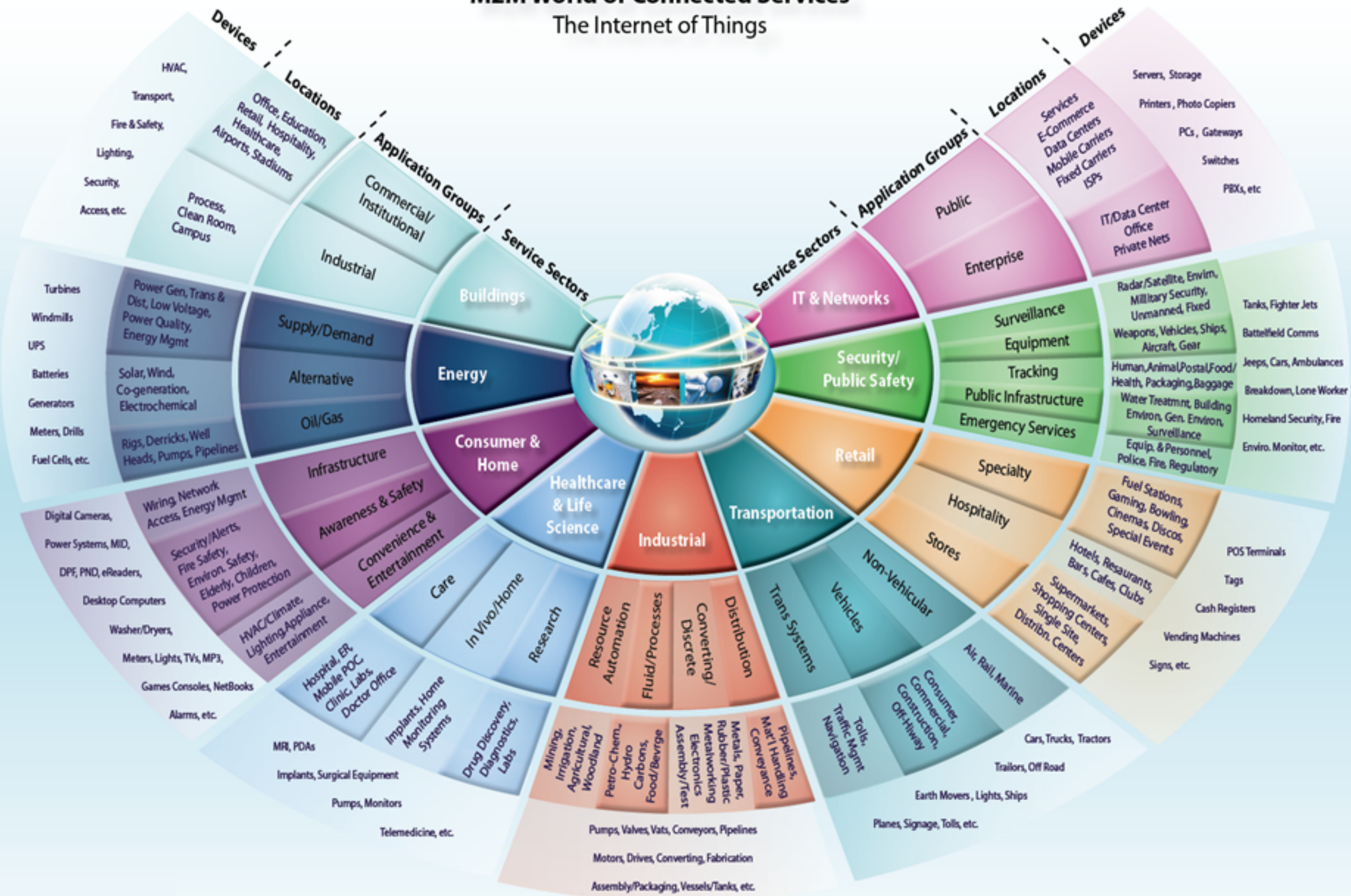
Internet of Things

Modified from **David E. Culler, Bob Kinicki, Shahriar Nirjon, Richard Martin, Christopher Giles, Mehmet Gunes**

Why “Real” Information is so Important

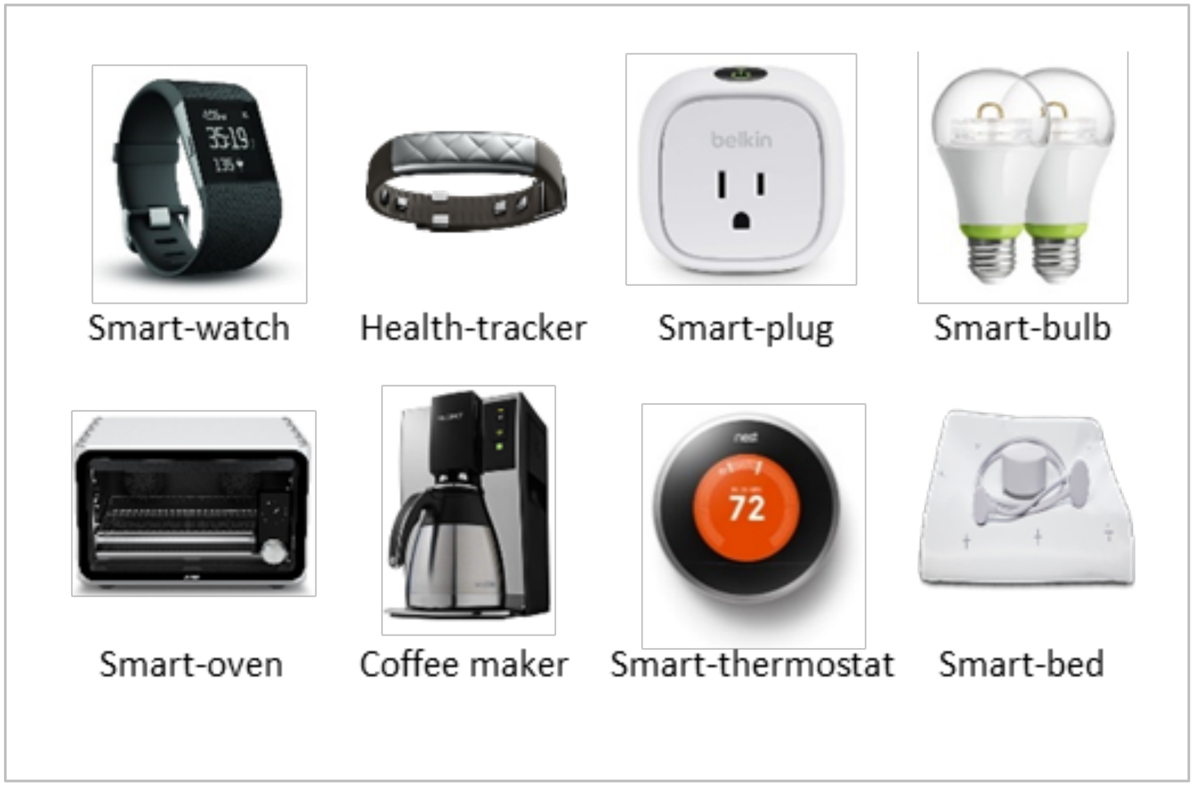
M2M World of Connected Services

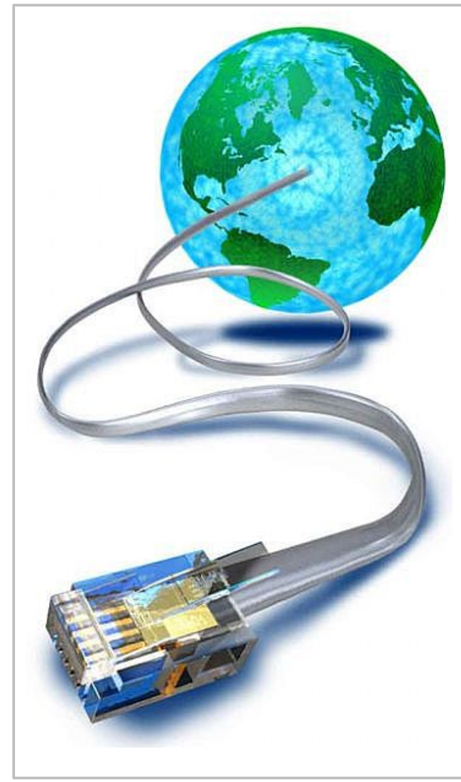
The Internet of Things



The Internet of Things

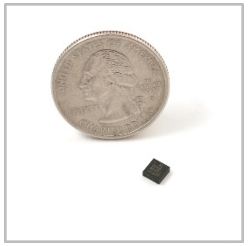
A fabric that (is going to) connects every object in the world





Why IoT is happening now?

- Advancements in: (1) sensor technology, (2) miniature computers, (3) low-power wireless communication, (4) mobile devices, and (5) cloud.



Accelerometer

Pulse Sensor

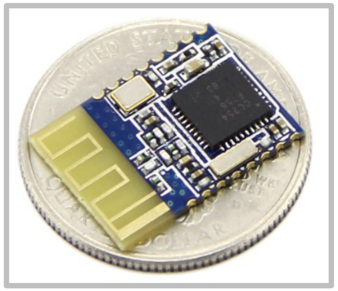
Force Sensor

VGA Camera

(1)

Intel Joule 570X
(1.7 GHz, Quad-Core, 4 GB RAM, 16 GB storage)

(2)

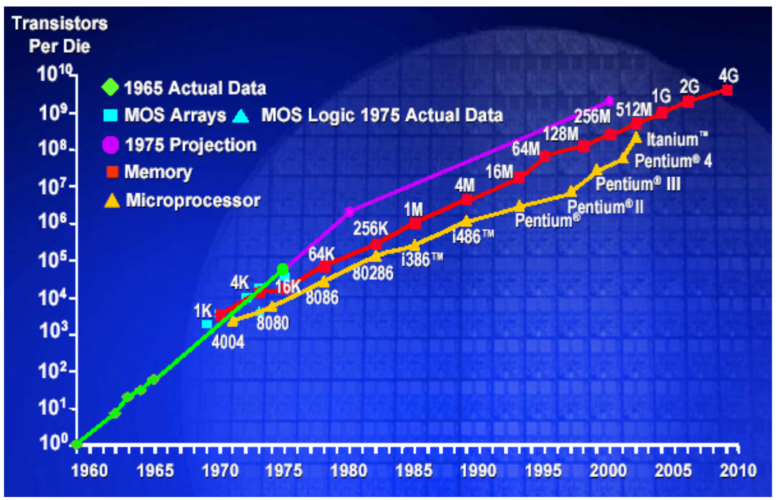


Bluetooth LE
(up to 2 years lifetime on a single coin-cell battery)

(3)

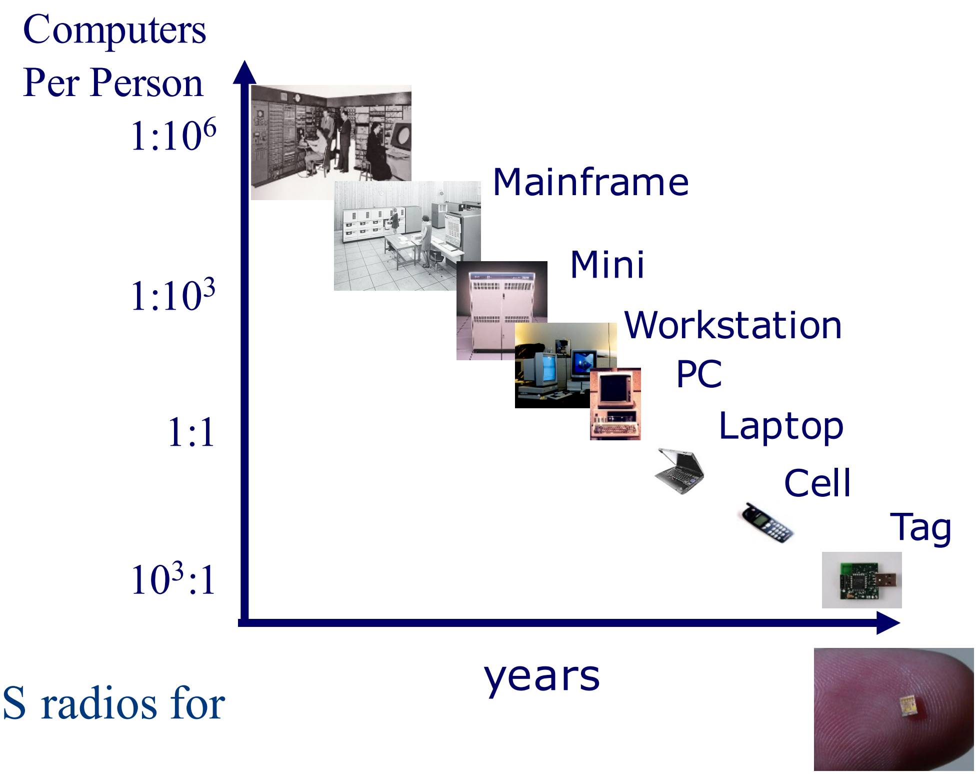
The Opportunity

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



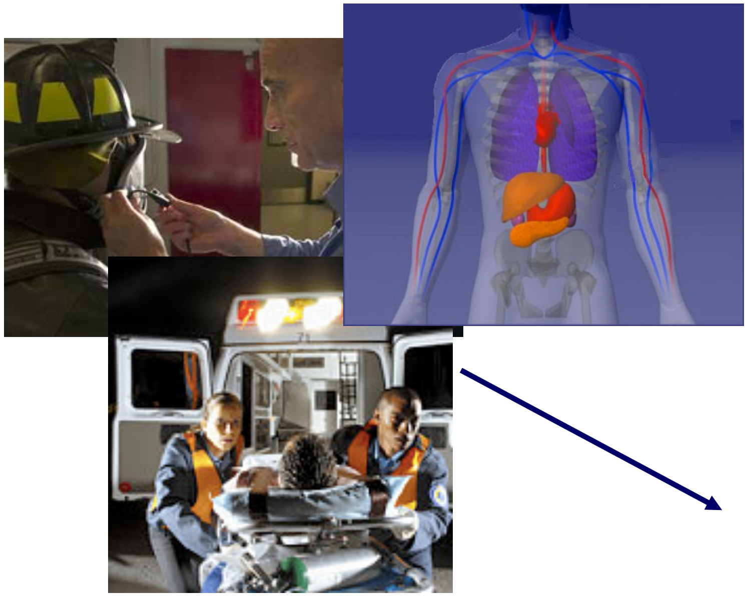
Today: 1 million transistors per $

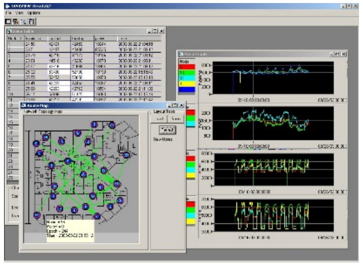
Bell's Law: a new computer class emerges every 10 years

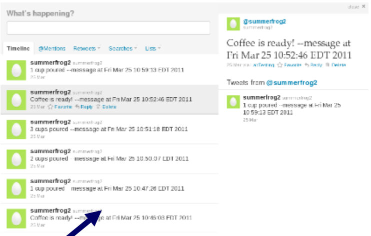


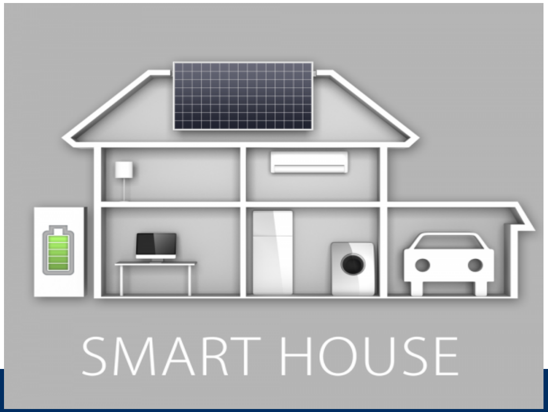
Same fabrication technology provides CMOS radios for communication and micro-sensors

The Vision



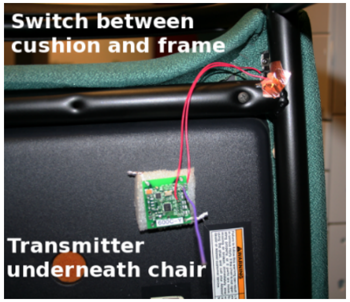



What's happening?
Coffee is ready! --message at Fri Mar 25 10:52:46 EDT 2011

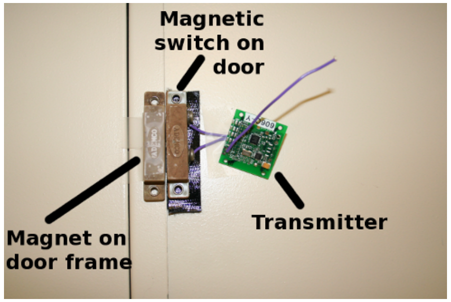

SMART HOUSE

Sensor examples

Chair occupancy

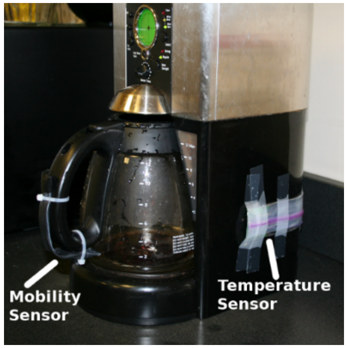


Door open/close

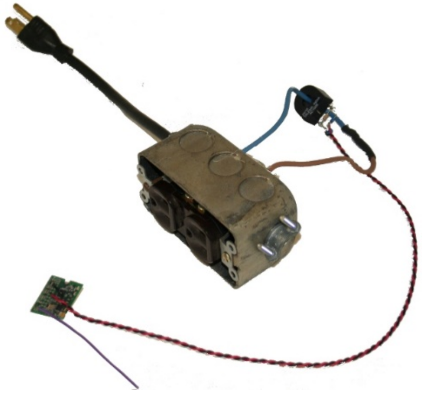


Kinect Skeleton

Coffeepot Temperature



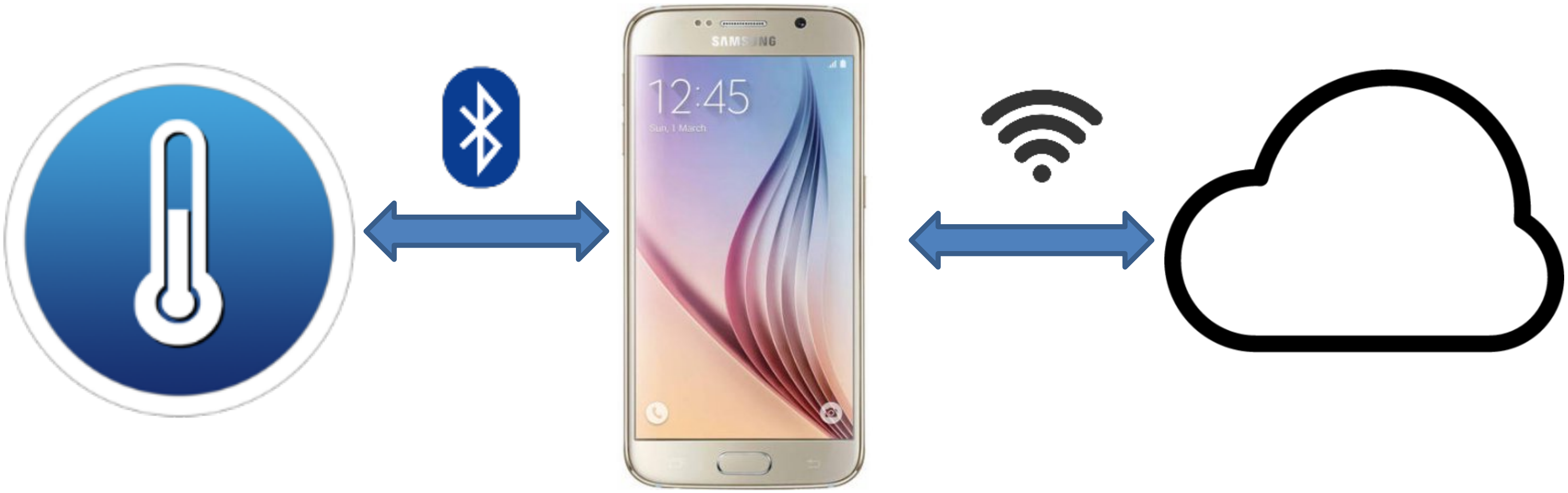
Power Consumption



Phone Tracking

Putting them together

- An IoT system – consisting of {sensors, mobile devices, computers, and the cloud} who will talk to each other over {BLE and WiFi} as appropriate.



A rose by any other name

- 1999 Smart Dust
- 2000 Sensor Networks
- 2004 Internet of Things
- 2005 Ambient Intelligence
- 2009 Swarms

~15 years on, we still have not realized the vision

- What happened?

Problems

- Problems people talked about:
  - Energy conservation
  - Scaling number of sensors
  - Efficiency of code data size in small sensors
  - Routing

- More meaningful problems:
  - Too expensive for application domains
  - Difficult to develop applications
  - Can't re-use infrastructure
  - Not general purpose

A Few IoT Facts

- The phrase ‘Internet of Things’ was first used in 1999
  - First Article about IoT in 2004 from MIT researchers called I0 (Internet 0)

- Why it is important?

