The Once and Future Internet of EveryThing…

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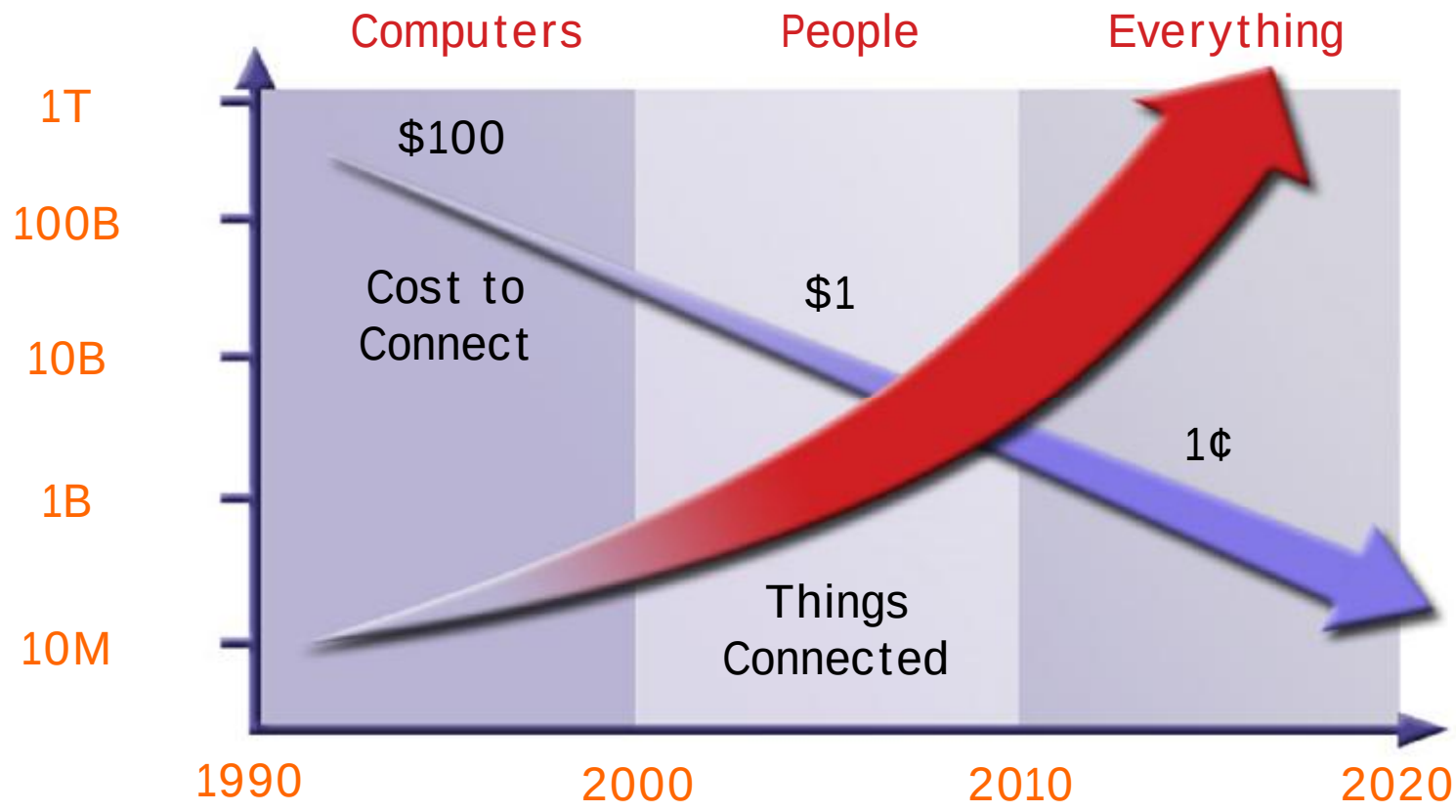
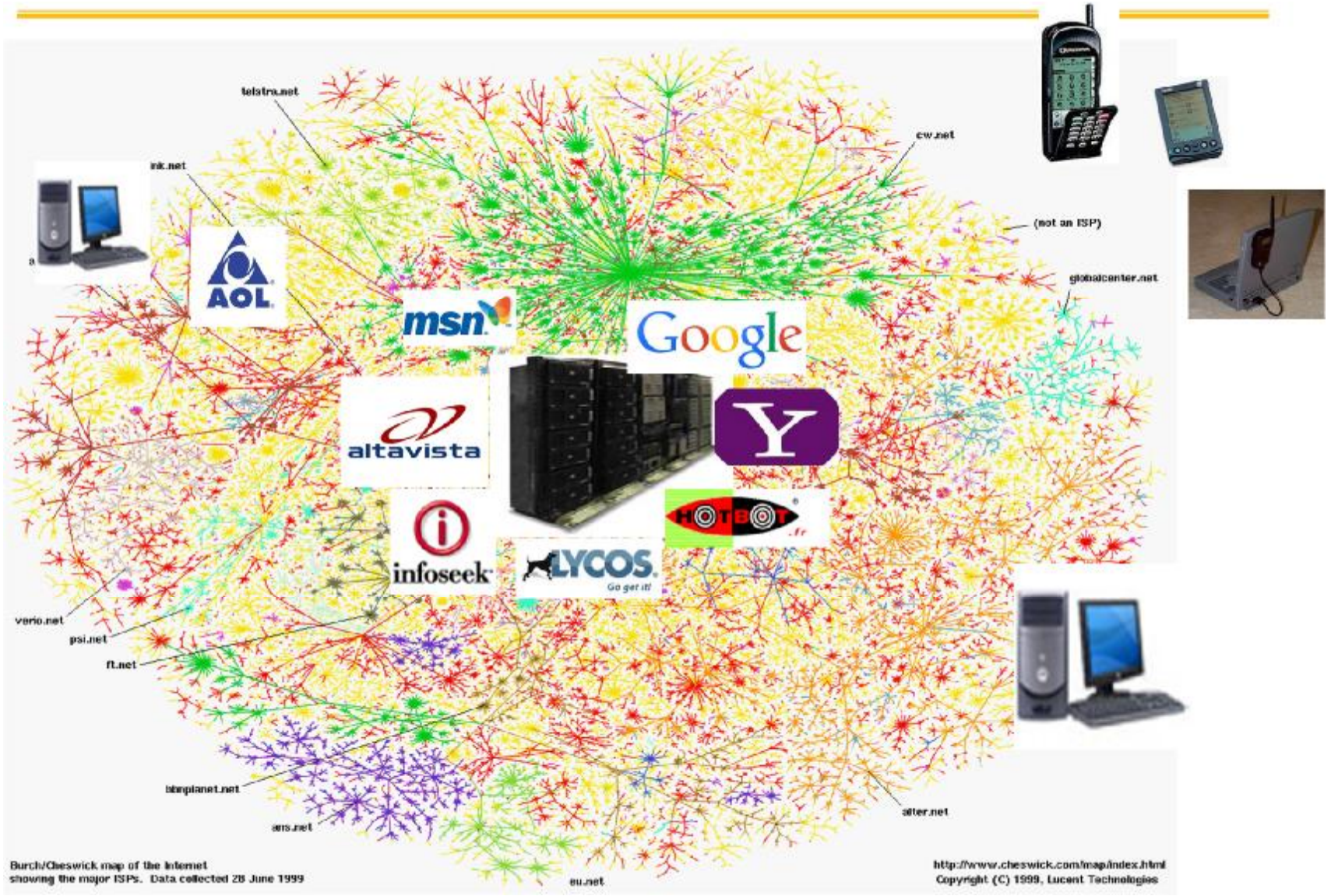
In 1999, we said "…

