The Internet of Things

The principles that gave rise to the Internet are now leading to a new kind of network of everyday devices, an "Internet-0"

By Neil Gershenfeld, Raffi Krikorian and Danny Cohen

In Barcelona about a century ago, Antoni Gaudí pioneered a fluid building style that seamlessly integrated visual and structural design. The expressive curves of his buildings were not just ornamental facades but also integral parts of the load-bearing structure. Unfortunately, a similar unification has yet to happen for the electronic infrastructure in a building. Switches, sockets and thermostats are grafted on as afterthoughts to the architecture, with functions fixed by buried wiring. Appliances and computers arrive as after-the-fact intrusions. Almost nothing talks to anything else, as evidenced by the number of devices in a typical house or office with differing opinions as to the time of day.

These inconveniences have surprisingly broad implications for construction economics, energy efficiency, architectural expression and, ultimately, quality of life. In the U.S., building buildings is a $1-trillion industry. Of that, billions are spent annually on drawing wiring diagrams, then following, fixing and revising them. Over the years, countless "smart home" projects have sought to find new applications for intelligent building infrastructure—neglecting the enormous existing demand for facilities that can be programmed by their occupants rather than requiring contractors to fix their functionality in advance.

Any effort to meet that demand, though, will be doomed if a lightbulb requires a skilled network engineer to install it and the services of a corporate IT department to manage it. The challenge of improving connectivity requires neither gigabit speeds nor gigabyte storage but rather the opposite: dramatic reductions in the cost and complexity of network installation and configuration.

Over the years, a bewildering variety of standards have been developed to interconnect household devices, including X10, LonWorks, CEBus, BACnet, ZigBee, Bluetooth, IrDA and HomePlug. The situation is analogous to that in the 1960s when the Arpanet, the Internet's predecessor, was developed. There were multiple types of computers and networks then, requiring special-purpose hardware to bridge these islands of incompatibility.

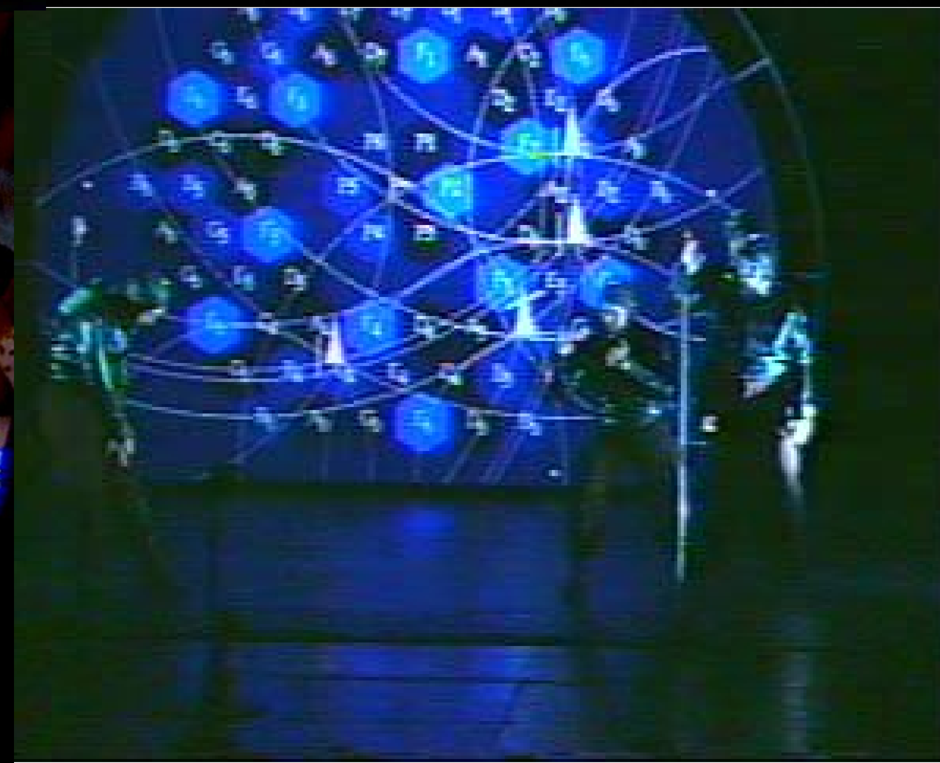
The solution to building a global network out of heterogeneous local networks, called internetworking, was found in two big ideas. The first was packet switching: data are chopped up into packets that can be routed independently as needed and then recombined. This technique marked a break from the traditional approach, used in telephone networks, of dedicating a static circuit to each connection. The second idea was the "end-to-end" principle: the behavior of the network should be determined by what is connected to it rather than by its internal construction, a concept embodied in the Internet Protocol (IP). Gradually the Internet expanded to handle applications ranging from remote computer access to e-commerce to interactive video. Each of these services introduced new types of data for packets to carry, but engineers did not need to change the network's hardware or software to implement them.

