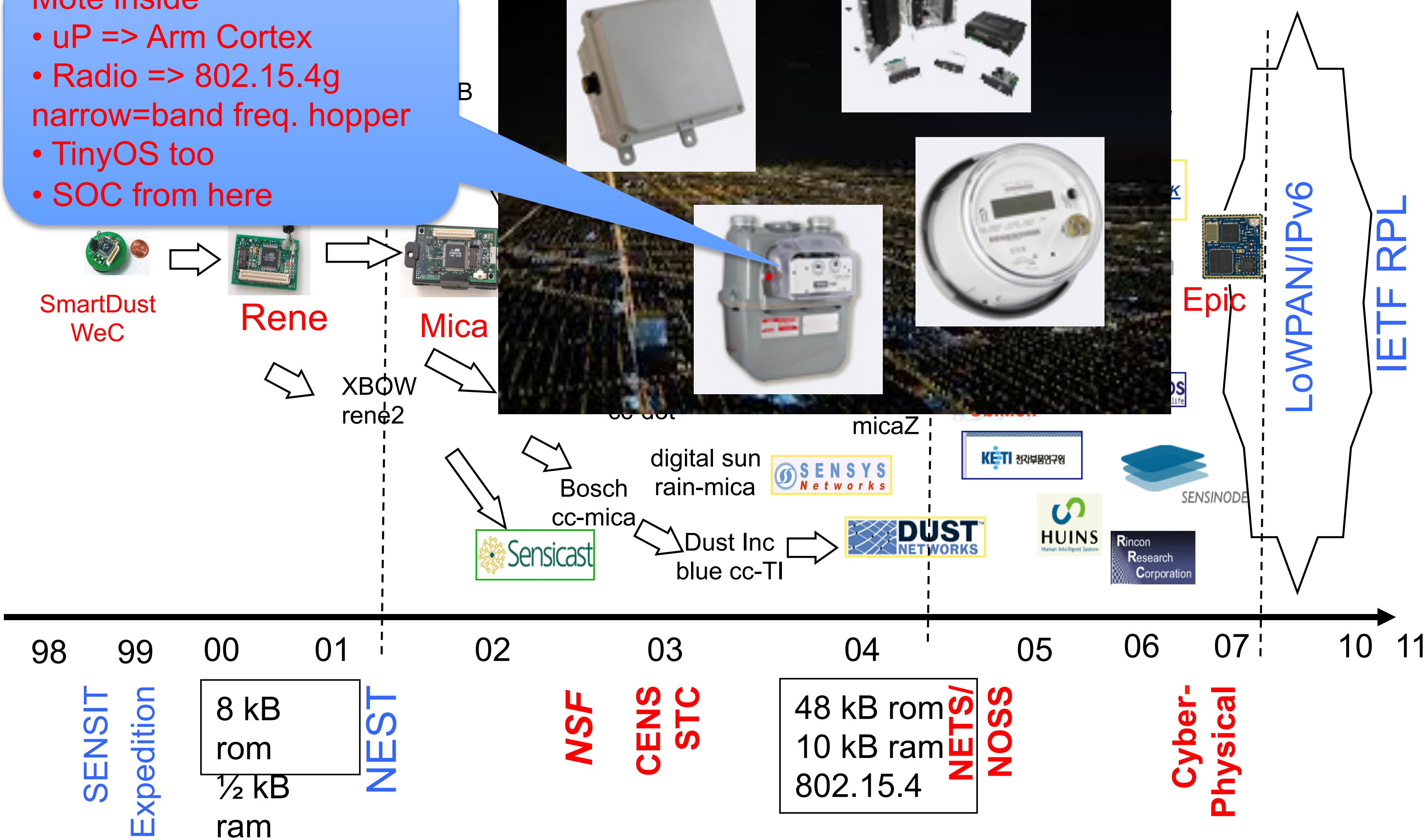


http://www.edisonfoundation.net/iee/Documents/IEE_SmartMeterRollouts_0512.pdf

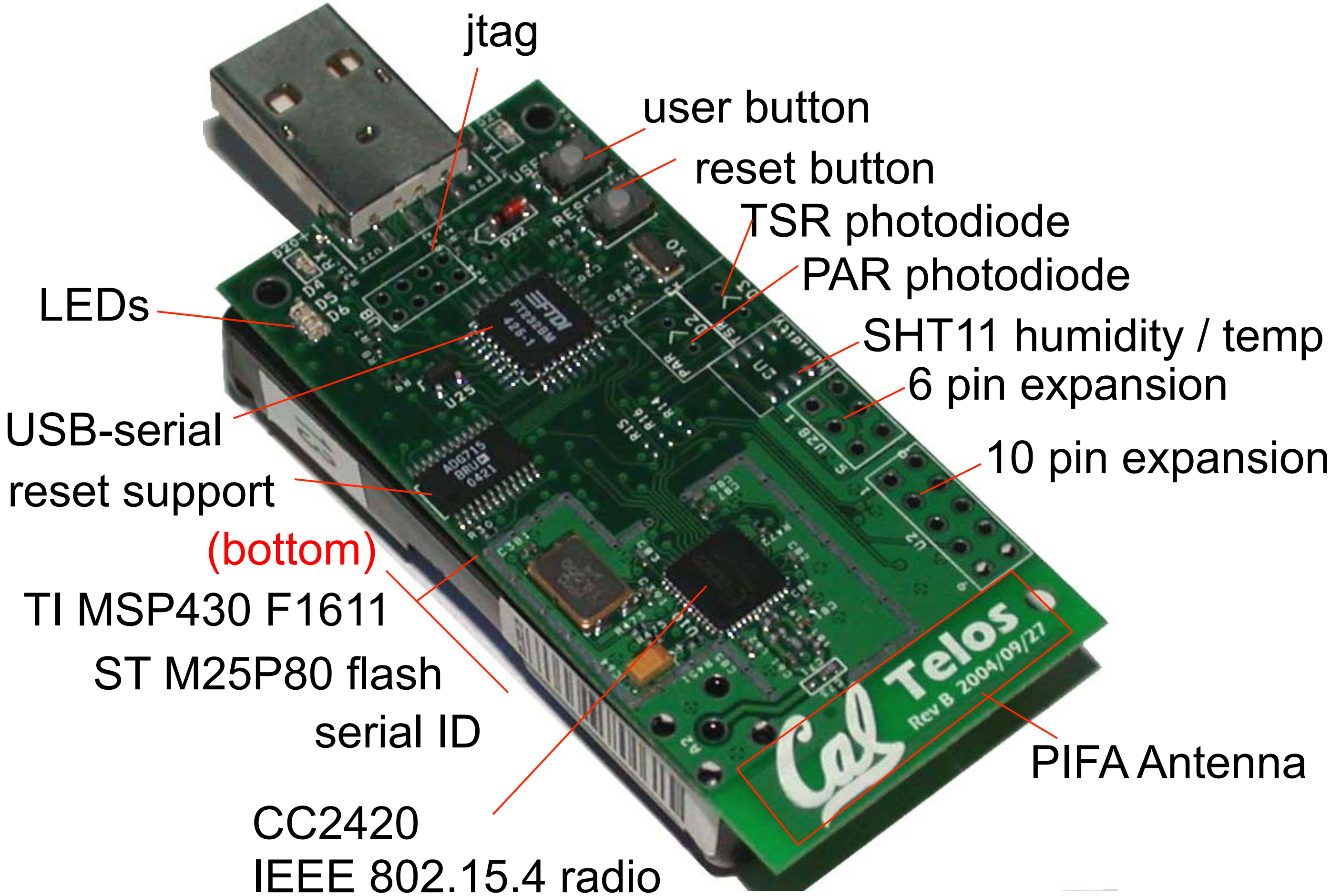
Hardware

The Mote/TinyOS revolution…

Mote inside
- uP => Arm Cortex
- Radio => 802.15.4g narrow=band freq. hopper
- TinyOS too
- SOC from here



Example 2004 Mote: TelosB



Microcontrollers

48K ROM
10K RAM

250 kbps

Mote Type Year	WeC 1998	René 1999	René 2000	Dot 2000	Mica 2001	Mica2Dot* 2002	Mica2* 2002	Telos 2004
Microcontroller								
Type	AT90LS8535		ATmega163		ATmega128			TI MSP430
Progra	8		16		128			48
RAM (	0.5		1		4			10
Active P	15		15		8		33	3
Sleep Power (μW)	45		45		75		75	15
Wakeup Time (μs)	1000		36		180		180	6
Nonvolatile storage								
Chip	24LC256				AT45DB041B			ST M25P80
Connection type	I^2C				SPI			SPI
Size (KB)	32				512			1024
Communication								
Radio	TR1000				TR1000	CC1000		CC2420
Data ra	10				40	38.4		250
Modulation type	OOK				ASK	FSK		O-QPSK
Receive Power (mW)	9				12	29		38
Transmit Power at 0dBm (mW)	36				36	42		35
Power Consumption								
Minimum Operation (V)	2.7		2.7		2.7			1.8
Total Active Power (mW)	24				27	44	89	41
Programming and Sensor Interface								
Expansion	none	51-pin	51-pin	none	51-pin	19-pin	51-pin	16-pin
Communication	IEEE 1284 (programming) and RS232							USB
Integrated Sensors	no	no	no	yes	no	no	no	yes

Mote Characteristics

- **Limited resources**
  - RAM, ROM, Computation, Energy
    - ➔ *Wakeup, do work as quickly as possible, sleep*
- **Hardware modules operate concurrently**
  - No parallel execution of code (not Core 2 Duos!)
    - ➔ *Asynchronous operation is first class*
- **Diverse application requirements**
    - ➔ *Efficient modularity*
- **Robust operation**
  - Numerous, unattended, critical
    - ➔ *Predictable operation*

What we mean by "Low Power"

- 2 AA => 1.5 amp hours (~4 watt hours)
- Cell => 1 amp hour (3.5 watt hours)

Cell: 500 -1000 mW => few hours active
WiFi: 300 - 500 mW => several hours
GPS: 50 – 100 mW => couple days

WSN: 50 mW active, 20 uW passive
450 uW => one year
45 uW => ~10 years

$$\text{Ave Power} = \boxed{f_{act}} * \boxed{P_{act}} + f_{sleep} * \boxed{P_{sleep}} + \boxed{f_{waking}} * P_{waking}$$

* System design

* Leakage (~RAM)