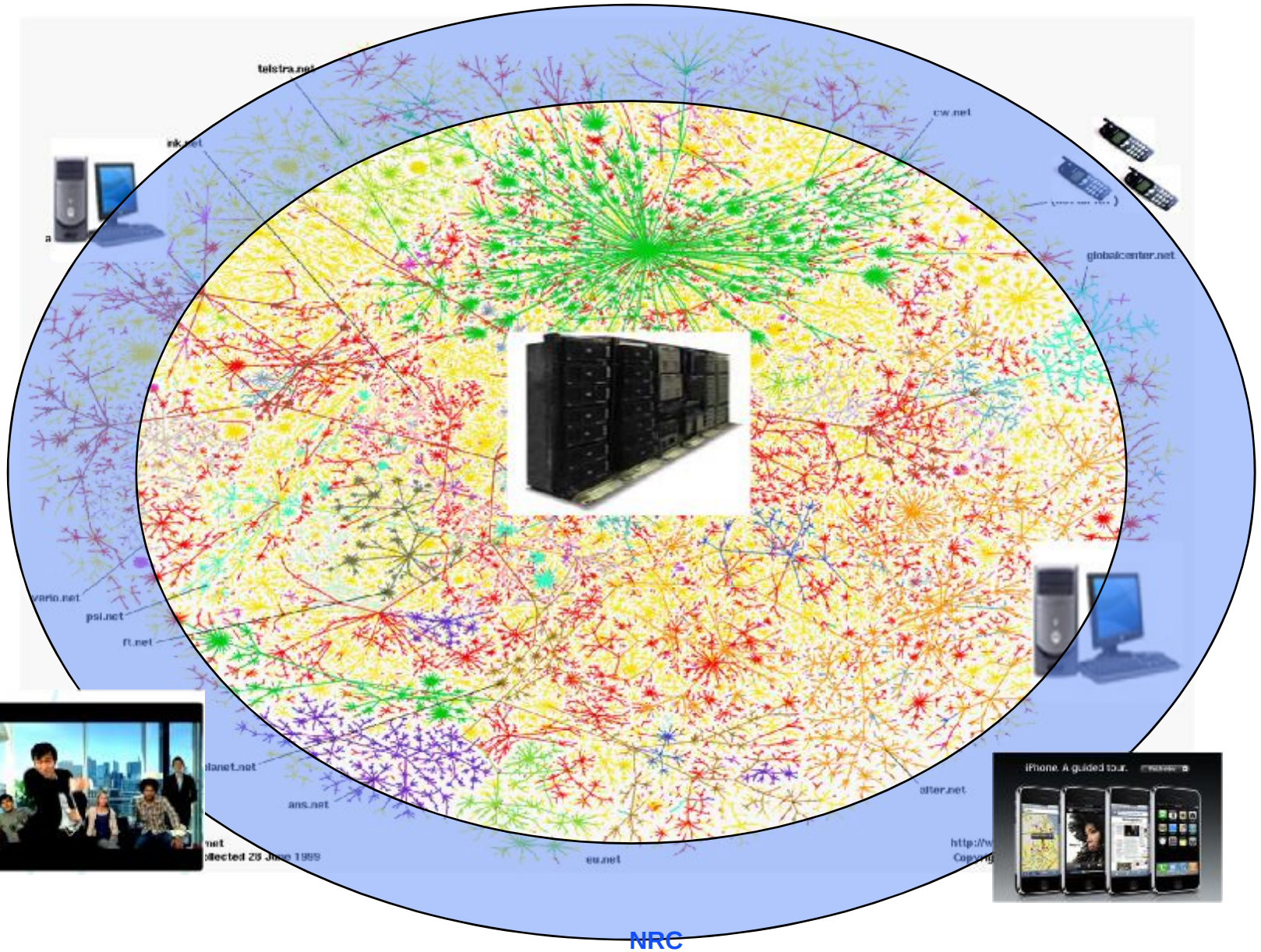
… in 15 years we will have connected all the people on the planet and we will have the technology to connect all the things."