  Optimistic prediction: 7 trillion devices for 7 billion people by 2020

Fight Poverty?

- **Try to reduce the difference in price of water between Dharavi and Warden Road in Mumbai.**
- **Price disparities are due to the high cost of delivering utilities.**

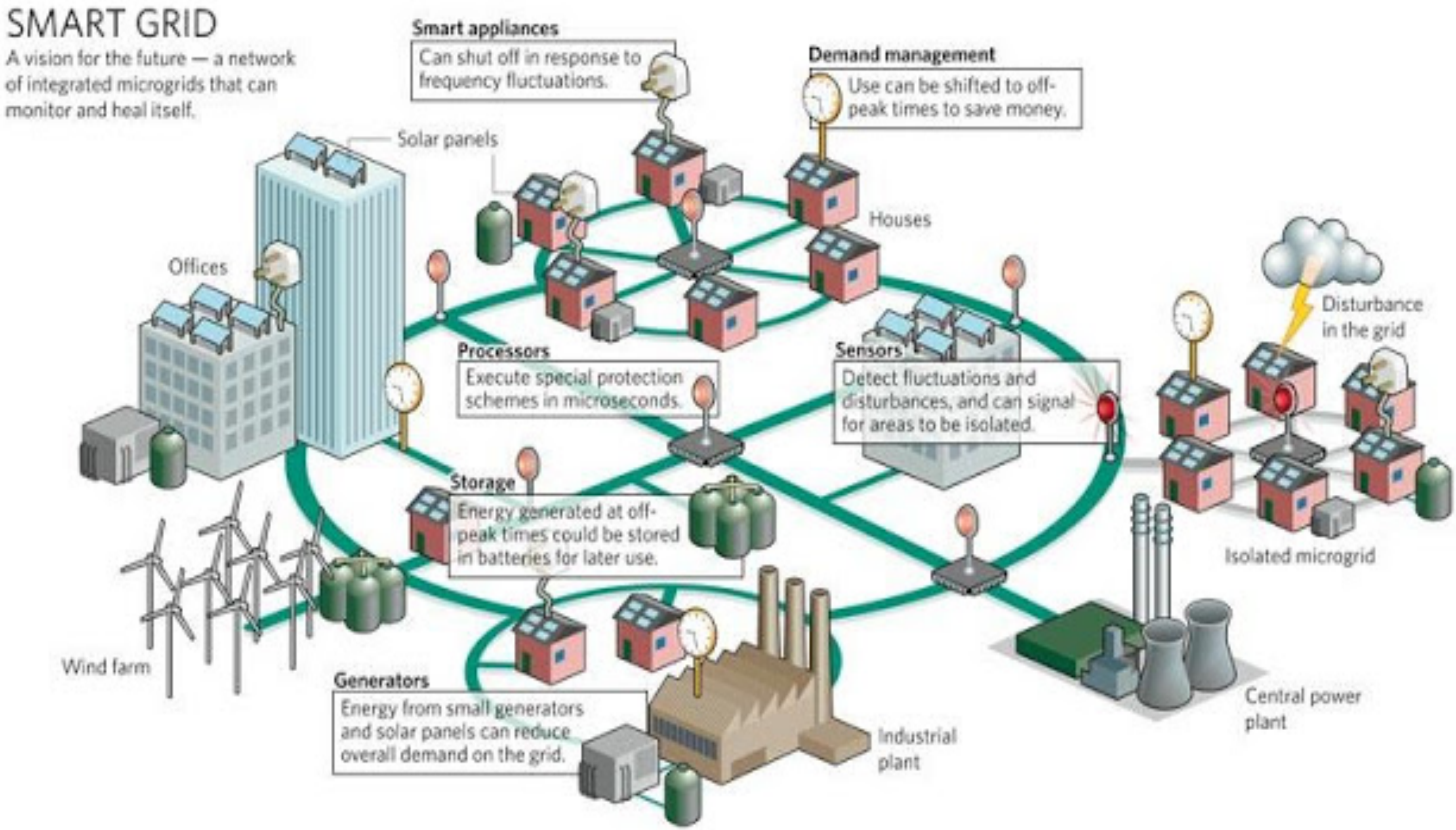
Example:

in India

Figure 5. Electric Utility Inefficiencies in India.

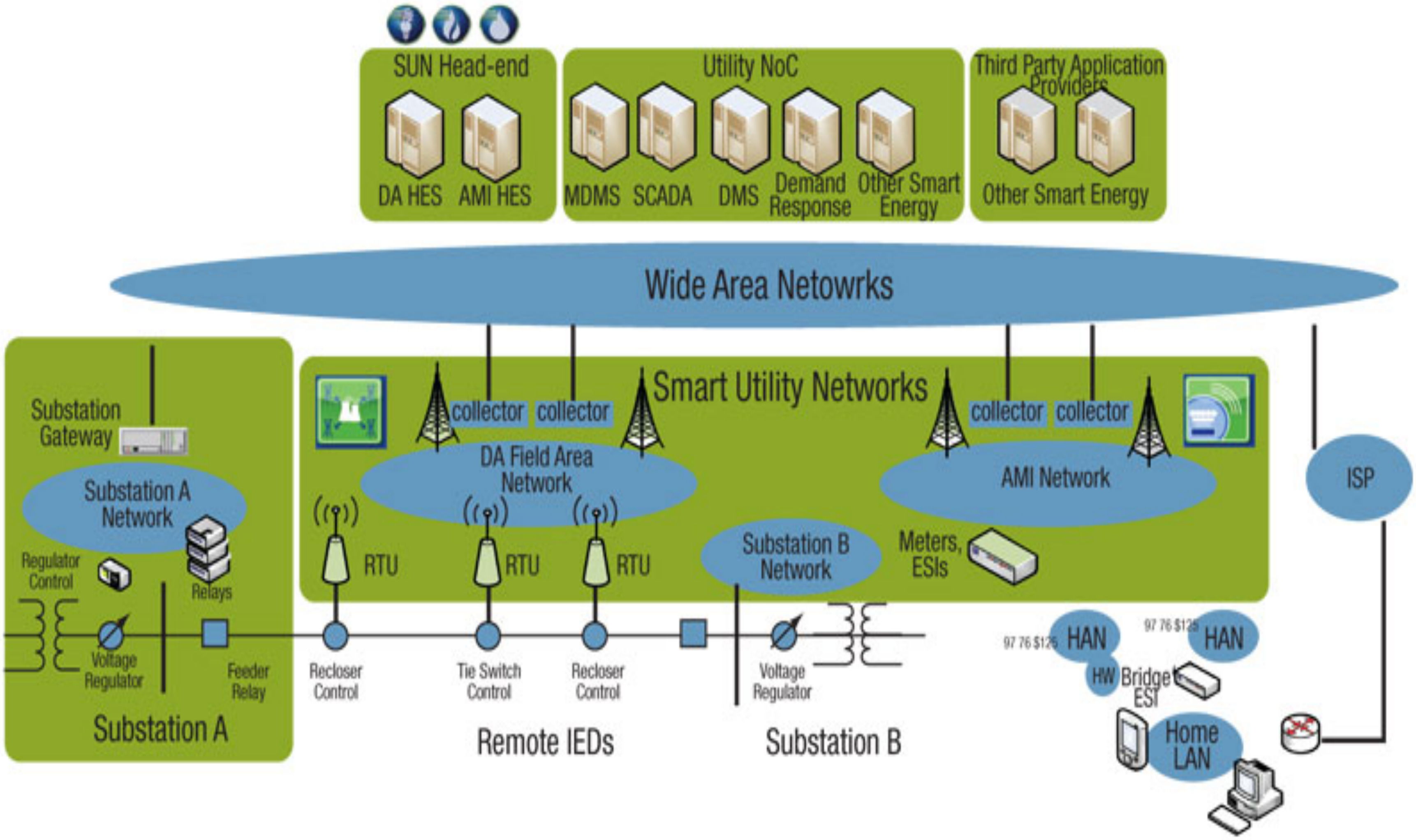
Source: *The Wall Street Journal*, 2009.

Smart Grid



SMART GRID
A vision for the future — a network of integrated microgrids that can monitor and heal itself.
Smart appliances
Can shut off in response to frequency fluctuations.
Demand management
Use can be shifted to off-peak times to save money.
Solar panels
Houses
Offices
Disturbance in the grid
Processors
Execute special protection schemes in microseconds.
Sensors
Detect fluctuations and disturbances, and can signal for areas to be isolated.
Storage
Energy generated at off-peak times could be stored in batteries for later use.
Isolated microgrid
Wind farm
Generators
Energy from small generators and solar panels can reduce overall demand on the grid.
Industrial plant
Central power plant

Smart Utility Networks (SUNs)



Smart Homes

Figure 3 – Smart home for smart people

Source: ITU adapted from Line9

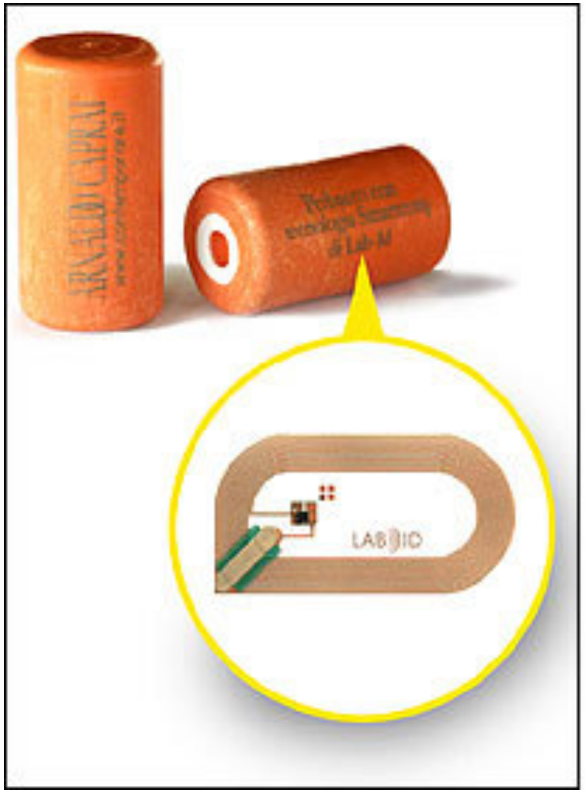
The Smart *Internet of Things* School

A Smart Light (Philips' Hue)

- **Tunable light, 16 million colors**
- **Activated by smart phone or over Zigbee wireless**
- **Can serve as alarm clock**
- **Can synch colors to movies or possibly music**

Philips never anticipated the demand - sold out in 3 months at Apple stores!

Smart Corks



The RFID read-write tags embedded into the corks use Philips' ISO 15693 I-Code SLI 13.56 MHz chip with 1,024 bits of memory.

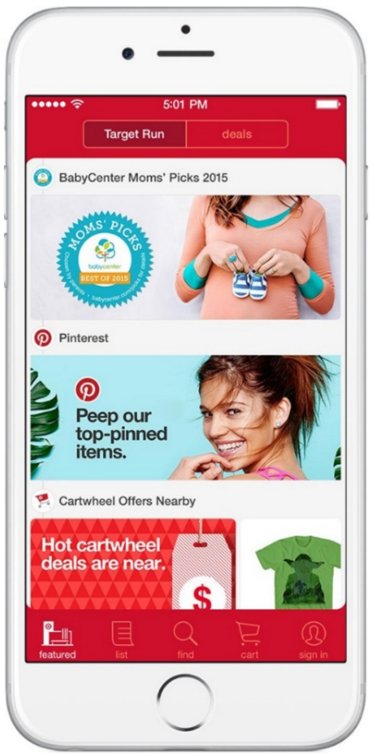
More Smarts

- Smart bathroom cabinet for medicine
- Smart refrigerator
- Smart traffic
- Smart history (in museums)
- Smart health (RFID in running shoes)
- Smart buying (Near Field Communication)
  - Use smart phone to make payments

IoT Analytics (Examples)

- Categories of applications include: (1) **push notifications**, (2) predictive maintenance, and (2) real-time stream analysis.

beacons
'nearables'



https://www.rtinsights.com/iot-analytics-use-cases-tdwi/

IoT Analytics (Examples)

- Categories of applications include: (1) push notifications, (2) **predictive maintenance**, and (2) real-time stream analysis.

US Air Force saved $1.5M through real-time vehicle tracking.

ThyssenKrupp predicts when to repair elevators

https://www.rtinsights.com/u-s-air-force-sees-benefits-from-condition-based-maintenance/
https://www.thyssenkrupp-elevator.com/en/

IoT Analytics (Examples)

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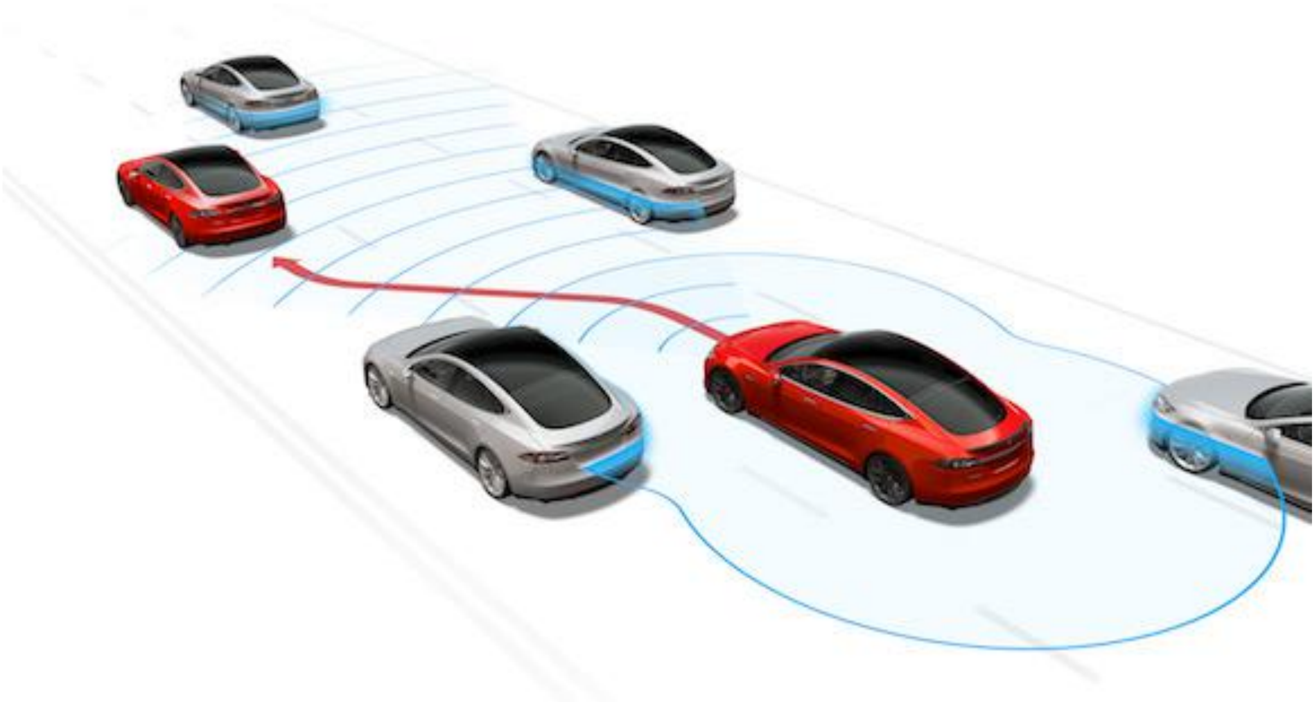
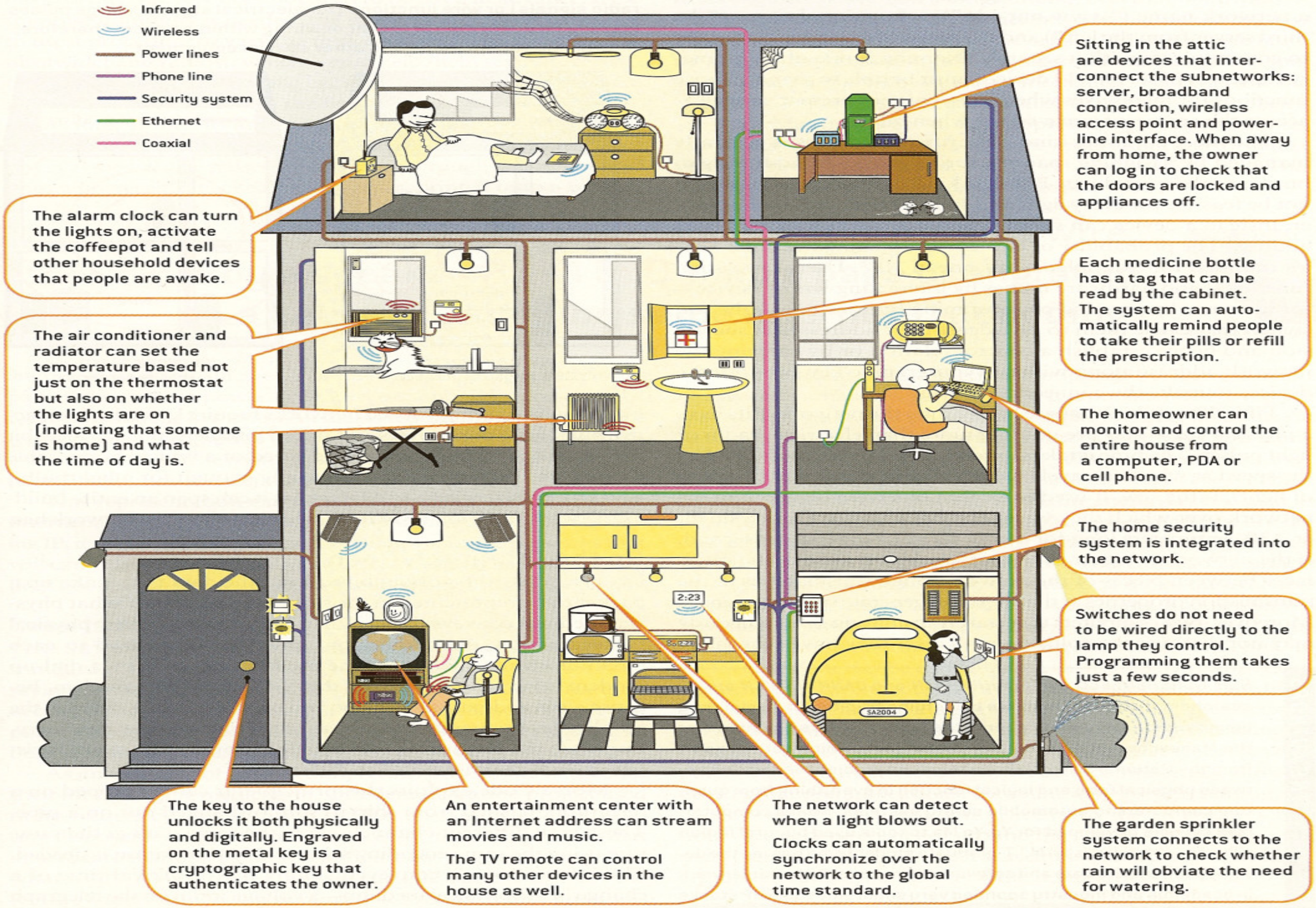
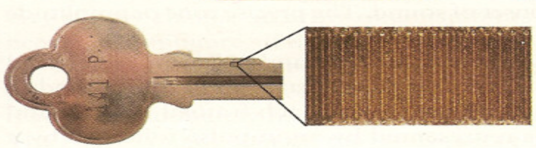


http://www.fool.com/investing/general/2016/04/29/what-the-internet-of-things-means-for-car-companie.aspx

One Network to Connect Them All

Internet-0 allows myriad devices to intercommunicate and interoperate: pill bottles can order refills from the pharmacy; light switches and thermostats can talk to lightbulbs and heaters; people can check on their homes from their offices. Existing technologies already allow many of these functions, but Internet-0 provides a single consistent standard. It can handle information sent through the AC power line, over a wireless connection or even engraved on a metal key, and it seamlessly integrates with the local and global computer networks. Devices can be configured by interacting with them rather than by typing on computers.





Internet-0 packets can be engraved onto a key (*left*) or printed as a bar code (*below*). In both cases, the vertical bars represent pulses and, once converted into electrical signals, can be put onto the network without further translation. The key engraving is a cryptographic key that allows the holder to reconfigure devices. The bar code contains "IO" preceded by the address of the destination device.

