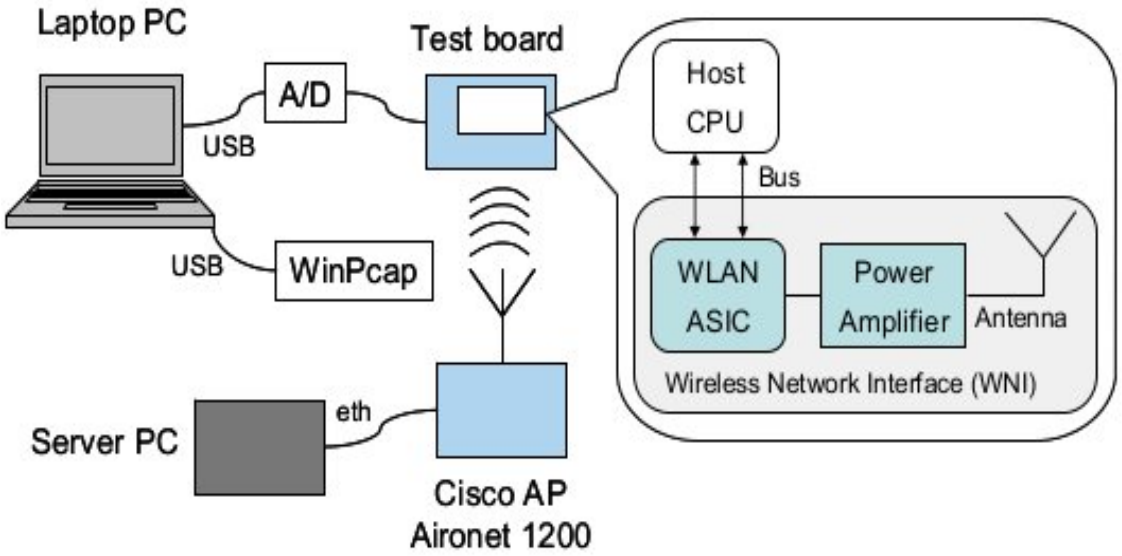
Energy Consumption Anatomy of 802.11 Devices and its Implication on Modeling and Design

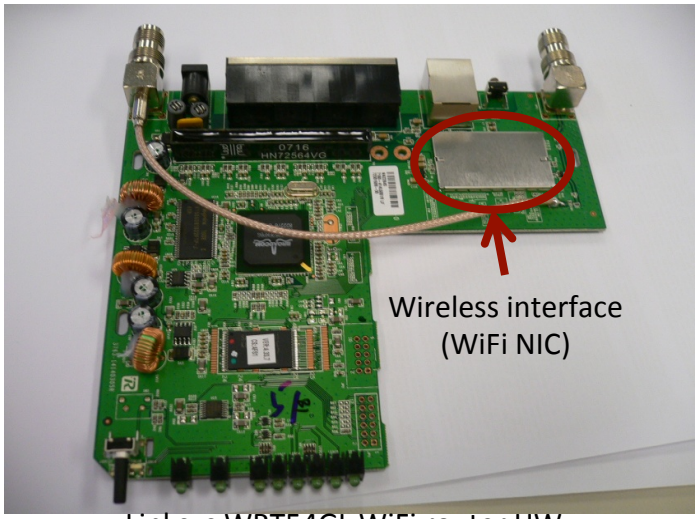
A. García-Saavedra[1], P. Serrano[1],
A. Banchs[1,2], G. Bianchi[3]

1: Universidad Carlos III de Madrid
2: Institute IMDEA Networks
3: CNIT / Università Tor Vergata

What we wanted

- To design an energy efficient comm. protocols we need to understand the power consumption
- Previous experimental work
  - Per-packet analysis of the wireless interface



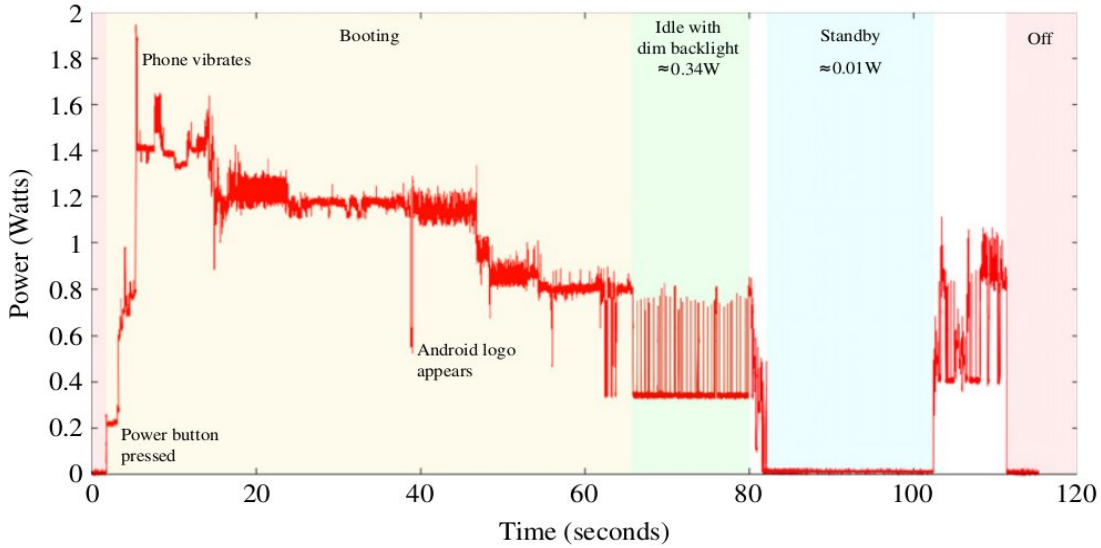


Linksys WRT54GL WiFi router HW

Rantala et al. "Modeling energy efficiency in wireless internet communication" , ACM Mobiheld, 2009

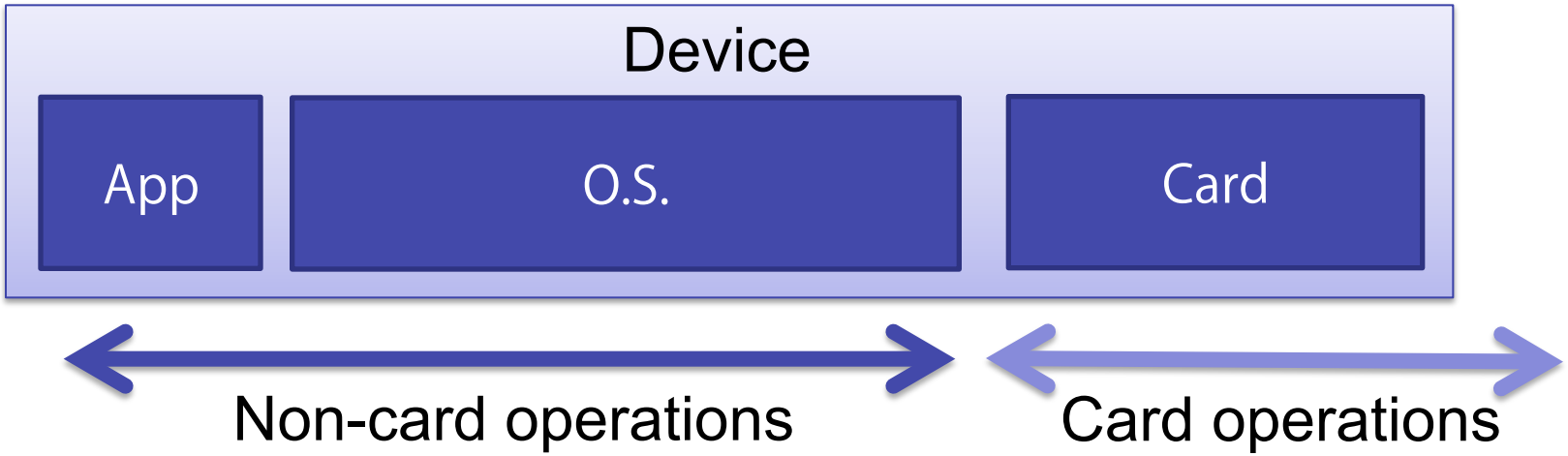
What we wanted

- To design an energy efficient comm. protocols we need to understand the power consumption
- Previous experimental work
  - Per-packet analysis of the wireless interface
  - Per-state measurements of the device