These principles have carried the Internet through three decades of growth spanning seven orders of magnitude in both performance and size—from the Arpanet's 64 sites to today's 200 million registered hosts. They represent timeless insights into good system design, and, crucially, they contain no specific performance requirements. With great effort and discipline, technology-dependent parameters were kept out of the specifications so that hardware could evolve without requiring a revision of the Internet's basic architecture.

These same ideas can now solve the problem of connecting

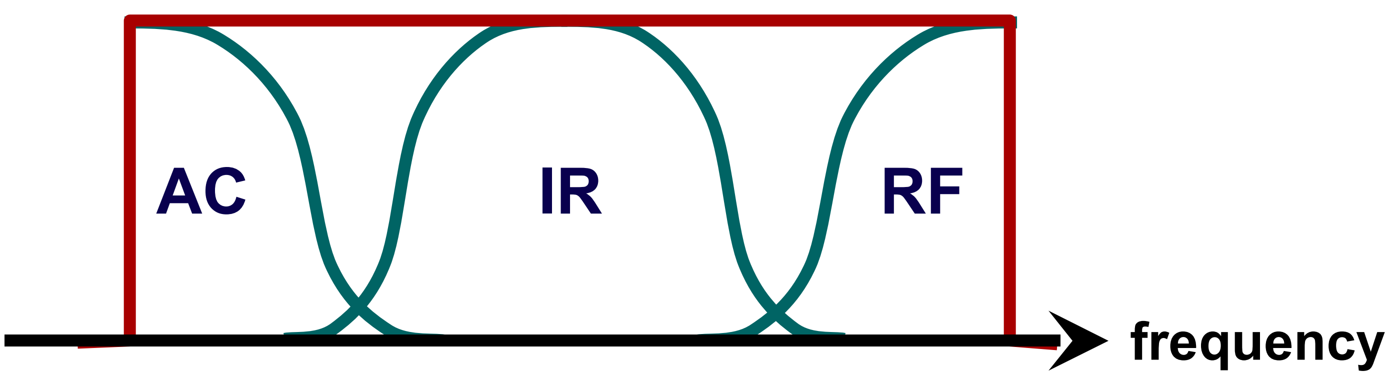
EVEN SOMETHING AS SIMPLE as a lightbulb could be connected directly to the Internet, if suitably equipped with cheap circuitry that sends signals along the electrical wiring.


For More Information:
www.si.edu/americasmillennium
C-SPAN
Fri.