IP header — UDP header — "IO"

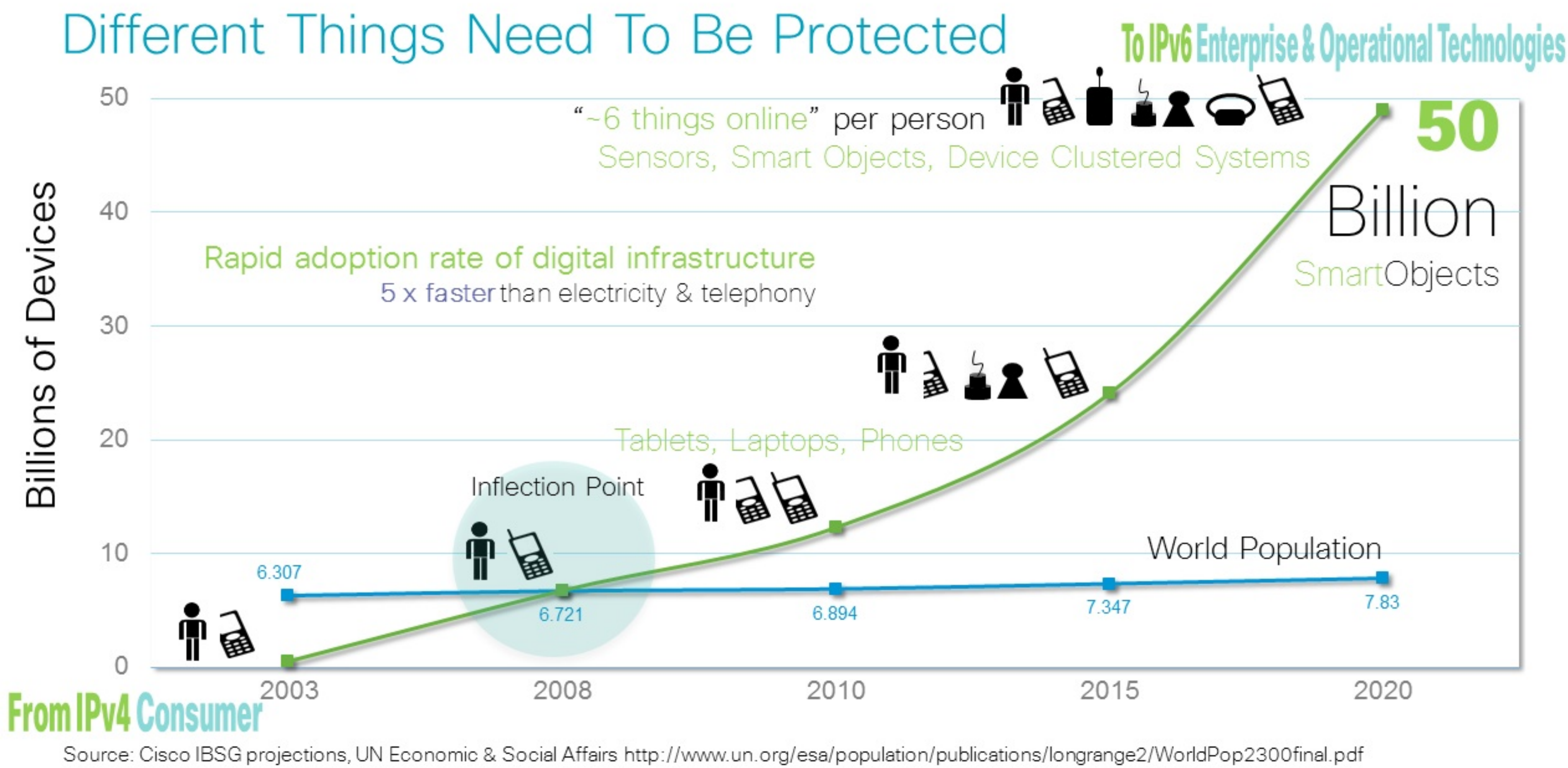
Corporate IoT Players

- Cisco
- IBM
- Philips
- Walmart
- Nokia (Finland)
- Google - announces Brillo as IoT OS!

"Europe's biggest chip maker, STMicroelectronics, and the world's third-largest chip maker, Texas Instruments, are to use the tiny Mist operating system developed by Sweden's Thingsquare for use by devices on the "Internet of things". It should make it easier to connect anything from streetlights to thermostats."

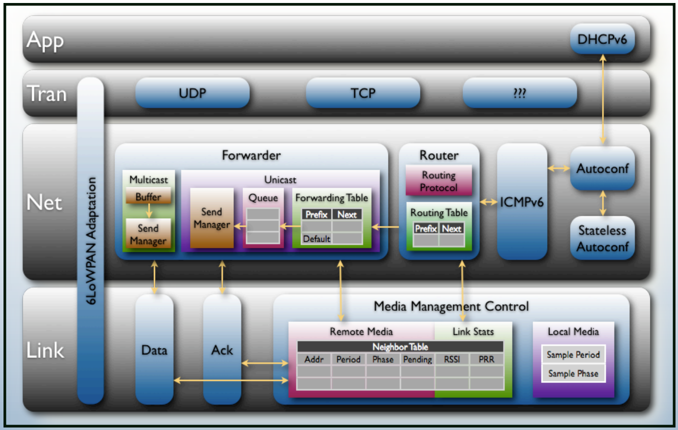
- March 13,2013 Wall Street Journal 'Tech Europe'

Birth of IoT?



Different Things Need To Be Protected
To IPv6 Enterprise & Operational Technologies
"~6 things online" per person
Sensors, Smart Objects, Device Clustered Systems
50
Billion
SmartObjects
Rapid adoption rate of digital infrastructure
5 x faster than electricity & telephony
Tablets, Laptops, Phones
Inflection Point
World Population
Billions of Devices
50
40
30
20
10
0
6.307
6.721
6.894
7.347
7.83
2003
2008
2010
2015
2020
From IPv4 Consumer
Source: Cisco IBSG projections, UN Economic & Social Affairs http://www.un.org/esa/population/publications/longrange2/WorldPop2300final.pdf

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
Internet-Draft
Intended status: Standards Track
Expires: April 4, 2011

T. Winter, Ed.

P. Thubert, Ed.
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

One Vision of the Internet of Things

The IoT includes many objects (preferably smart objects) connected and communicating effectively with people on the Internet to help solve the problems of the world.

"IoT can make a significant difference in closing the poverty gap."

IoT Definition

"Internet of Things semantically means a world-wide network of interconnected objects uniquely addressable, based on standard communication protocols."

Challenges include object unique addressing and the representation and storing of exchanged information.

Things Vision

- Smart items can relate to concept of a spime

- Spime:: an object that can be tracked through space and time throughout its lifetime and will be sustainable, enhanceable and uniquely identified.

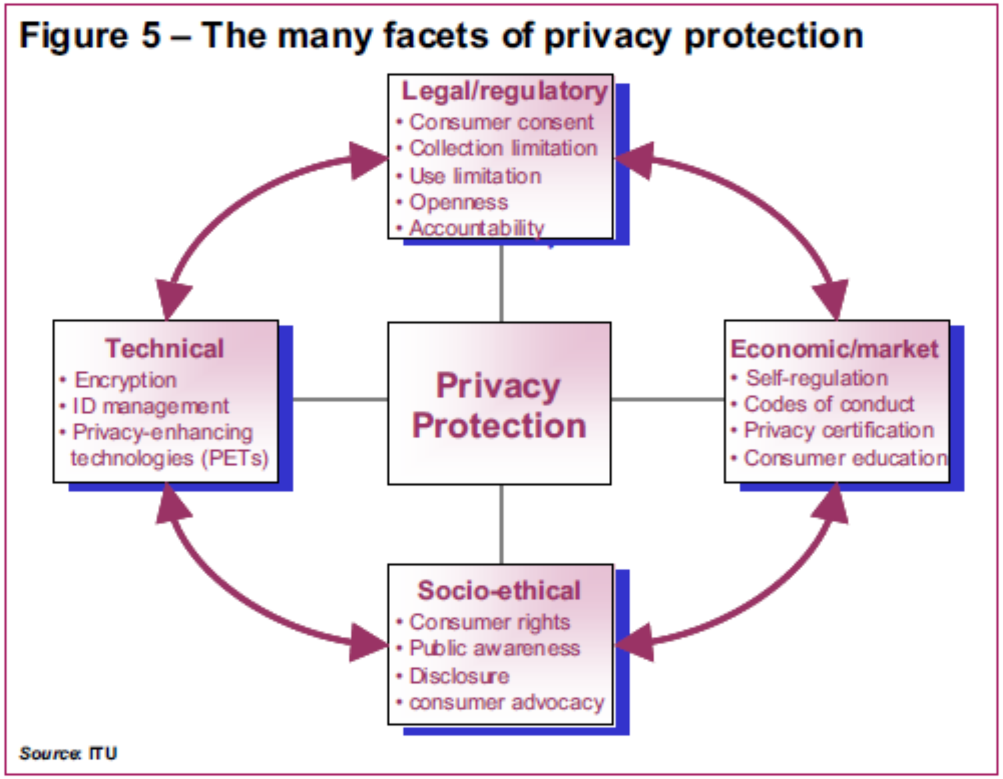
Semantic Vision

- Issues involved with handling IoT object information is very challenging and modeling, reasoning and semantic execution environments and architectures will be needed to address the scalability of storing and communicating about IoT objects.

Service Management

- Middleware
  - Layers between the technology and the application.
- Basic set of services encompass:
  - Object dynamic discovery
  - Status monitoring
  - Service configuration
- Functionalities related to QoS and lock management

IoT Issues



- Privacy, security and trust concerns
  - Social network blunders
- Big Brother – security cameras, police state

Trust, Privacy and Security

- Personal objects communicating potentially enables a surveillance system.

- Hence middleware must manage trust, privacy and security.

Attacking IoT

- Default, weak, and hardcoded credentials
- Difficult to update firmware and OS
- Lack of vendor support for repairing vulnerabilities
- Vulnerable web interfaces (SQL injection, XSS)
- Coding errors (buffer overflow)
- Clear text protocols and unnecessary open ports
- DoS / DDoS
- Physical theft and tampering

Security

- Authentication is a major problem as current authentication procedures are not feasible in the IoT
  - Lack of solutions in the IoT space for proxy attacks and man-in-the-middle attacks

- Data integrity gets more complicated when you have unattended nodes like RFID tags

Security

- Cryptography solutions expend energy and bandwidth resources at both source and destination and therefore cannot be readily applied to IoT
  - Some light symmetric key schemes have been proposed

Privacy

- Concerns about privacy protection have been a significant barrier against diffusion of the technologies involved in IoT

- Unlike the Internet where privacy problems mostly arise from active users, IoT privacy problem scenarios can threaten even people not using any IoT service

Privacy


HELLO, WELCOME TO OUR HOUSE!
THANKS FOR INVITING US!
ALEXA, ORDER TWO TONS OF CREAMED CORN.
ALEXA, CONFIRM PURCHASE.
WHEN VISITING A NEW HOUSE, IT'S GOOD TO CHECK WHETHER THEY HAVE AN ALWAYS-ON DEVICE TRANSMITTING YOUR CONVERSATIONS SOMEWHERE.

Privacy - Tracking

- In tracking systems, position movement of individual users needs to handled in terms of aggregate users
  - Namely, this motion information should not be linkable to identities
- People need to be informed about the scope of the tracking information
- Tracking info collected should be processed and then deleted
  - e.g., heating and lighting controls

Case Study: Trane

- Connected thermostat vulnerabilities detected by Cisco's Talos group allowed foothold into network
- 12 months to publish fixes for 2 vulnerabilities
- 21 months to publish fix for 1 vulnerability
- Device owners may not be aware of fixes, or have the skill to install updates

Case Study: Lessons Learned

- All software can contain vulnerabilities
- Public not informed for months
- Vendors may delay or ignore issues
- Product lifecycles and end-of-support
- Patching IoT devices may not scale in large environments

Threat vs. Opportunity

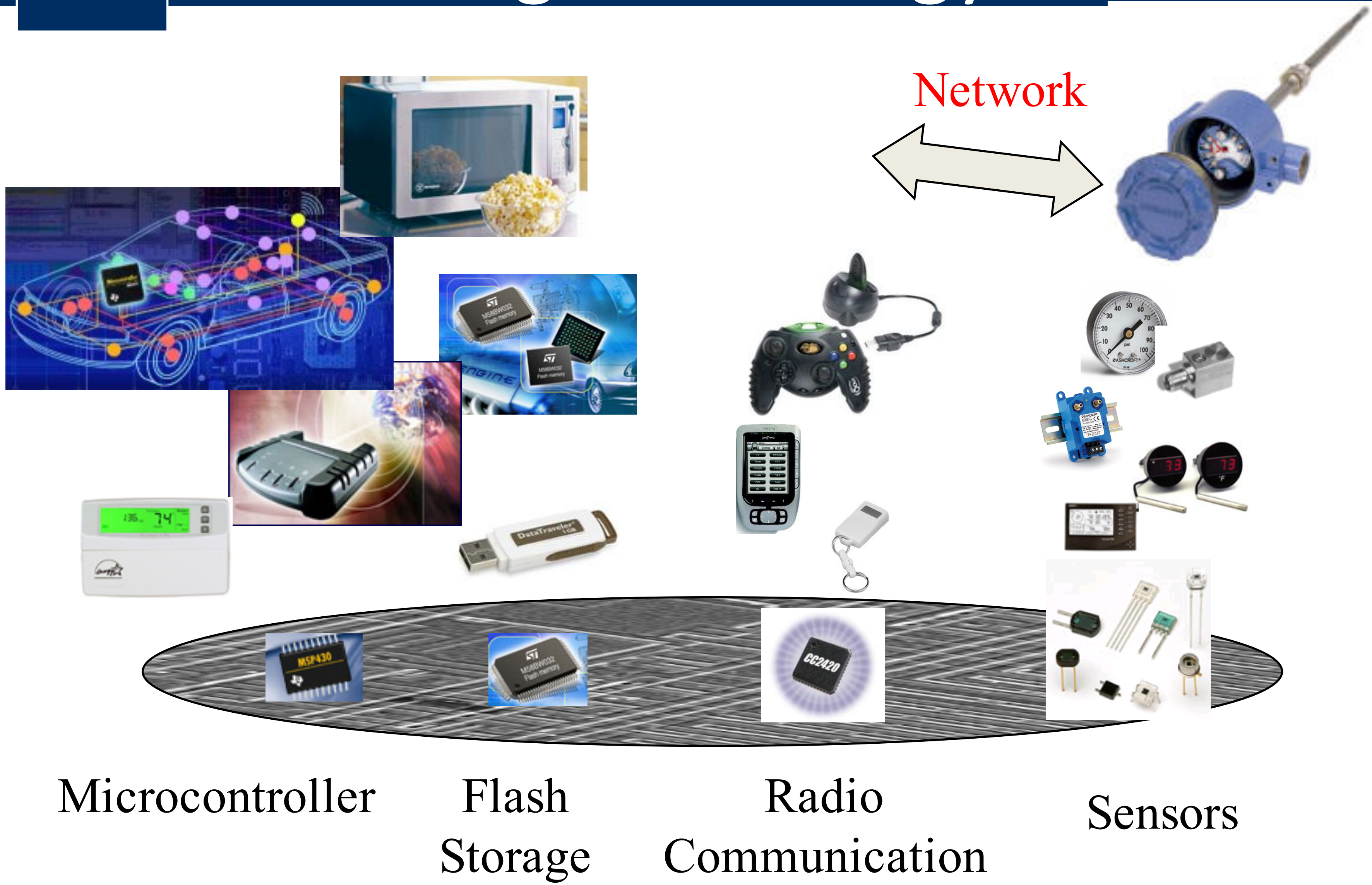
- If misunderstood and misconfigured,
  - IoT poses risk to our data, privacy, and safety

- If understood and secured,
  - IoT will enhance communications, lifestyle, and delivery of services

Summary

- There is more than one vision for the Internet of Things
  - Much “buzz” now but when will it be a reality
- Interoperability is essential and requires standards agreements
- Many opportunities and challenges
  - As a new area, IoT research is not well-established
- IoT has potential to add a new dimension to the concept of moving the interactions between people at a virtual level on the Internet
  - This potential comes from enabling communication among smart objects

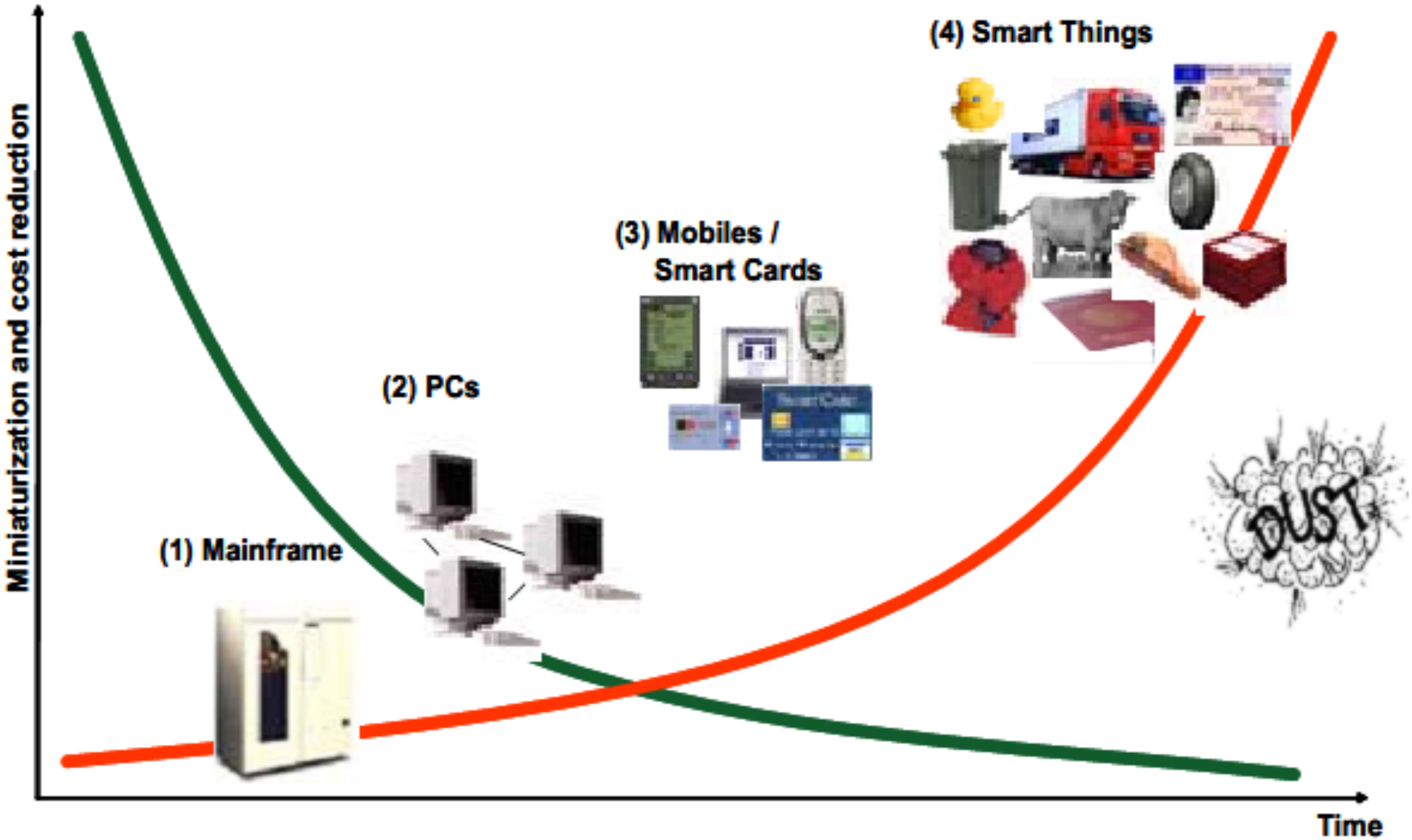
Enabling Technology



Enabling Technologies

- Technologies needed:
  - RFID
    - RSNs (RFID Sensing Networks)
  - WSNs
    - 802.15.4
  - Power for Sensors*
  - Mobile and Smart phones
  - Nanoscience and Miniaturization
  - Smart Objects (intelligence) and Robotics
  - M2M (Machine-to- Machine) communication
  - Standardization* of communication, protocols, security
  - IPv6*, 6LoWPAN, Zigbee
- Others
  - Big Data
  - The Cloud