The Internet in 1999



2007 - The Internet of Every Body



2013: Many Th

BLE

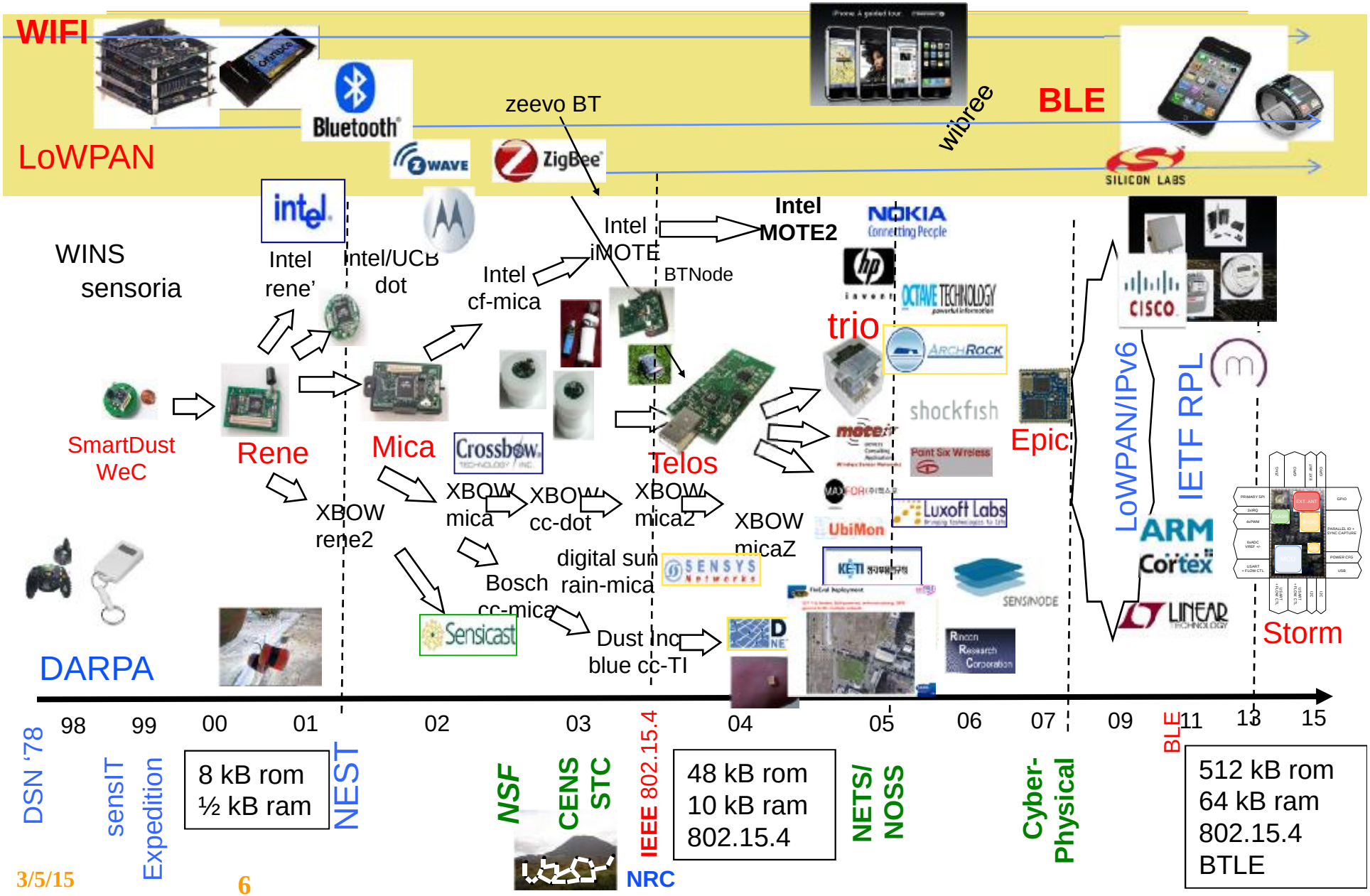
RGB LED Controller

WiFi

LoWPAN

WiFi

A Device / $ Centric Perspective



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 (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