A.Rice, S. Hay "Measuring mobile phone energy consumption for 802.11 wireless networking", PMC. 2010

What we found



- Non-card can dominate the consumption
- Questions previous schemes
  - E.g. relaying in multihop
- Enables new designs
  - E.g. packet batching

Energy Consumption Anatomy

- Hardware used

Protek 3033B

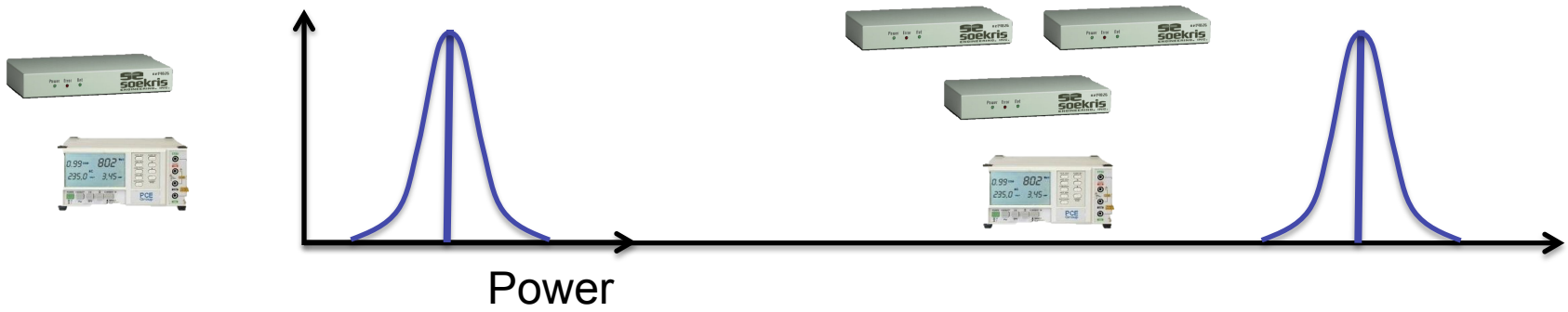
PCE PA-6000

Device running controlled experiments

Device	WiFi chipset	CPU	Memory	Software
Soekris net4826-48	Atheros AR5414 (11a/b/g)	233 MHz AMD SC1100	128 MB SDRAM	Gentoo 10.0 Kernel 2.6.24 / OpenBSD 5.1
Alix 2d2	Broadcom BCM4319 (11b/g)	500 MHz AMD LX800	256 MB SDRAM	Ubuntu 10.04 Kernel 2.6.29
Linksys WRT54GL	Broadcom BM4320 (11b/g)	200 MHz BCM5352	16 MB RAM	OpenWrt Backfire Kernel 2.6.32

Methodology

- With one device
  - Results are not very precise (e.g. ~6%)

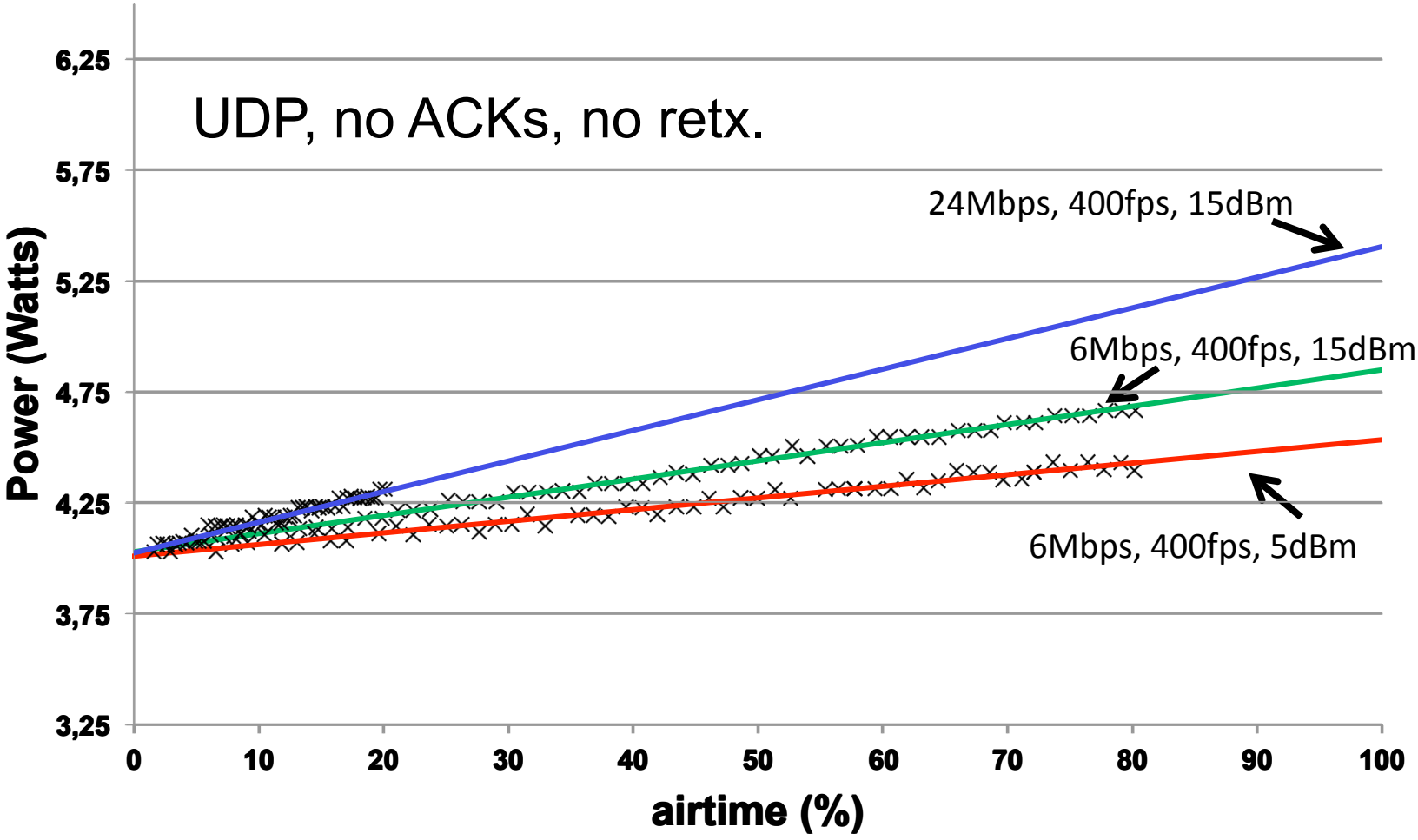


  - We added more devices (~2%)