Miniaturization



Devices

Device	Processor	Mem	Storage	Connectivity
Laptop (Macbook Pro)	2.80 GHz	16 GB	512 GB	WiFi
Smartphone (Nexus 6P)	1.55 GHz	3 GB	128 GB	WiFi, Cellular, BLE, NFC
Wearables (Gear S)	1 GHz	512 MB	4 GB	WiFi, BLE, NFC
Raspberry Pi 3	1.2 GHz	1 GB	microSD	Ethernet, WLAN, BLE
Arduino UNO (ATmega328P)	16 MHz	2 KB	32 KB	Various shields
Intel Joule	1.7 GHz	4 GB	16 GB	WiFi, BLE

http://www.gsmarena.com/

https://www.raspberrypi.org/magpi/raspberry-pi-3-specs-benchmarks/

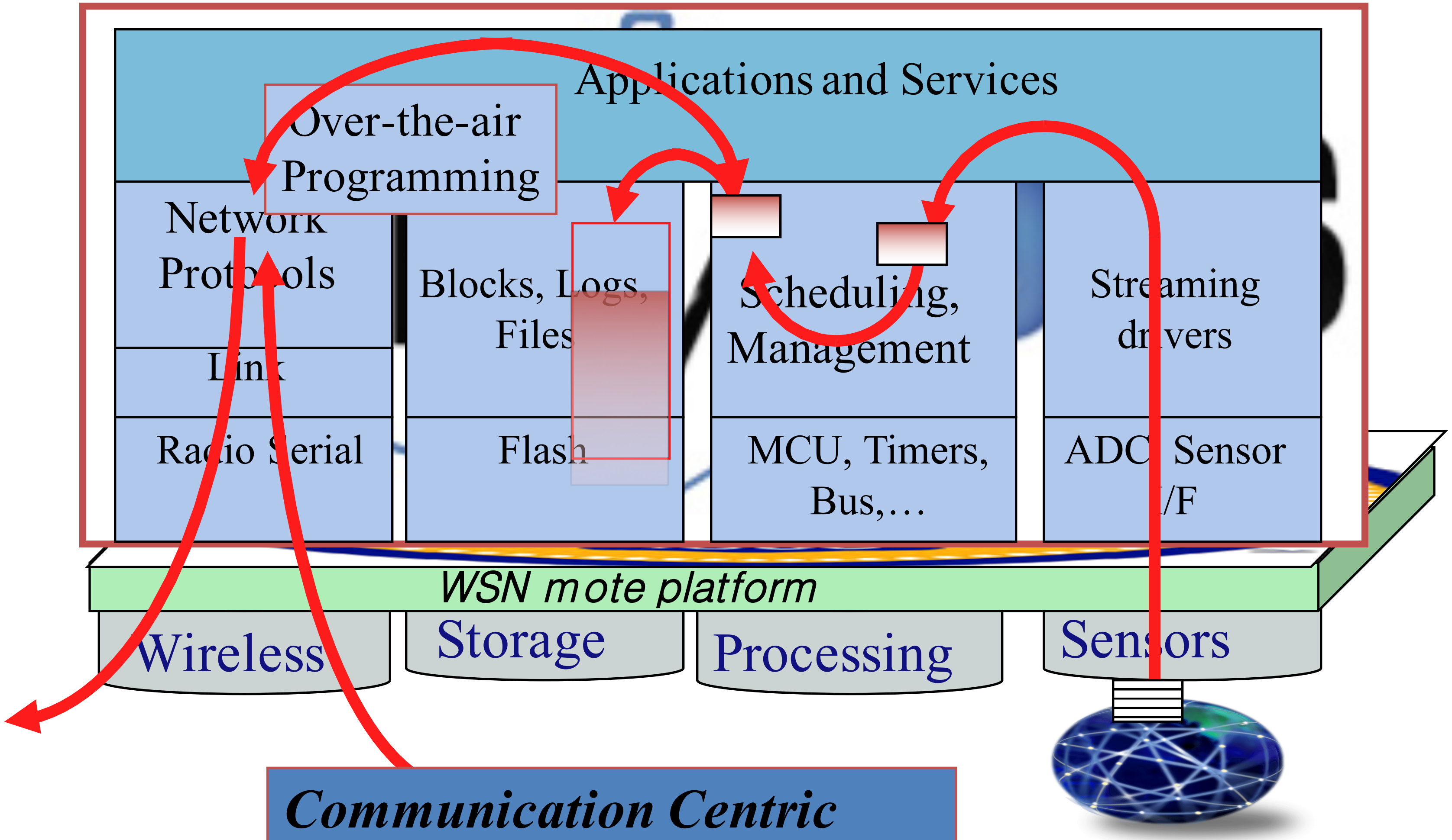
Wireless Networks

Network Type	Speed	Range	Power	Common Use
WLAN	600 Mbps	45 m – 90 m	100 mW	Internet.
LTE	5-12 Mbps	35km	120 – 300 mW	Mobile Internet
3G	2 Mbps	35km	3 mW	Mobile Internet
Bluetooth	1 – 3 Mbps	100 m	1 W	Headsets, audio streaming.
Bluetooth LE	300 Kbps	100+ m	.01–.5 W	Wearables, fitness.
Zigbee	100 Kbps	100 m	0.45 mW	WSN

(The numbers are not that simple to estimate exactly, but should give you an idea)

http://dl.acm.org/citation.cfm?id=1644927
http://dl.acm.org/citation.cfm?id=2307658
http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=6616827&tag=1

TinyOS – Framework for Innovation



Communication Centric

Resource-Constrained

Event-driven Execution

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

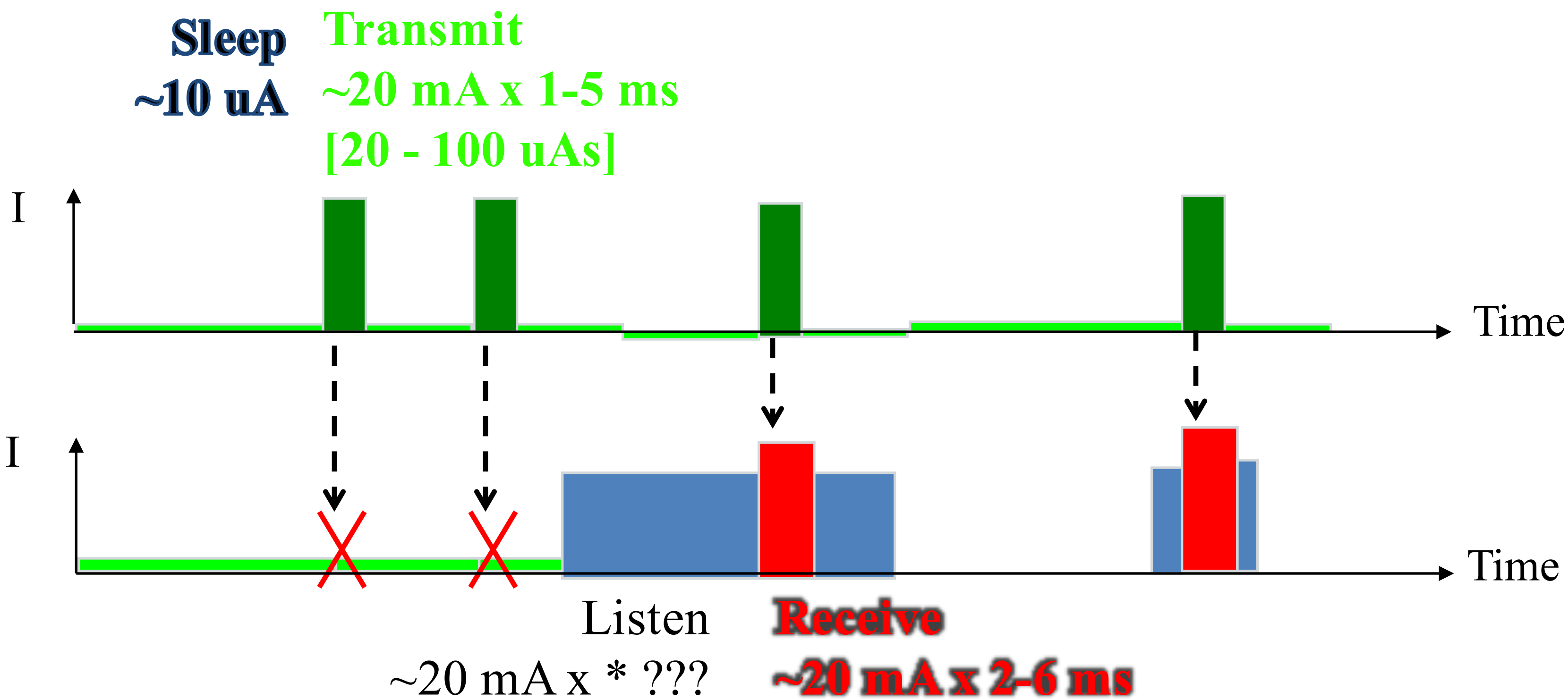
The "Idle Listening" Problem

- 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*

⇒*Do Nothing Well*

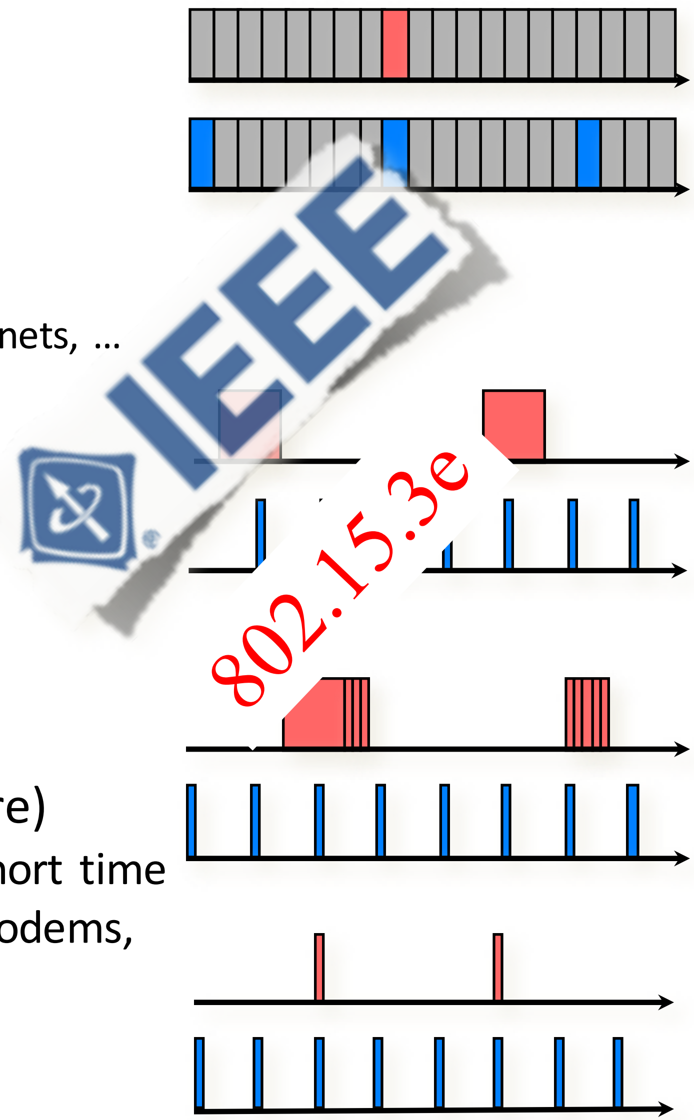
Communication Power – Passive Vigilance



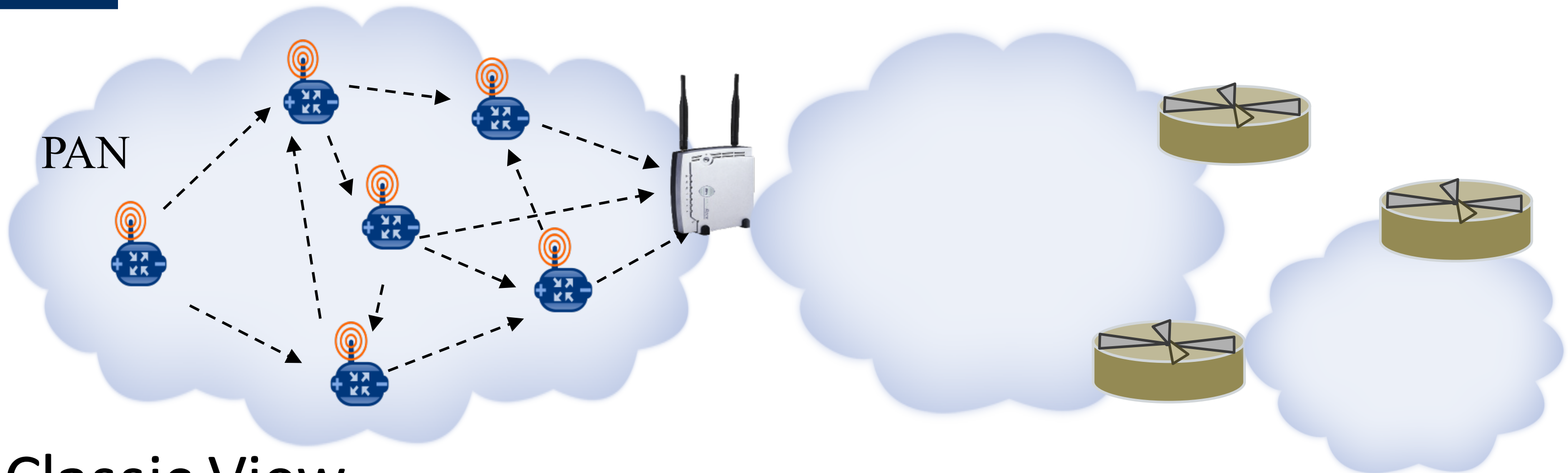
- Listen just when there is something to hear …

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 eminent transmissions
  - On detection, listen actively to receive
  - DARPA packet radio, LPL, BMAC, XMAC, …
  - 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

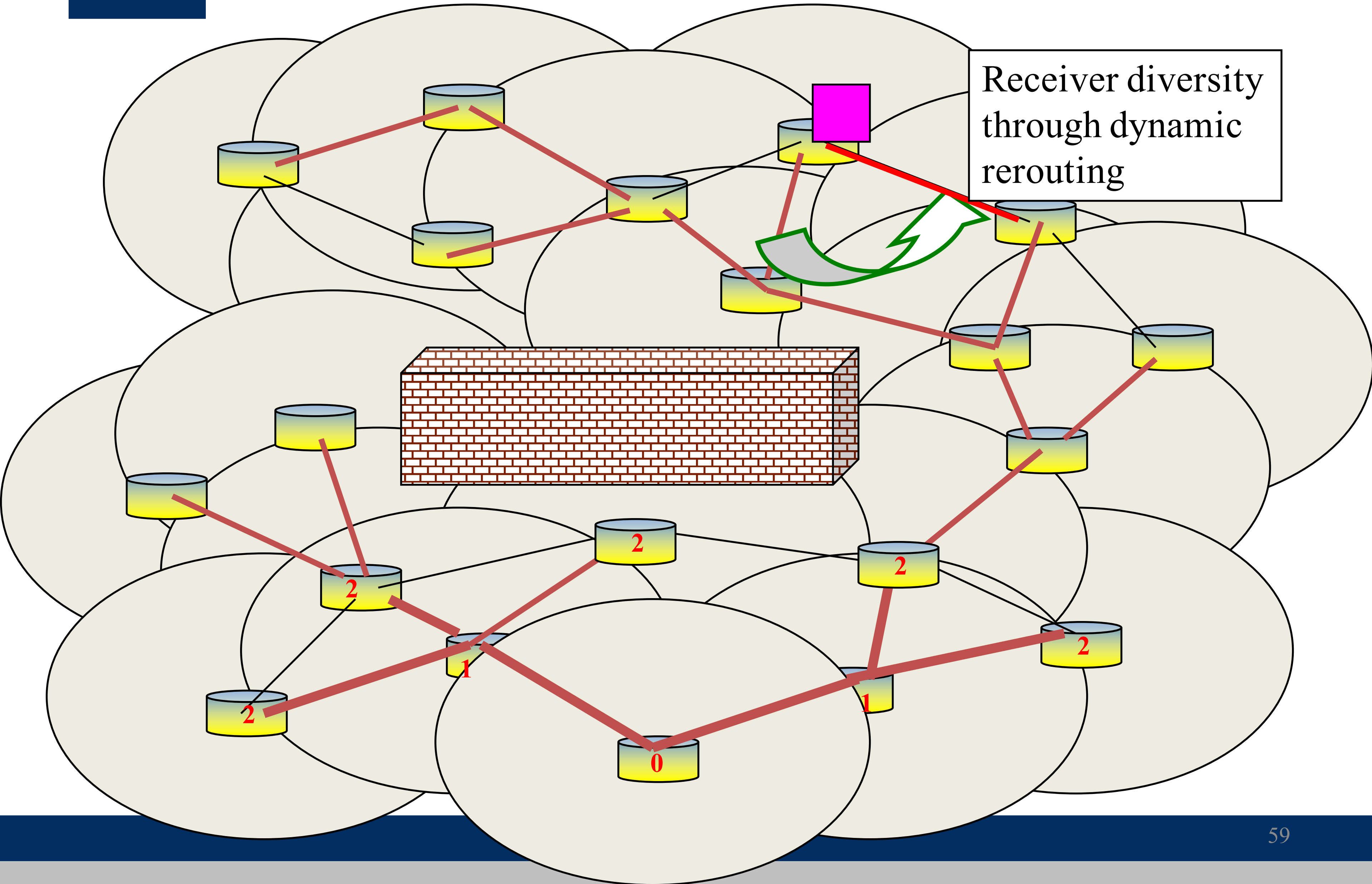


Routing in Low Power Wireless Networks



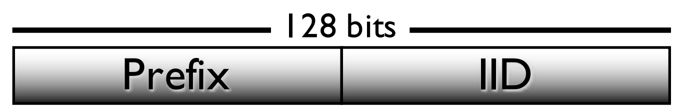
- Classic View
  - Network = Graph of routers and links
    - Like a street map
  - Routing is a (distributed) algorithm for finding good paths in this (slowly changing) graph
  - Realized (hop by hop) by tables and addressing
- But, … there is no graph
  - Discover it by attempting to communicate
  - Changes due to environment