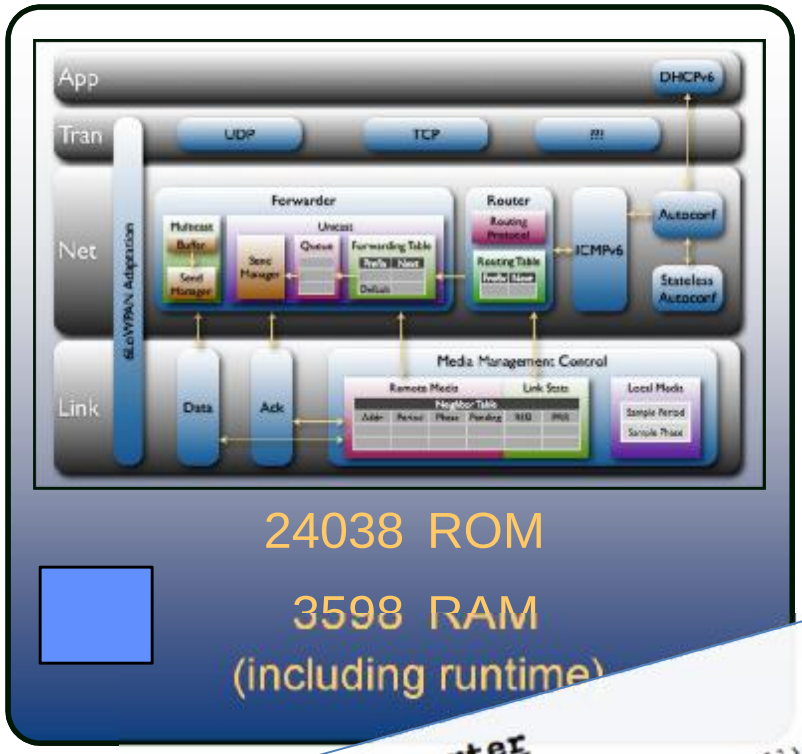
802.15.4e

- **Reliable routing on Low-Power & Lossy Links**
  - Power, Range, Obstructions => multi-hop
  - Always at edge of SNR => loss is common

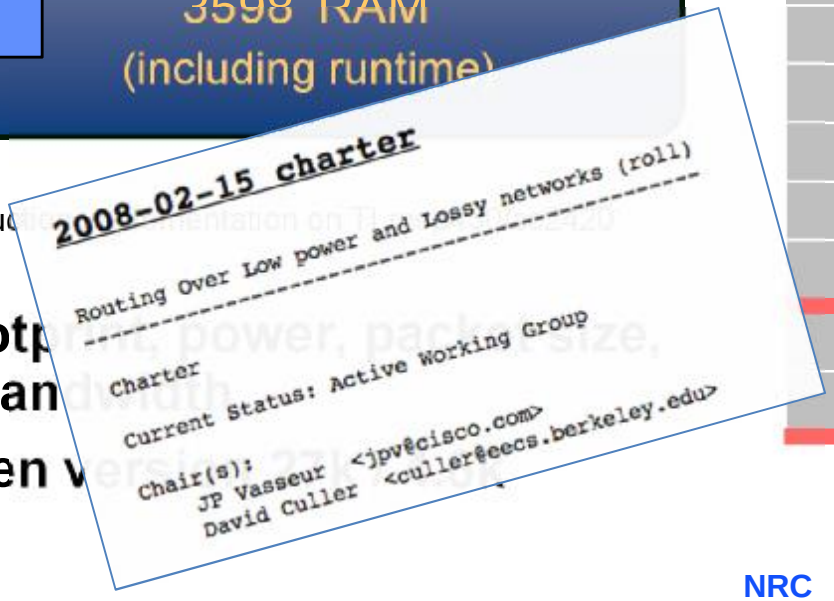
  => monitoring, retransmission, and local rerouting (routing diversity)

