IP and Low-Power Wireless: Madness, the Future, or Both?

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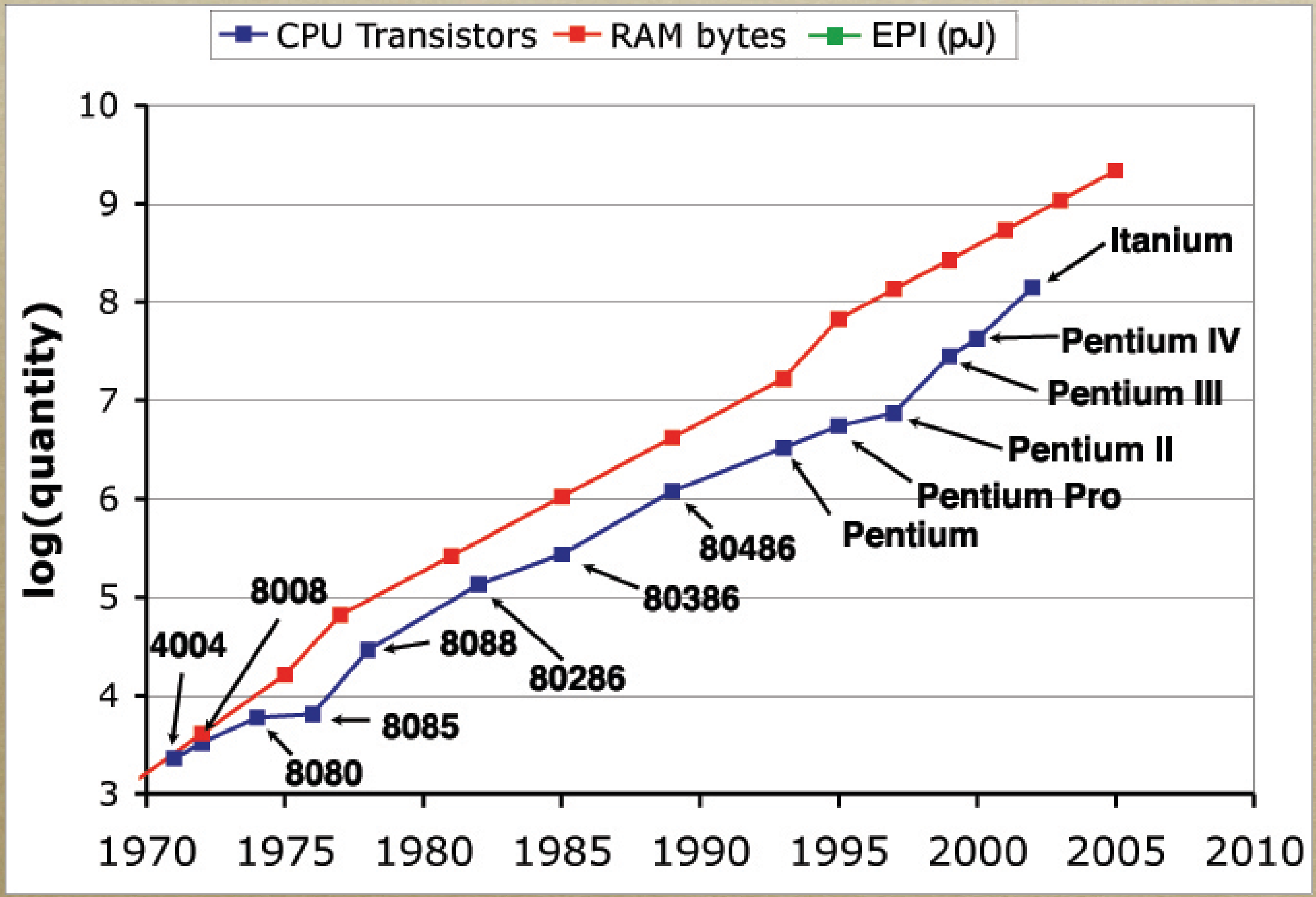
Moore’s Law



CPU Transistors
RAM bytes
EPI (pJ)
log(quantity)
10
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2010
Itanium
Pentium IV
Pentium III
Pentium II
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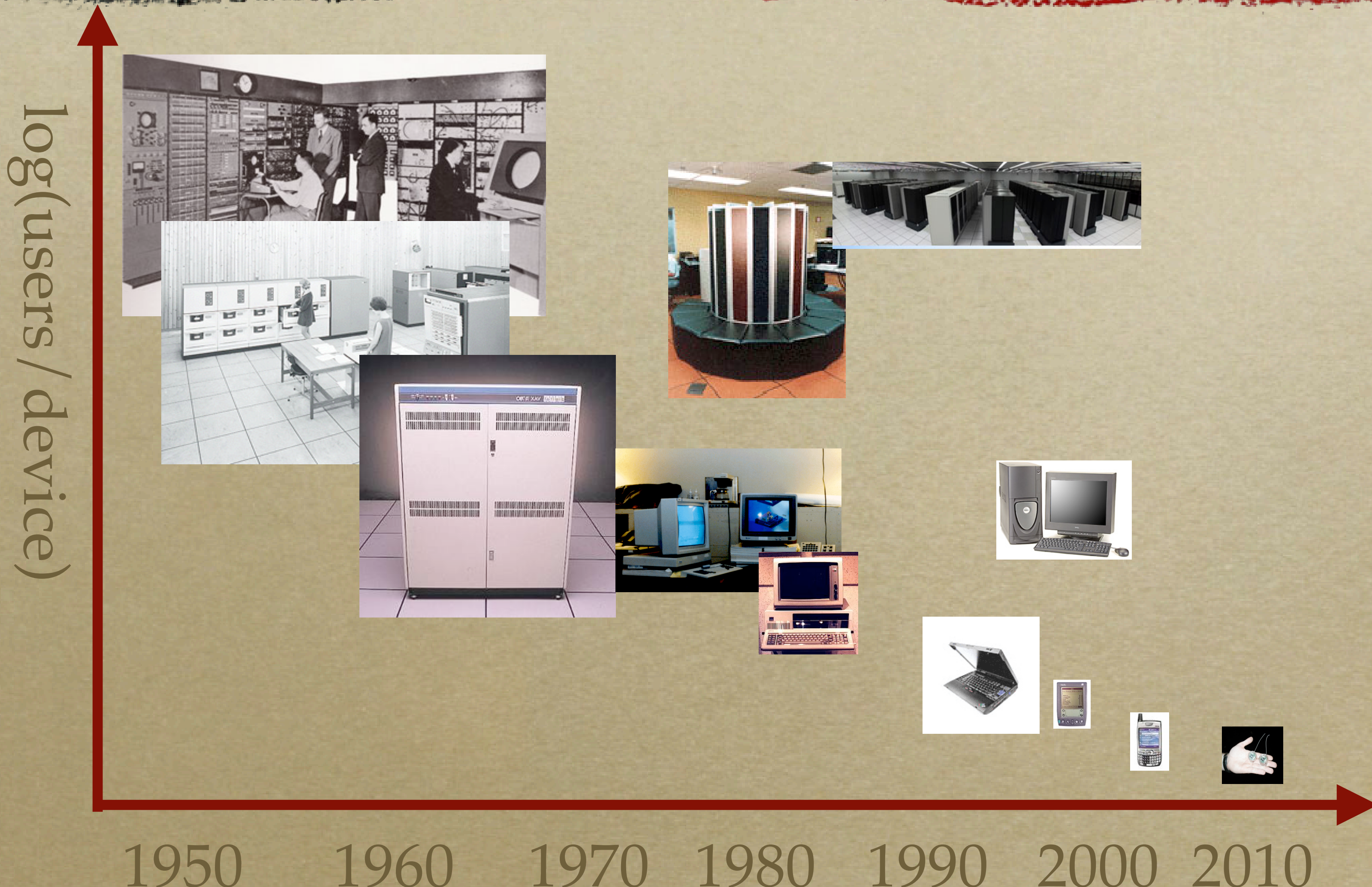
4004