Self-Organized Routing - nutshell



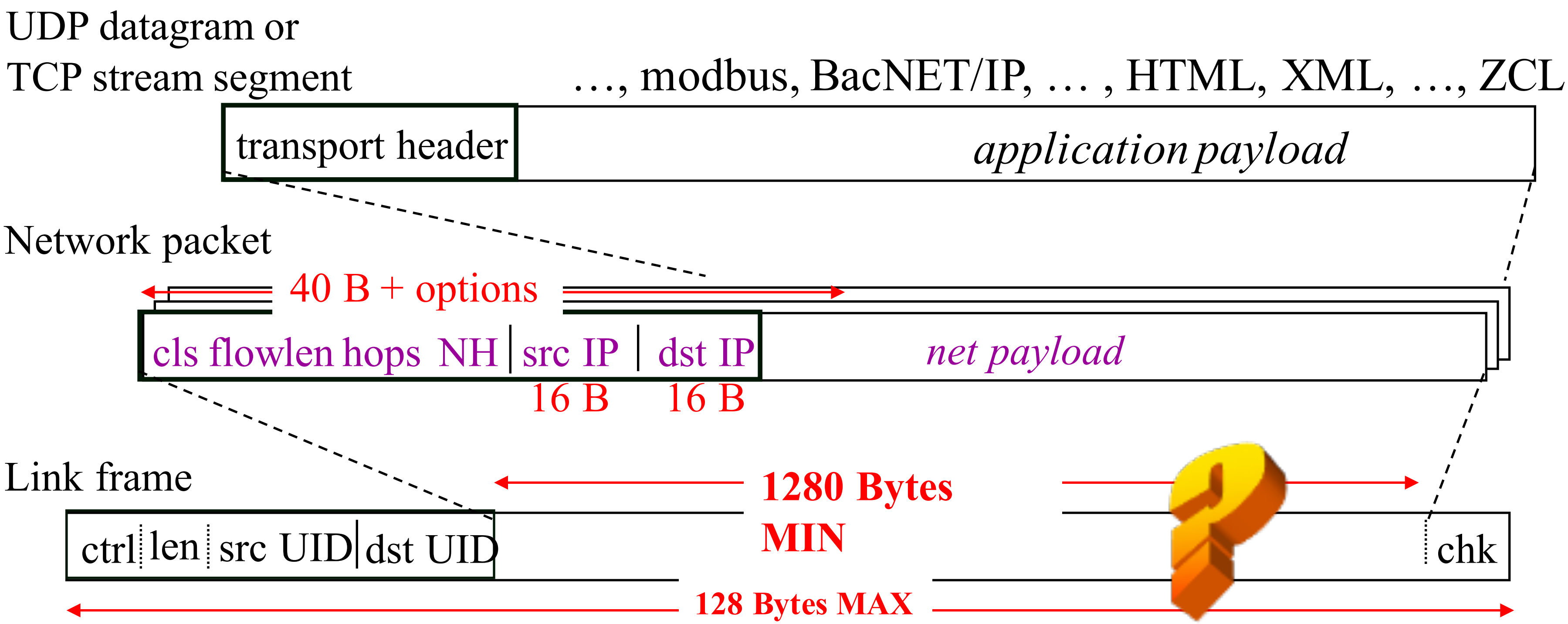
Key IPv6 Contributions

- 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



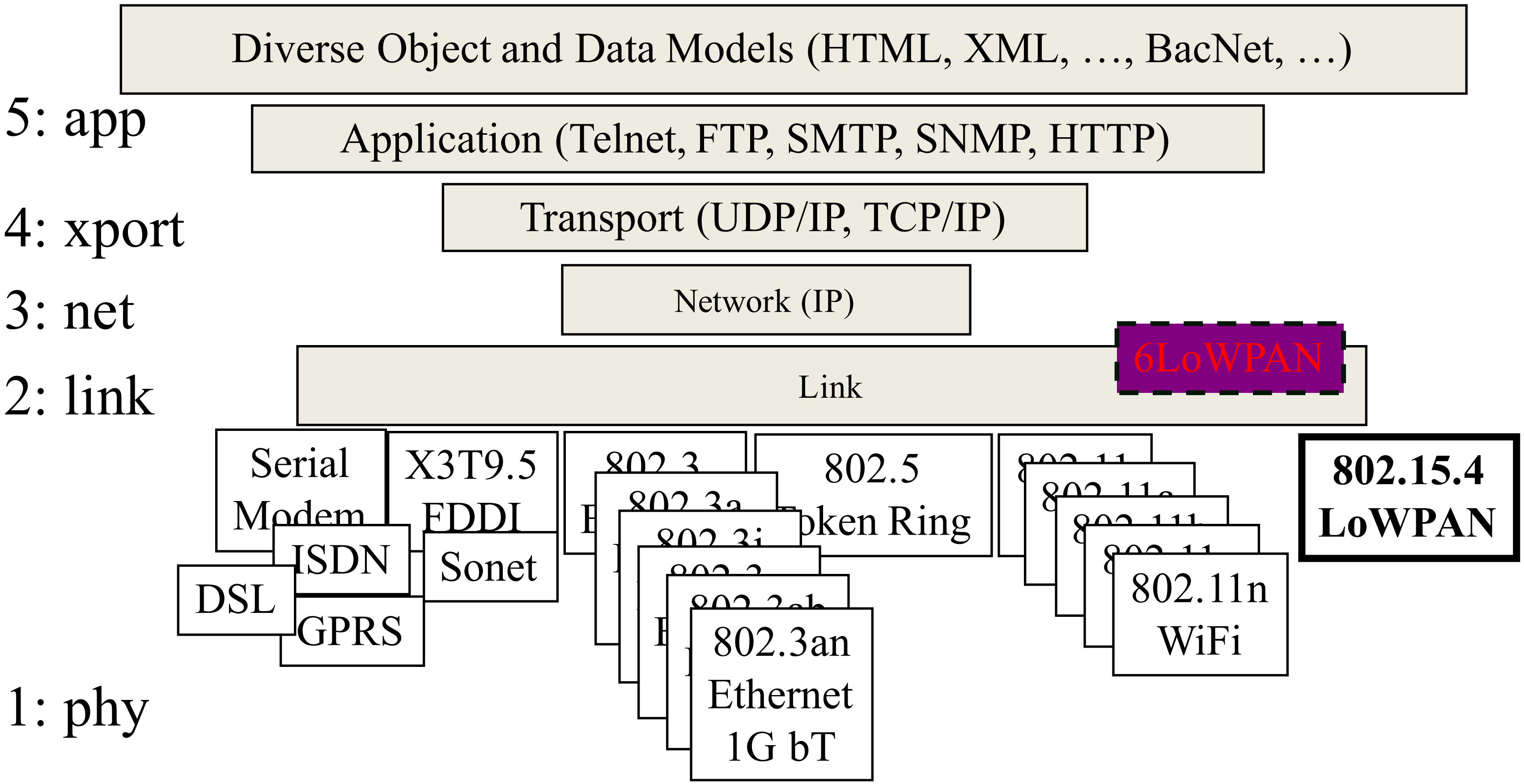
6LoWPAN – IPv6 over 802.15.4

IPv6 over Low power Wireless Personal Area Networks

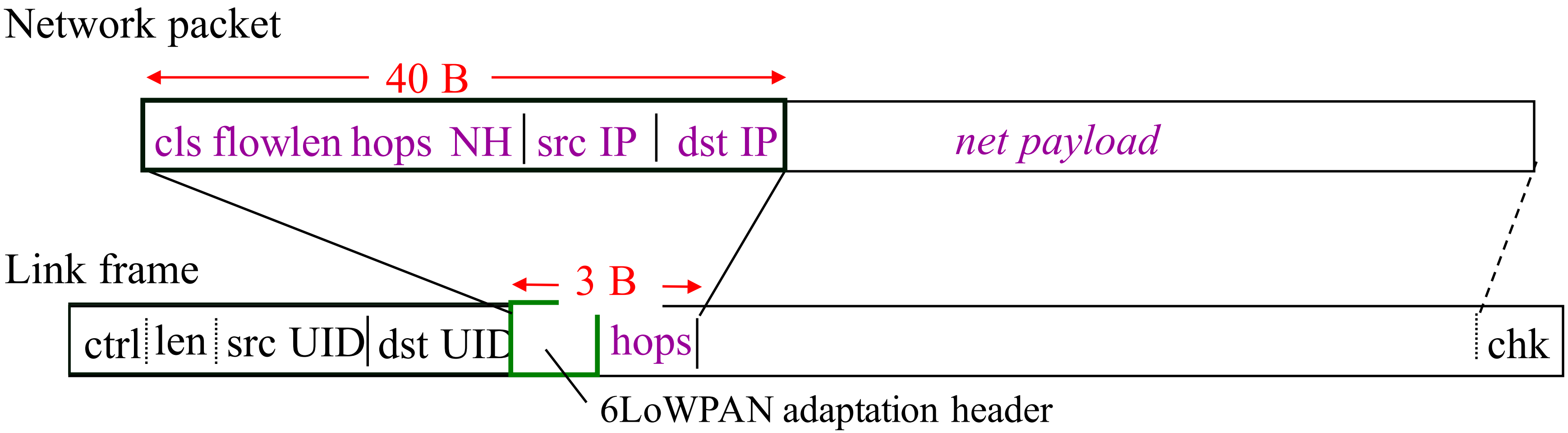


- Large IP Address & Header => 16 bit short address / 64 bit EUID
- Minimum Transfer Unit => Fragmentation
- Short range & Embedded => Multiple Hops

6LoWPAN adaptation layer

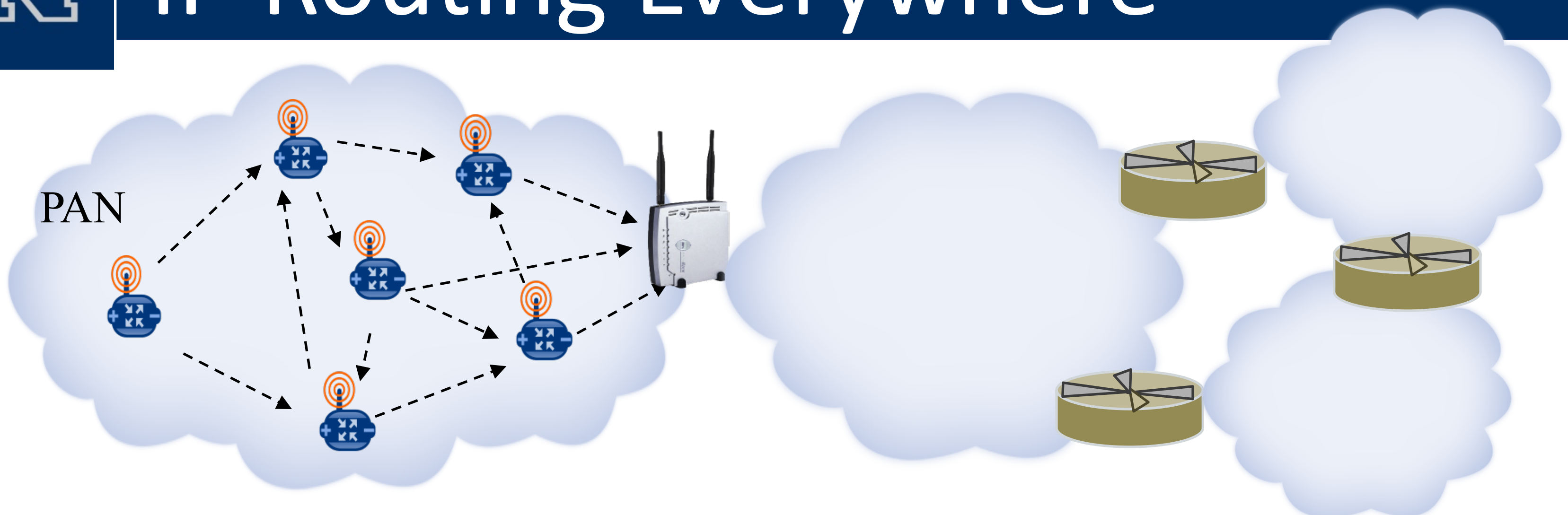


6LoWPAN – IP Header Optimization



- 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

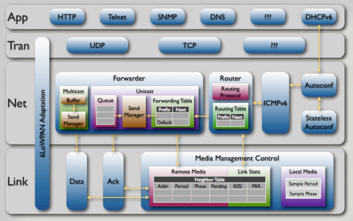
IP Routing Everywhere



- Conventional IP link is a full broadcast domain
  - Routing connects links (i.e, networks)
- Many IP links have evolved from a broadcast domain to a “mesh” with emulated broadcast
  - ethernet => switched ethernet
  - 802.11 => 802.11s
- Utilize high bandwidth on powered links to maintain the illusion of a broadcast domain
- 802.15.4 networks are limited in bandwidth and power so the emulation is quite visible.

Embedded IPv6 in Concept

Structured Decomposition



- ✔ Retain strict modularity
  Some key cross-layer visibility

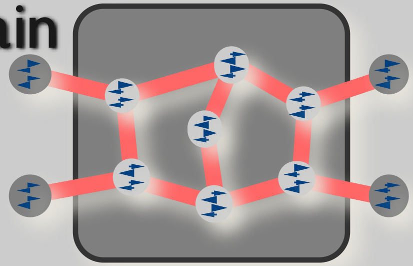
IP Link ⇒ Always On

- ✔ Retain illusion even when always off

IP Link ⇒ "Reliable"

- ✔ Retain best-effort reliability over unreliable links

IP Link ⇒ Broadcast Domain



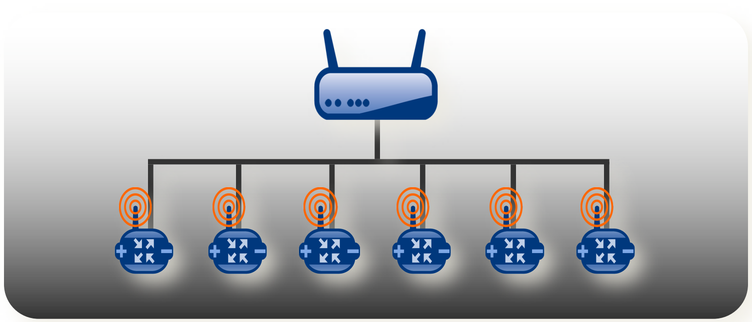
- ✘ IPv6 can support a semi-broadcast link with few changes

Example: Autoconfiguration

Configuring Large Numbers of Interfaces

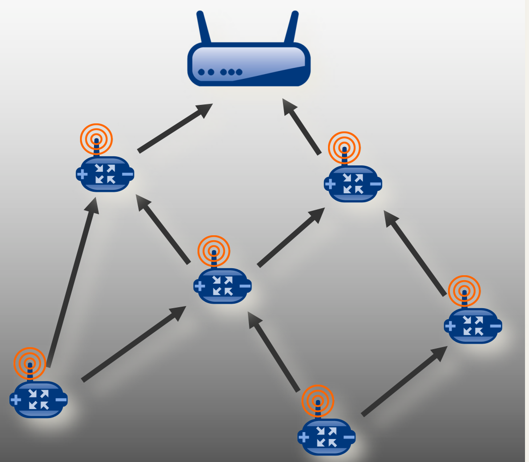
RFC 4861 – Neighbor Discovery
RFC 4862 – Stateless Addr Autoconf
RFC 3315 – DHCPv6

	Existing Options		New Options
ICMPv6 Hdr	Router Adv	Prefix Info	MHop Info
	Cur Hop Limit	Prefix Length	Network ID
	Managed Addr Config	Autonomous Config	Sequence Number
	Other Config	Valid Lifetime	Router Hops
	Router Lifetime	Preferred Lifetime	Flags
	Reachable Time	Prefix	



Example: Routing with IPv6 options

Default Routes



Discovering Links

ICMPv6 Hdr	Router Adv	MHop Info

Building a Connectivity Graph

Low Routing Cost

High Routing Cost

Routing Table

Prefix	Next

Selecting the Next Hop

Routing Table

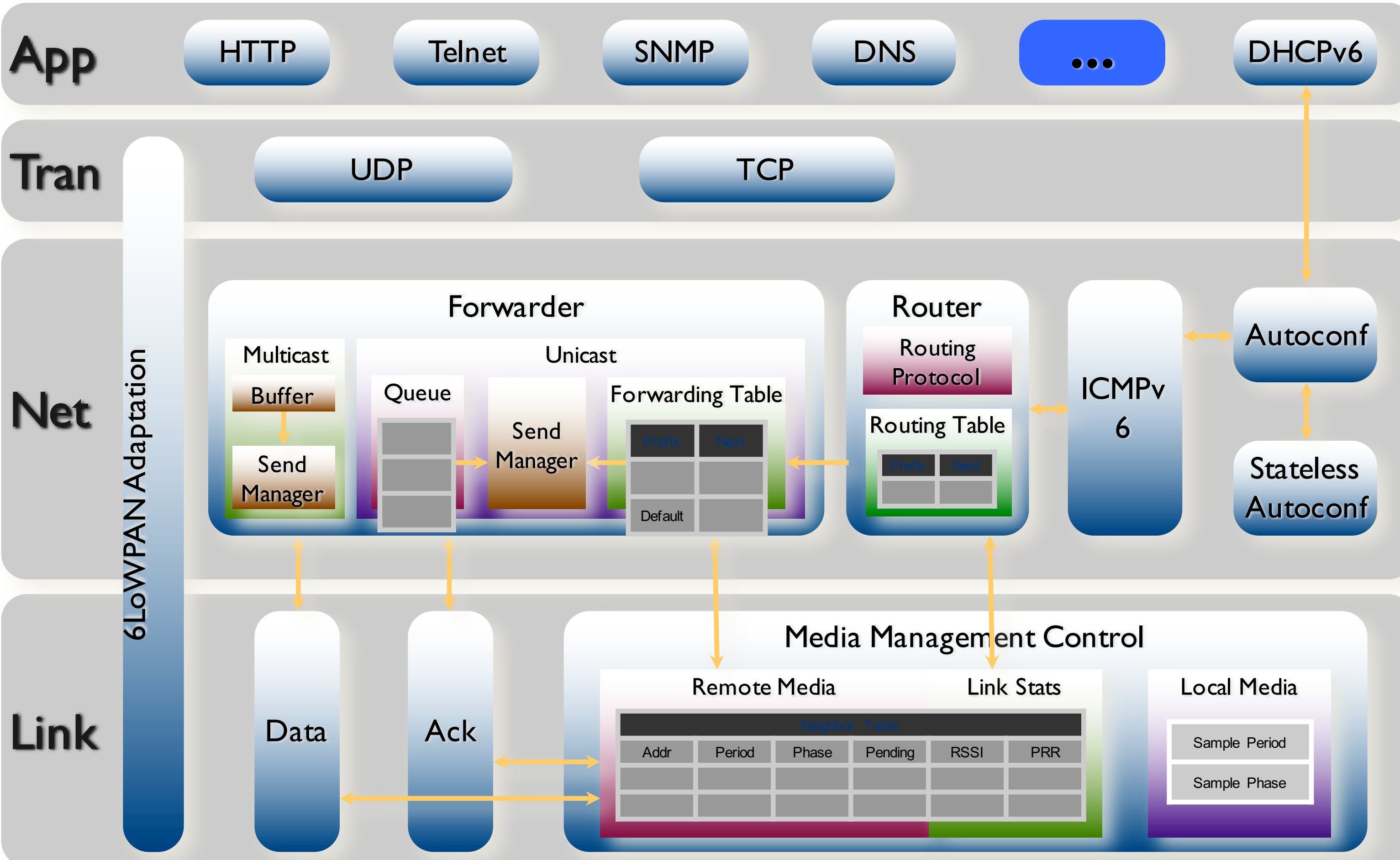
Prefix	Next

Forwarding Table

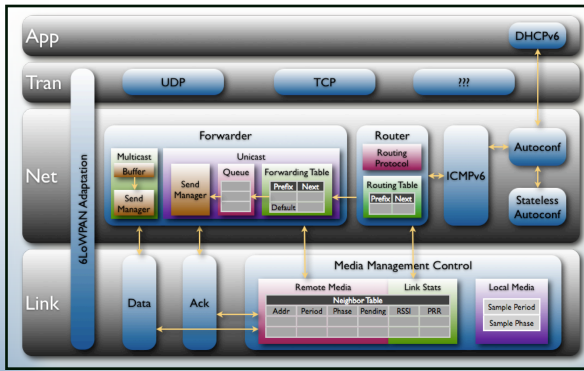
Prefix	Next
Default	

- Default route
- Hop-by-hop retry
- Reroute on loss

Complete Embedded IPv6 Stack



Adding up the pieces



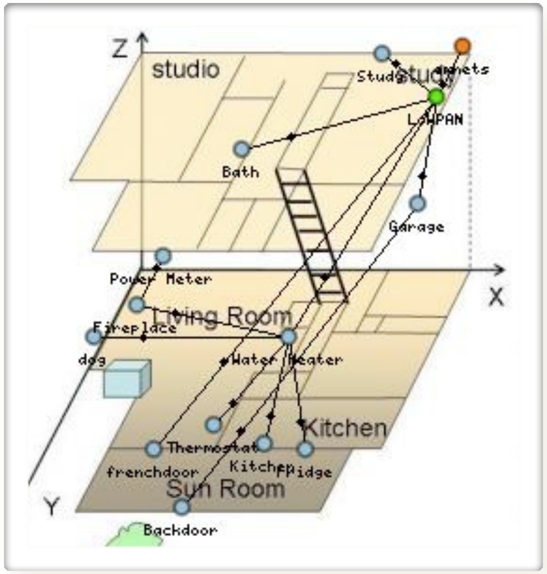
24038 ROM

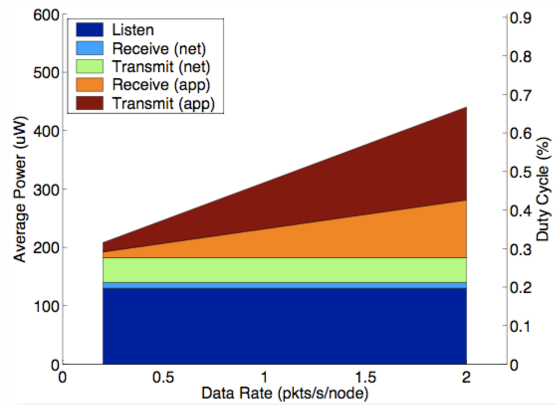
3598 RAM
(including runtime)

* Production implementation on TI msp430/cc2420

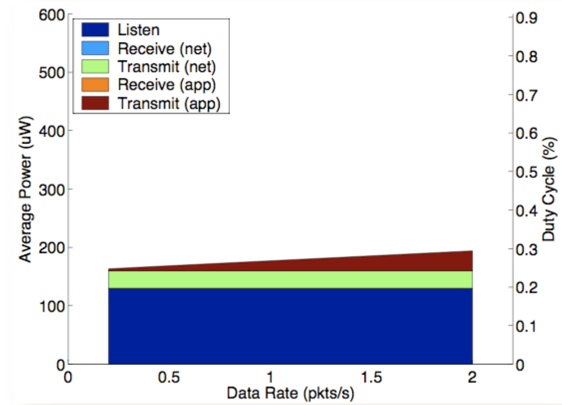
	ROM	RAM
CC2420 Driver	3149	272
802.15.4 Encryption	1194	101
Media Access Control	330	9
Media Management Control	1348	20
6LoWPAN + IPv6	2550	0
Checksums	134	0
SLAAC	216	32
DHCPv6 Client	212	3
DHCPv6 Proxy	104	2
ICMPv6	522	0
Unicast Forwarder	1158	451
Multicast Forwarder	352	4
Message Buffers	0	2048
Router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

and Power and reliability …

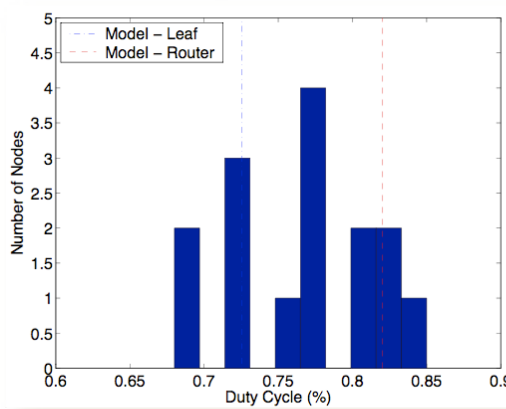




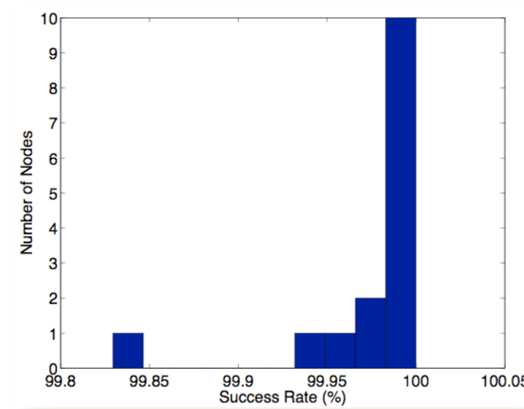
Data Rate Sensitivity
(Router)



Data Rate Sensitivity
(Edge)