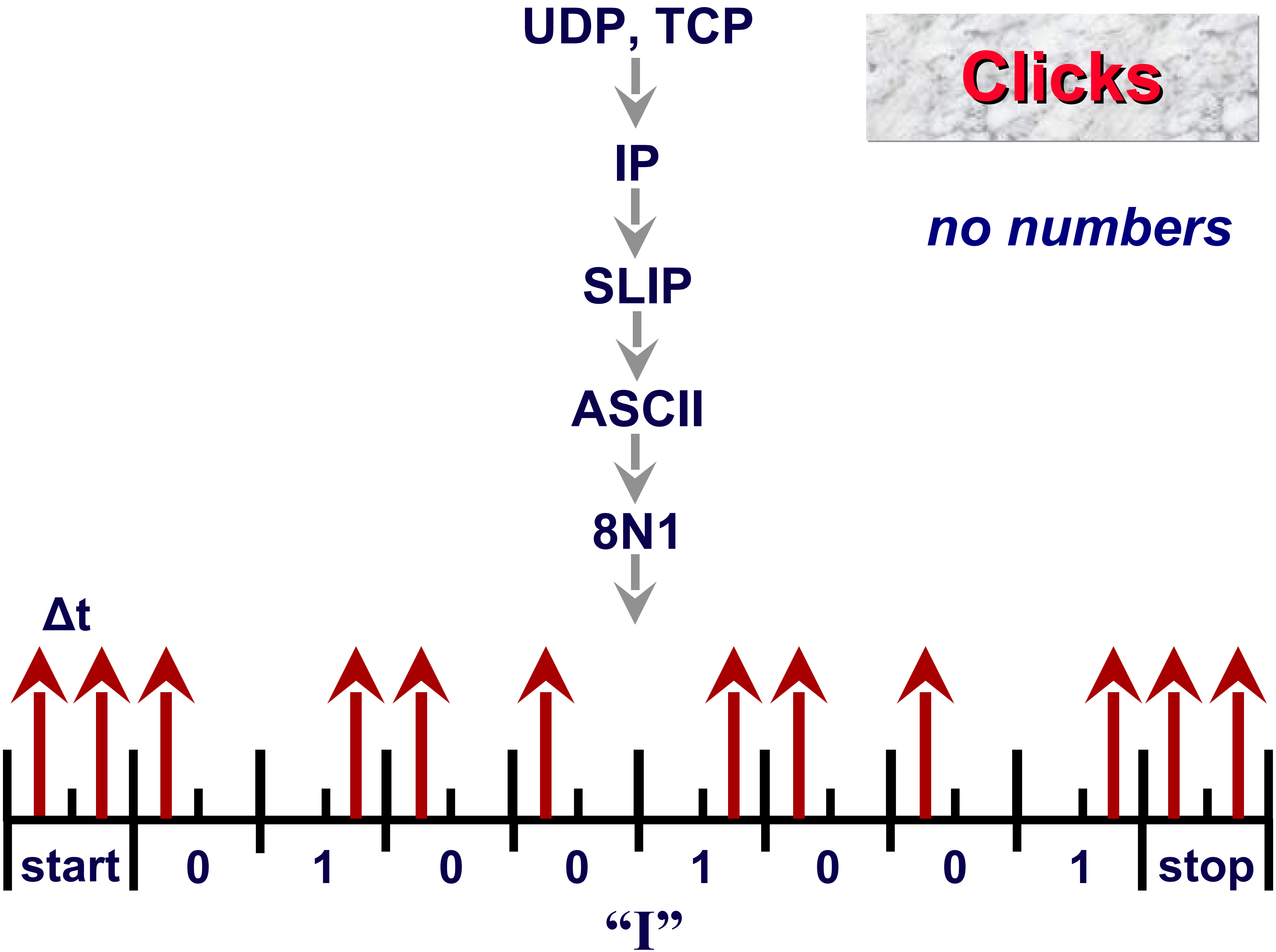
$3x10^8$ m/s / 100 m = $3x10^6$ s^{-1}

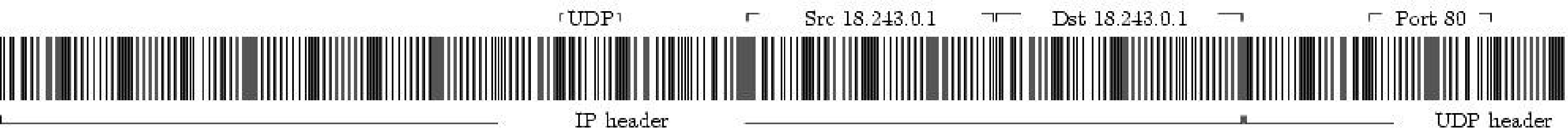
Big Bits

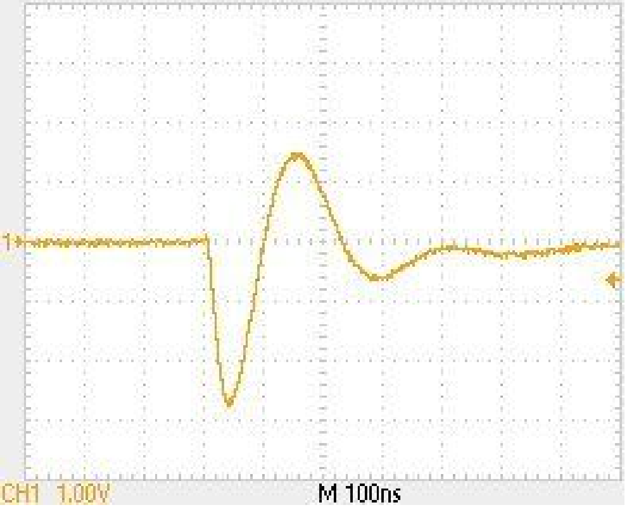


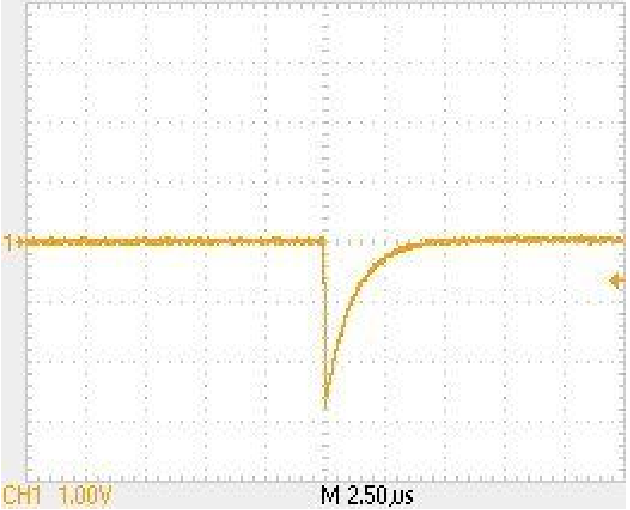
Clicks

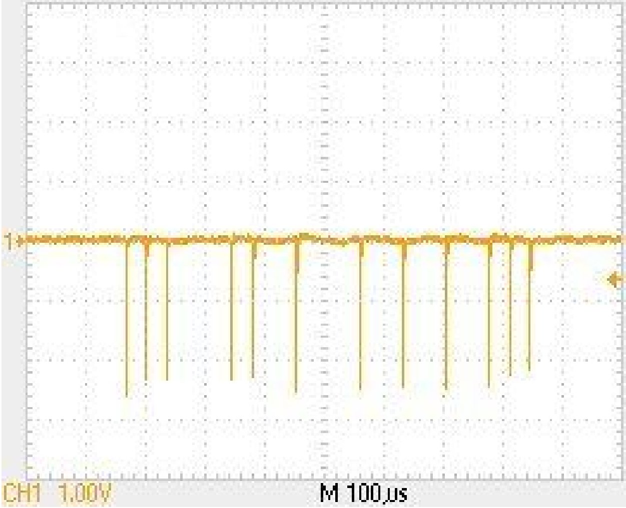
no numbers

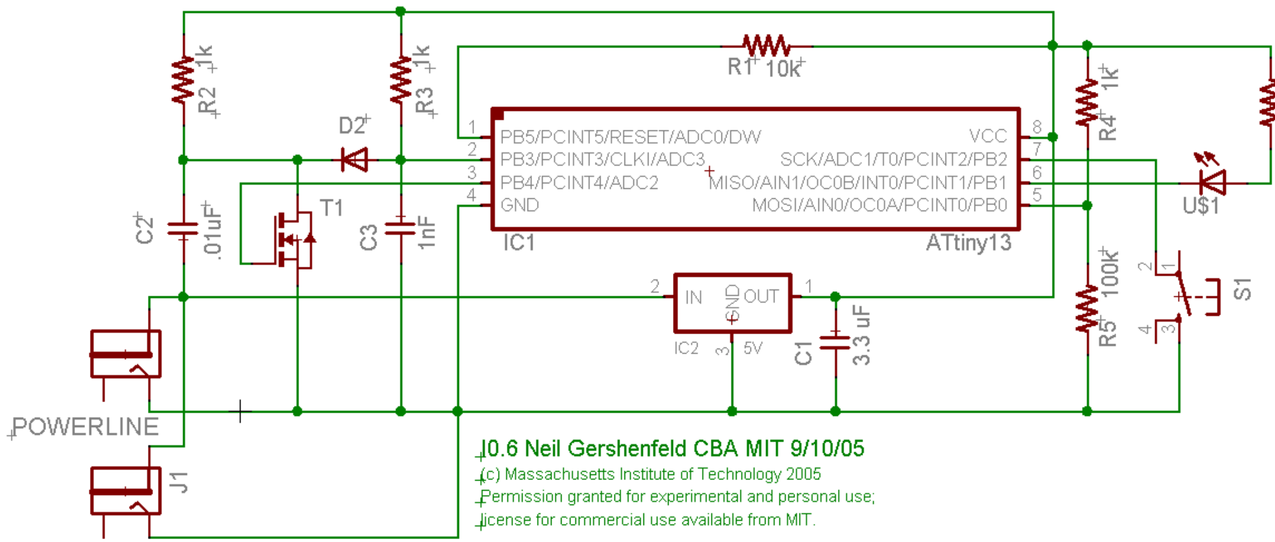



UDP
Src 18.243.0.1
Dst 18.243.0.1
Port 80
IP header
UDP header


CH1 1.00V
M 100ns


CH1 1.00V
M 2.50µs


CH1 1.00V
M 100µs