Bell's Law



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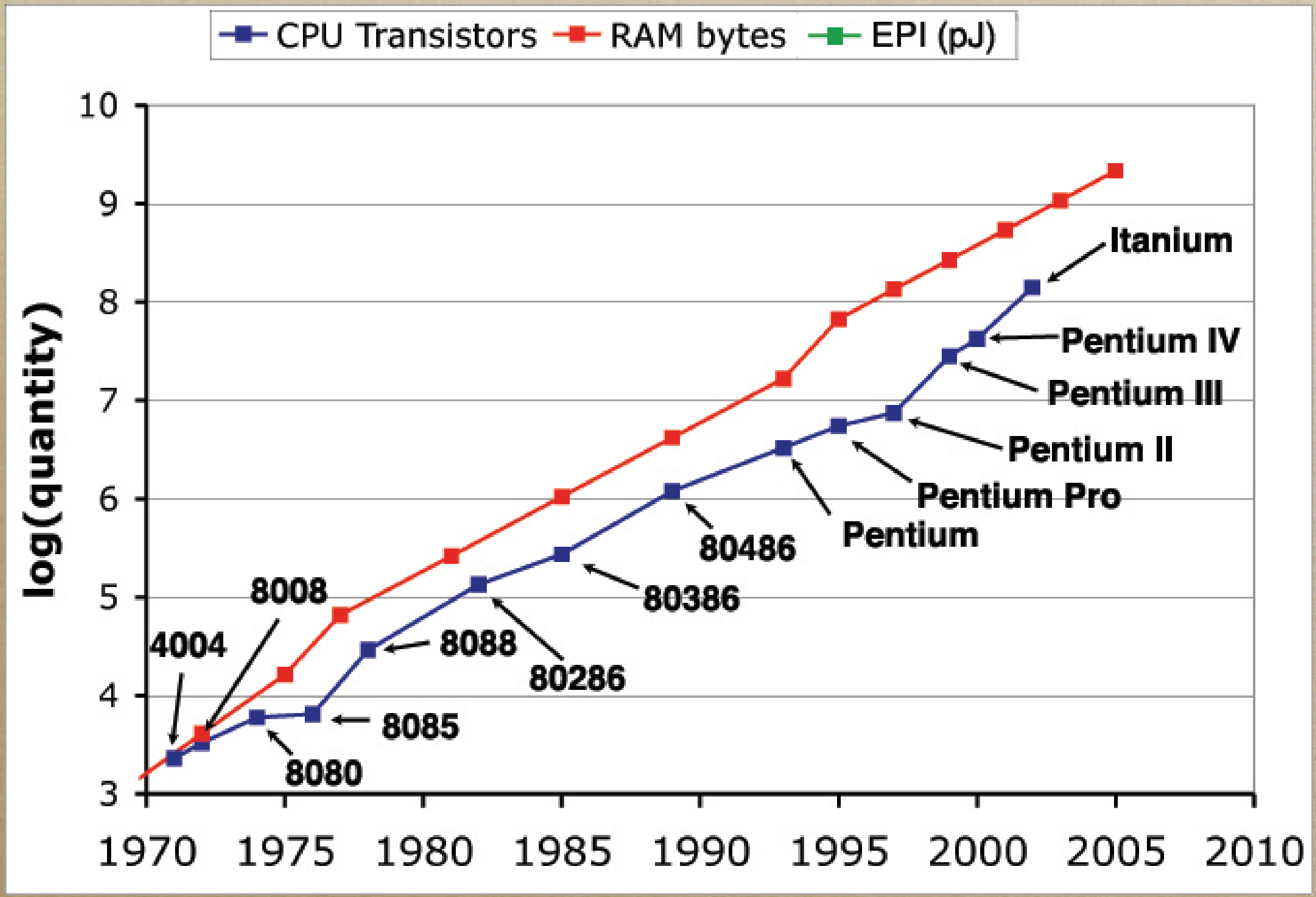

