The Once and Future Internet of EveryThing…

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In 1999, we said “…

… in 15 years we will have connected all the people on the planet and we will have the technology to connect all the things.”
The Internet in 1999
2007 - The Internet of Every Body
2013: Many Things

CES 2014: Connected Home And Wearables To Take Center Stage

An ocean of gadgets at CES 2014 will highlight the powers of Bluetooth and wearable computing, the connected home and the quantified self.

RGB LED Controller

BLE

LoWPAN

WiFi

Cooper Wiring Devices RF950/5/TDS ASPIRE RF 15A Split Control Duplex Receptacle - Desert

NRC
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.”
Key WSN Research Developments

• **Event-Driven Component-Base Operating System**
  – Framework for building System & Network abstractions
  – Low-Power Protocols (do nothing well)
  – 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 (routing diversity)

• **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
## Internet of Things – Realized 2008

*Production implementation on TI msp430/cc2420*

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

### CC2420 Driver
- ROM: 3149
- RAM: 272

### 802.15.4 Encryption
- ROM: 1194
- RAM: 101

### Media Access Control
- ROM: 330
- RAM: 9

### Media Management Control
- ROM: 1348
- RAM: 20

### 6LoWPAN + IPv6
- ROM: 2550
- RAM: 0

### Checksums
- ROM: 134
- RAM: 0

### SLAAC
- ROM: 216
- RAM: 32

### DHCPv6 Client
- ROM: 212
- RAM: 3

### DHCPv6 Proxy
- ROM: 104
- RAM: 2

### ICMPv6
- ROM: 522
- RAM: 0

### Unicast Forwarder
- ROM: 1158
- RAM: 451

### Multicast Forwarder
- ROM: 352
- RAM: 4

### Message Buffers
- ROM: 0
- RAM: 2048

### Router
- ROM: 2050
- RAM: 106

### UDP
- ROM: 450
- RAM: 6

### TCP
- ROM: 1674
- RAM: 50

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2008-02-15 charter

Routing Over Low power and Lossy networks (roll)

Current Status: Active Working Group

Chair(s): JF Vasseur <jfp@cisco.com>, David Culler <culler@eecs.berkeley.edu>

3/5/15
Framework abstractions to emerge

Communication Centric Resource-Constrained Event-driven Execution
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, piconets, ...
    » S-MAC, T-MAC, PEDAMACS, ...

• Sampled Listening
  – Listen for very short intervals to detect imminent 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
Self-Organized Routing - nutshell

Receiver diversity through dynamic rerouting

Retrans. rate < 1/density
Neighbor table exceeds RAM
Dissem. rate < change
Key IPv6 Contributions (???)

• Large simple address
  – Network ID + Interface ID
  – Plenty of addresses, easy to allocate and manage

• Autoconfiguration and Management
  – ICMPv6, zeroconf (???)

• Integrated bootstrap, discovery, proximity
  – Neighbors, routers, DHCP, FF00::2

• Protocol options framework
  – Plan for extensibility

• Simplify for speed
  – MTU discovery with min

• 6-to-4 translation
To Here …

• Much of IoT is cost/size reduced 802.11 + 386 PC equivalent
  – everything with a plug or a person to charge it daily

• Transition of BT to promiscuous link opened G2G ecosystem
  – local link, yet-another-1-2-7 app profile mess
  – little useful research engagement in the design, only in usage

• Industrial Forums may retard development
  – Zigbee, zwave, ISA-100, wireless-HART, …
  – IETF ???, Industrial Internet ???, IoTC ???, IEEE P2413 ???, Thread ???

• 1-hop @ low power is constrained, but simple

• Routing over “wireless mesh” is hard, largely “solved”, but seriously broken
  – Good research & startup solutions, Zigbee (largely deprecated before implemented), RPL (grossly complicated by IETF mess)

• Low-power listening, trickle, routing diversity, power-proportional design are critical
... and beyond

- Great networks are ‘uninteresting’ – and embedded wireless networks are becoming that way too!
- It’s about webs and ensembles (finally!)
  - discovery, integration, scripting across things near and far
  - Physical mash-ups, its all about the metadata