R2 1k
R3 1k
D2
R1 10k
PB5/PCINT5/RESET/ADC0/DW
PB3/PCINT3/CLKI/ADC3
PB4/PCINT4/ADC2
GND
VCC
SCK/ADC1/T0/PCINT2/PB2
MISO/AIN1/OC0B/INT0/PCINT1/PB1
MOSI/AIN0/OC0A/PCINT0/PB0
IC1
ATtiny13
R4 1k
R6 1k
U$1
C2 .01uF
T1
C3 1nF
IN GND OUT
IC2 5V
C1 3.3 uF
R5 100k
S1
POWERLINE
J1
I0.6 Neil Gershenfeld CBA MIT 9/10/05
(c) Massachusetts Institute of Technology 2005
Permission granted for experimental and personal use;
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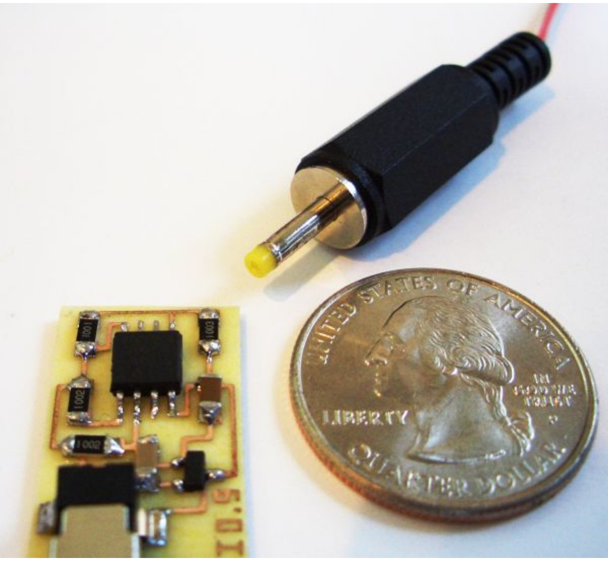
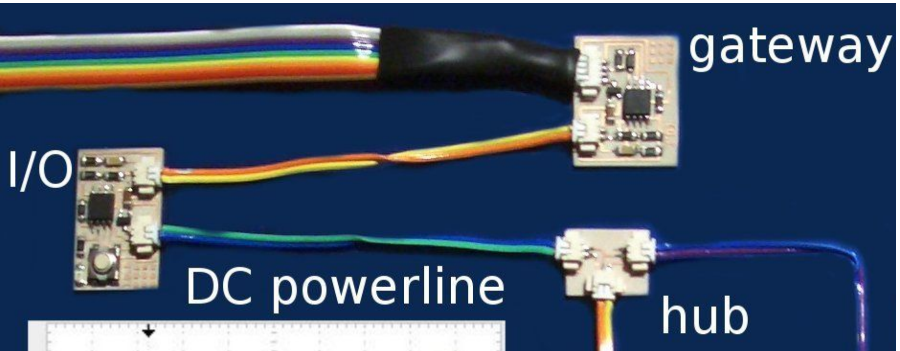

LIBERTY
QUARTER DOLLAR


gateway
I/O
DC powerline
hub


http://127.0.0.1:4096/192.168.1.102 - Microsoft Internet Explorer
File Edit View Favorites Tools Help
Back Search Favorites
Address http://127.0.0.1:4096/192.168.1.102
Go Links
Internet 0

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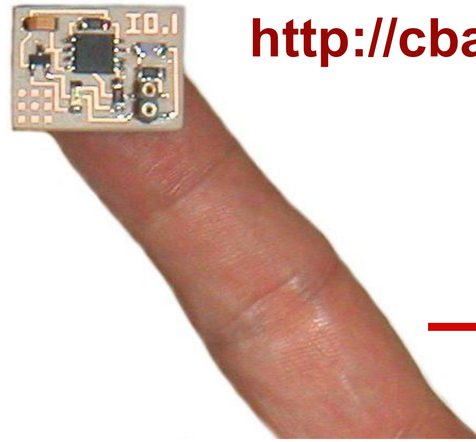