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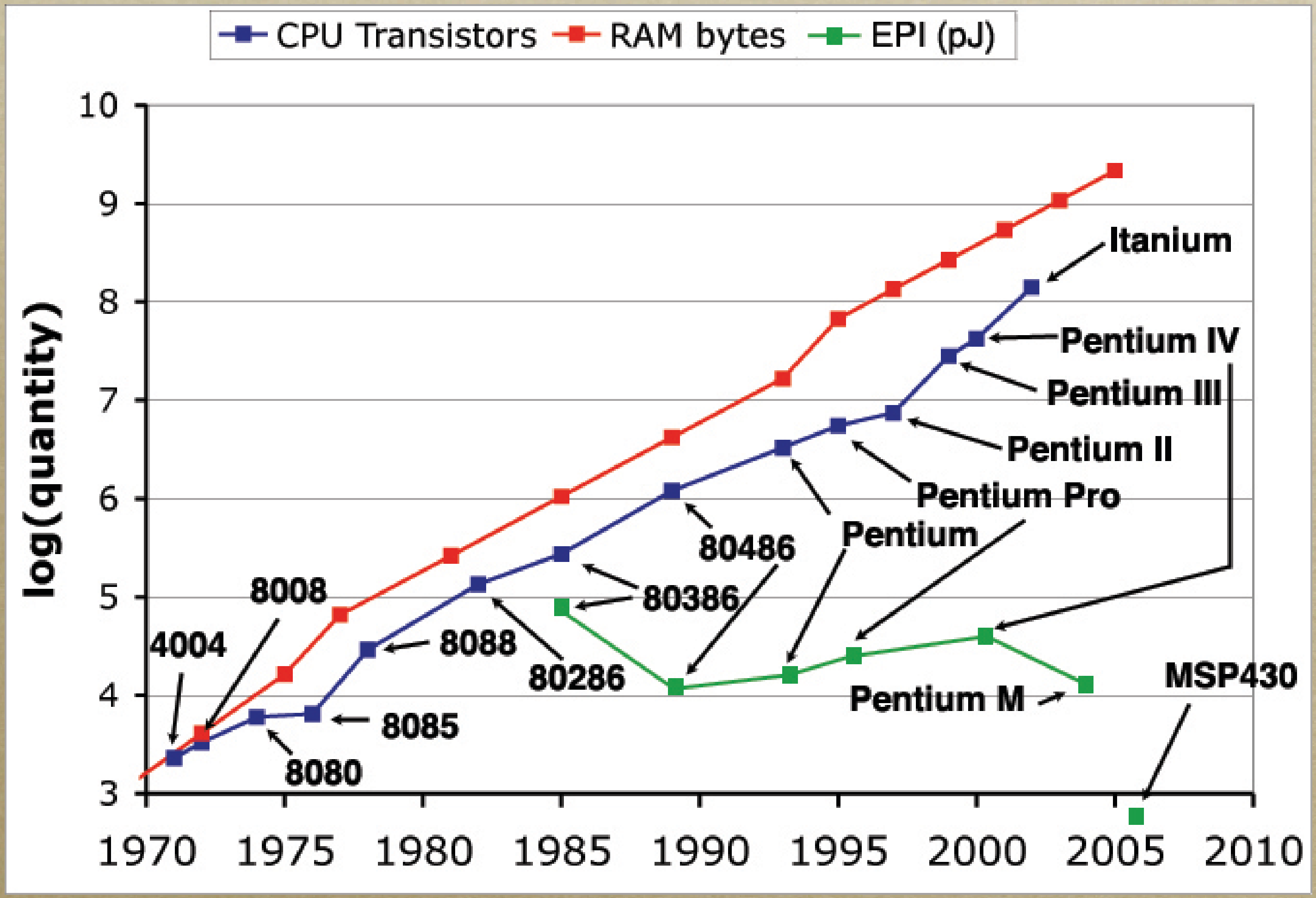
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MSP430

Low Cost, Low Power Wireless

- Most numerous class of node (and increasing)
  - 1 billion Internet users, 2 billion mobile phone users (2006)
    - Nokia claims will reach 3 billion by 2007
  - 440 million Internet hosts, 1.5 billion mobile phones (2006)
- Energy determines form factor
  - Sleep power and set-up times are important
- Usage models based on infrequent activity
  - Communication is expensive
- How should they network?

The Case Against IP

- ZigBee, SP100, and sensornets
- Sheer number of devices calls for data-centric naming
- Pervasive computing: PANs have predominantly local communication
- Discovery, naming, energy...

The Case For IP

- It's flexible: conquered many unforeseen domains
- It's simple: cheaper devices
- It's universal: cheaper interoperability
- Make it work well first: optimize later
  - If you can't communicate, doesn't matter how efficient you are
- IETF 6lowpan: IPv6 over 802.15.4

What Would It Take?

- How do low cost, low power wireless networks behave?
- What are the implications for IP routing (6lowpan)?
  - Different optimization criteria?

Outline

- The future of networking?
- Case study: 802.15.4 and IPv6
- Packet reception rates
- Acknowledgments
- Implications

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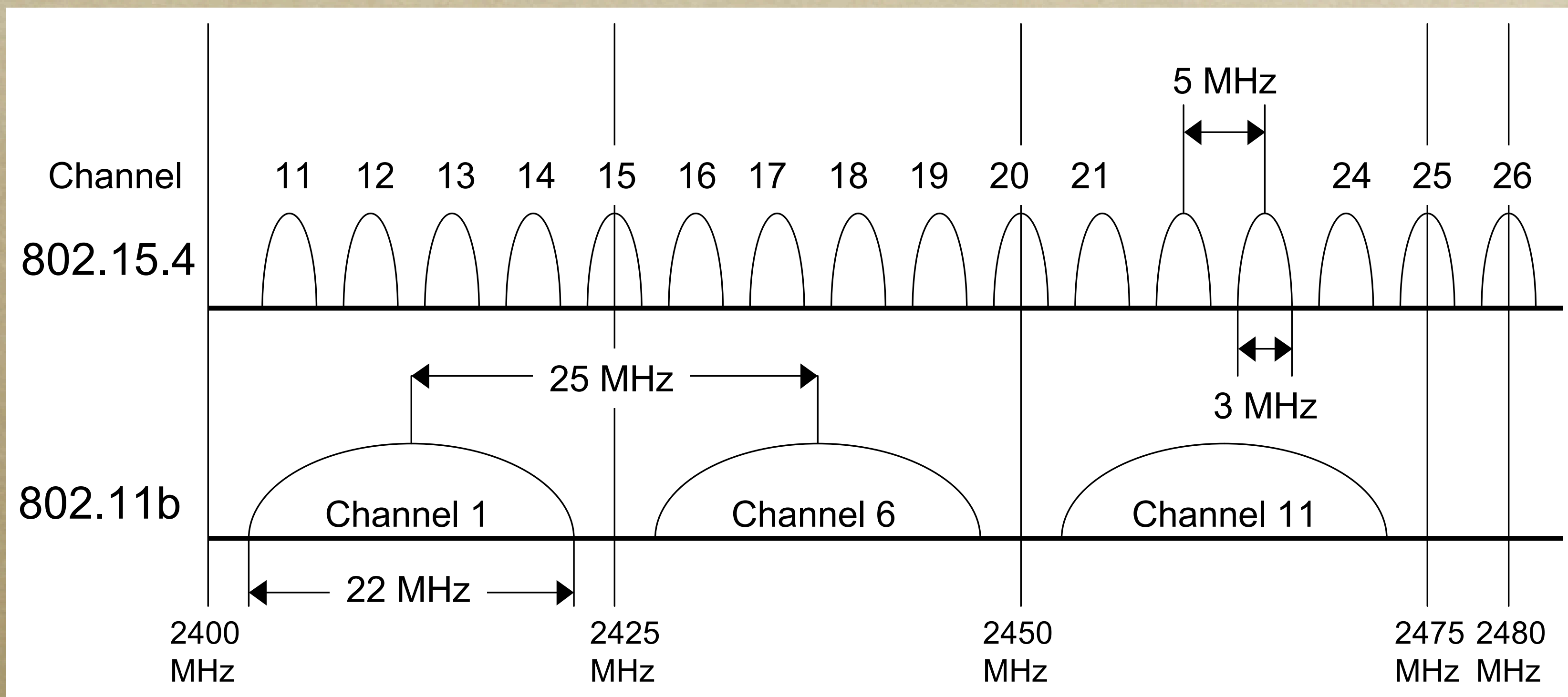
802.15.4 Spectrum