Baseline power consumption

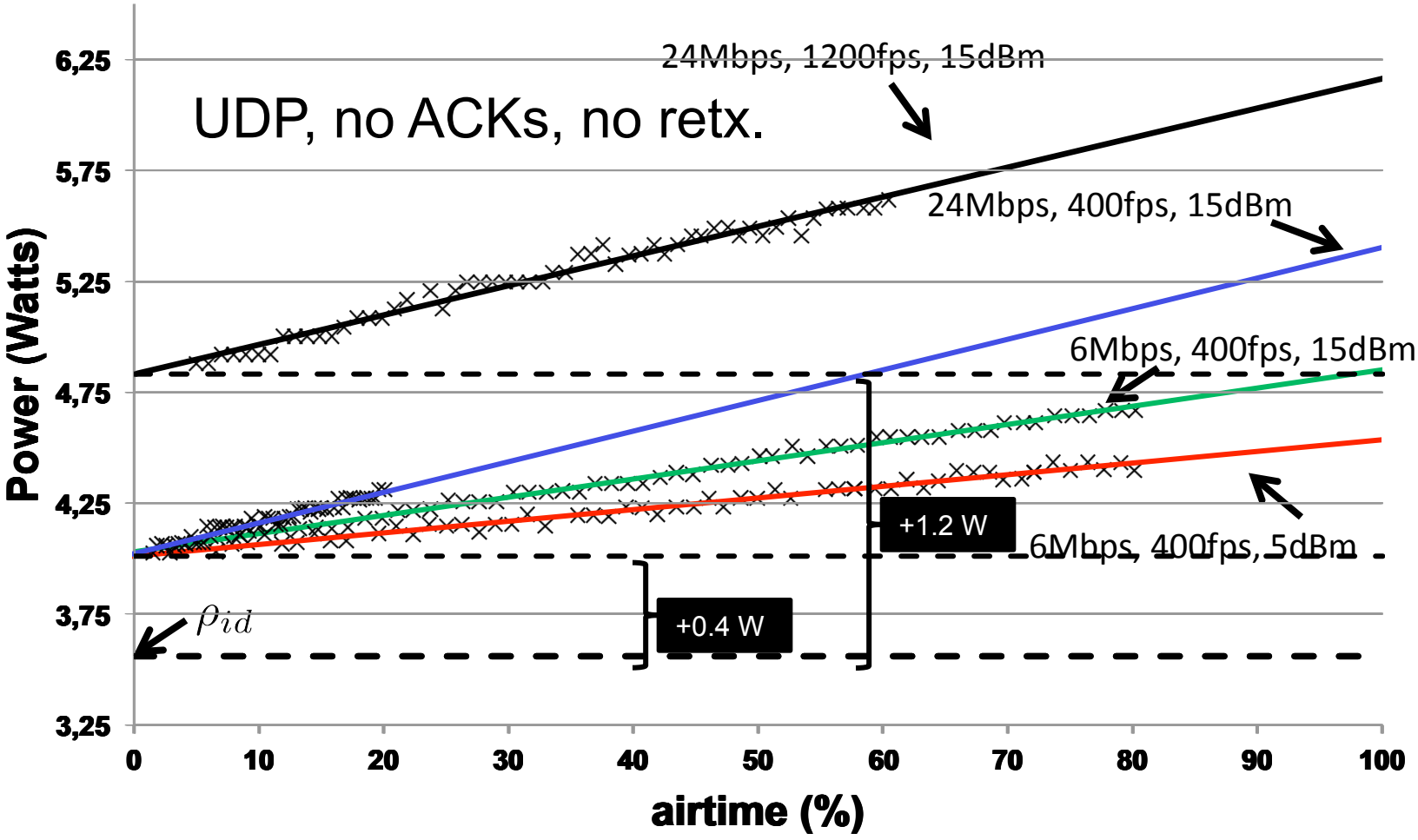
Config.	Description	Cons. (W)
w/o card	no NIC connected	$2.29 \pm 2.2\%$
WiFi off	NIC connected driver not loaded	$2.58 \pm 2.0\%$ $(+0.29)$
Idle (ρ_{id})	NIC activated+associated to AP no RX/TX besides beacons	$3.56 \pm 1.7\%$ $(+0.98)$

Power consumption: Transmission



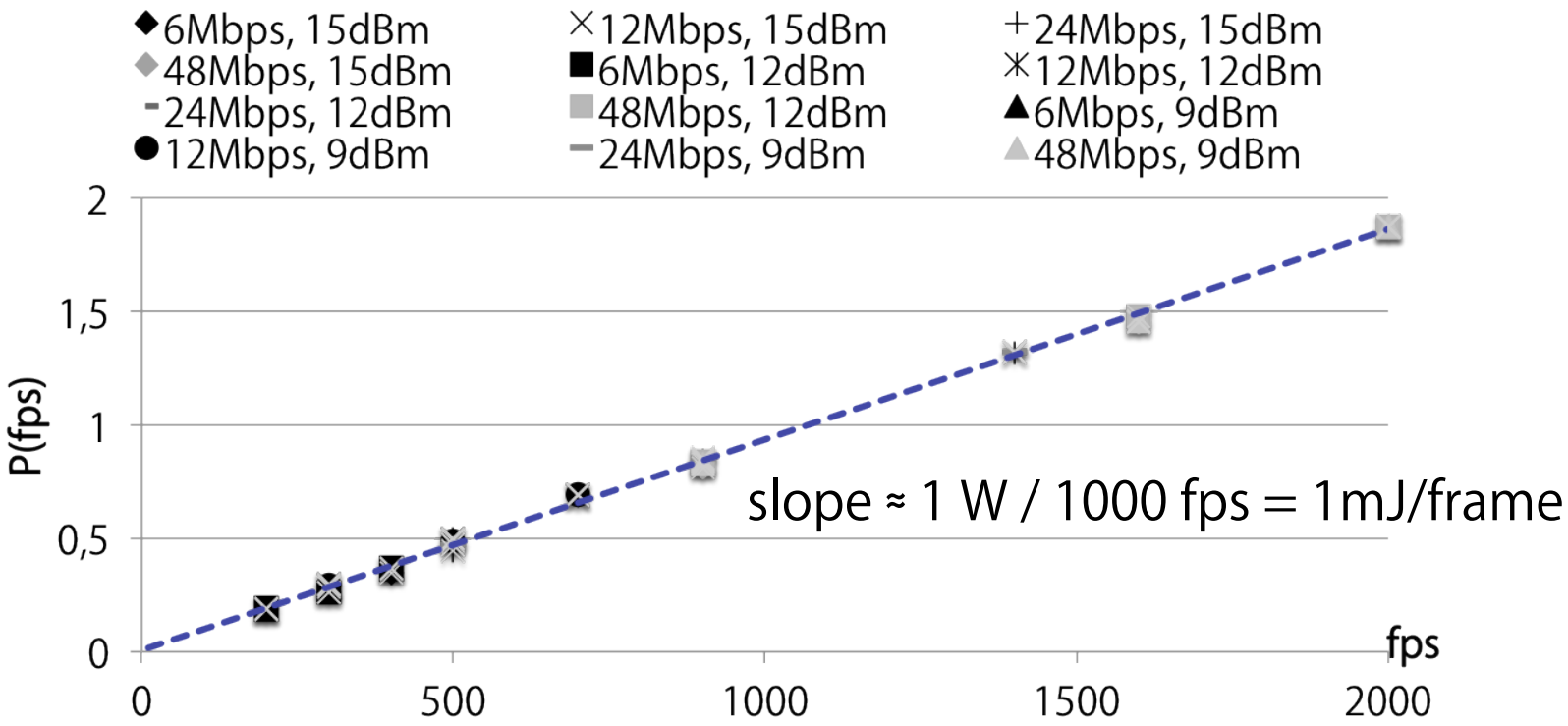
- Varying frame length -> Airtime = T_{plcp}+(H+L)/R