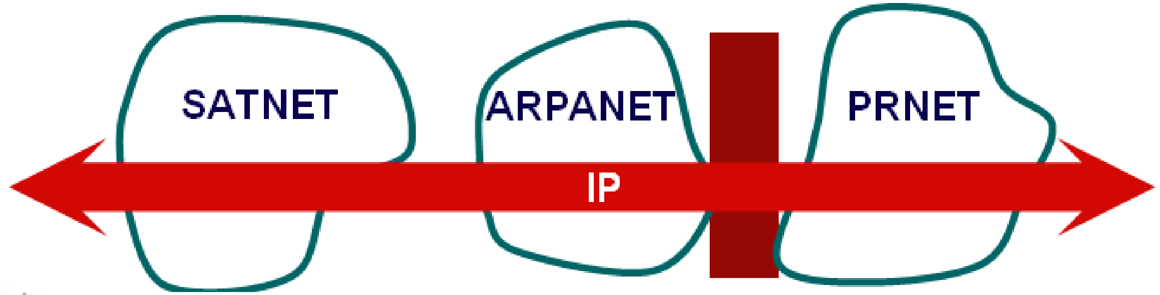
http://cba.mit.edu/events/04.09.I0/

Internet 0: Past, Present, and Future

October 1, 2004

The Bartos Theater
Building E15
MIT

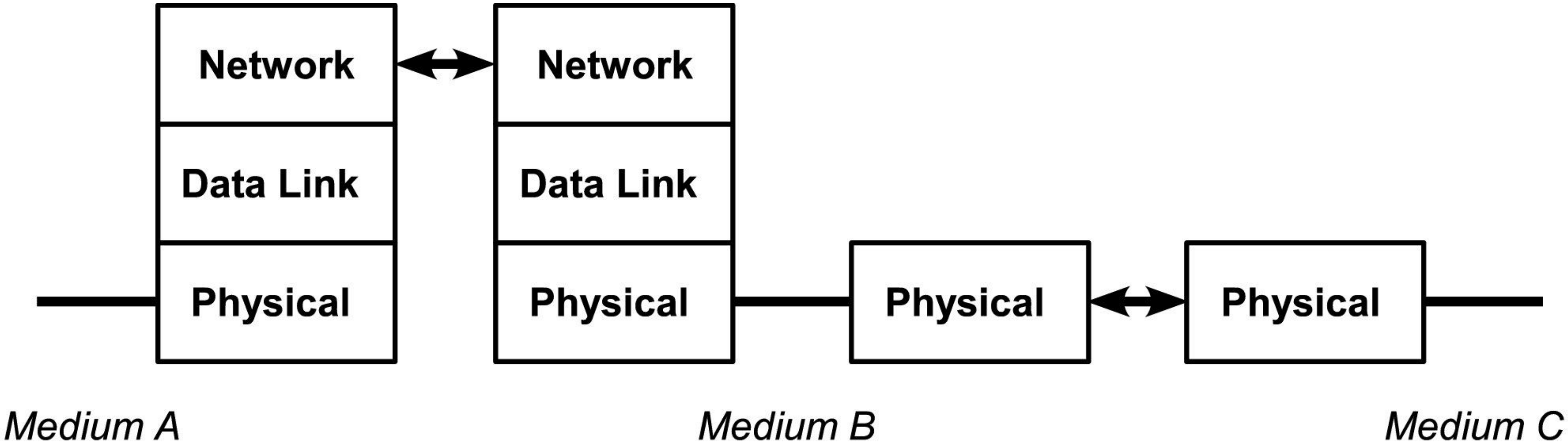
8:00-9:00 **Breakfast**
9:00-10:00 **Internet 0** (*video*)
  Neil Gershenfeld: *The Past*
  Raffi Krikorian: *The Present*
  Danny Cohen: *The Future*
10:00-10:30 **Break**
10:30-12:00 **Foundations** (*video*)
  Len Kleinrock: *Principles from the Past*
  Barry Wessler: *Addressing* *Risk Management*
  Bob Kahn: *Myths, Critical Decisions, and Lessons Learned*
  Dave Reed: *Layering, End-to-End, and Security*
12:00-1:00 **Lunch**
1:00-2:30 **Frontiers** (*video*)
  Bob Briscoe: *Event Notification*
  Jean-Jacques Quisqater *Security: Frontiers*
  Steven Low: *Optimizing Internet Protocols*
  Mung Chiang: *Layering*
2:30-4:00 **Working Groups**
  I0 Implementation
  Security
  Applications
  Protocols and Standards
  Community Process



end-to-end modulation

interdevice internetworking

"UDP" Src 18.7.22.69 Dst 209.249.116.195 Port 1234
IP header UDP header "Hello"



internetworking

interdevice internetworking

The Internet may be the most complex system ever engineered; from the first host in 1969, it's grown to comprise more than 1 billion routable host addresses [1]. Its future expansion may be more dramatic still due to the demand to extend the Internet from people to things [2], but the frontiers of high-speed networking have receded further and further from the requirements of small, cheap, slow devices. These things need the Internet's original insights, rather than their current implementation; this is being done in the IØ initiative.

The demand for networking embedded devices has led to a proliferation of standards and protocols, including X10, HomePlug, LonWorks, BACnet. CEBus, Fieldbus, ModBus, CAN, Lin, I^2C, SPI, SSI, ASI, USB, EPC, IrDA, Bluetooth, 802.15.4, and ZigBee. While each of these has been optimized for a particular domain, all are encountering many of the same issues that the Internet faced as it grew, including inadequate address space, the need for naming and routing across networks, and mutual incompatibility. This situation is in fact analogous to the early days of the Internet itself.