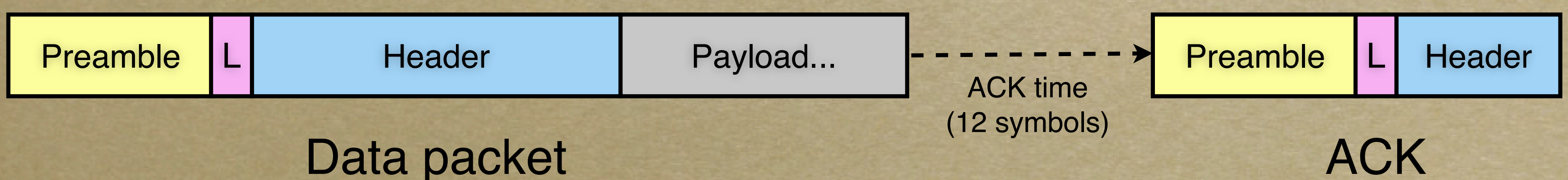


IPv6 (RFC 2460)

- Section 5:
  - IPv6 requires that every link in the internet have an MTU of 1280 octets or greater. On any link that cannot convey a 1280-octet packet in one piece, link-specific fragmentation and reassembly must be provided at a layer below IPv6.

802.15.4 Packets

- OQPSK (802.11 is BPSK or QPSK)
- DSSS: 32 chips -> one 4 bit symbol
  - e.g., 11011001110000110101001000101110 -> 0000
- 256 kbps (2 Mchips)
  - Max is 250 pps, no MAC max is 650 pps
- Maximum packet length: 127 bytes, including header
- Synchronous layer 2 acknowledgments



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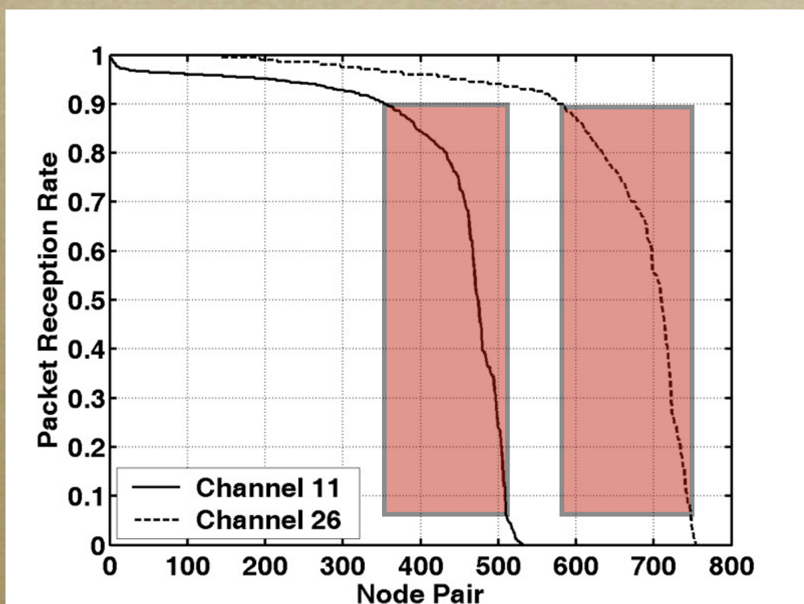
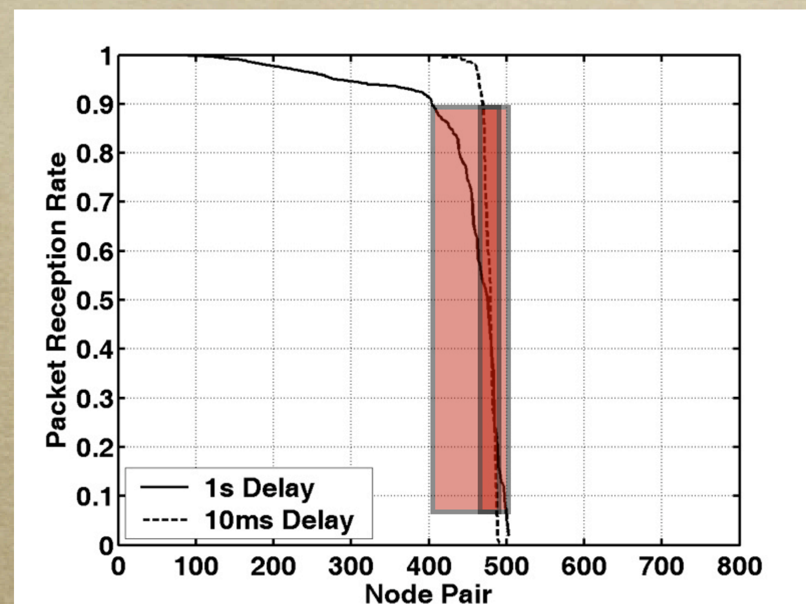
Link Behavior

- The good, the bad and the ugly
  - Intermediate links, 10% < PRR < 90%
- What do links look like over time?
- Indoor lab testbed