* Nobody fools mother nature

Storm 2014

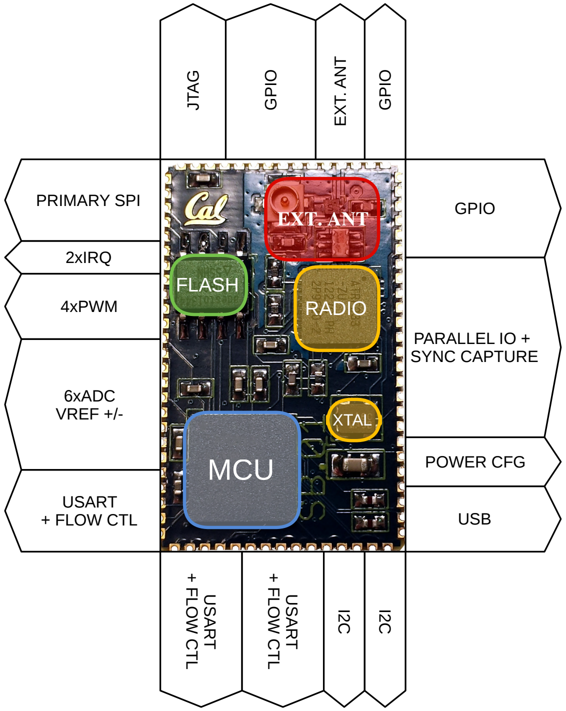
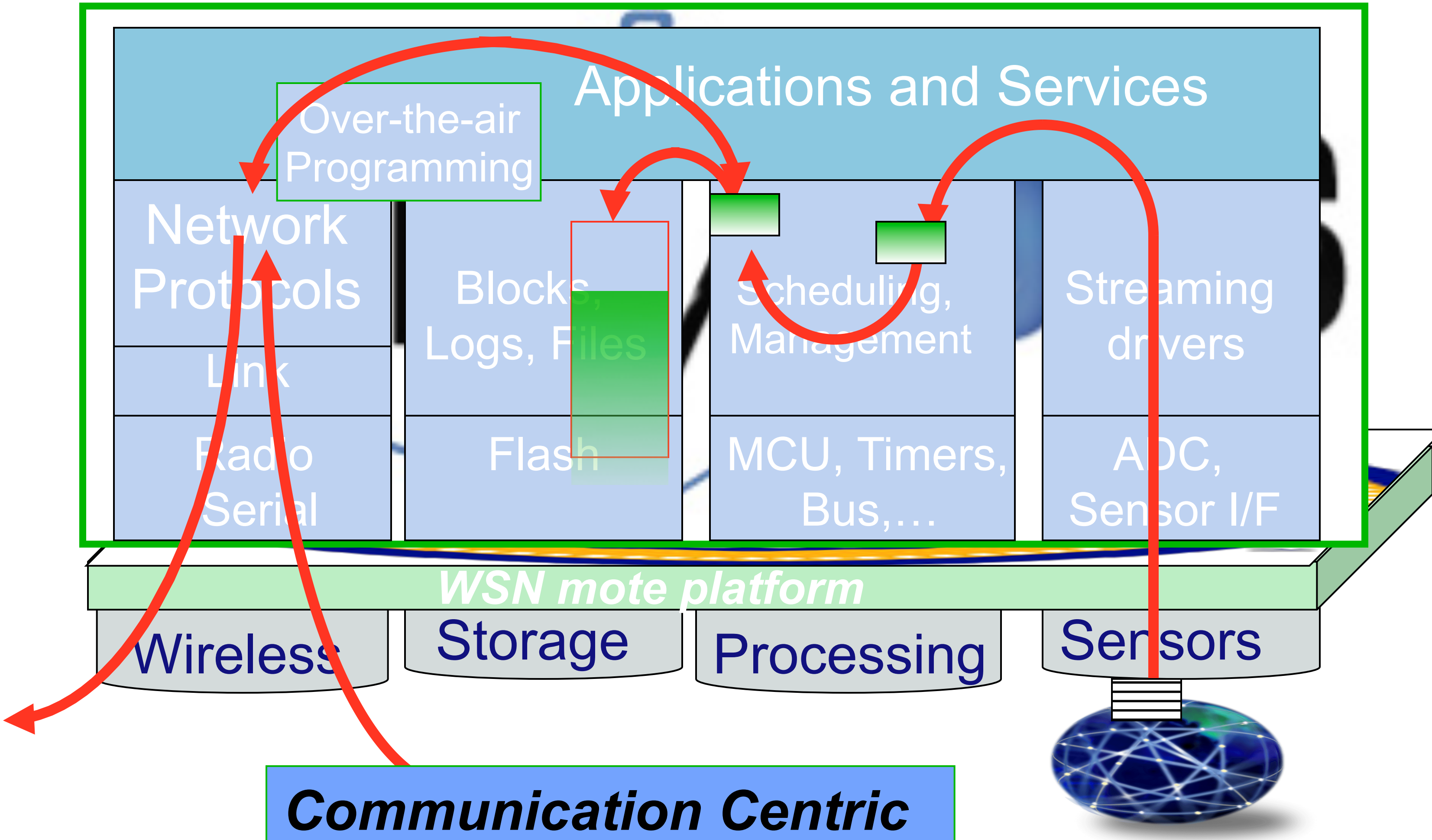


Table 4: A small sample of available Cortex-M4 processors

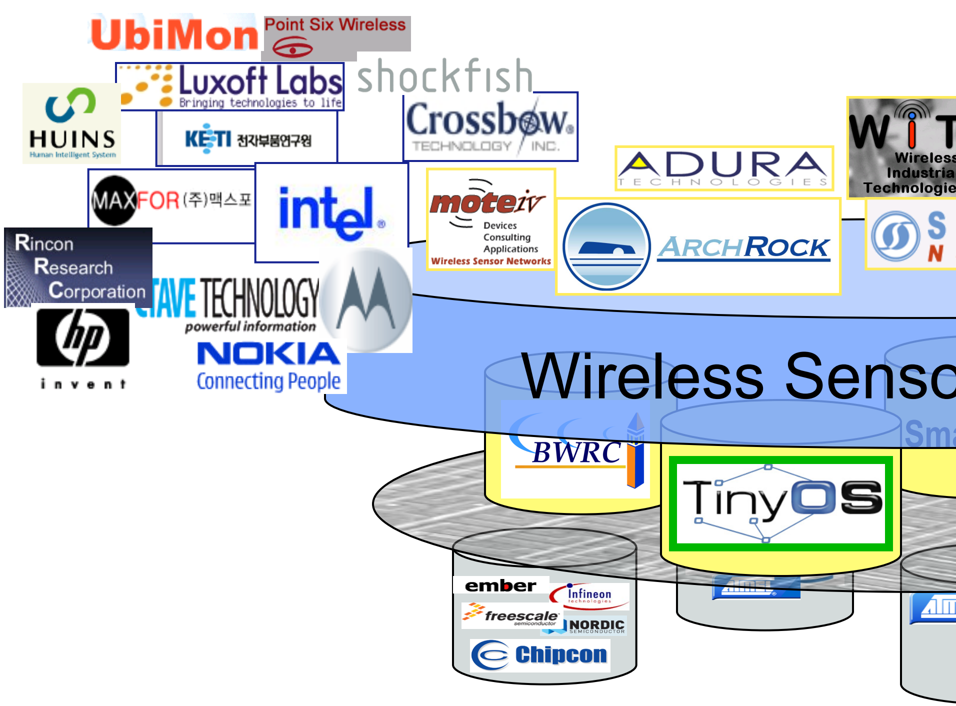
Vendor	Device	f_{max}(Mhz)	SRAM(KB)	Flash(KB)	Sleep(μA)	Wake(μS)
NXP	LPC408x	120	96	512	550	240
STMicro	STM32F372xx	72	32	256	1.32	42.7
Silabs	EFM32WG990	48	32	256	0.95	2
Freescale	K20Dx	50	16	128	1.3	130
Atmel	**SAM4L**	**48**	**64**	**512**	**3**	**1.5**

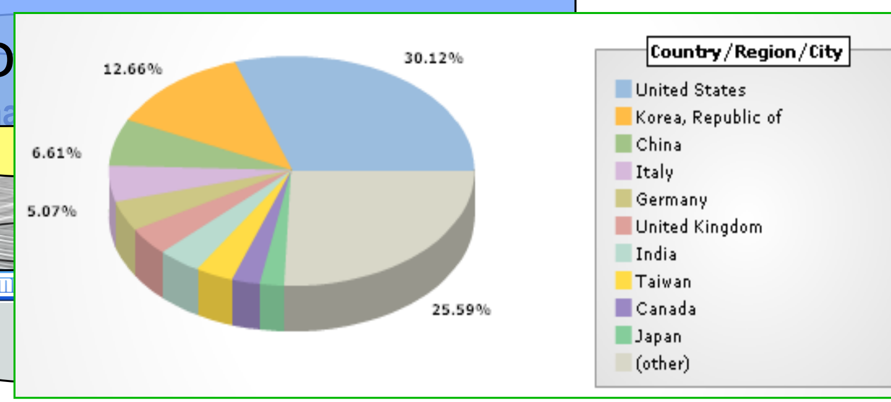
TinyOS – Framework for Innovation



Communication Centric
Resource-Constrained
Event-driven Execution

UCB => A worldwide community





Low Power Networking in the Real World

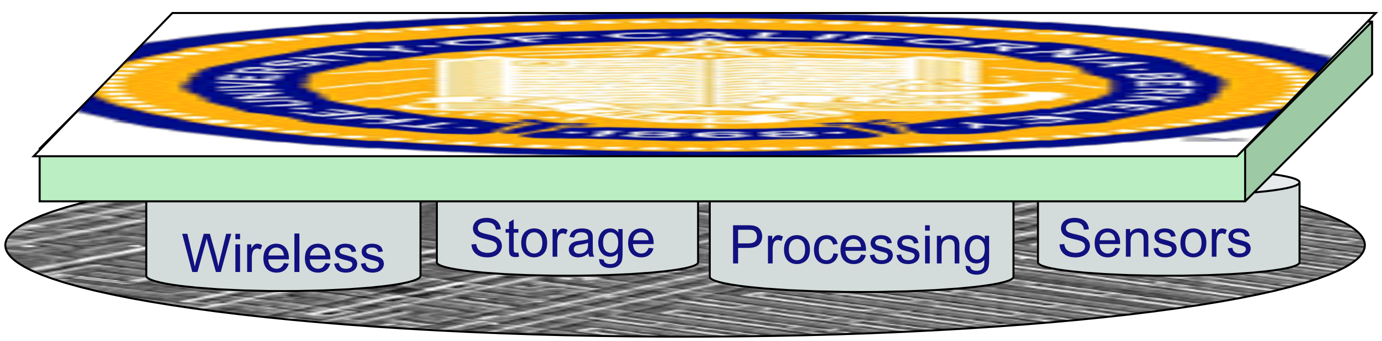
Applications

Network

system

architecture

Technology



A Low-Power Standard Link

	802.15.4	802.15.1	802.15.3	802.11	802.3
Class	WPAN	WPAN	WPAN	WLAN	LAN
Lifetime (days)	100-1000+	1-7	Powered	0.1-5	Powered
Net Size	65535	7	243	30	1024
BW (kbps)	20-250	720	11,000+	11,000+	100,000+
Range (m)	1-75+	1-10+	10	1-100	185 (wired)
Goals	Low Power, Large Scale, Low Cost	Cable Replacement	Cable Replacement	Throughput	Throughput

- **Low Transmit power, Low Signal-to-noise Ratio (SNR), modest BW, Little Frames**