Neil Gershenfeld and Danny Cohen

Early packet-switched networks, including ARPANET, PRNET, and SATNET either relied on complex protocol converters at their

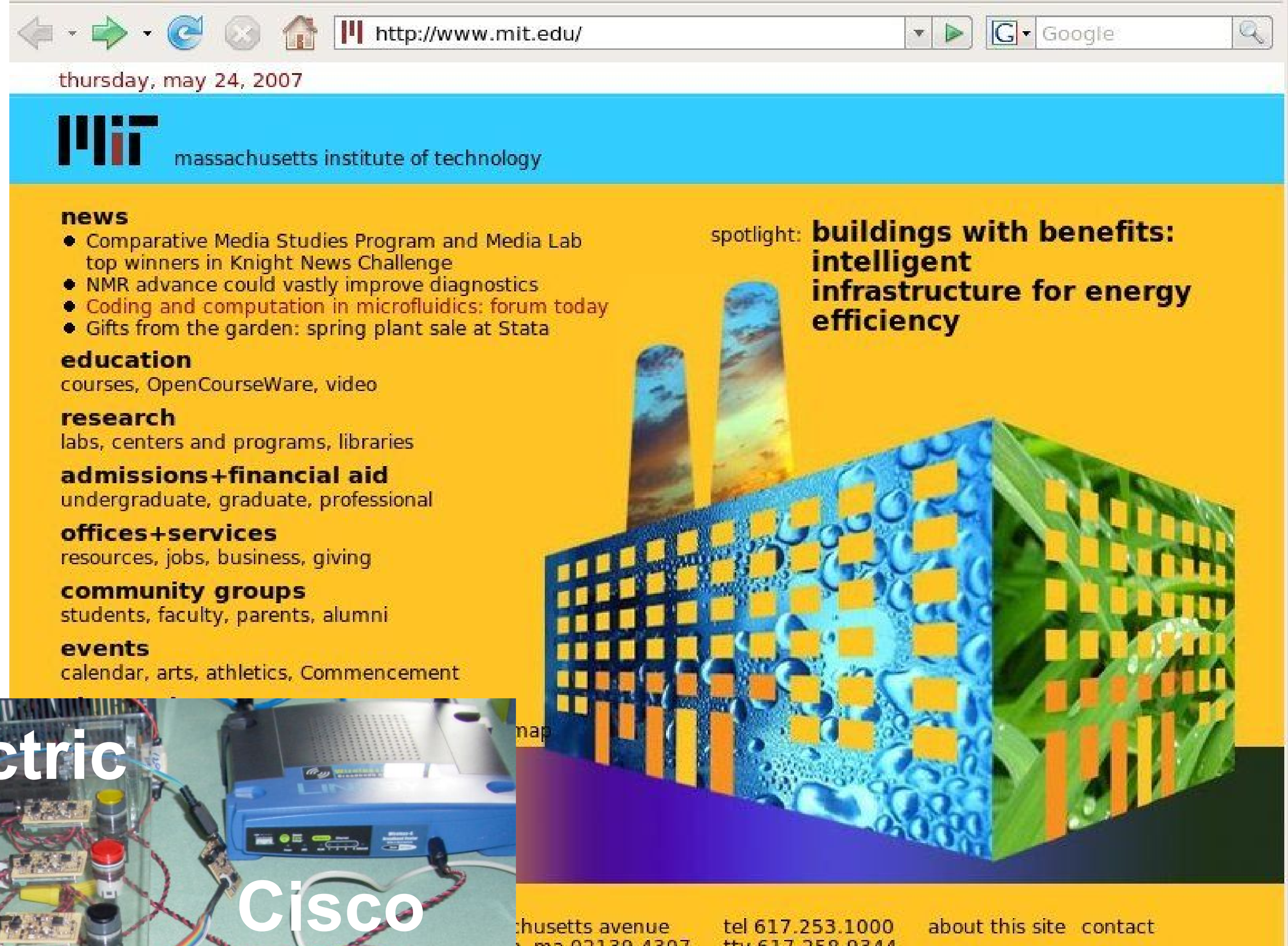
IR	→	IRDA		
RF	→	Bluetooth		
powerline	→	Homeplug		
multidrop	→	RS-485		
RFID	→	ISO 18000/EPC	→	IØ
bar codes	→	UPC		
mag stripe	→	ANSI/ISO		
telephone	→	V.92		
telegraph	→	Morse Code		