Power consumption: Transmission



- $P = P_{base} + P(fps) + P_{tx}(MCS,power) \times Airtime$

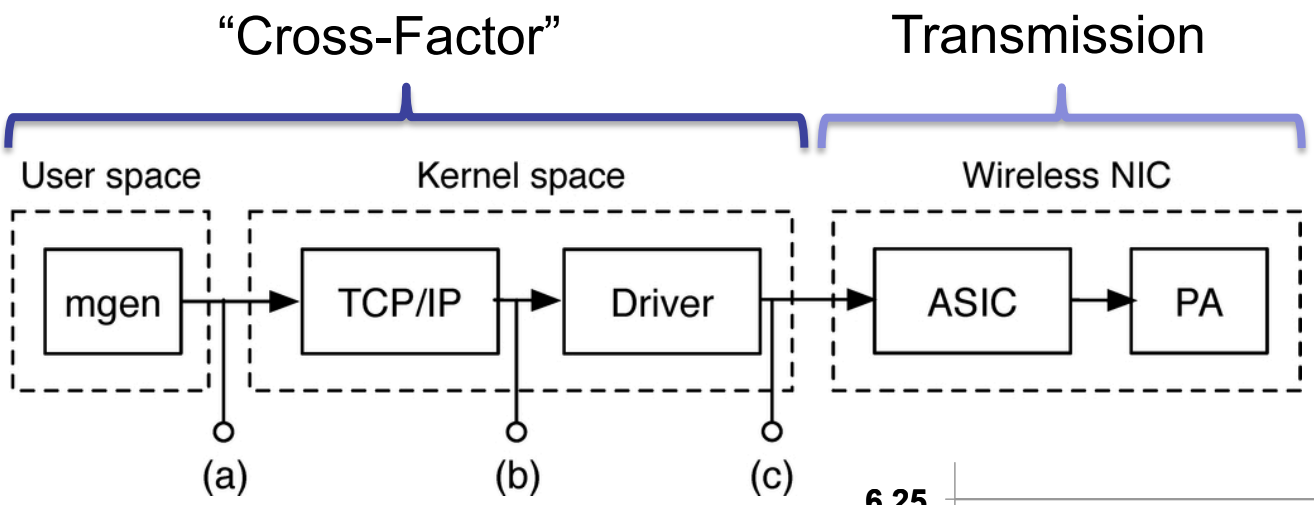
Per-Packet “energy toll”



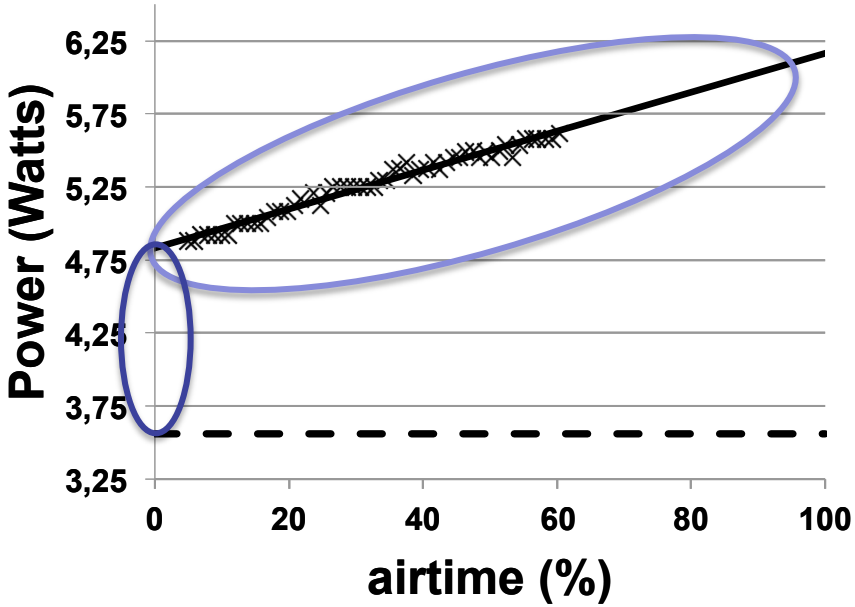
Soekris: 0.93 mJ/frame (Linux), 1.27 mJ/frame (OpenBSD)

Linksys: 0.46 mJ/frame **Alix**: 0.11 mJ/frame

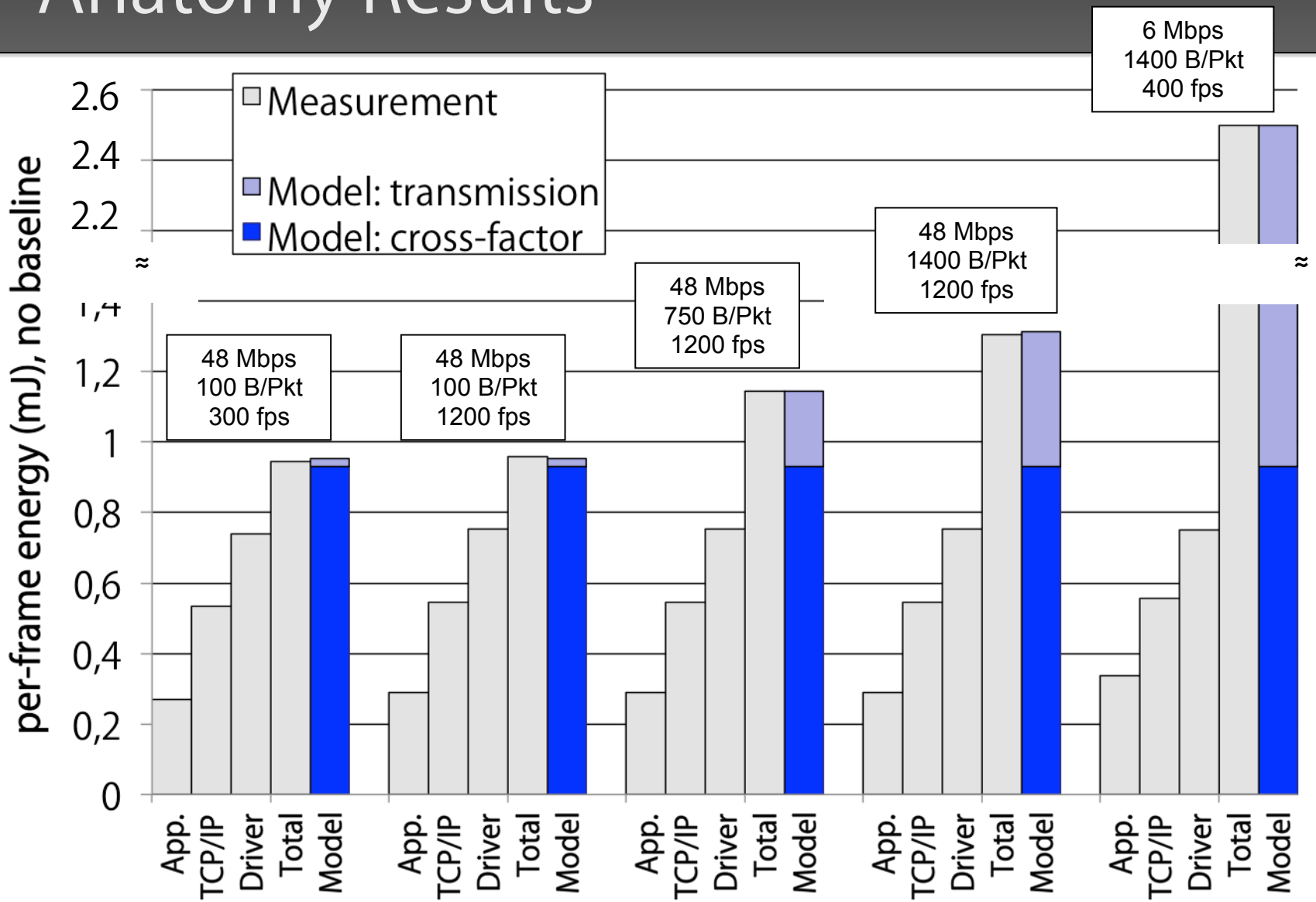
Energy Consumption Anatomy



- (a) App.: disc. before the OS
- (b) TCP/IP: disc. before driver
- (c) Driver: disc. after driver
- Total