Deployment Duty Cycle



Deployment Reliability

Many Important Details

- Header format specifics and trade-offs
- ICMPv6 ND (RA etc.) replaced with RPL ND
  - DIS, DIO, DAO
- Routing Security framework from the start
- Limited Tolerance for Routing Inconsistency
- Source routing as compact hop-by-hop option
  - 6MAN
- Not limited to 802.15.4 or LoWPAN
  - PLC
- …

Rough Consensus and Running Code

- IETF Standard requires multiple independent interoperable implementations
  - Two major open-source ones already (next)
  - Many commercial and research ones of varying quality
- Standards bodies in transformation
  - ZIGBEE has become compliance body
  - 802.15.4 | 6LoWPAN |RPL ipv6 | TCP/UDP | … ??
  - IETF CORE developing compact http over UDP
  - IEEE 802.15.4e/g wrapping up low power MAC
- Lots of vested interest positioning & cruft

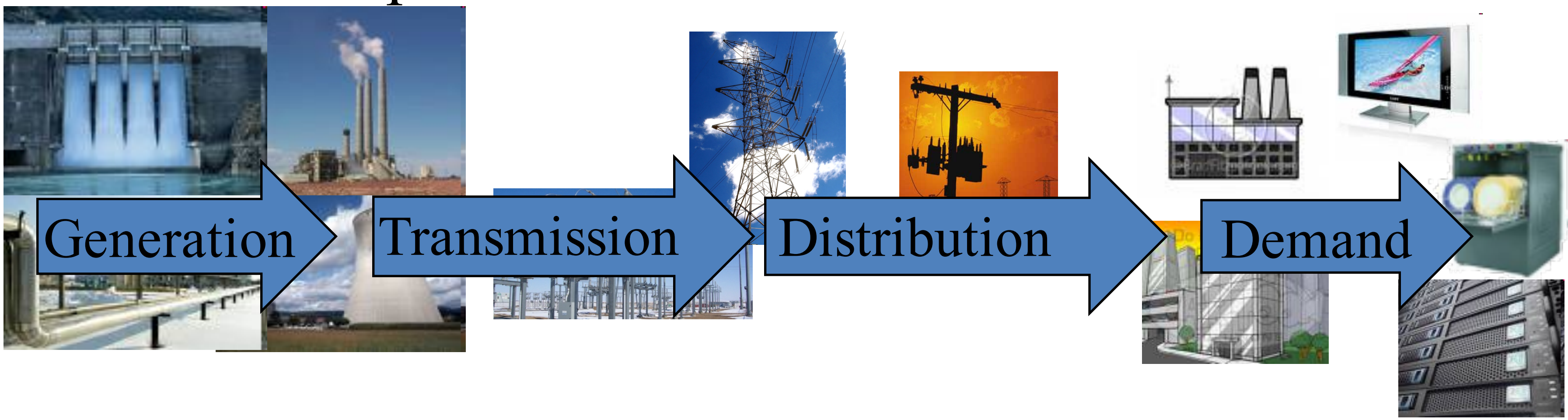
Opportunities and Open Problems

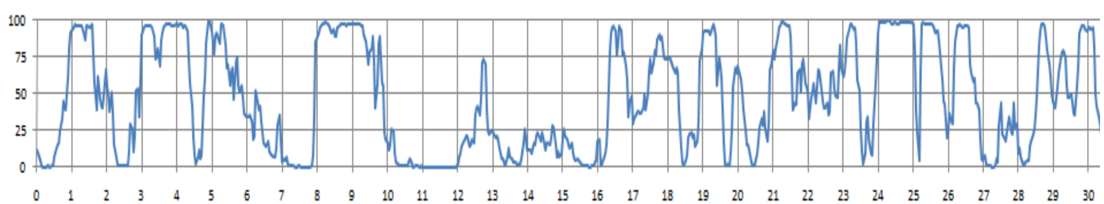
- Quantitative Analysis and Design of WSNs in context of layered IPv6 architecture
  - Objective function trade-offs, utility, table management algorithms, …
- Classic issues in new context
  - Transport protocol, compression, cross-layer optimization, …
- Ideas set aside for lack of knowledge
  - Piecewise source routing, reactive backtracking, …
- “Let chaos Reign, then Rein in the Chaos”

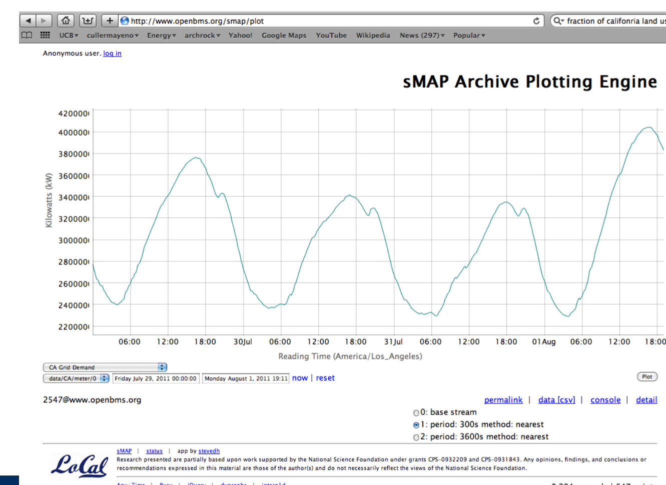
Traditional Load-Following Grid

Baseline + Dispatchable Tiers

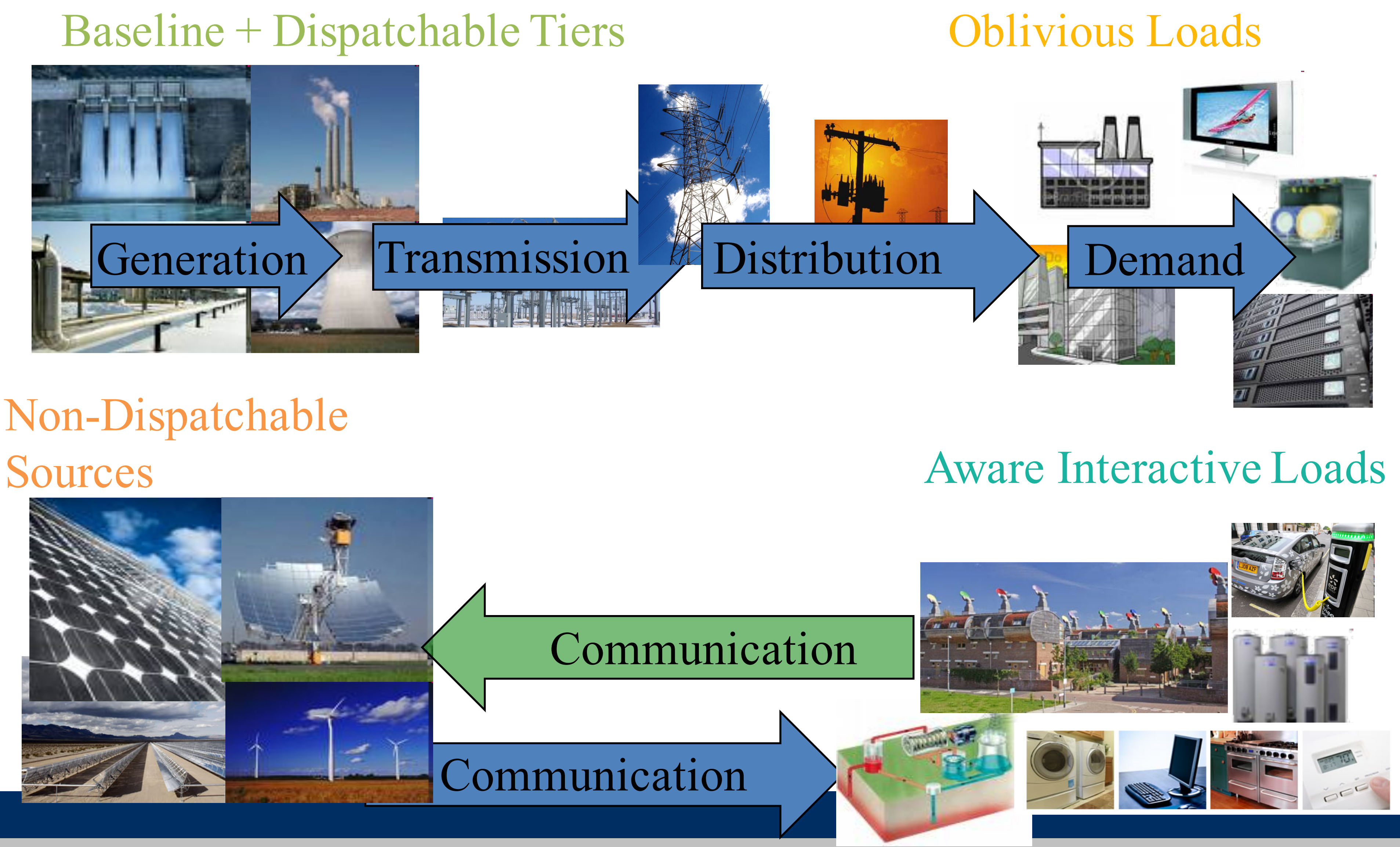
Oblivious Loads





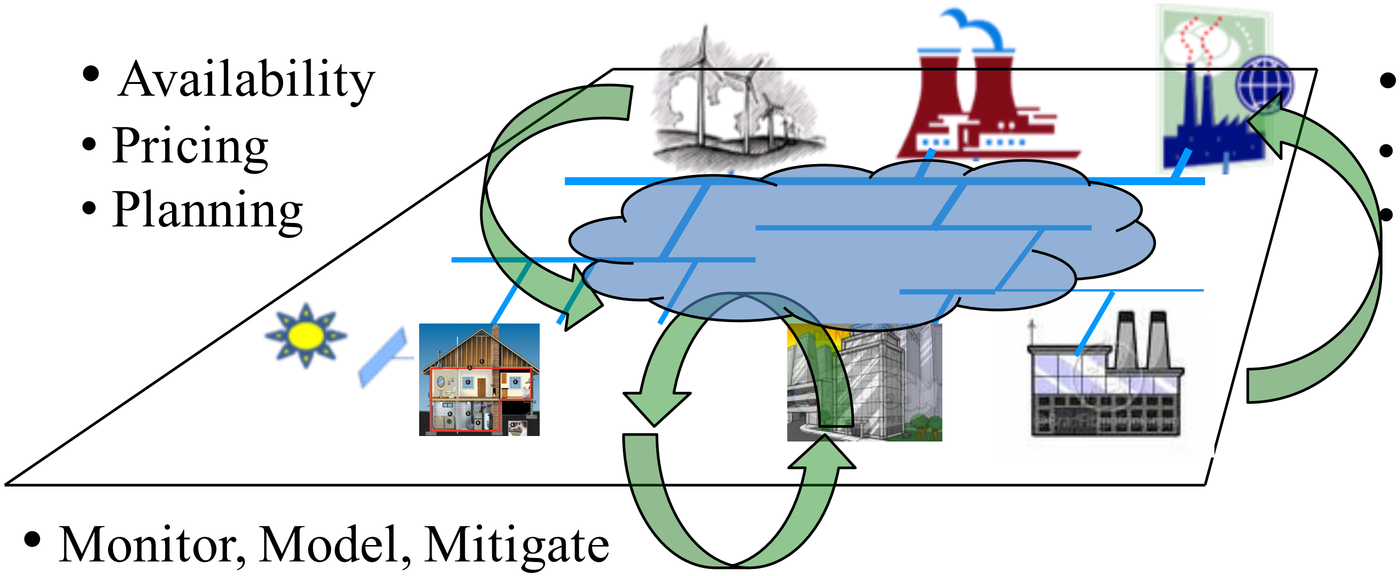


Towards an 'Aware' Energy Infrastructure



Aware Co-operative Grid

- Availability
- Pricing
- Planning

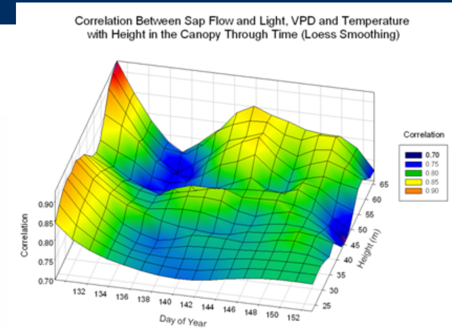


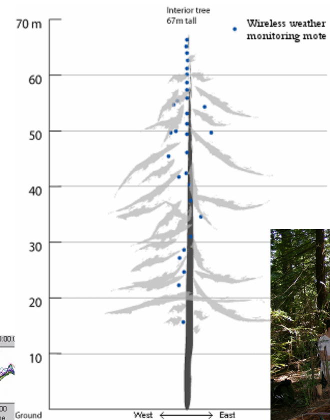
- Forecasting
- Tracking
- Market

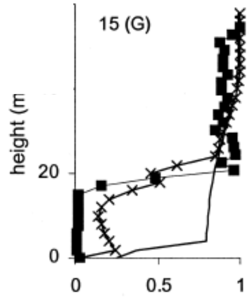
- Monitor, Model, Mitigate
  - Deep instrumentation
  - Waste elimination
  - Efficient Operation
- Shifting, Scheduling, Adaptation

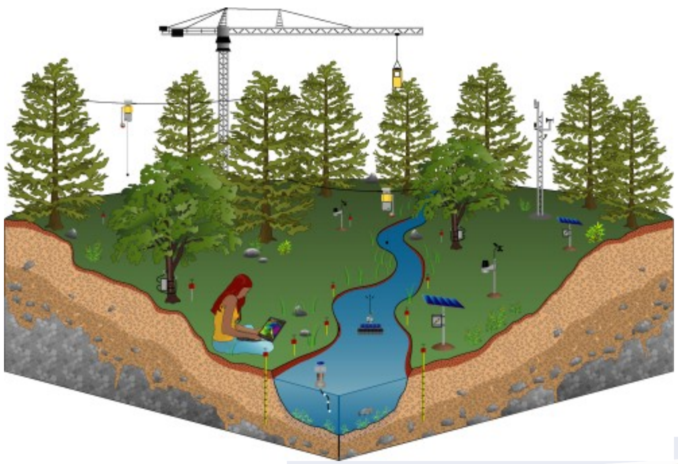
The “Macroscope”

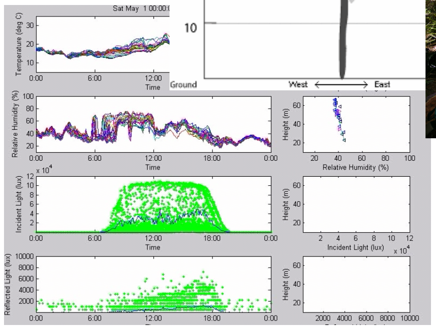
- Observe complex interactions over time and space

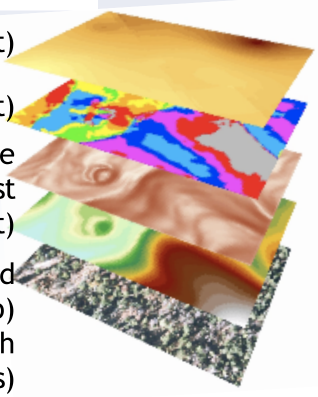






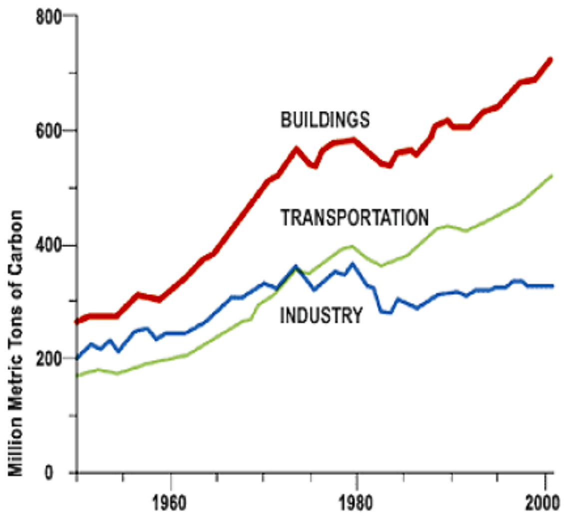


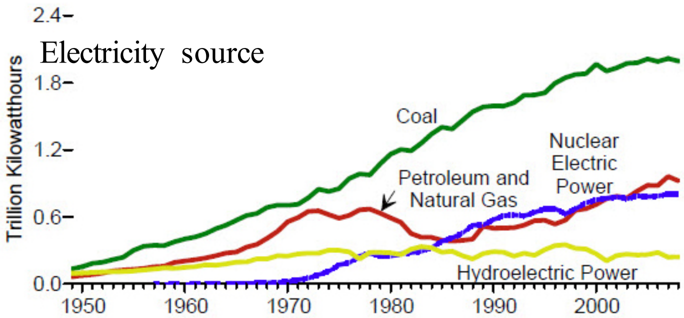


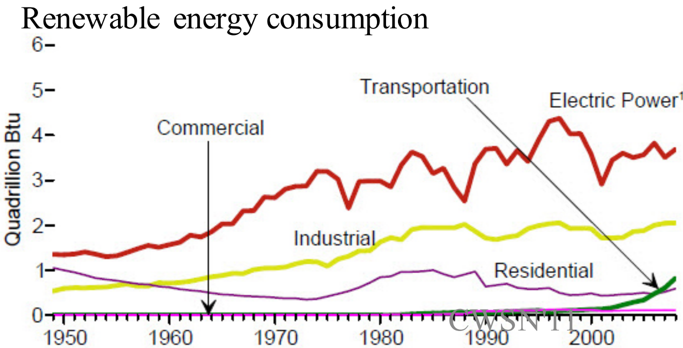


Where to Start?

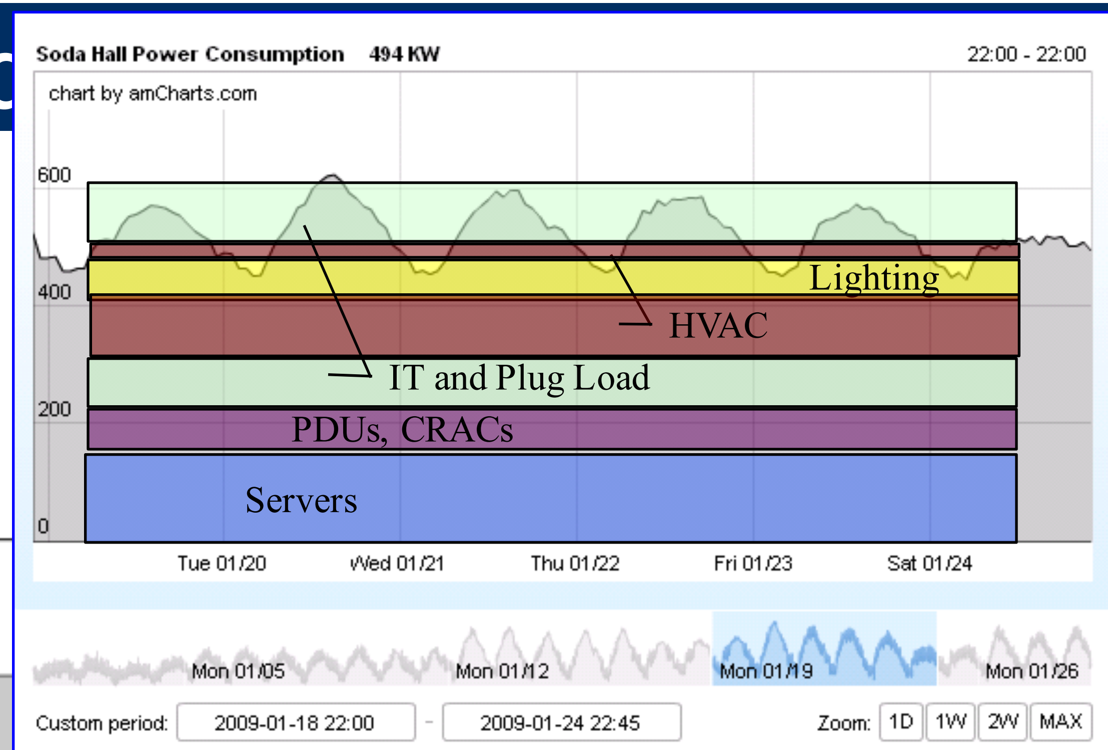
- Buildings
  - 72% of electrical consumption (US),
  - 40-50% of total consumption,
  - 42% of GHG footprint
  - US commercial building consumption doubled 1980-2000, 1.5x more by 2025 [NREL]
- Where Coal is used
- Prime target of opportunity for renewable supplies