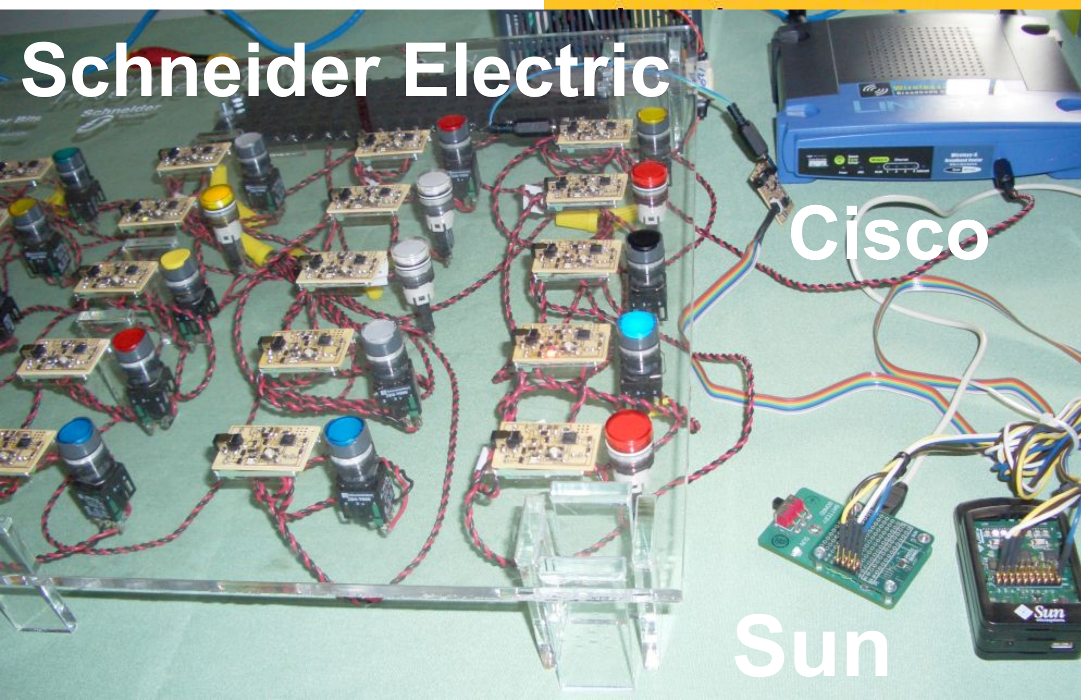
buildings:

~40% energy

~70% electricity

~1/3 recovery





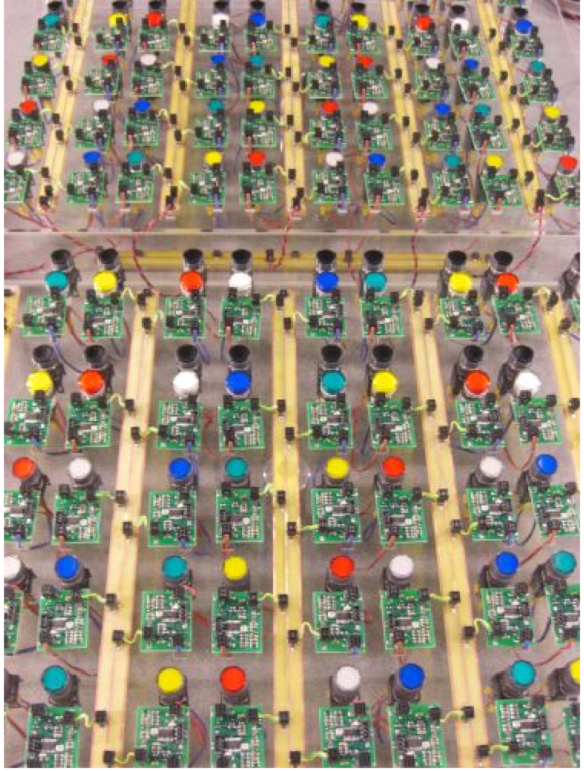
Network Working Group	N. Gershenfeld
Internet-Draft	CBA/MIT
Intended status: Informational	D. Johnson
Expires: June 15, 2007	Sun Microsystems, Inc.
	T. Snide
	Schneider Electric
	K. Lynn
	Cisco
	December 12, 2006

Internet 0 Workshop

December 12, 2007

engineering workshops

- 9:00-10:00 wired and wireless transports
- 10:00-11:00 building and industrial automation
- 11:00-12:00 thin servers and thinner clients
- 12:00-1:00 lunch
- 1:00-2:00 security
- 2:00-3:00 application protocols
- 3:00-4:00 system management and control
- 4:00-5:00 RFCs



December 13, 2007

9:00-12:00 planning workshops

- building testbeds
- field trials
- community process, standardization, commercialization

12:00-1:00 lunch

1:00-4:00 review presentations

- history
- implementation
- demonstration
- application
- plans