Anatomy Results



The Cross Factor

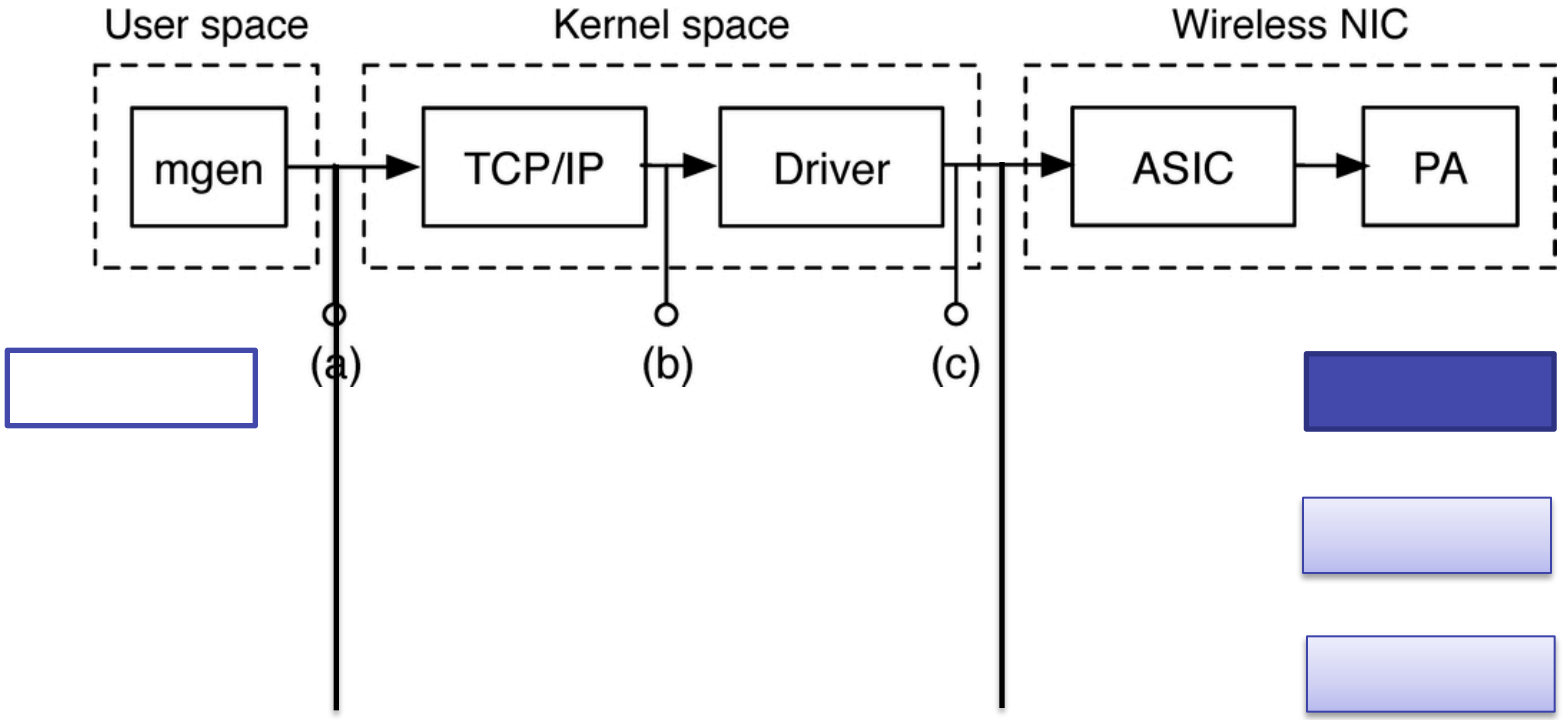
- Energy toll to handle a frame
  - Independent of frame size
  - Total power > base power + card power
- Energy split:

App	TCP/IP	Driver	NIC
24%	33%	21%	22%

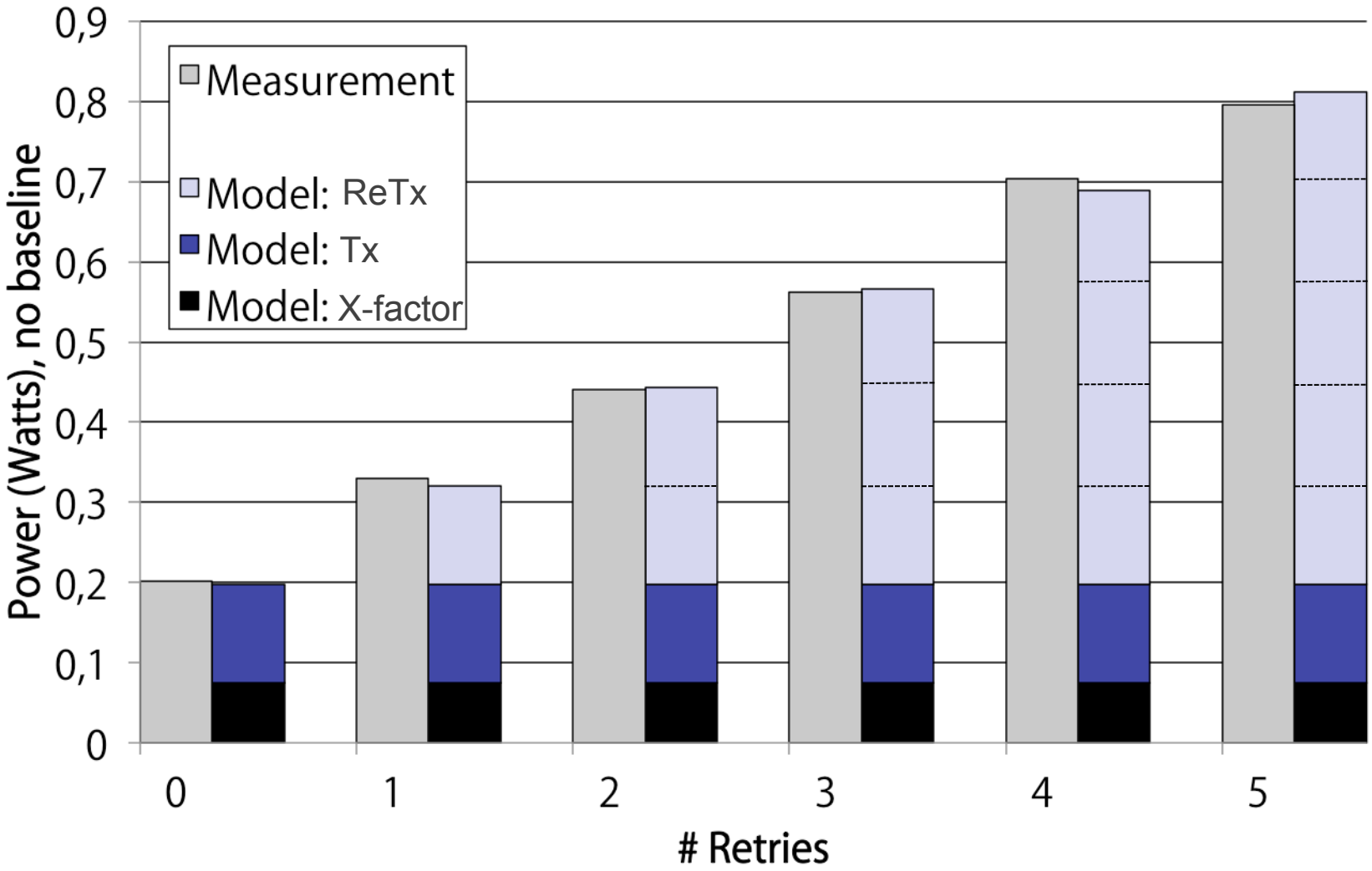
- Very far from negligible (vs. Tx Power)
  - Previous slide: 37% ~ 97% energy/frame