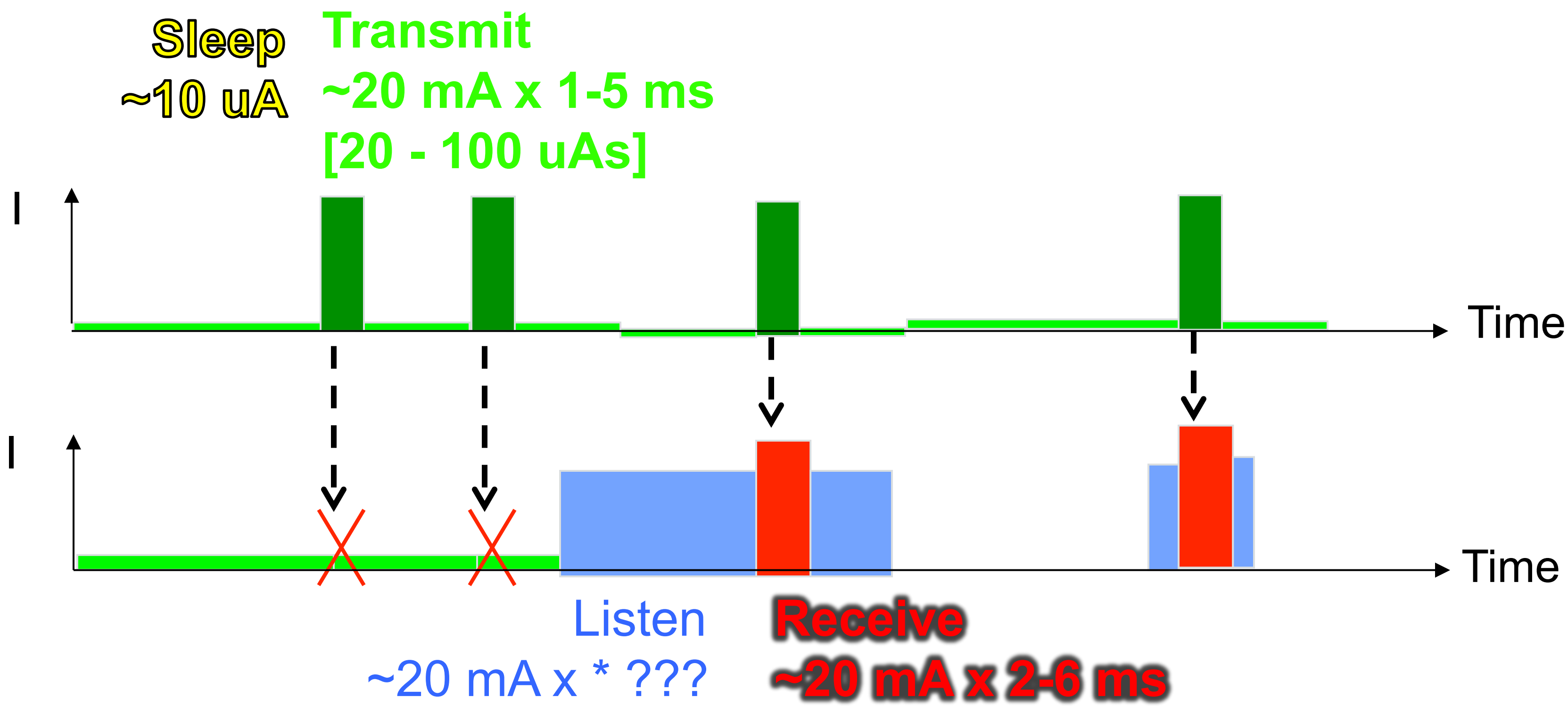
BTLE

The "Idle Listening" Problem

- The power consumption of "short range" (i.e., low-power) wireless communications is roughly the same when
  - transmitting,
  - receiving,
  - or simply ON, "listening" for potential reception.
  - IEEE 802.15.4, Zwave, Bluetooth, …, WiFi
- Radio must be ON (listening) in order receive anything.
  - Transmission is rare
  - Listening happens all the time

⇒**Energy consumption dominated by *idle listening***

Communication Power – Passive Vigilance

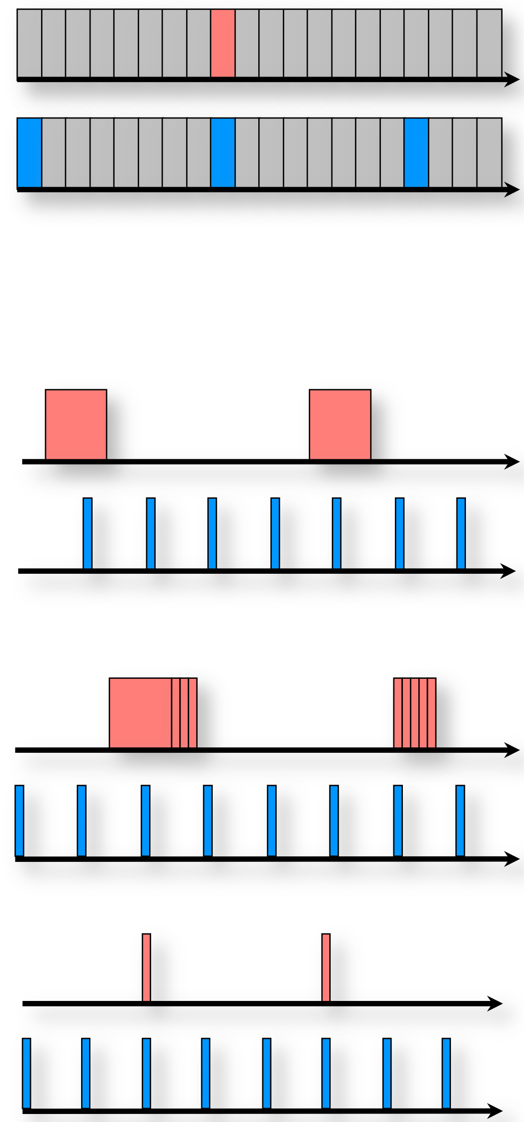


- **Listen just when there is something to hear …**

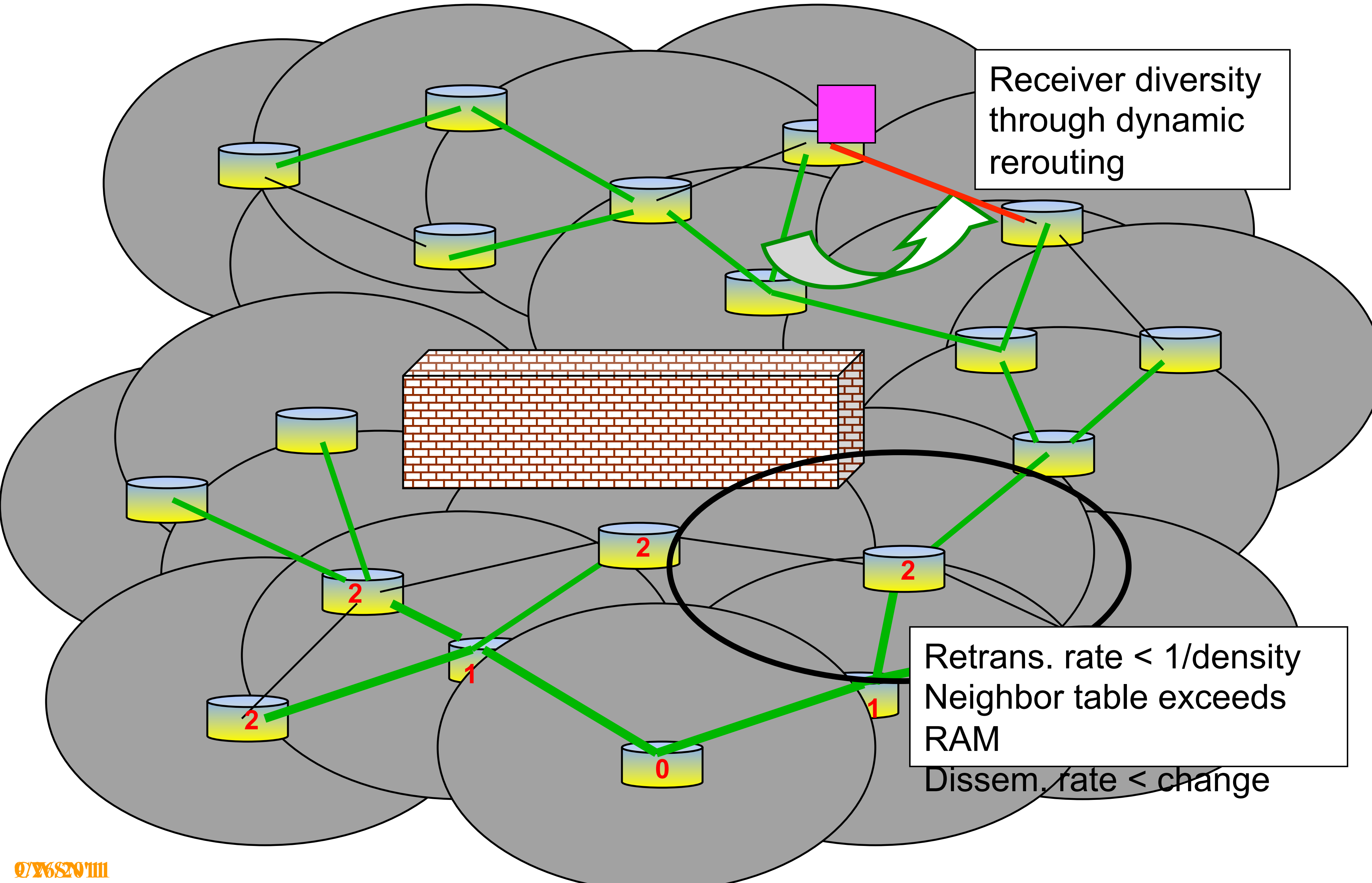
3 Basic Solution Techniques

- **Scheduled Listening**
  - Arrange a schedule of communication Time Slots
  - Maintain coordinated clocks and schedule
  - Listen during specific "slots"
  - Many variants:
    - » Aloha, Token-Ring, TDMA, Beacons, Bluetooth piconets, …
    - » S-MAC, T-MAC, PEDAMACS, TSMP, FPS, …
- **Sampled Listening**
  - Listen for very short intervals to detect em… transmissions
  - On detection, listen actively to receive
  - DARPA packet radio, LPL, BMAC, X… …
  - Maintain "always on" illusion, Robust
- **Listen after send** (with powered infrastructure)
  - After transmit to a receptive device, listen for a short time
  - Many variants: 802.11 AMAT, Key fobs, remote modems, …
- **Many hybrids possible**

802.15.4e

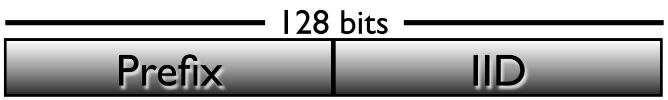


Self-Organized Routing - nutshell

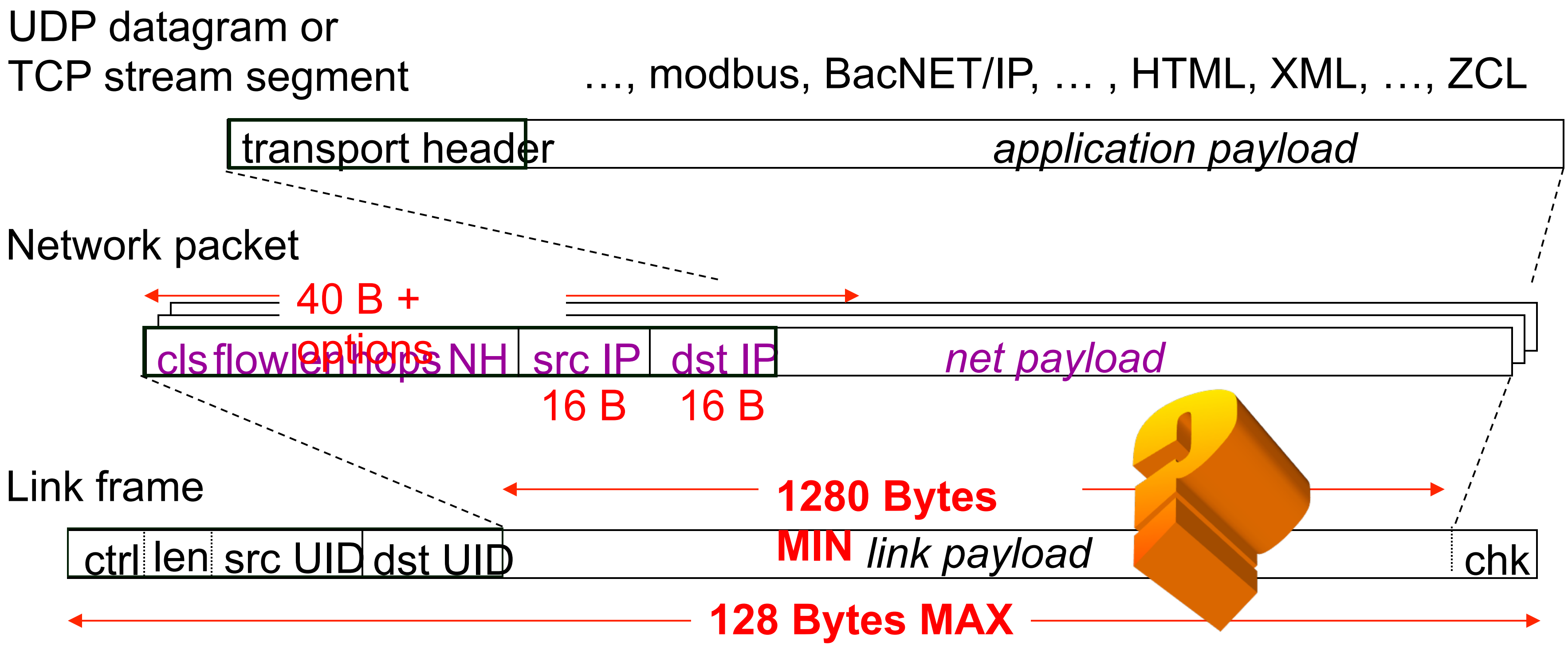


Key IPv6 Contributions

- Large simple address
  - Network ID + Interface ID
  - Plenty of addresses, easy to allocate and manage
- Autoconfiguration and Management
  - ICMPv6
- Integrated bootstrap and discovery
  - Neighbors, routers, DHCP
- Protocol options framework
  - Plan for extensibility
- Simplify for speed
  - MTU discovery with min
- 6-to-4 translation for compatibility