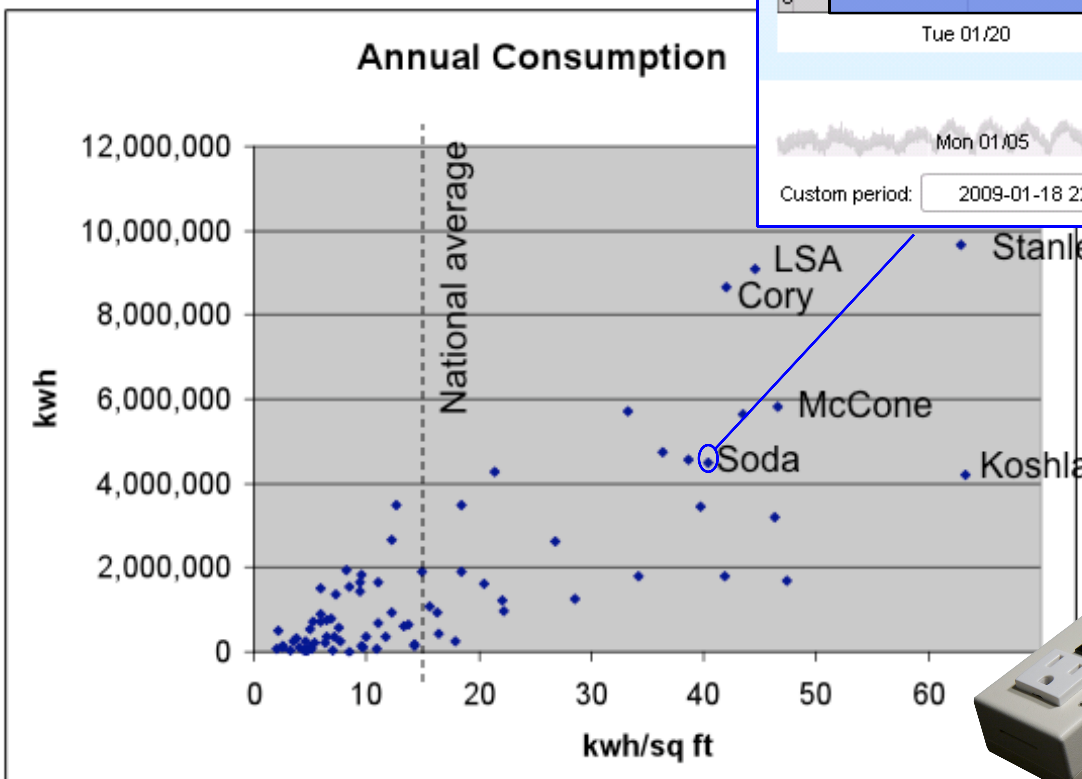




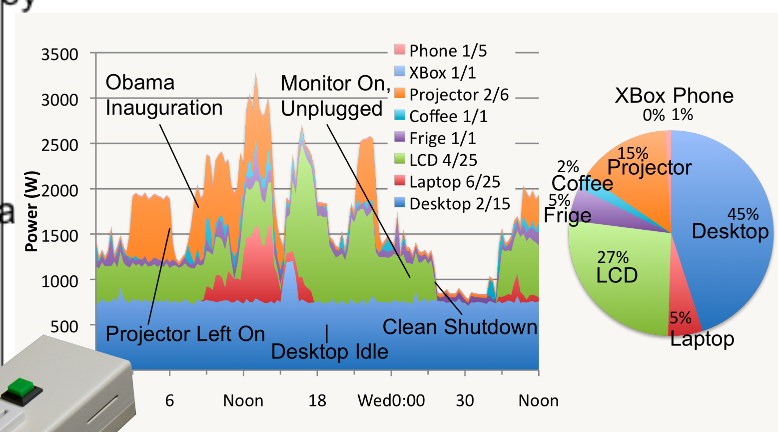
Our Build



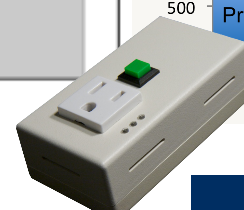
Soda Hall Power Consumption 494 KW
22:00 - 22:00
chart by amCharts.com
600
400
200
0
Lighting
HVAC
IT and Plug Load
PDUs, CRACs
Servers
Tue 01/20
Wed 01/21
Thu 01/22
Fri 01/23
Sat 01/24
Mon 01/05
Mon 01/12
Mon 01/19
Mon 01/26
Custom period:
2009-01-18 22:00
2009-01-24 22:45
Zoom:
1D
1W
2W
MAX



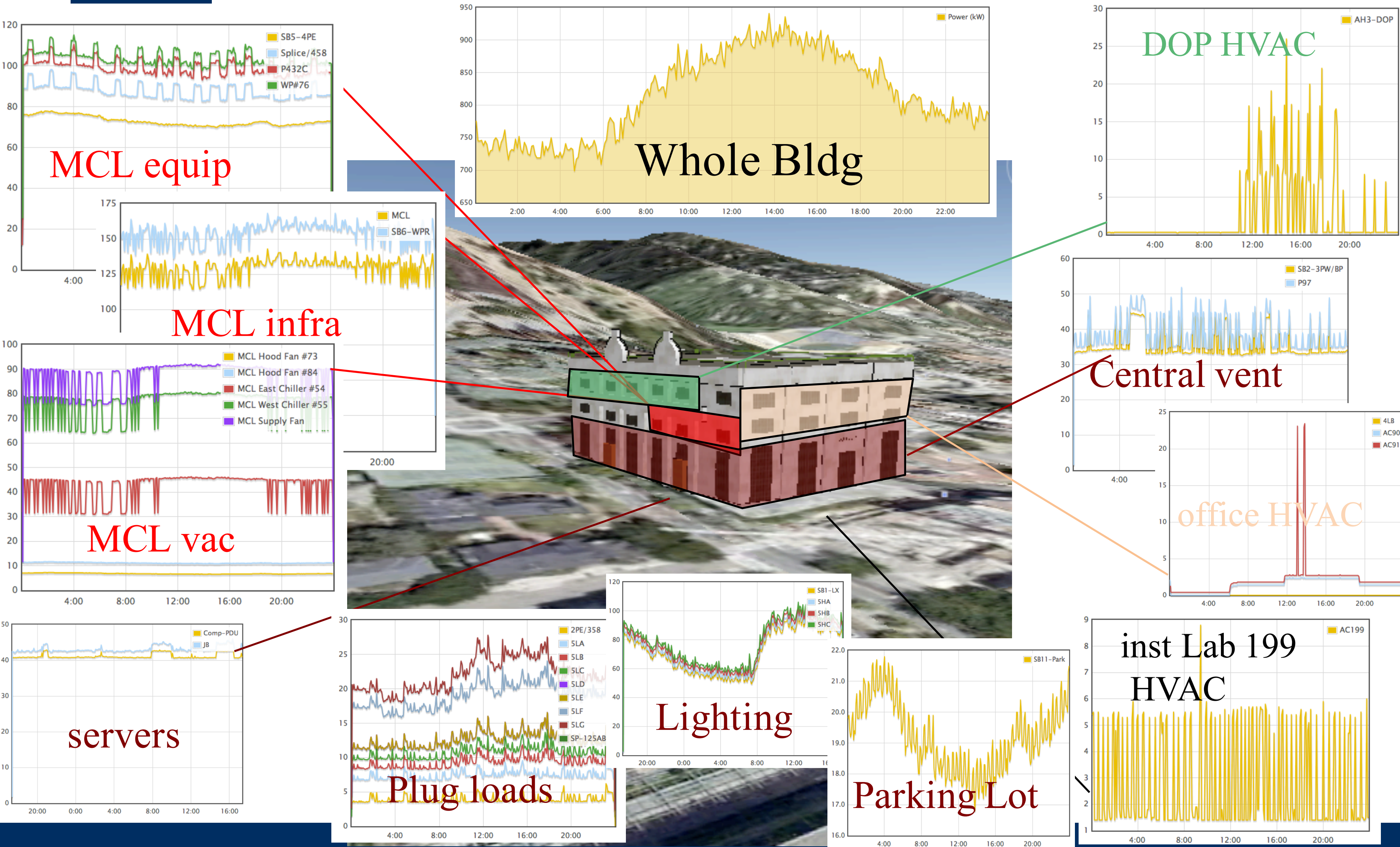
Annual Consumption
kwh
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
National average
LSA
Cory
Stanley
McCone
Soda
Koshla
0
10
20
30
40
50
60
kwh/sq ft



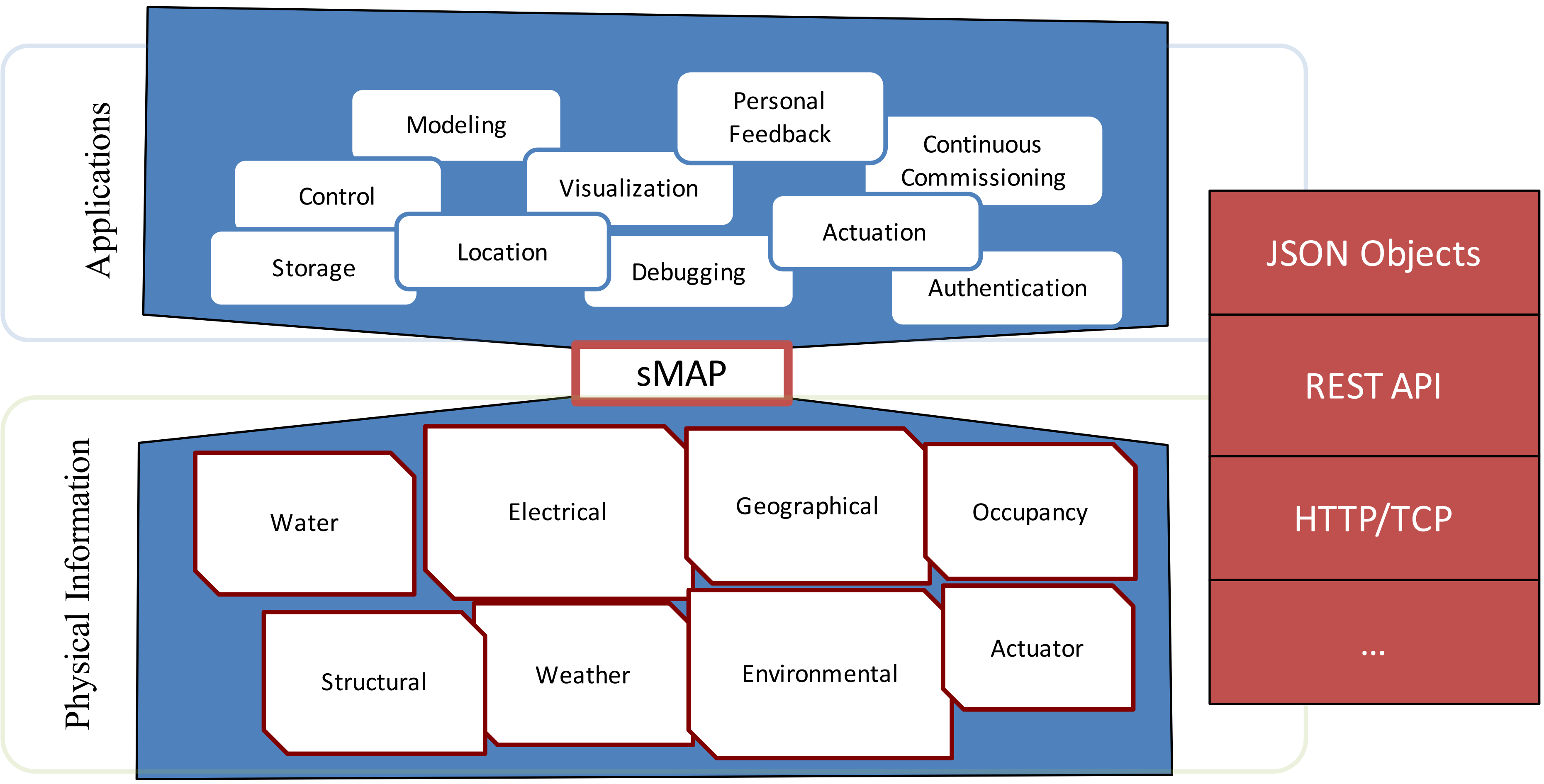
Power (W)
3500
3000
2500
2000
1500
1000
500
Obama Inauguration
Monitor On, Unplugged
Projector Left On
Desktop Idle
Clean Shutdown
6
Noon
18
Wed0:00
30
Noon
Phone 1/5
XBox 1/1
Projector 2/6
Coffee 1/1
Frige 1/1
LCD 4/25
Laptop 6/25
Desktop 2/15
XBox Phone
0% 1%
15%
Projector
2%
Coffee
5%
Frige
45%
Desktop
27%
LCD
5%
Laptop



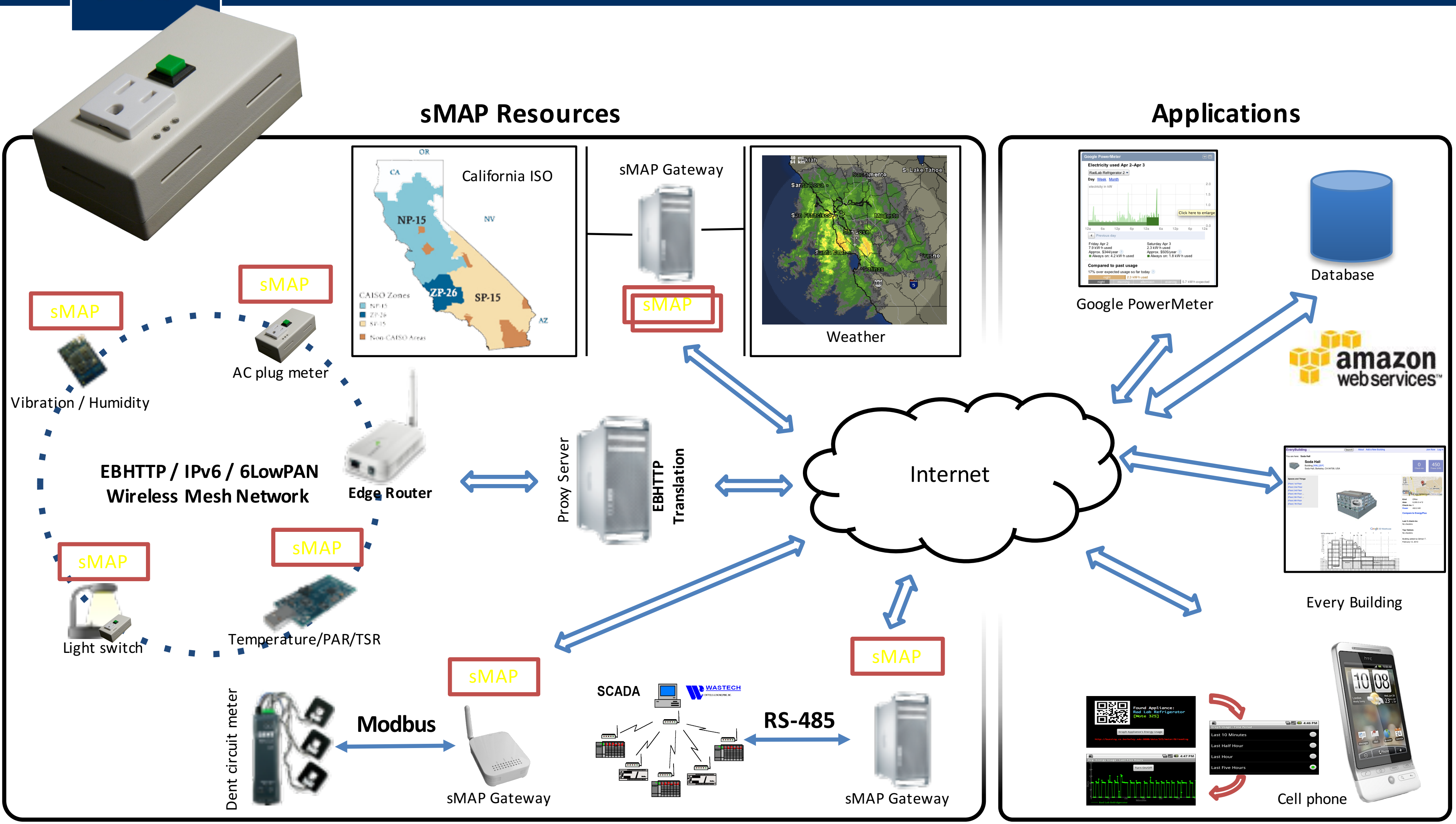
Energy Transparent Building



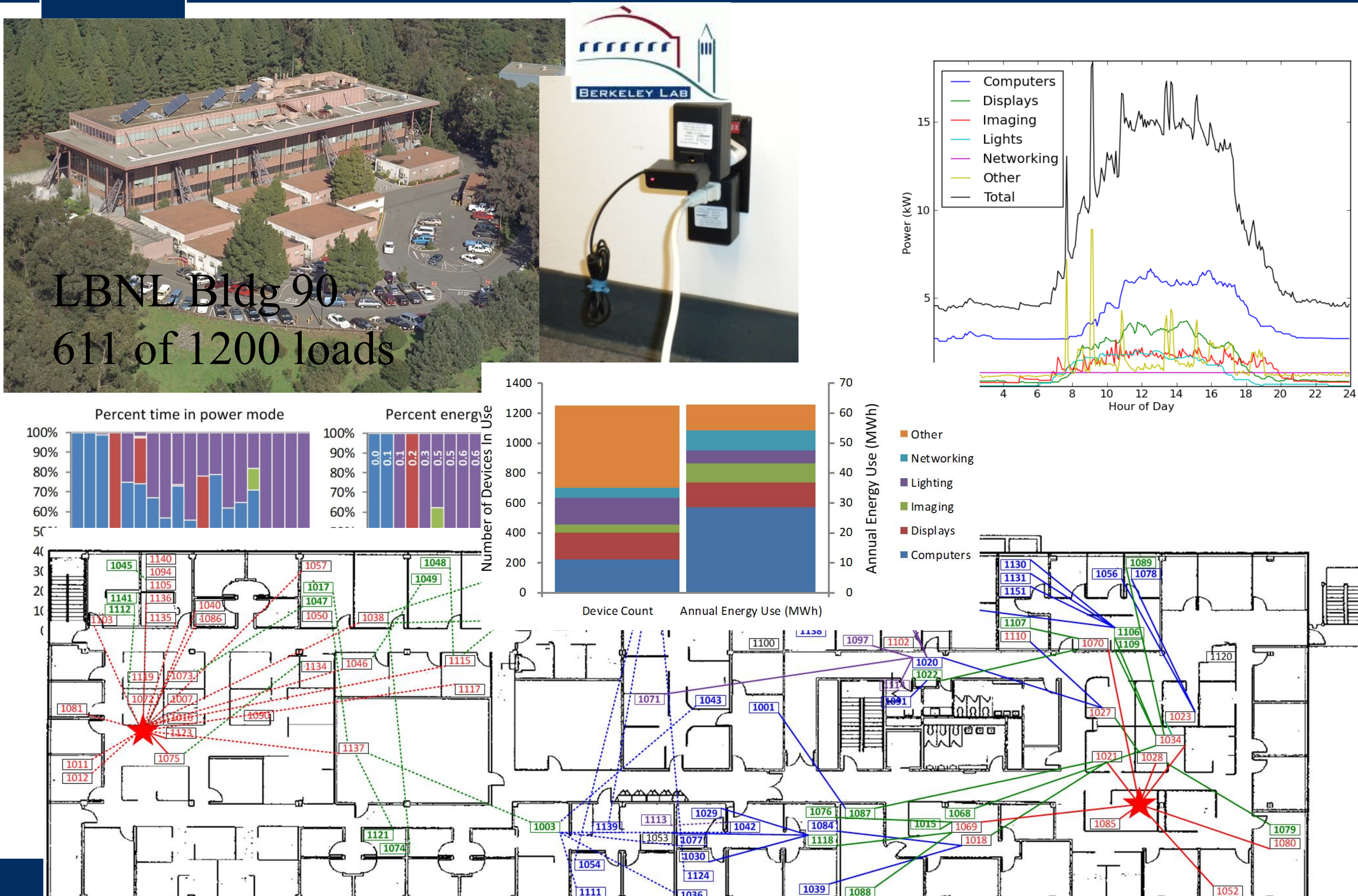
sMAP: Uniform Access to Diverse Physical Information