Retransmissions (and control frames)

- E.g. 2 retries, but only 1 cross factor



Retransmissions



Model for the power consumption

- Similar results for reception.
- Model: $\mathbf{P}$

$$
\begin{aligned}
&= \rho_{id} && \text{Baseline} \\
&+ \rho_{tx}(\tau_{tx}) && \text{TX airtime} \\
&+ \rho_{rx}(\tau_{rx}) && \text{RX airtime} \\
&+ \gamma_{xg}\lambda_g + \gamma_{xr}\lambda_r && \text{Packet processing}
\end{aligned}
$$

"Classical" — New

- Parametrization for the Soekris, Linksys, Alix

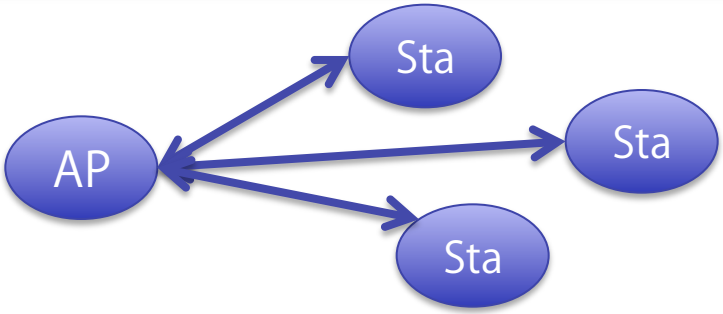
MCS	6 Mbps	12 Mbps	24 Mbps	48 Mbps
ρ_{rx} (W)	$0.24 \pm 4.2\%$	$0.27 \pm 3.7\%$	$0.31 \pm 6.4\%$	$0.44 \pm 6.8\%$

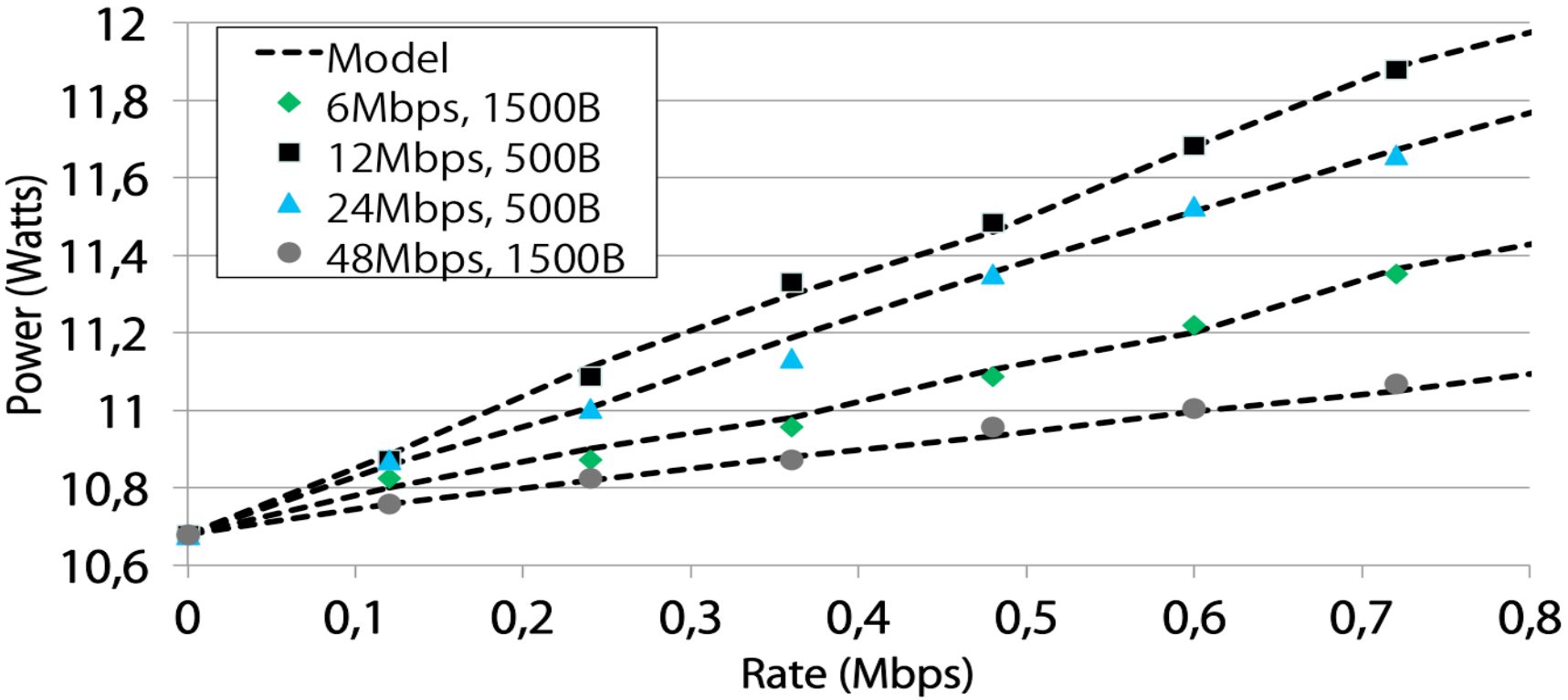
MCS	6 Mbps	12 Mbps	24 Mbps	48 Mbps
ρ_{rx} (W)	$0.19 \pm 5.3\%$	$0.29 \pm 3.4\%$	$0.53 \pm 2.3\%$	$0.74 \pm 4.4\%$

MCS		6 Mbps	12 Mbps	24 Mbps	48 Mbps
ρ_{rx} (W)		$0.16 \pm 8\%$	$0.27 \pm 5.6\%$	$0.6 \pm 11\%$	$1.14 \pm 3.5\%$
ρ_{tx} (W)	6 dBm	$0.52 \pm 3.1\%$	$0.55 \pm 4.6\%$	$0.81 \pm 5.3\%$	$1.2 \pm 1.6\%$
	9 dBm	$0.57 \pm 2.1\%$	$0.59 \pm 1.8\%$	$0.88 \pm 2.3\%$	$1.24 \pm 2.7\%$
	12 dBm	$0.70 \pm 1.7\%$	$0.73 \pm 2.2\%$	$1.02 \pm 2.8\%$	$1.37 \pm 3.1\%$
	15 dBm	$0.86 \pm 2.2\%$	$0.89 \pm 2.3\%$	$1.17 \pm 2.5\%$	$1.58 \pm 3.3\%$
ρ_{id} (W)	$3.56 \pm 1.7\%$	γ_{xg} (mJ)	$0.93 \pm 1.2\%$	γ_{xr} (mJ)	$0.93 \pm 2.2\%$