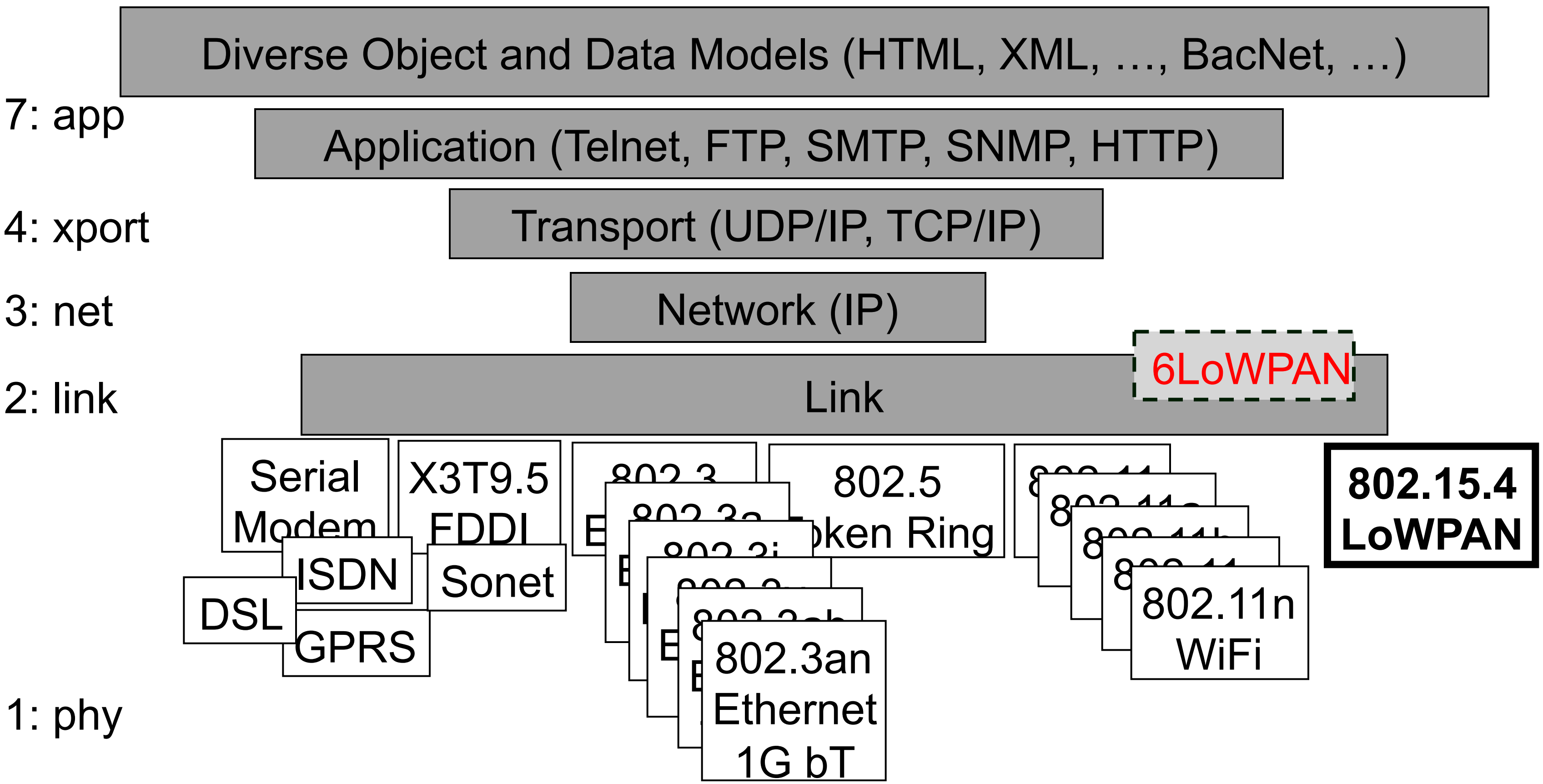


6LoWPAN – IPv6 over 802.15.4

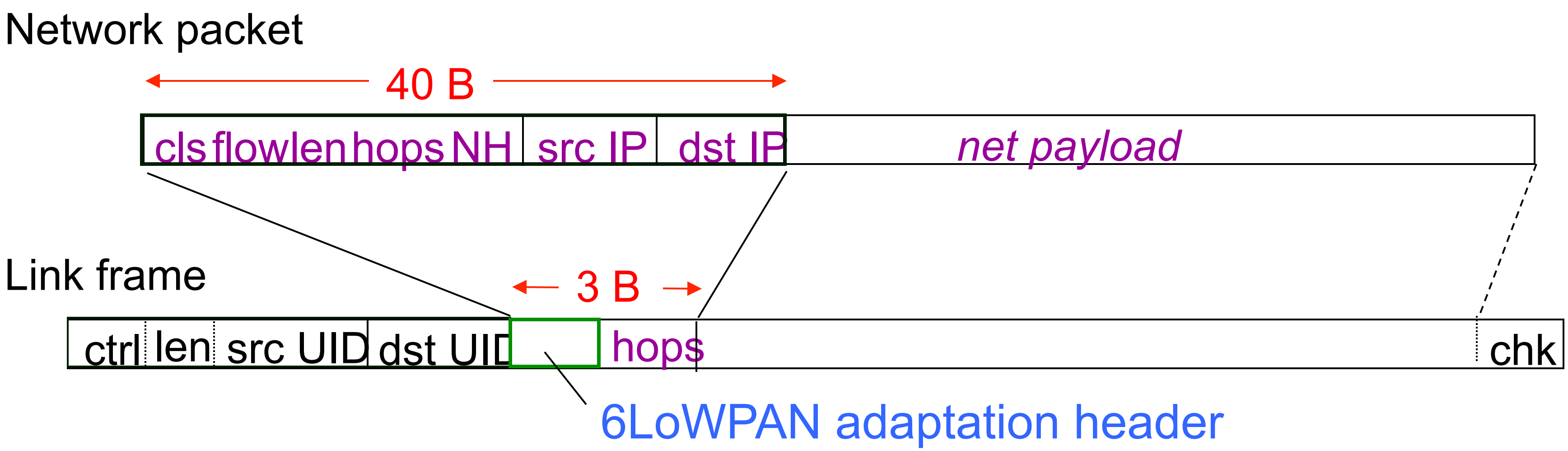


- **Large IP Address & Header => 16 bit short address / 64 bit EUID**
- **Minimum Transfer Unit => Fragmentation**
- **Short range & Embedded => Multiple Hops**