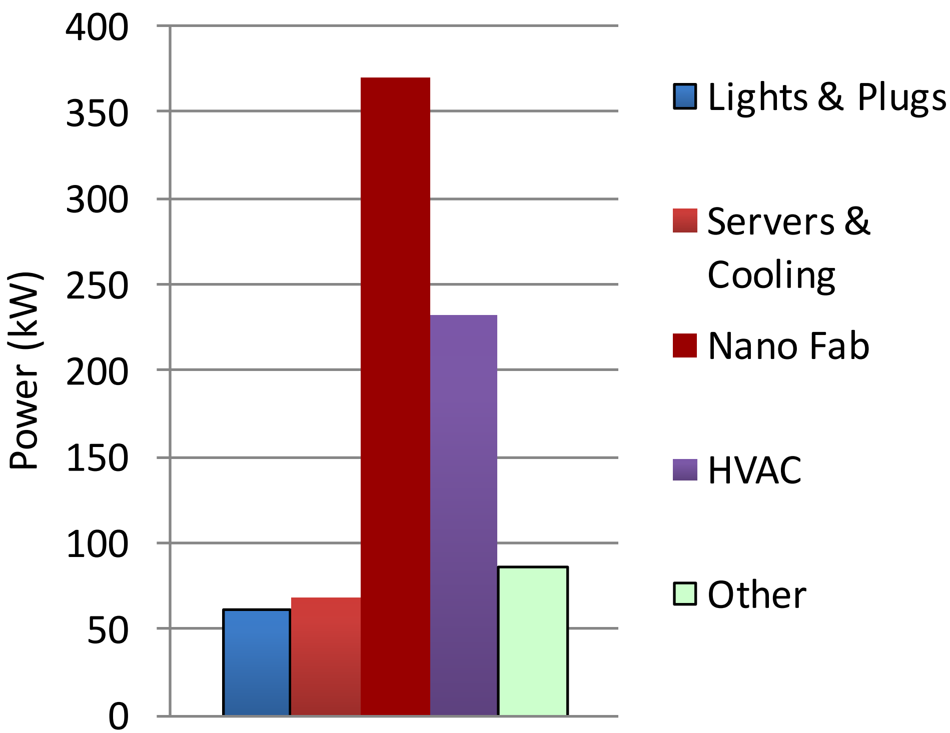
IP everywhere / Real World Web



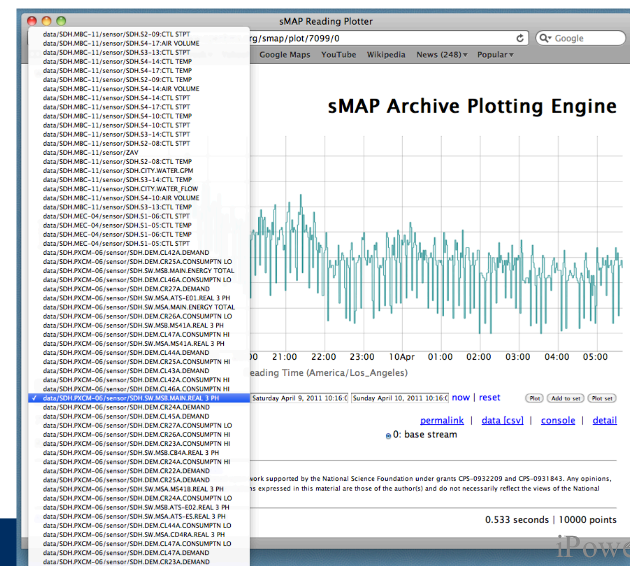
DOE Misc. and Electronic Loads



DOE/UCB/Siemens Auto Demand Response



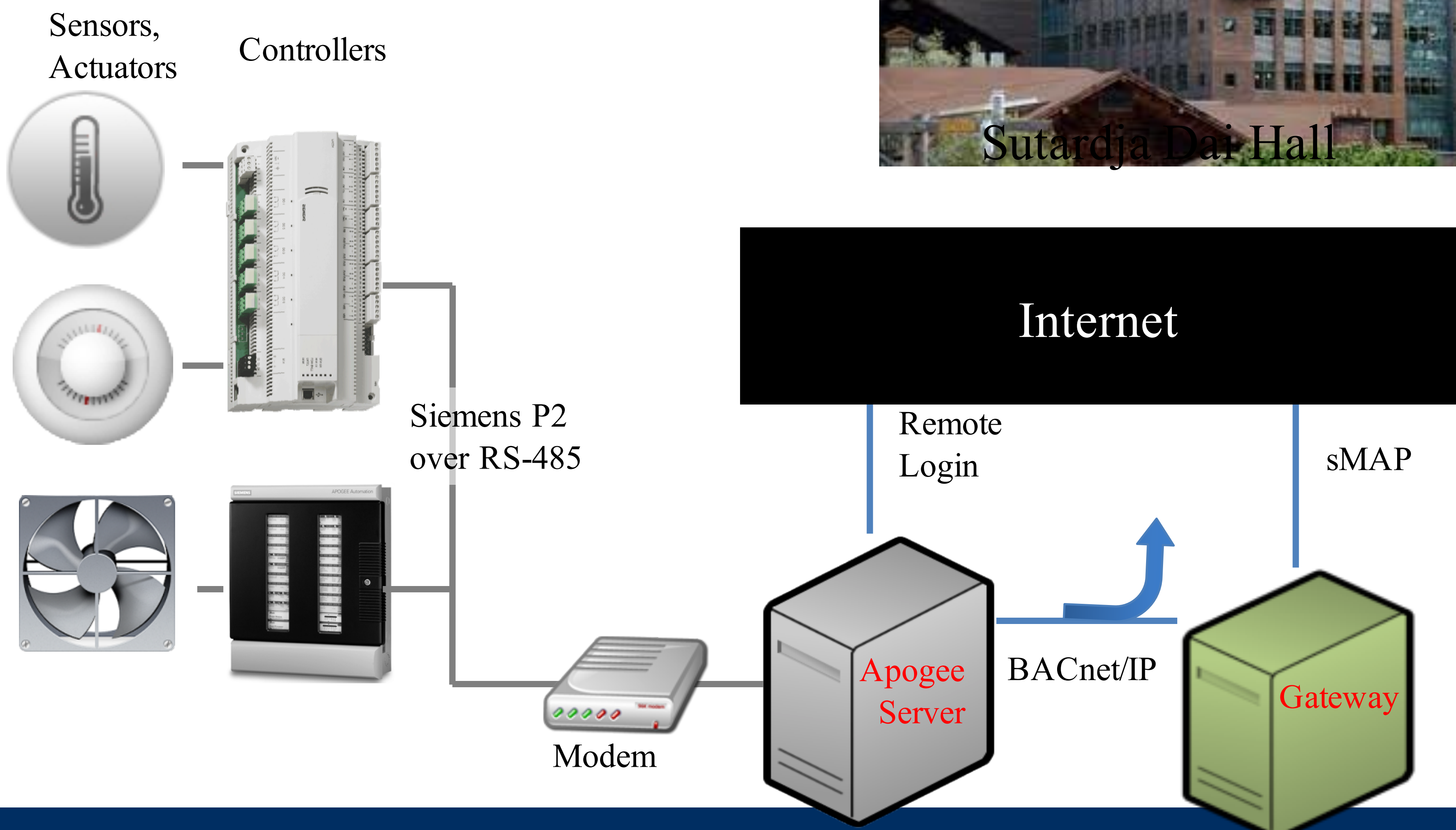
Sutardja Dai Hall



- www.openbms.org

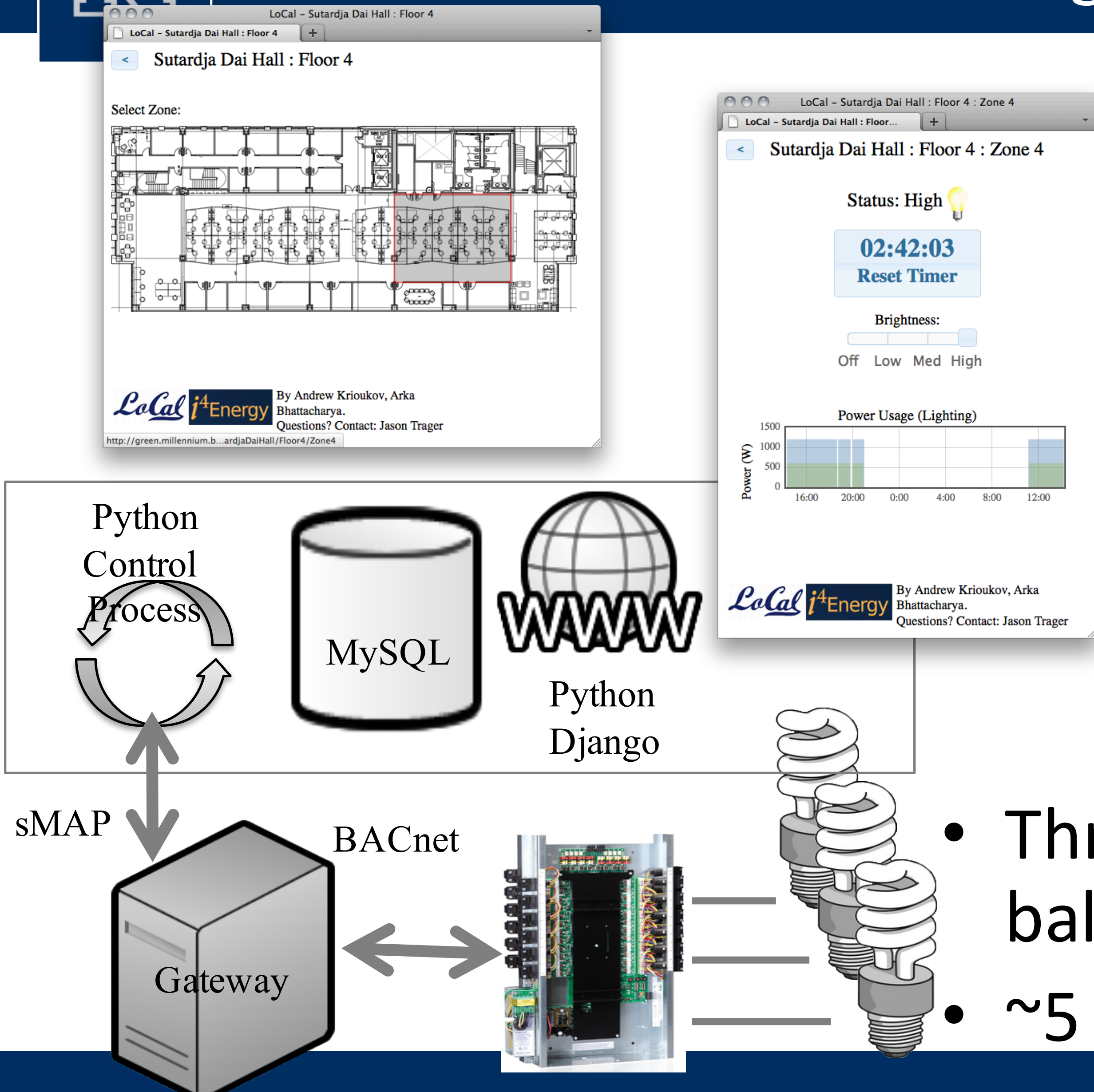
BACNet => sMAP

Sutardja Dai Hall



Sensors,
Actuators
Controllers
Siemens P2
over RS-485
Modem
Internet
Remote
Login
sMAP
Apogee
Server
BACnet/IP
Gateway

Personalized Automated Lighting Control



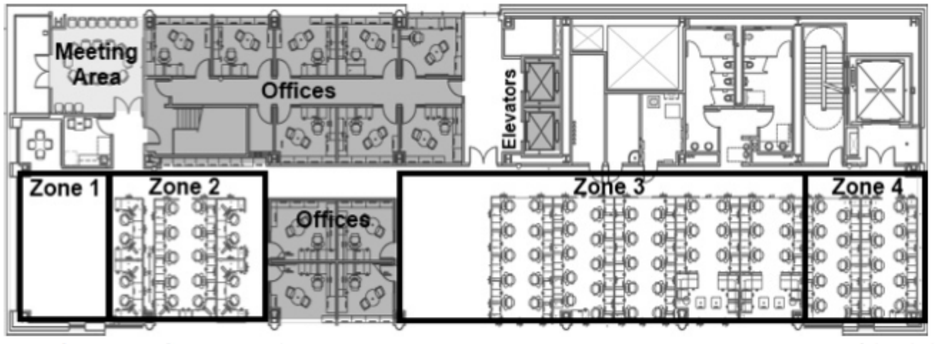
- Three controllable ballasts per fixture
- ~5 zones per floor

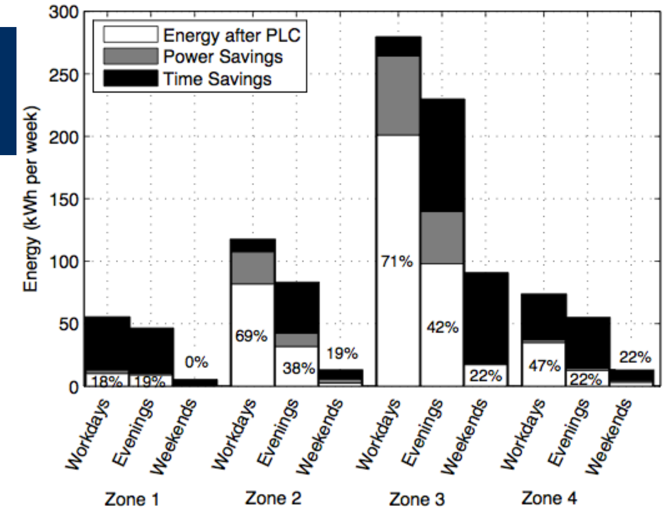
6,000+ Points in 1 Modern Building

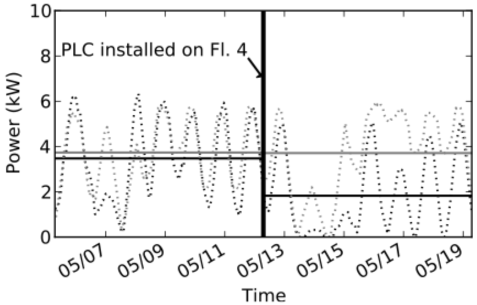
- 1358 control settings
  - Set points, Relays (lights, pumps, etc), Schedules
- 2291 meters/sensors
  - Power (building, floor, lights, chiller, pumps, etc)
    - Current, voltage, apparent, real, reactive, peak
  - Temp (rooms, chilled water, hot water)
  - Air volume
  - Alarms, Errors
- 2165 control outputs
  - Dampers, valves, min/max flow, fan speed, PID parameters
- 72 other

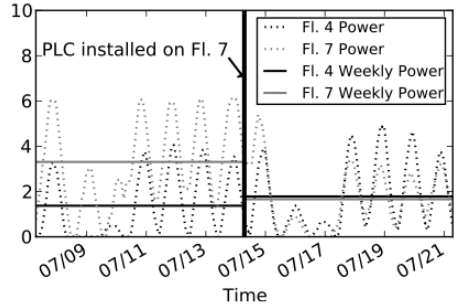
US: 4+ million Commercial, 110+ million Residential

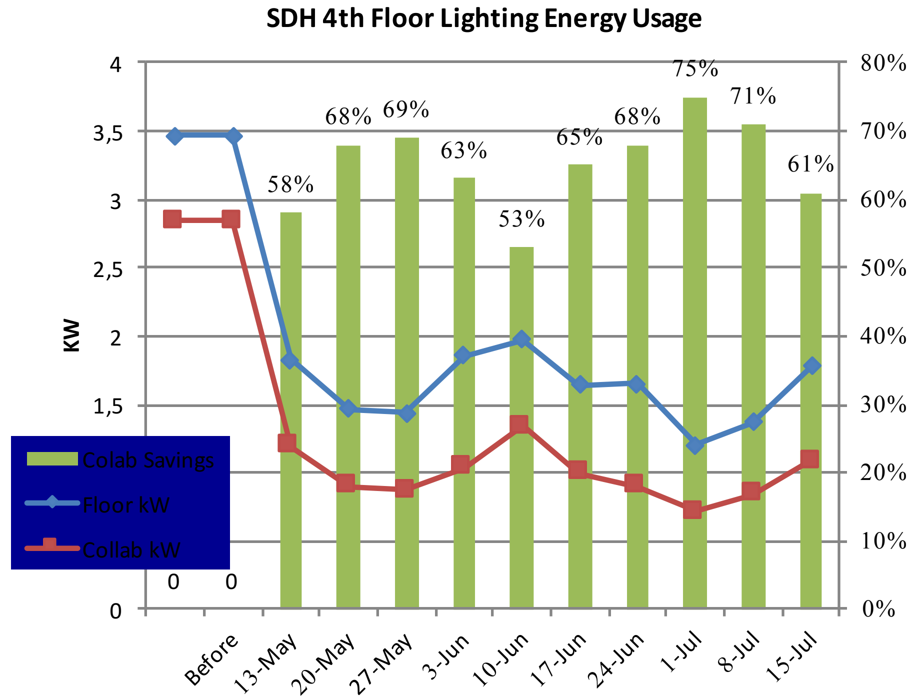
Real Energy Savings

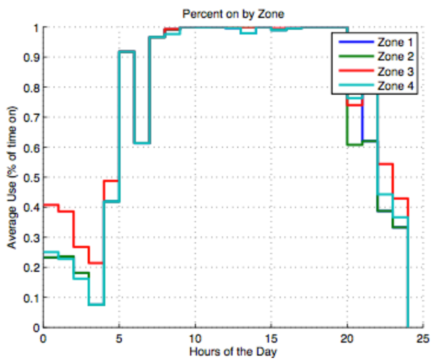


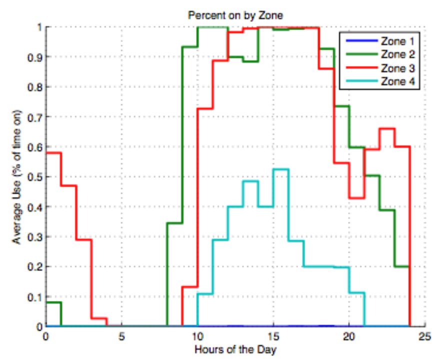




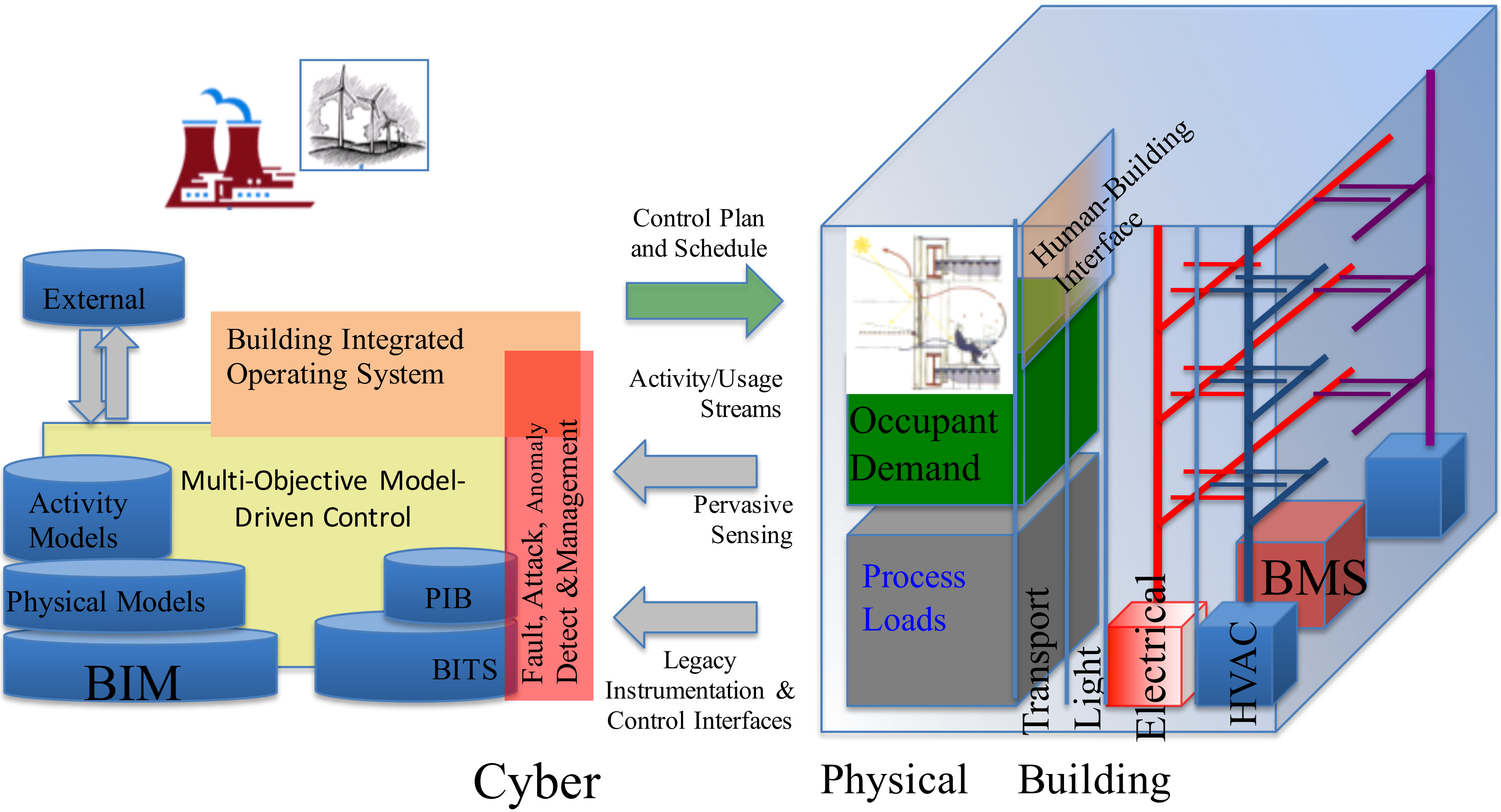








Cyber / Physical Buildings



Conclusions

- The Internet is Every Thing is Here
- 15 years of deep innovation and research
  - Critical WSN breakthroughs
  - Key IPv6 developments
- Worldwide community of students, faculty, and industry
- Engagement of International organizations
- Fundamentally a new Scientific Instrument focus it on the World's most important problem
  - Energy, productivity, and the environment