- **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



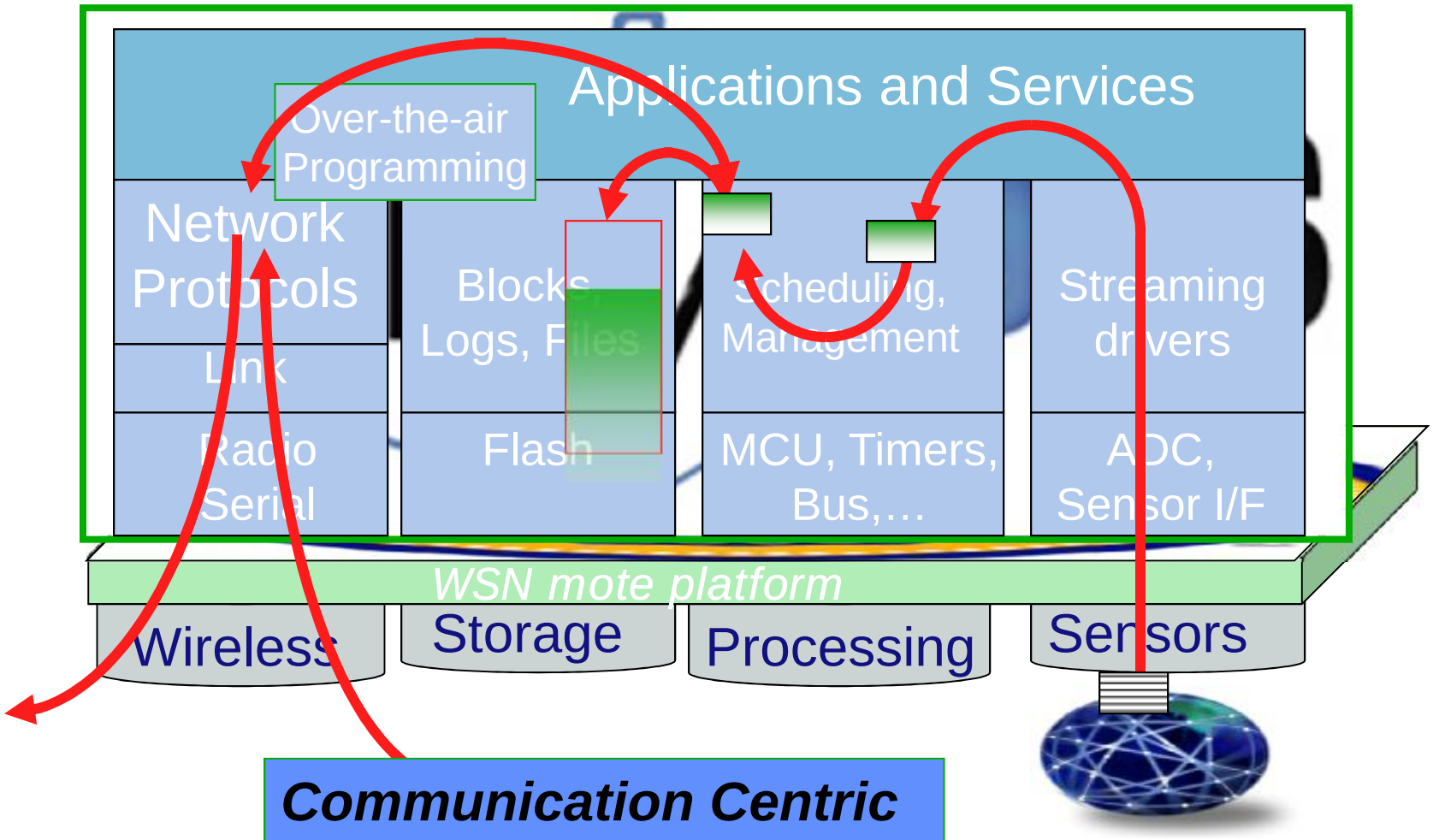
	ROM	RAM
CC2420 Driver	3149	272
802.15.4 Encryption	1194	101
Media Access Control	330	9
Media Management Control	1348	20
6LoWPAN + IPv6	2550	0
Checksums	134	0
SLAAC	216	32
DHCPv6 Client	212	3
DHCPv6 Proxy	104	2
ICMPv6	522	0
Unicast Forwarder	1158	451
Multicast Forwarder	352	4
Message Buffers	0	2048
Router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