6LoWPAN adaptation layer

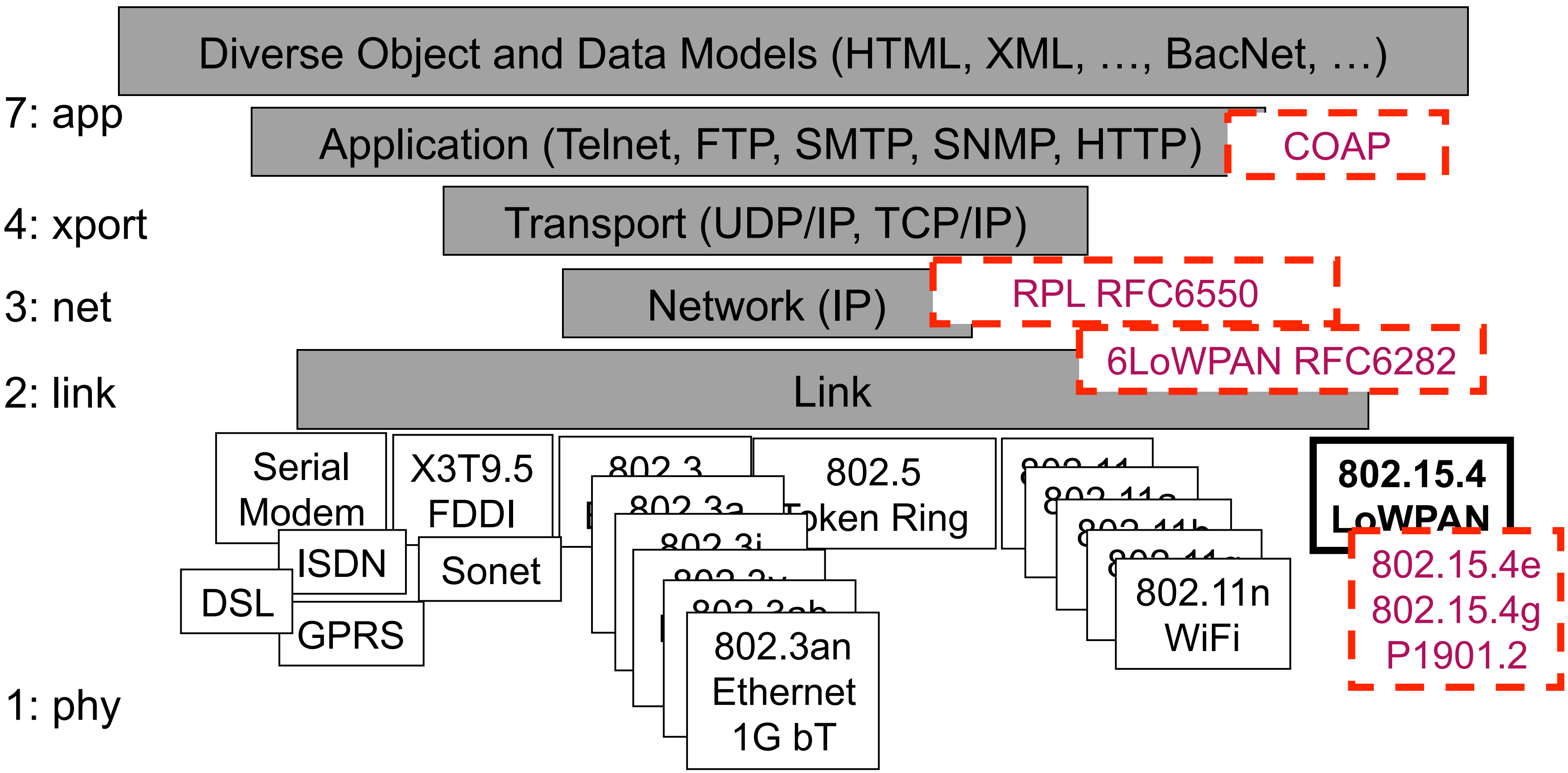


6LoWPAN – IP Header Optimization

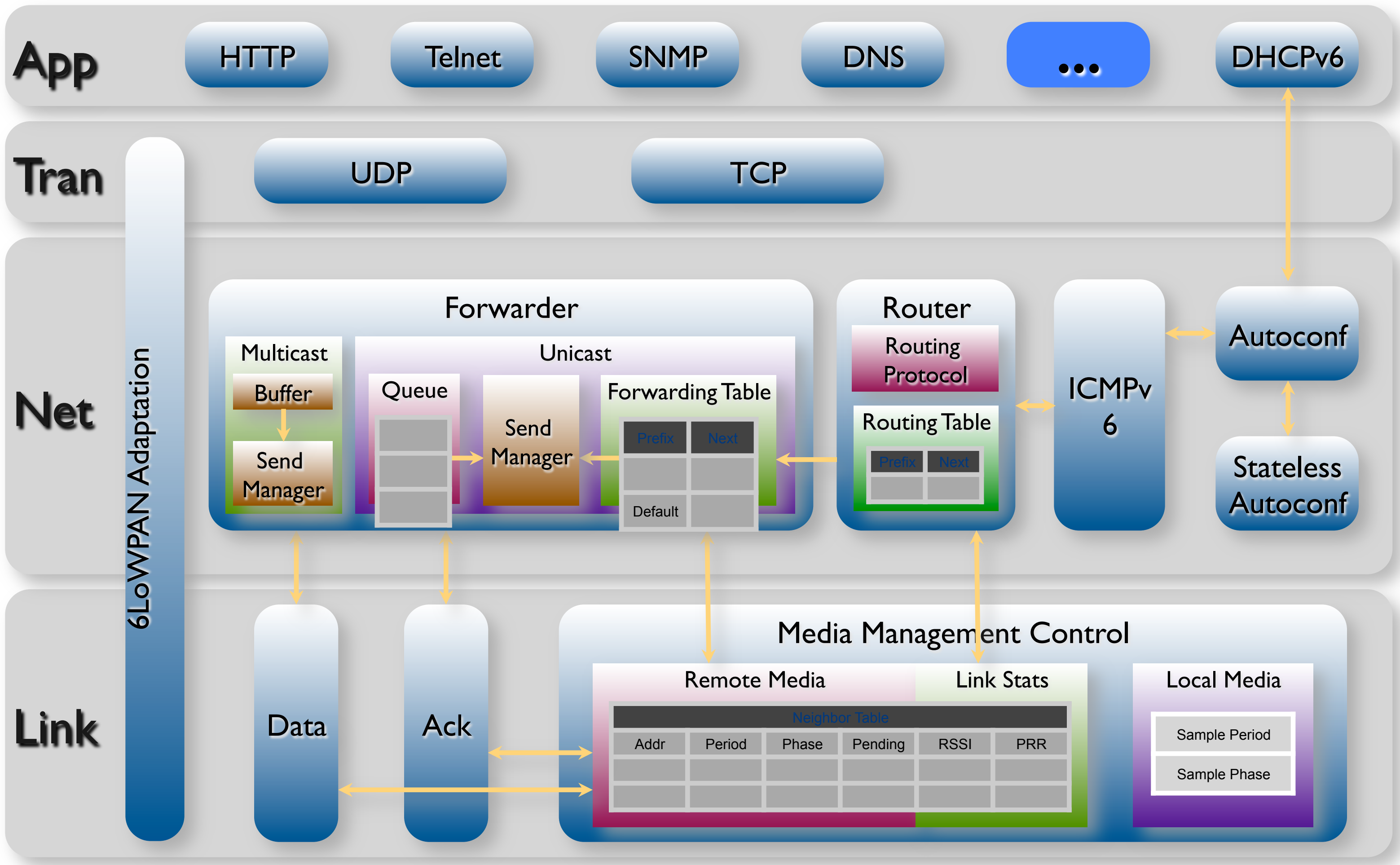


- **Eliminate all fields in the IPv6 header that can be derived from the 802.15.4 header in the common case**
  - **Source address : derived from link address**
  - **Destination address : derived from link address**
  - **Length : derived from link frame length**
  - **Traffic Class & Flow Label : zero**
  - **Next header : UDP, TCP, or ICMP**
- **Additional IPv6 options follow as options**

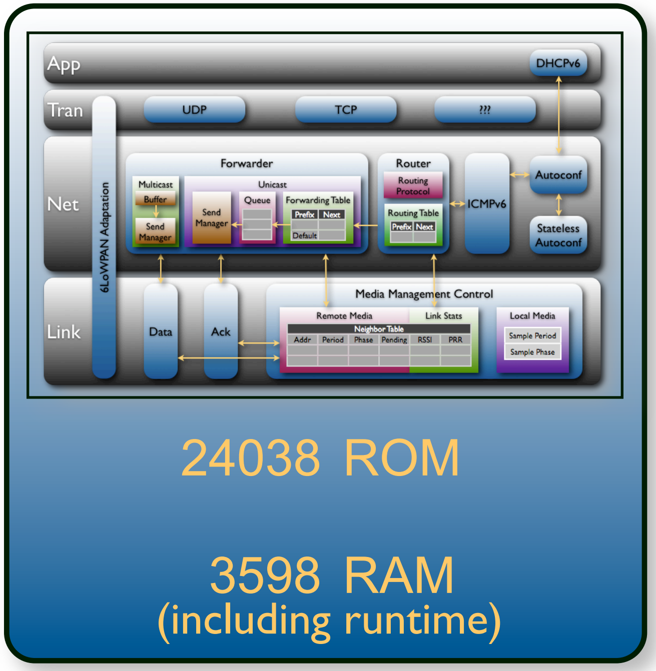
Internet – WSN assimilated



Complete Embedded IPv6 Stack



Adding up the pieces



* Production implementation on TI msp430/cc2420

	ROM	RAM
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802.15.4 Encryption	1194	101
Media Access Control	330	9
Media Management Control	1348	20
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Checksums	134	0
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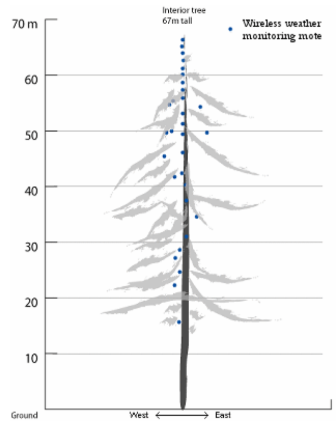
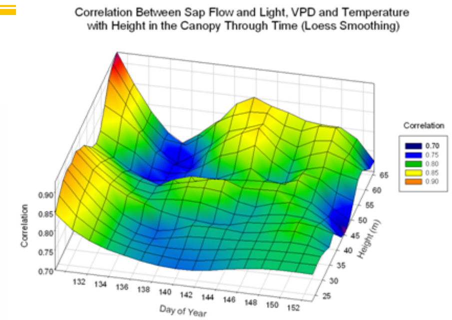
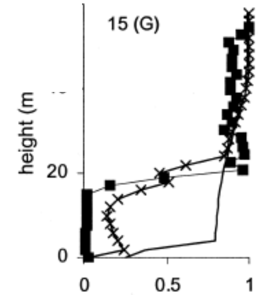
DHCPv6 Client	212	3
DHCPv6 Proxy	104	2
ICMPv6	522	0
Unicast Forwarder	1158	451
Multicast Forwarder	352	4
Message Buffers	0	2048
Router	2050	106
UDP	450	6
TCP	1674	50

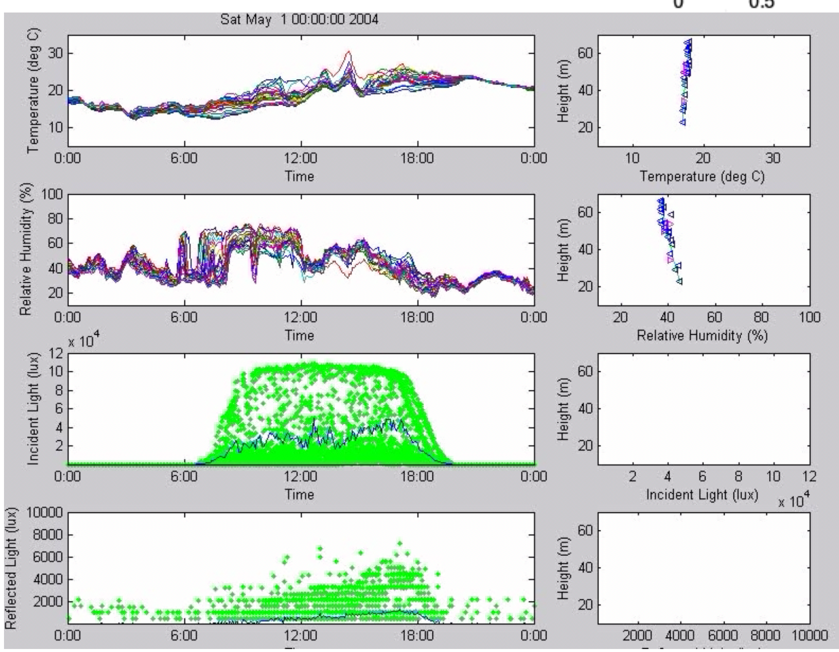
Real World - “Signals” and “Information”

- What is the bandwidth of the weather?
- What is the nyquist of the soil?
- What is the placement noise?
- What is the sampling jitter error?
- How do you classify it?
- How do you search it?