Effects of Packet Timing



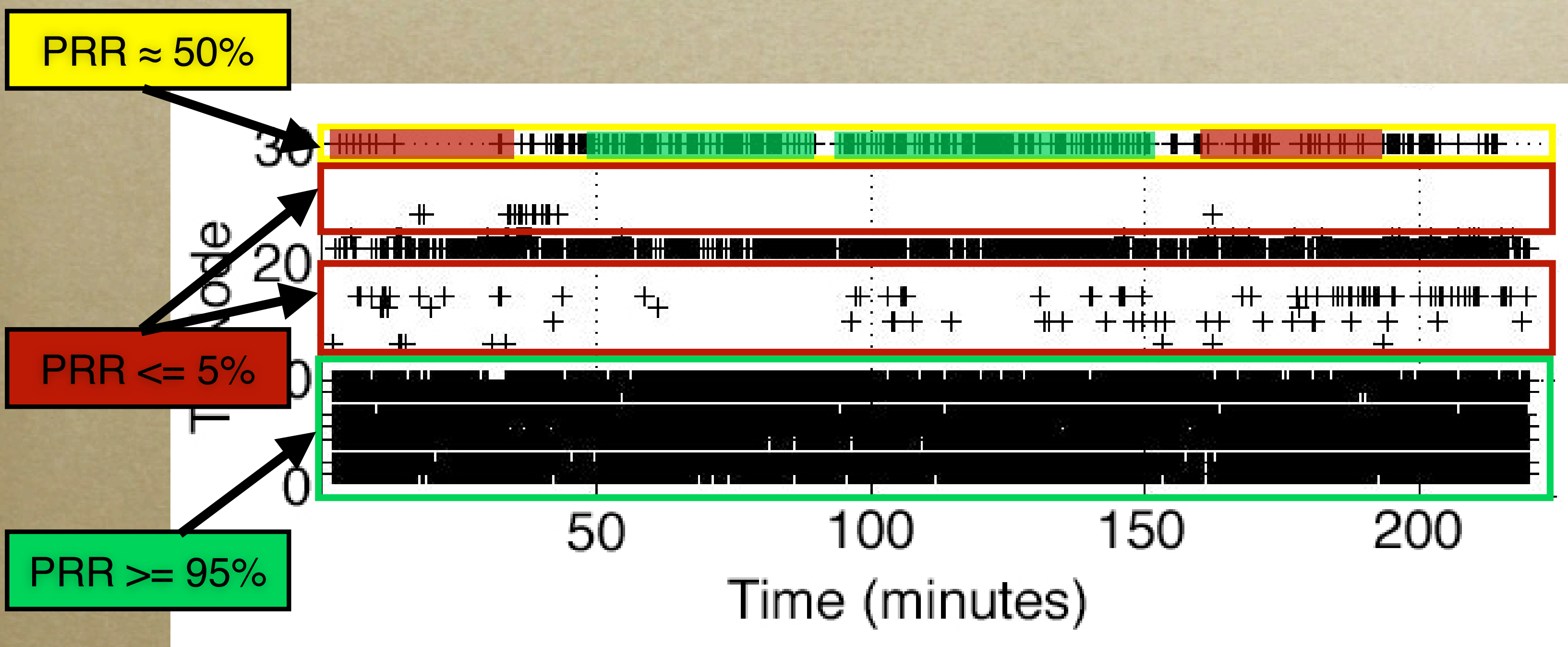
14 seconds



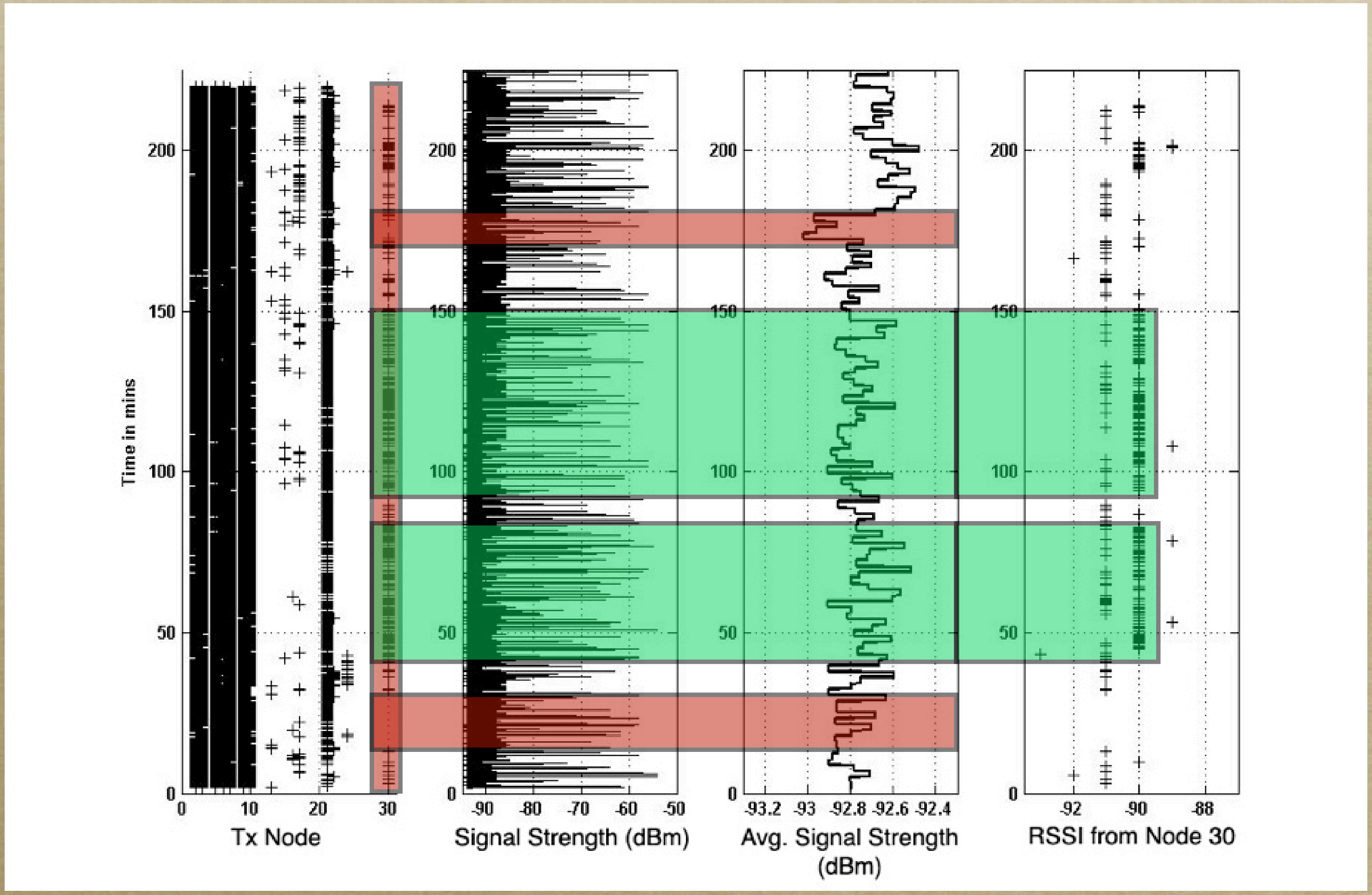
Channel 26

PRR over Time

- Receptions over time at one node (node 4)



Node 4 Details



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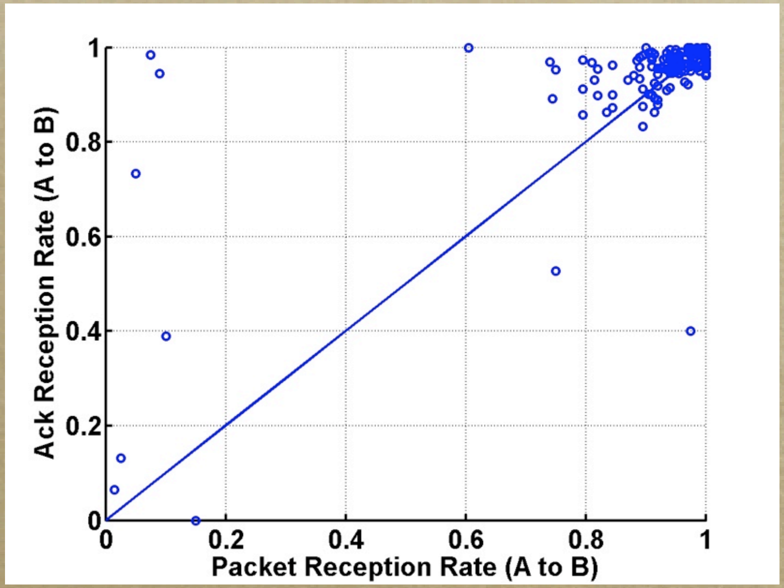
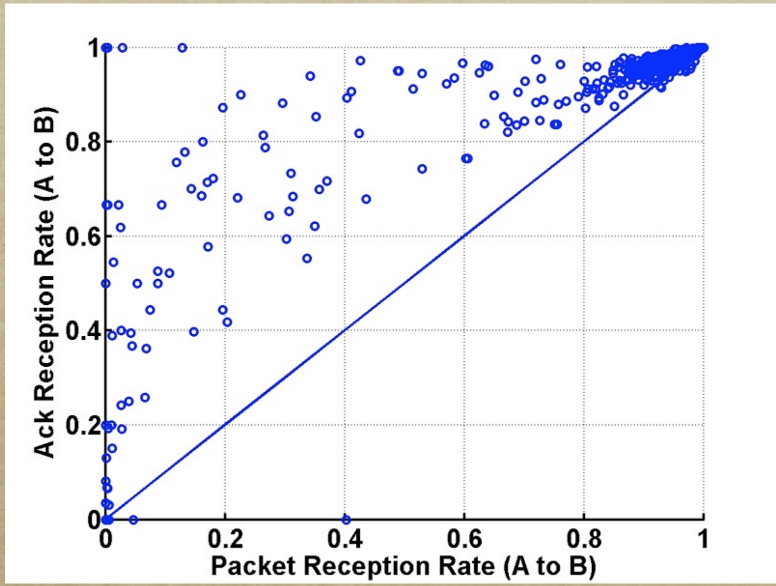
ETX