* Produc

- Footp & ban
- Open v

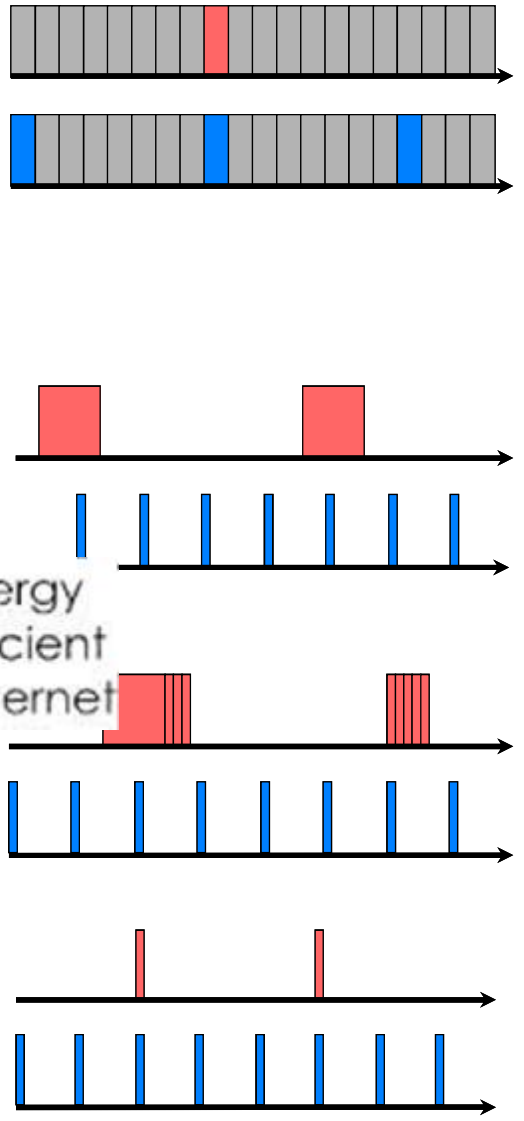
Framework abstractions to emerge



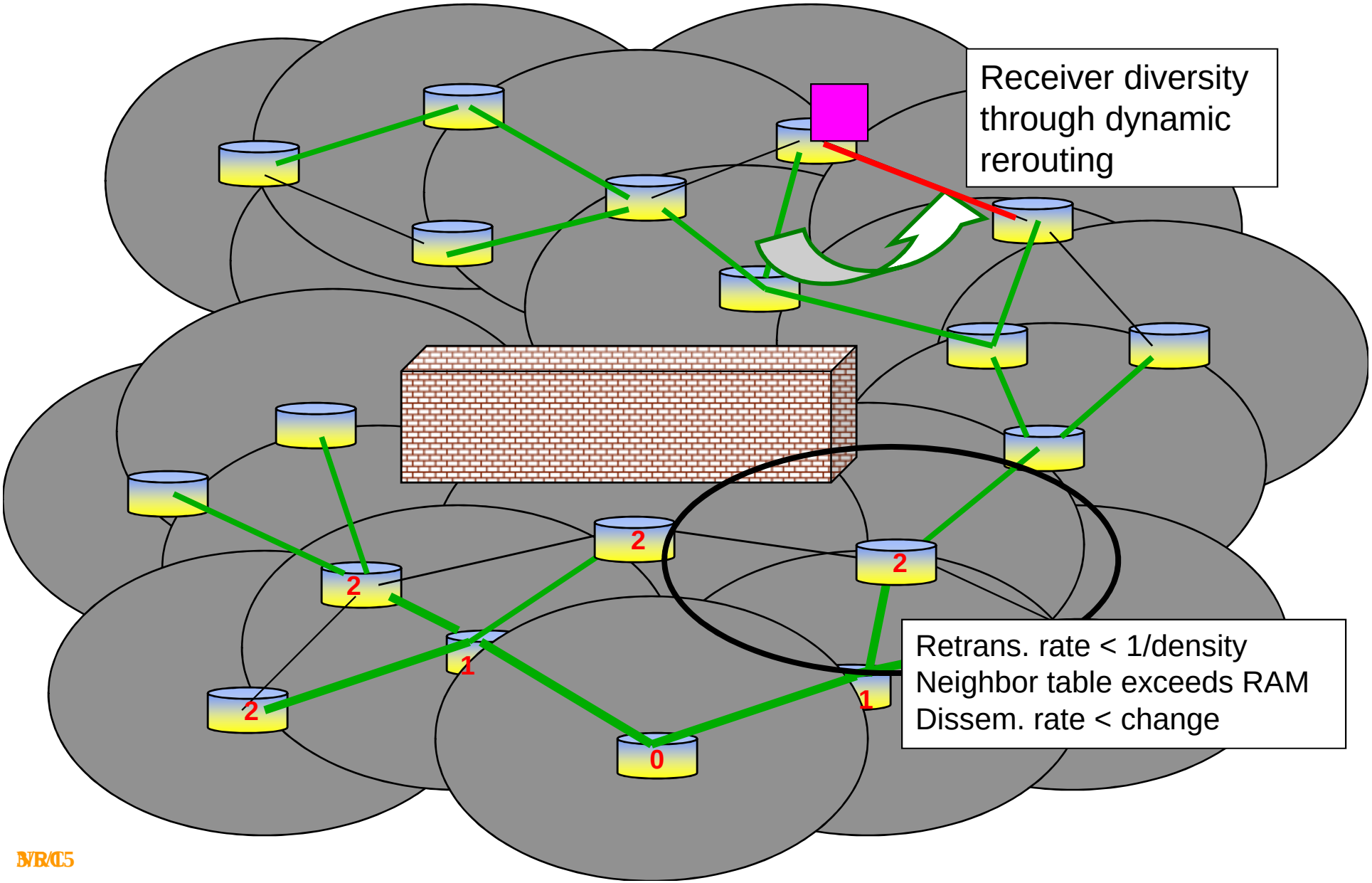
Communication Centric Resource-Constrained Event-driven Execution