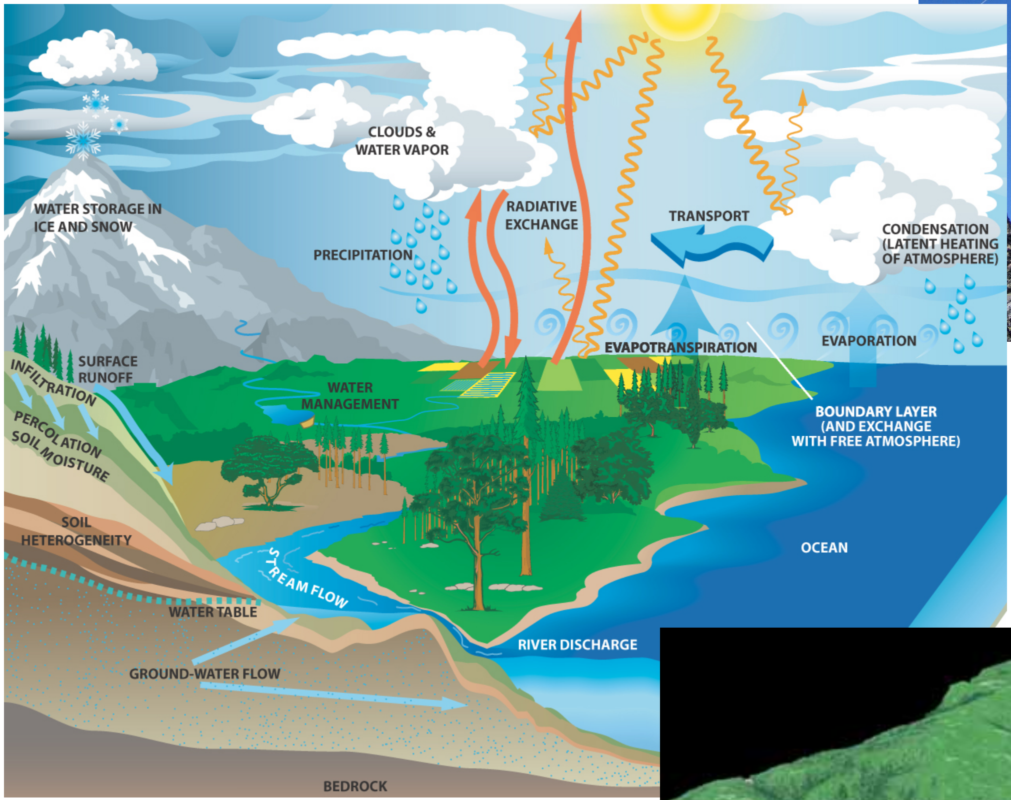




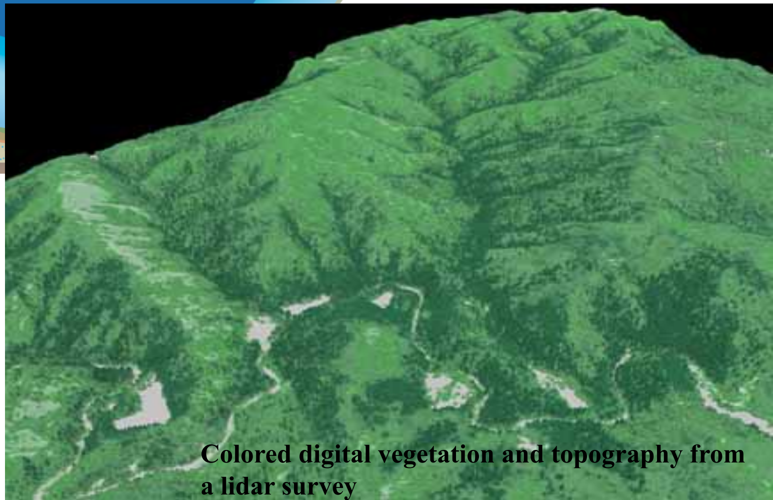




The Macroscope - Keck HydroWatch



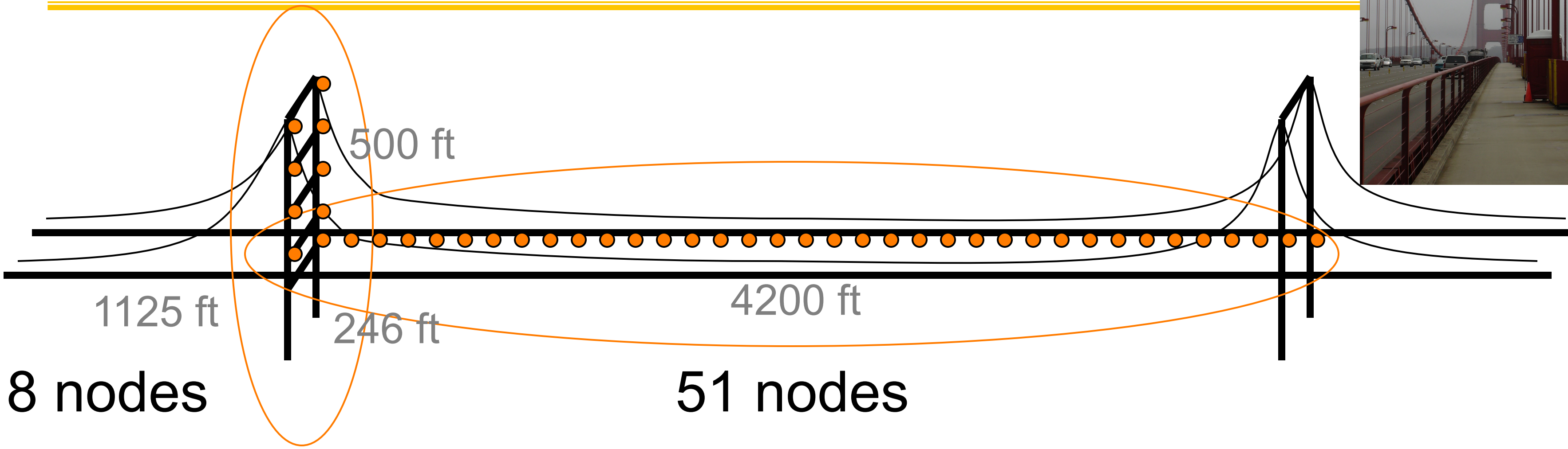
Sagehen wireless data infrastructure

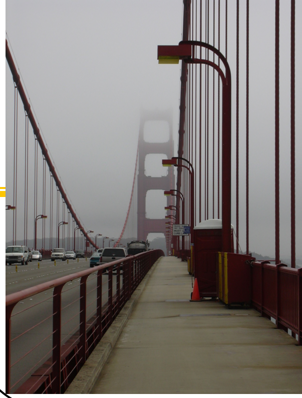


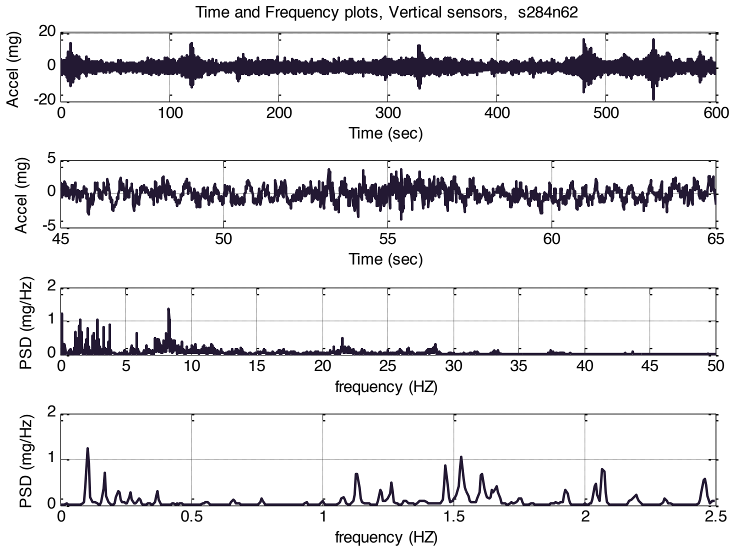
Colored digital vegetation and topography from a lidar survey

Networking the Physical World

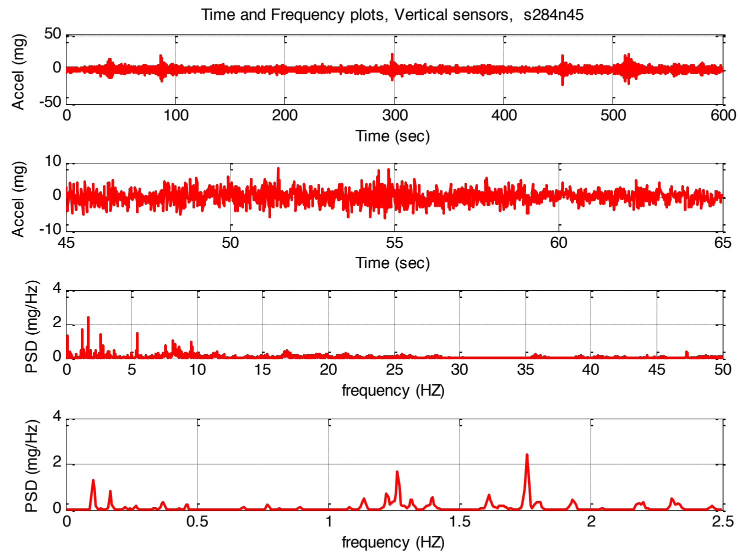
Ambient Vibration







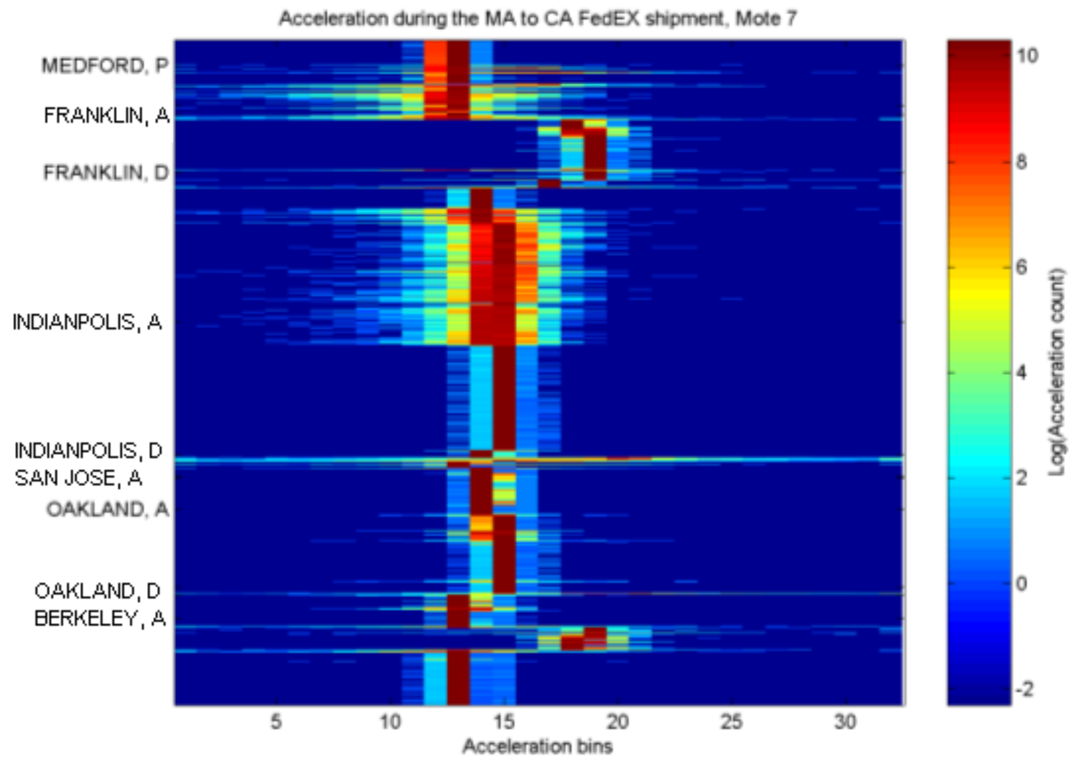
Vertical Sensor at Quarter-span
365m North of the South Tower

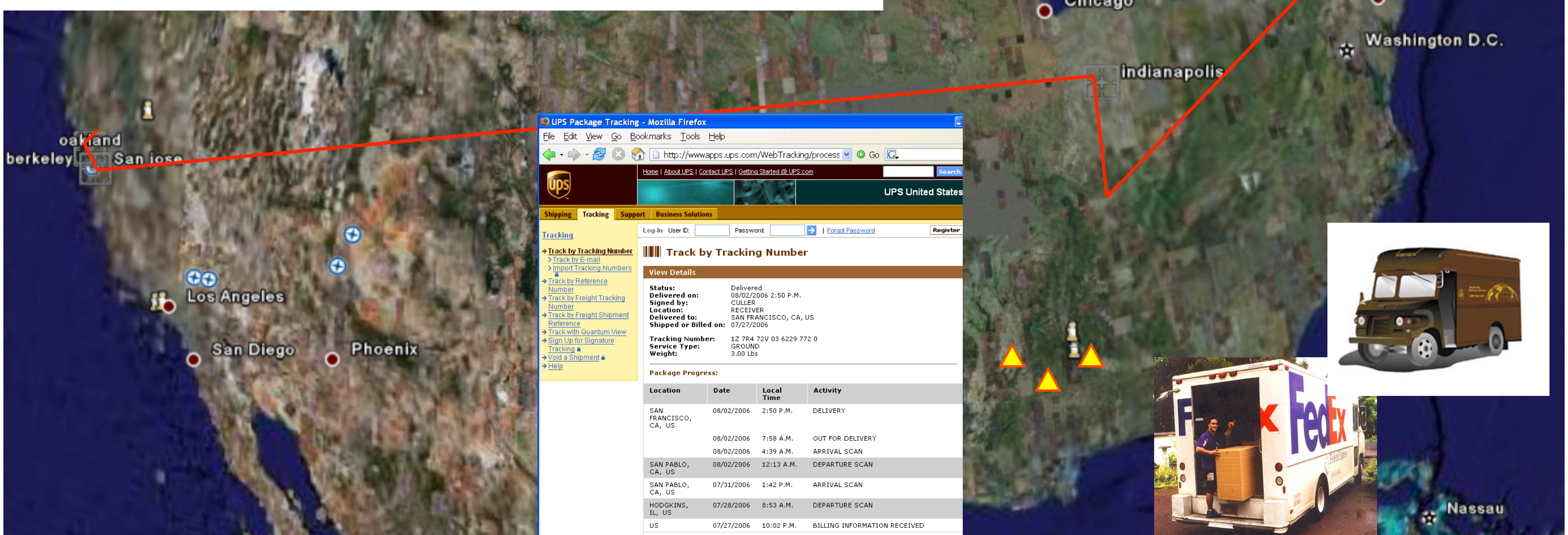


Vertical Sensor at Quarter-span
335m South of the North Tower


HYUNDAI
CHINA SHIPPI

Real World …





UPS Package Tracking - Mozilla Firefox

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Tracking

- Track by Tracking Number
  - Track by E-mail
  - Import Tracking Numbers
- Track by Reference Number
- Track by Freight Tracking Number
- Track by Freight Shipment Reference
- Track with Quantum View
- Sign Up for Signature Tracking
- Void a Shipment
- Help