- Energy-optimized routing metric
- Typically measured as $1/(PRR_{AB} \bullet PRR_{BA})$
  - Product of data and acknowledgment delivery probabilities
  - Assumes acknowledgment delivery is same as data delivery
- PRR is an average over time, and time scales matter

ARR vs. PRR

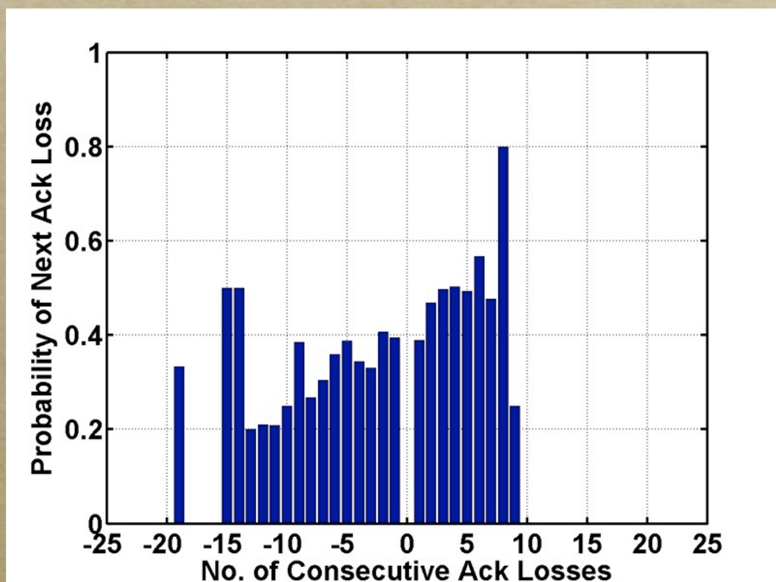


10ms

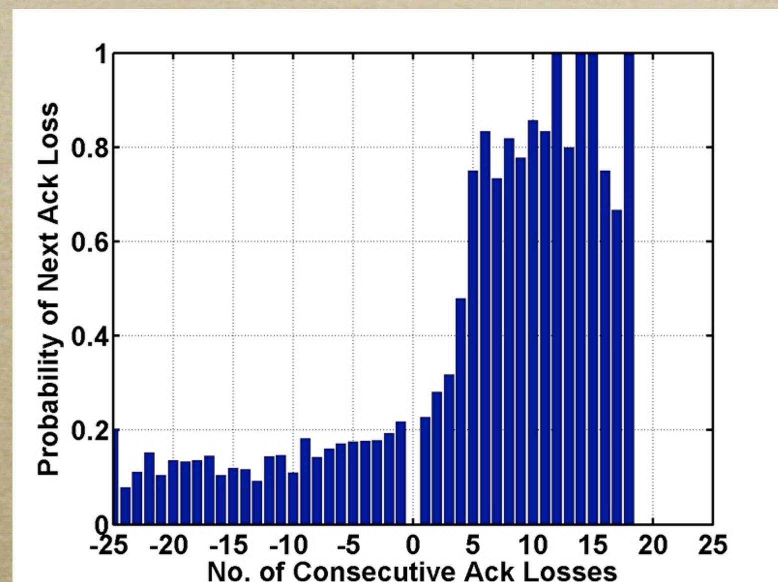


14s

Delivery Is Not Independent



A->B
(edge of sensitivity)



B->A
(5dBm RSSI transition)

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Implications to IP

- Packet duplication due to false ack negatives
  - Original 6lowpan RFC required discarding packets with overlapping fragments (since changed)
- Bimodal links require agile route selection
  - Poses complexities to fragmentation/assembly
  - End-to-end vs. per-hop approaches
- Link asymmetries may require asymmetric routes
  - E.g., not AODV, DYMO
  - Or could use link-filtering based on symmetry
- End-to-end vs. per-hop fragmentation/assembly

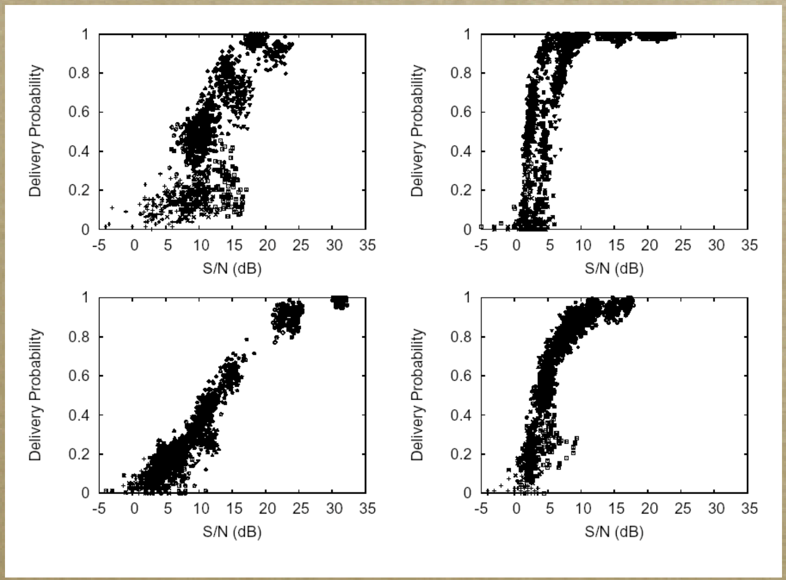
Wireless IP

- 802.15.4 differs from results of prior 802.11 studies
  - Asymmetry due to nodes (15.4), not locations (802.11)
  - SNR is a good measure of PRR
- Possible causes of discrepancies
  - Price point/engineering (ubiquitous)
  - Experimental methodology
- What's going on?
  - A whole new direction for wireless research?
  - A temporary market effect?
  - Have 802.11 studies just not seen these yet?