Validation of the model

- General scenarios



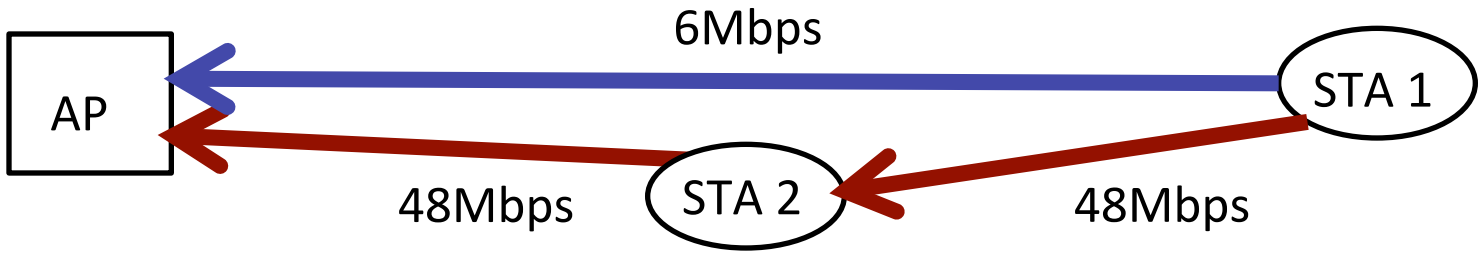


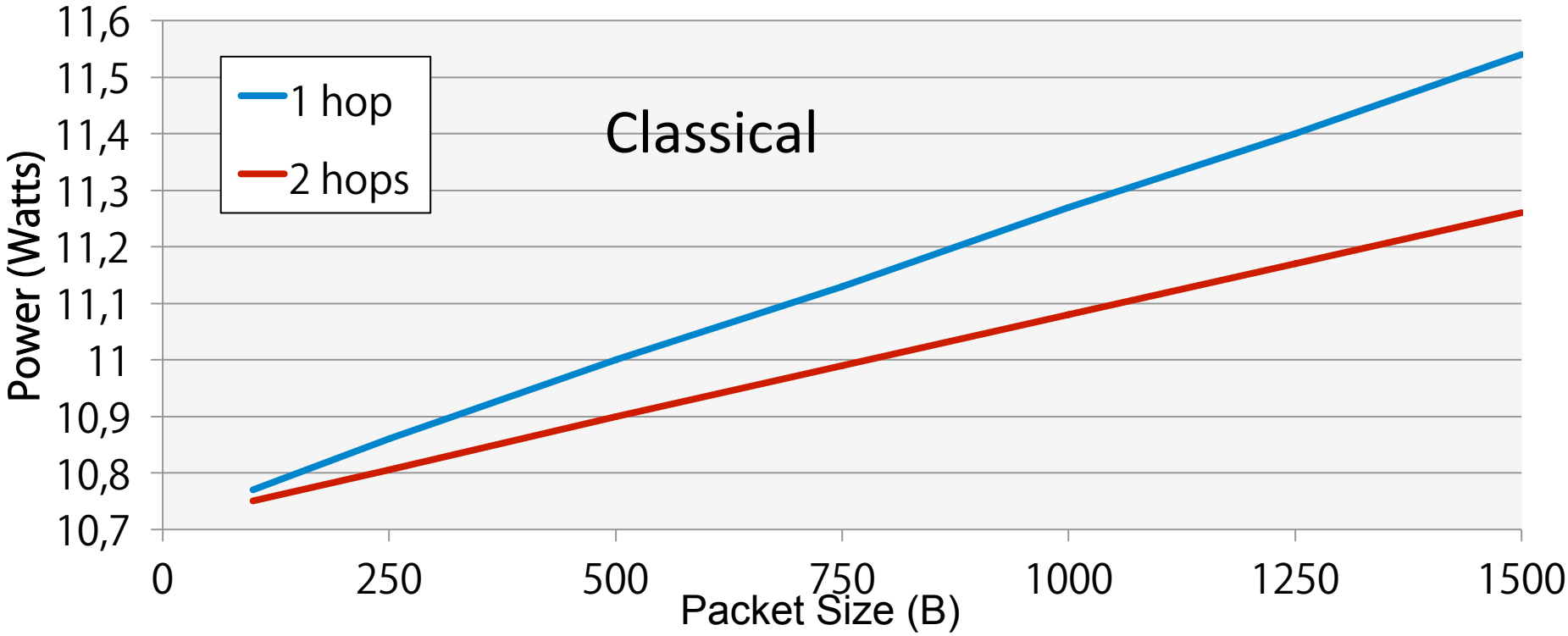
Ok, but...

- Does it matter?
- What are the implications?
- 1. Revisit old proposals based on the classical model
- 2. Design of new schemes building on the detailed anatomy

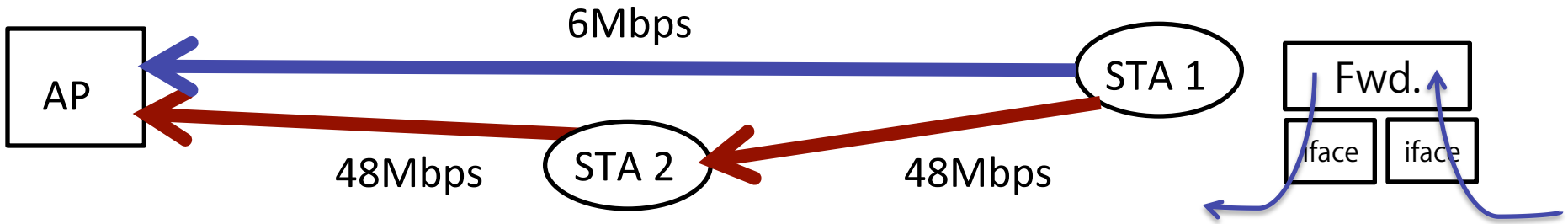
Cross factor:
37% ~ 97% △
energy / frame