Track by Tracking Number

View Details

Status: Delivered
Delivered on: 08/02/2006 2:50 P.M.
Signed by: CULLER
Location: RECEIVER
Delivered to: SAN FRANCISCO, CA, US
Shipped or Billed on: 07/27/2006

Tracking Number: 1Z 7R4 72V 03 6229 772 0
Service Type: GROUND
Weight: 3.00 Lbs

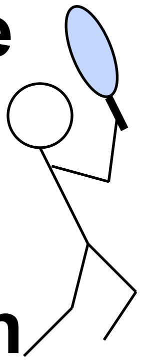
Package Progress:

Location	Date	Local Time	Activity
SAN FRANCISCO, CA, US	08/02/2006	2:50 P.M.	DELIVERY
	08/02/2006	7:58 A.M.	OUT FOR DELIVERY
	08/02/2006	4:39 A.M.	ARRIVAL SCAN
SAN PABLO, CA, US	08/02/2006	12:13 A.M.	DEPARTURE SCAN
SAN PABLO, CA, US	07/31/2006	1:42 P.M.	ARRIVAL SCAN
HODGKINS, IL, US	07/28/2006	8:53 A.M.	DEPARTURE SCAN
US	07/27/2006	10:02 P.M.	BILLING INFORMATION RECEIVED

Tracking results provided by UPS: 09/12/2006 1:03 A.M. Eastern Time (USA)

The “Killer App” for WSNs

- Energy and the environmental impact of extraction, use, and disposal
- THE problem of the Industrial Age
- We need to find Information Age solutions to THE Industrial Age Problem

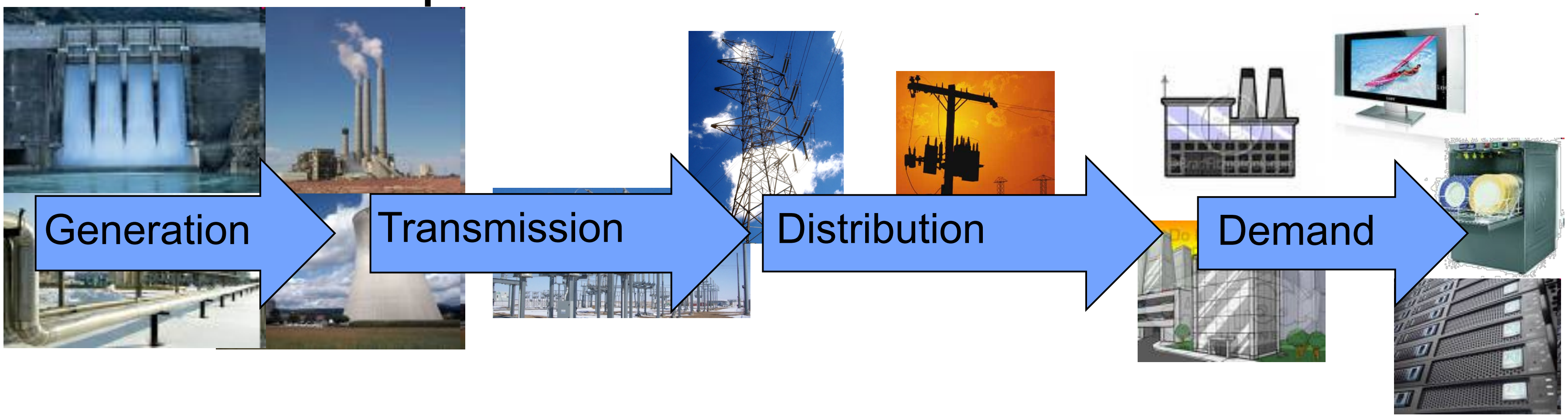


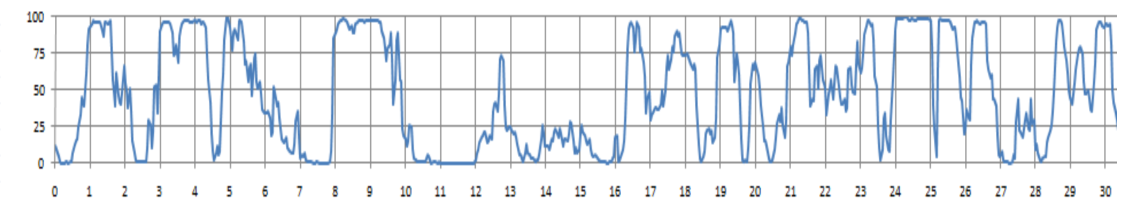
- => Fundamental transformation in the architecture of the electric grid