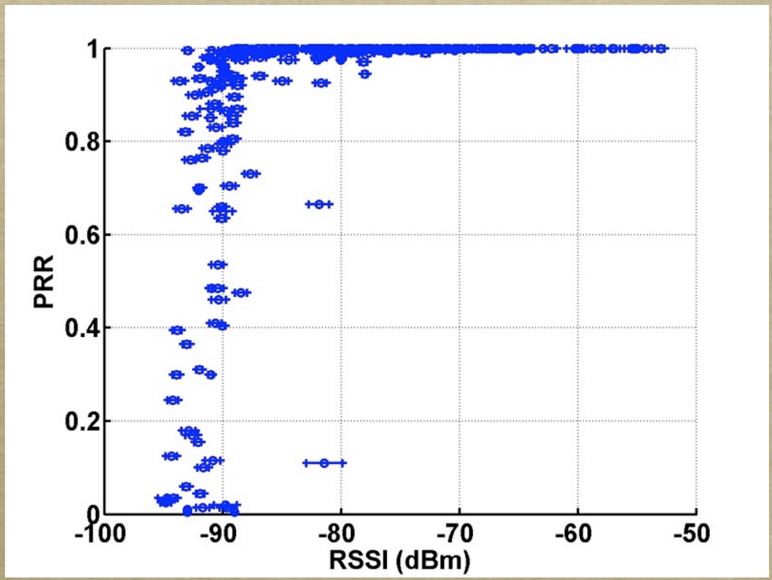
Differences from 802.11

(based on Aguayo data)

- SNR is not a good measure of 802.11 link quality in practice (Aguayo et al., SIGCOMM 2004)
  - Claim due to multipath effects
  - 802.15.4 shows opposite behavior: SNR curve is very sharp