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, Beacon[illegible] piconets, …
    - » S-MAC, T-MAC, PEDAMACS, T[illegible]
- **Sampled Listening**
  - Listen for very short interv[illegible]ct [illegible] transmissions
  - On detection, listen actively to [illegible]ceiv[illegible]
  - DARPA packet radio, LPL, BMAC, XMA[illegible], …
  - 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**



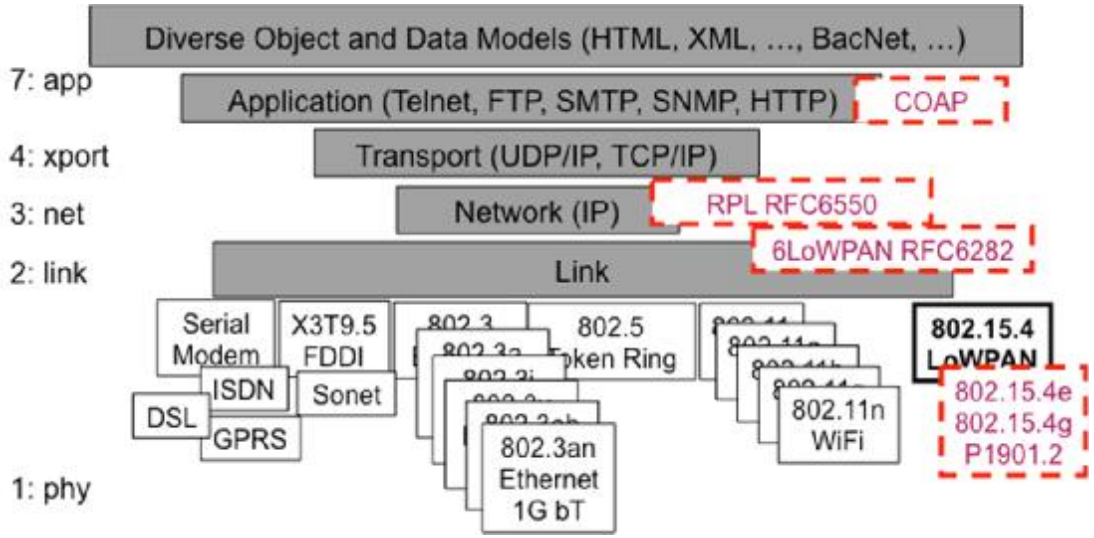
Self-Organized Routing - nutshell



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**

MANET ???



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**