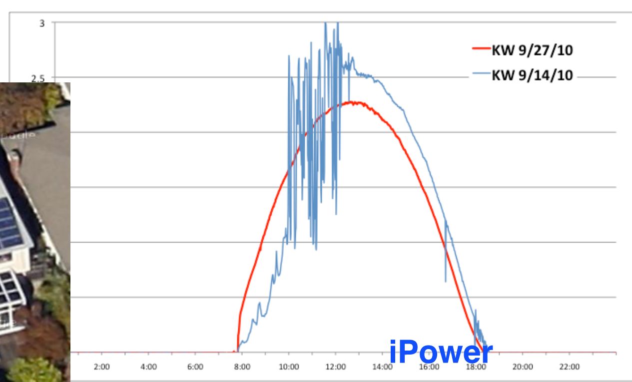
Traditional Load-Following Grid

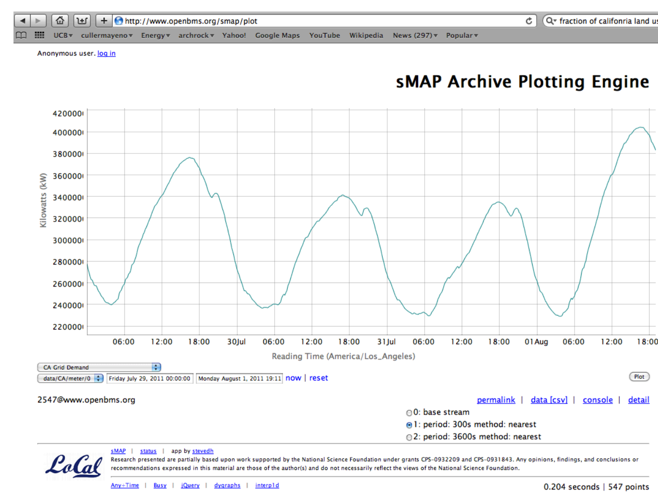
Baseline + Dispatchable Tiers

Oblivious Loads

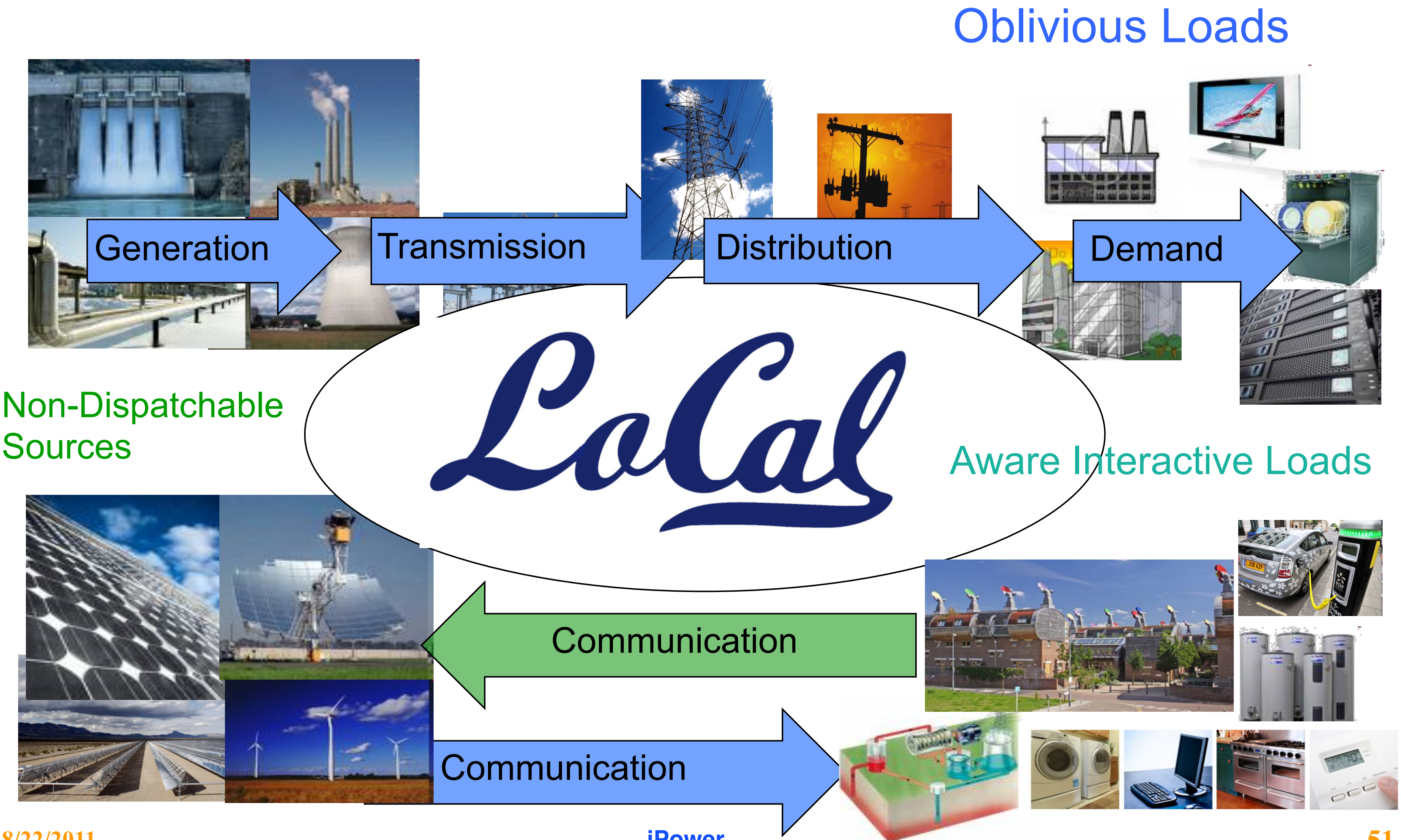








Towards an ‘Aware’ Energy Infrastructure



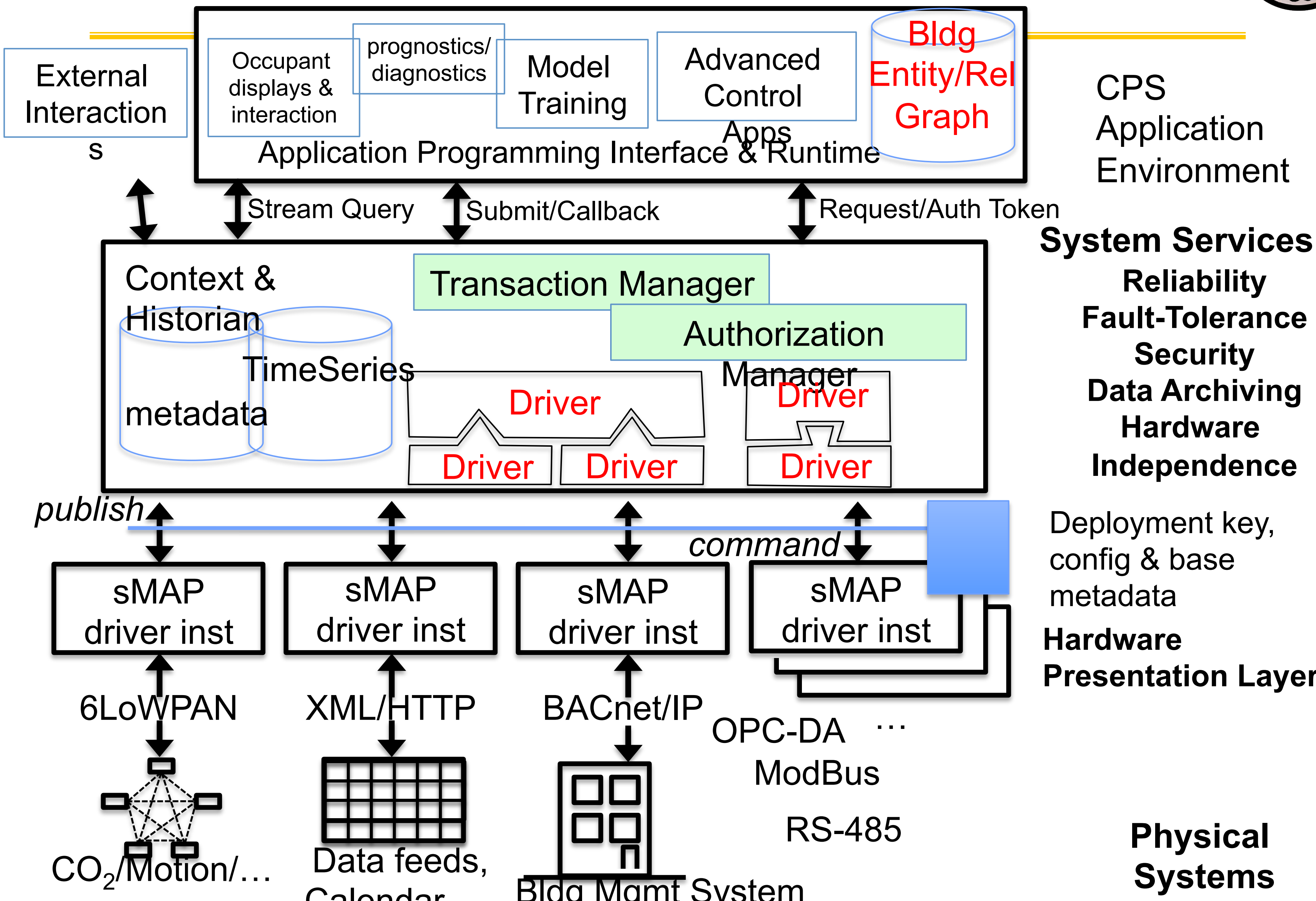
How can we transform buildings into fundamentally more agile machines?

- Programmable
- Separation of the hardware capabilities (primitives)
- from the universe of potential behaviors (applications)
- allow them to be tailored to our desires
  - To the full extent of the underlying capabilities
- And become good citizens of the grid

Software Defined Buildings

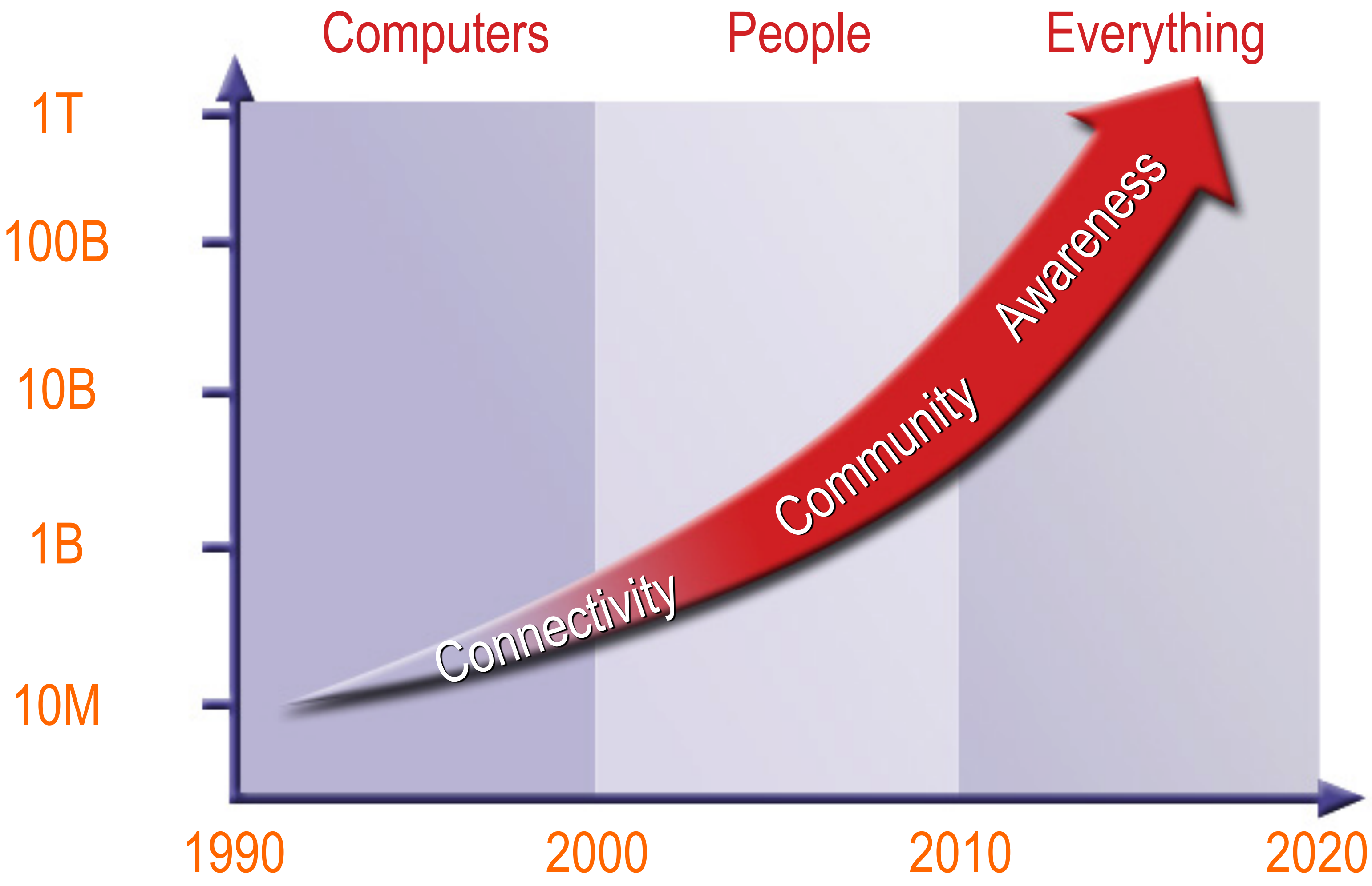
- Building Application Programming Interface (BAS)
  - Enable application portability and innovation
- Building Operation System & Services (BOSS)
  - Physical services and distributed device drivers
  - Middle services: mapping, transactions, RAS
  - Application services: baselining, ensemble, …
- Innovate in Model-Driven Predictive Control
  - objectives: efficiency, satisfaction, supply-following
- Rich Human-Building Interaction
  - Location, personal and ambient devices, gestures, …
- Introduce meaningful security

BOSS Architecture – first cut

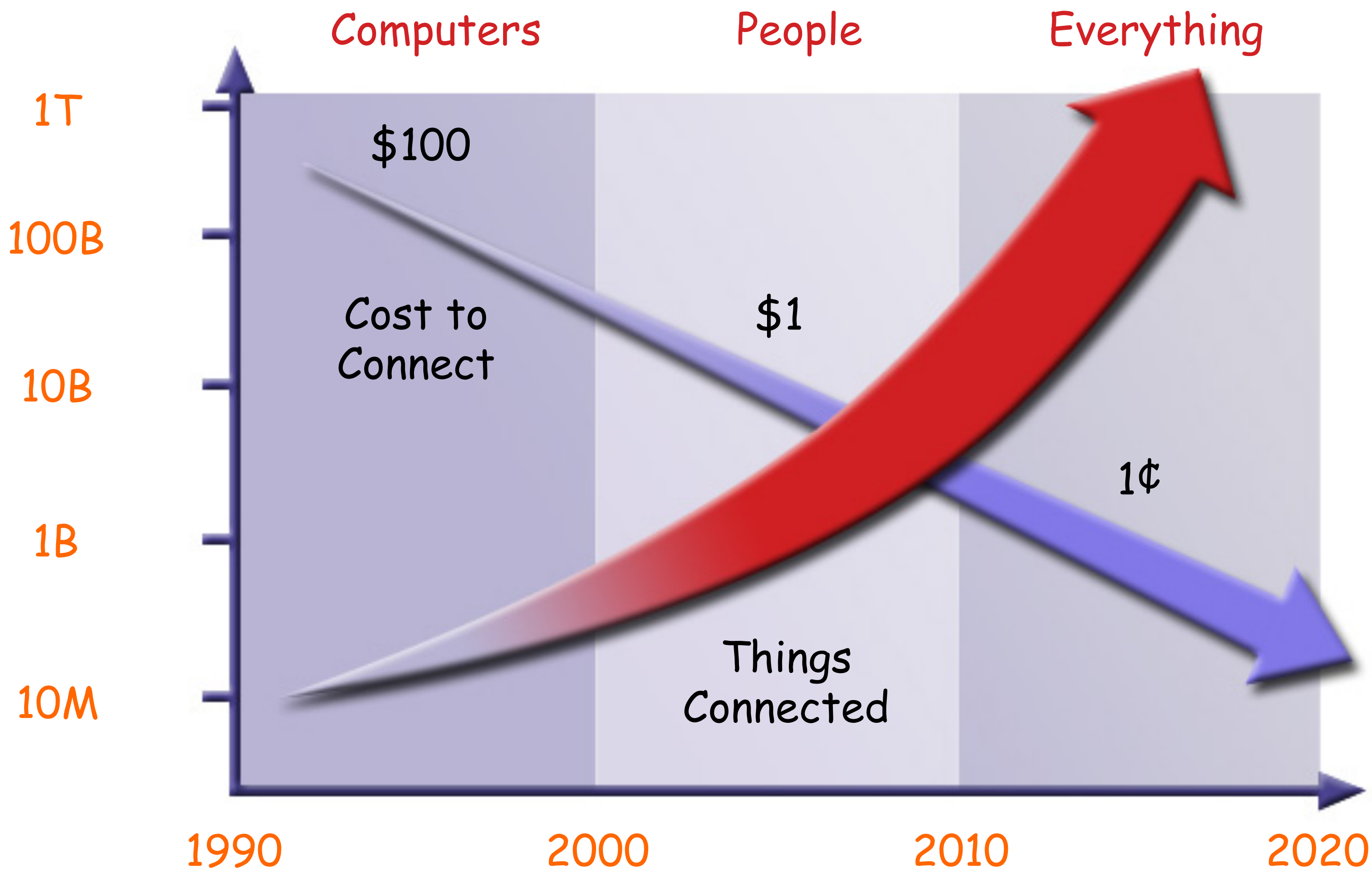


smap->BOSS->OpenBAS

The Revolution



The Revolution



CS162: Spiral