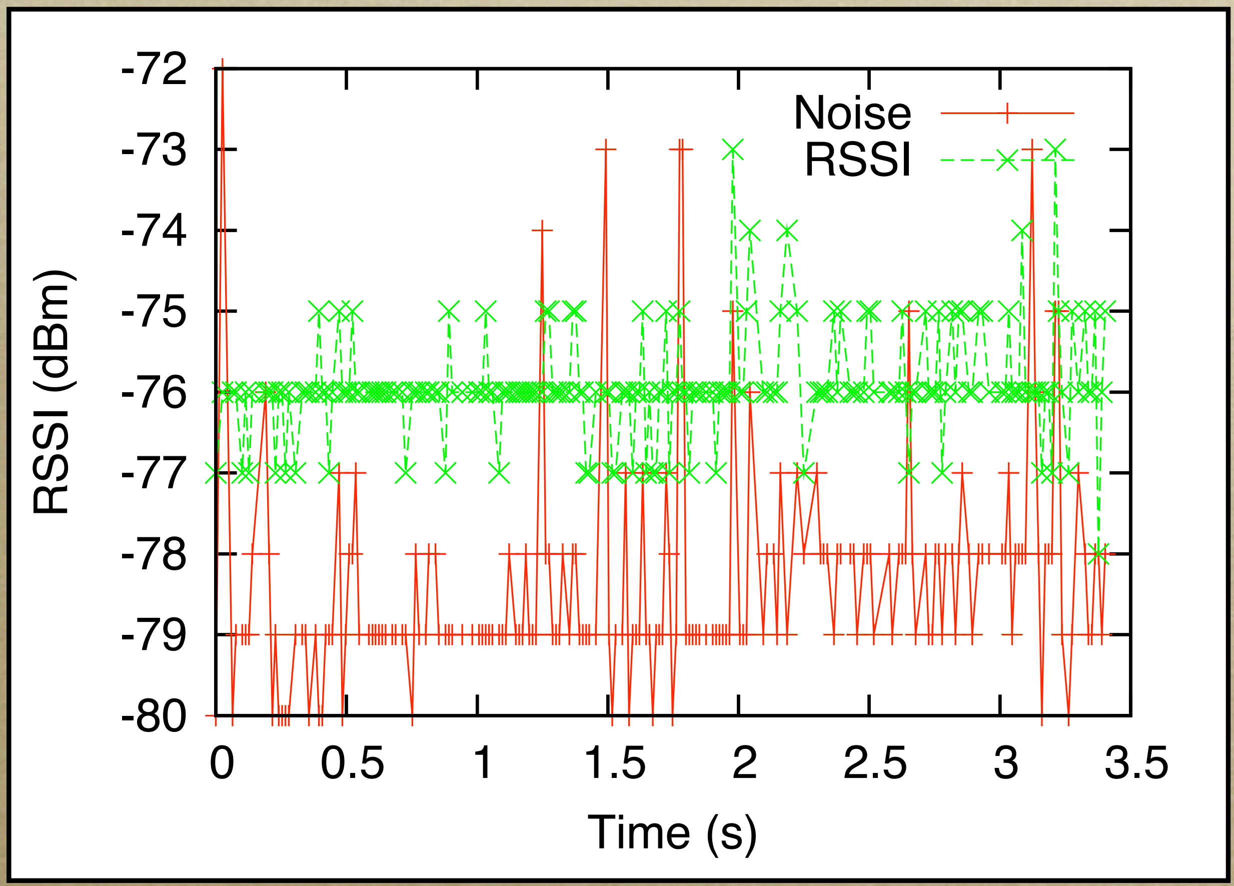


802.11

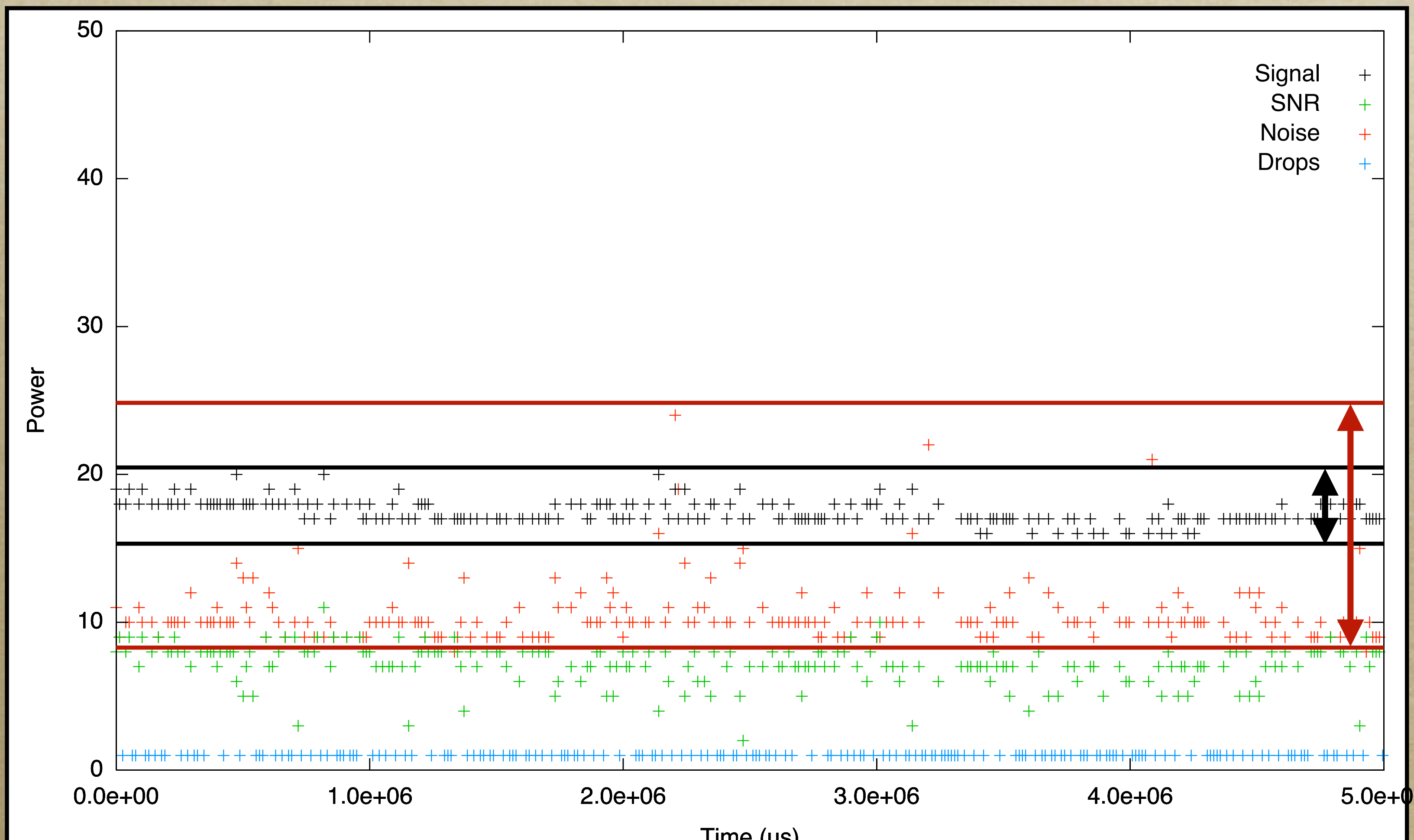


802.15.4

802.11 Signal and Noise



Looking Deeper



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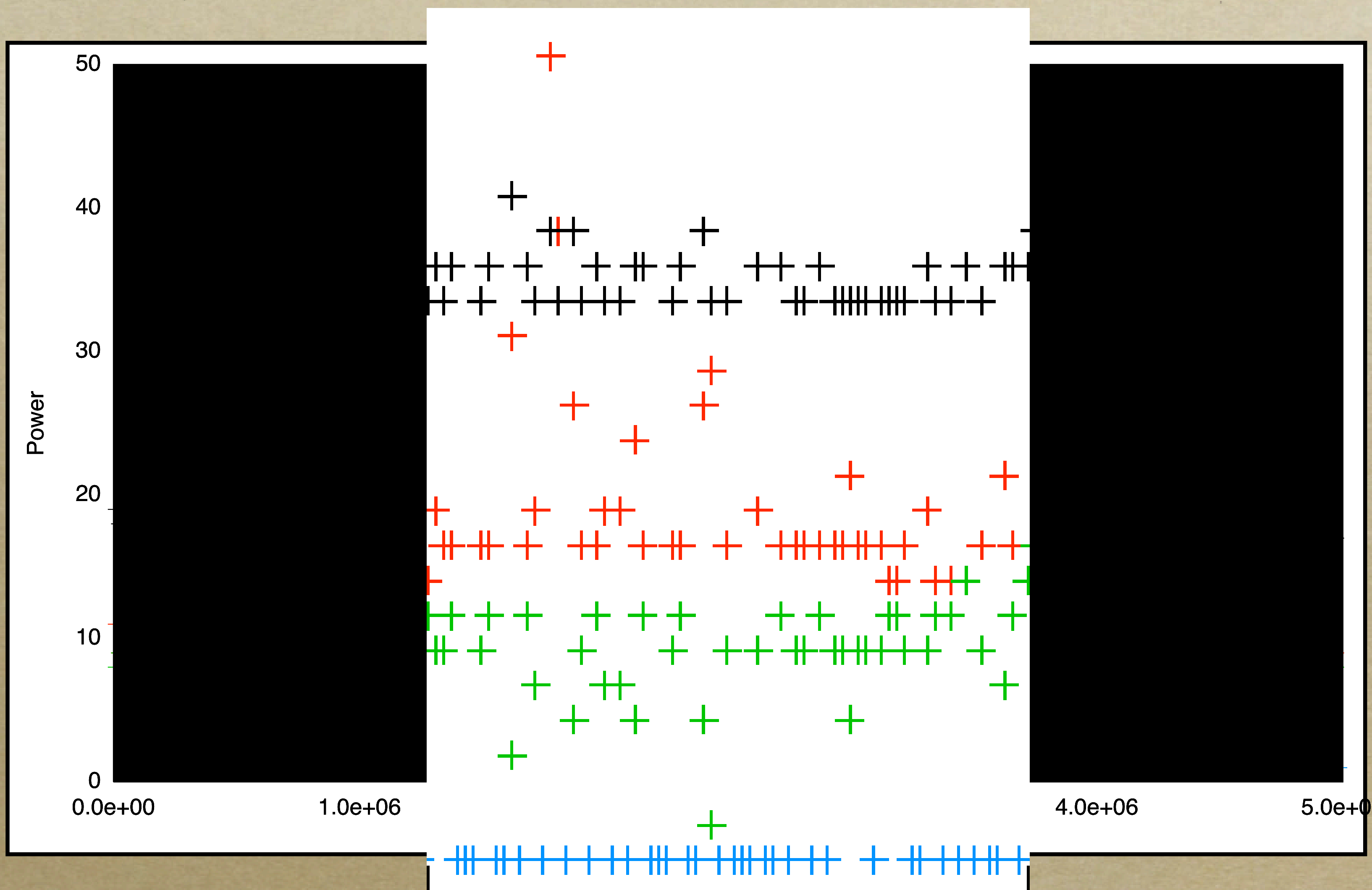

Questions

Extra Slides

More Differences

- General belief that 802.11 link asymmetries are due to environmental, not node effects (Reis et al., SIGCOMM 2006)
  - 802.15.4 shows opposite behavior: asymmetry is due to hardware variations (e.g., different HW noise floor)

802.11 Noise Distributions