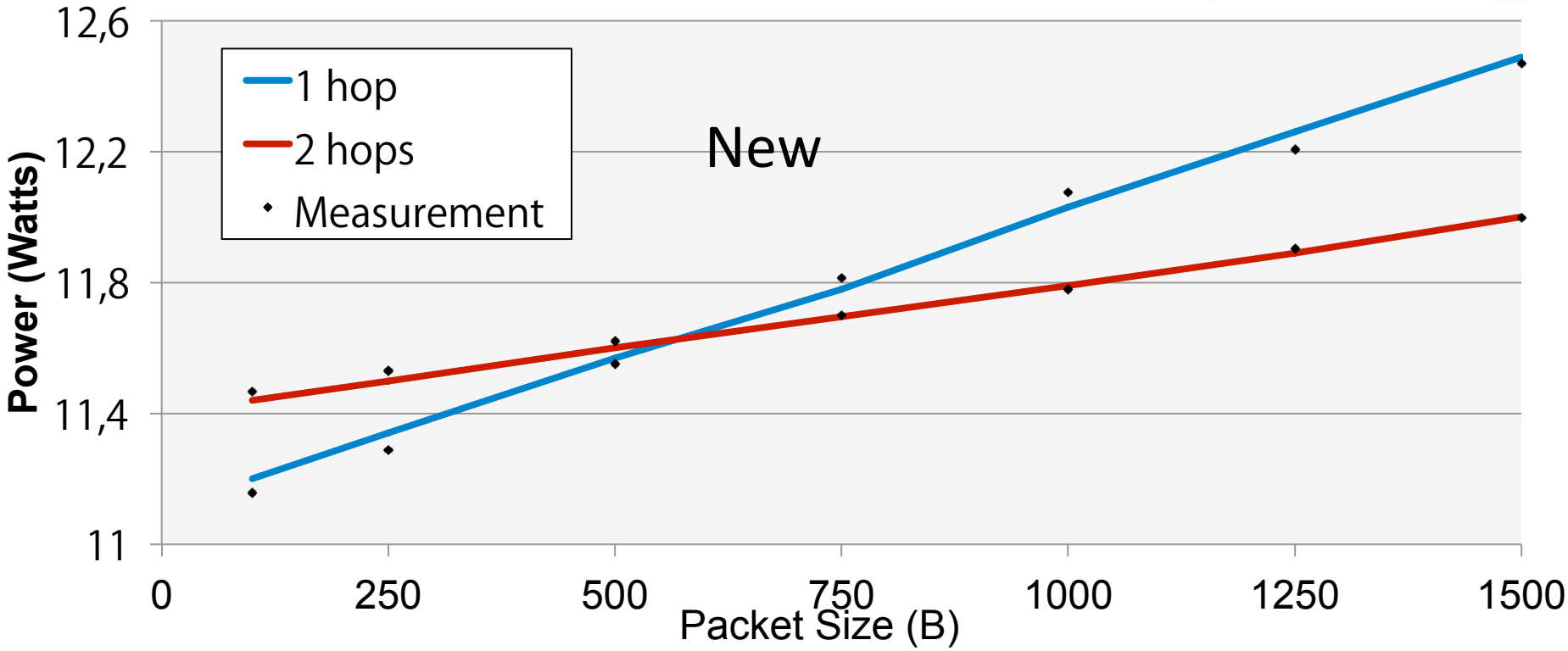
Old: Packet relays





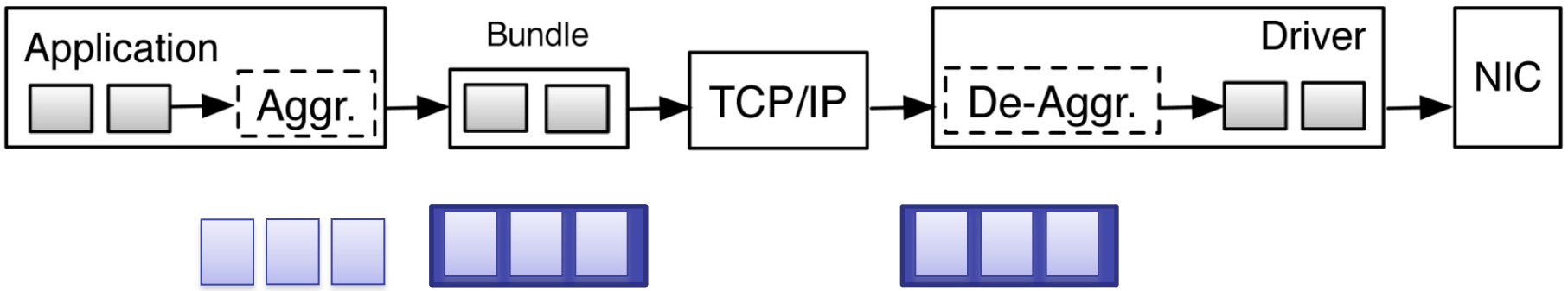
Old: Packet relays





New: Packet batching

- Group n packets before they transverse the protocol stack
  - Fixed energy cost per bundle
  - Same information over the medium



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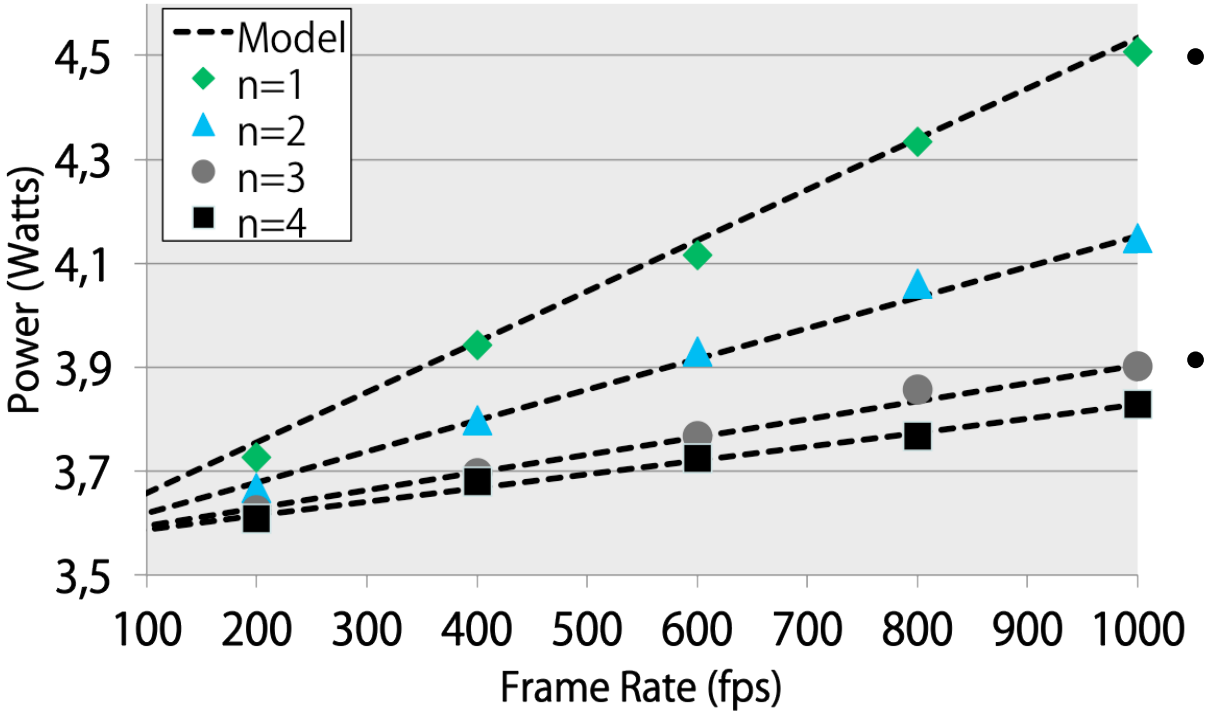
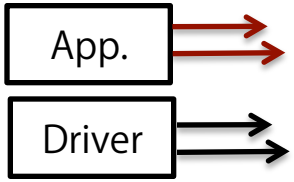


- Substantial savings (~80%)
- No savings according to the classical model

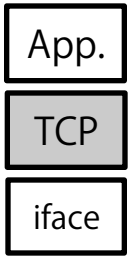
Other implications

- Data compression in multihop
  - Old model: savings
  - New model: not

- Directed Multicast
  - Where to generate frames



- Use of *raw* sockets
  - E.g., *skipping* TCP/IP: 0.2 mJ/frame



Summary

- Per-packet analysis of the energy consumption of a wireless device
  - Parametrized for various devices
- Characterization of the cross factor
- Two-fold impact
  - Revisit previous schemes
  - Enable new designs

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Thanks!