SloMo: Downclocking WiFi Communication

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WiFi Power Matters

- Consumers complain about smartphone battery life

- Researchers report active WiFi radio can consume up to 70% of a smartphone's energy [Rozner et al. MobiSys 2010]
- But commercial WiFi chipsets have efficient sleep
  - 700mW (active) to 10mW (sleep) [Manweiler *et al.* MobiSys 2011]

Can’t Sleep the Day Away

- Power saving based on duty cycling the radio
  - sleep when not used, wake up to send/receive data
- Many variants proposed by the research community for better sleep mechanisms and policies
- Still a challenge for WiFi energy savings on smartphones
  - real-time/chatty apps
  - developer may abuse WiFi sleep policy (constantly awake)

The WiFi Reality on Smartphones

- Frequent demand does NOT equal high demand
  - many smartphone apps are rather data rate conservative (10s kbps—100s kbps)

103kbps

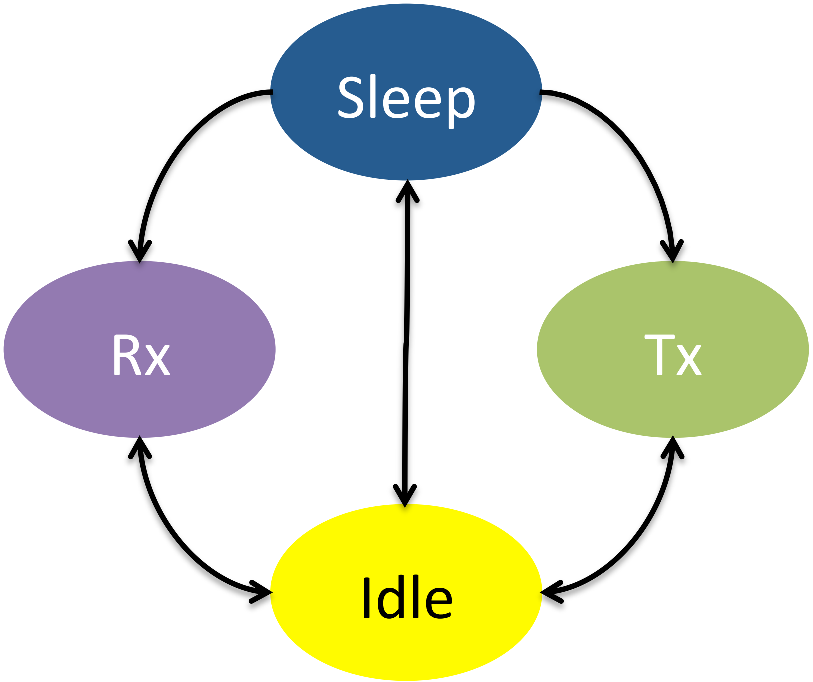
228kbps

35kbps

26kbps

- Primarily connected on WiFi ≥62% of time [Cisco 2012]
  - good WiFi signal-to-noise ratio (SNR) 5% link-layer retransmission [Chen *et al.* IMC2012]

WiFi State Transitions



[Zhang *et al.* MobiCom 2011]

WiFi State	Power
Sleep	~20 mW
Idle	1200 mW
RX	1600 mW
TX	1710 mW

$$P_{sleep} << P_{idle} \approx P_{rx} \approx P_{tx}$$

- Good SNR → send/receive data faster (state color)
- But apps with low data rate: Tx/Rx energy small
- Can we trade SNR for saving energy?

Downclocking WiFi

- Power consumption of CMOS devices are proportional to their clock rates

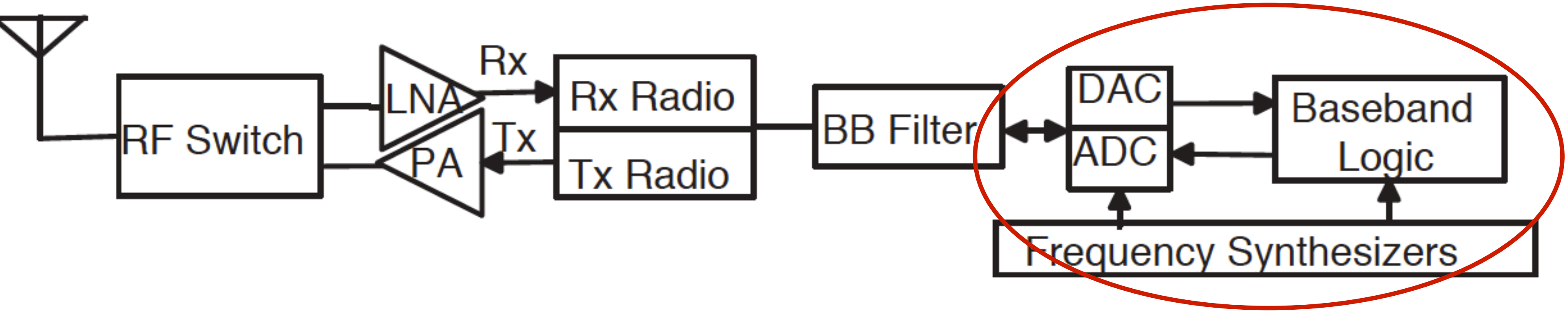
[Zhang *et al.* MobiCom 2011]

Clock rate	25%	50%	100%
Idle	640 mW	780 mW	1200 mW
RX	980 mW	1440 mW	1600 mW
TX	1210 mW	1460 mW	1710 mW

- Potential 30-46% power saving for commercial WiFi chipset if downclocked [Zhang *et al.* MobiCom 2011]
- DVFS for CPUs has been around for years

Why not on WiFi?

The Nyquist Wall



- Sampling rate > 2x signal bandwidth
- 22 MHz WiFi signal → at least 44 MHz sampling rate
- Clock rate on WiFi chipset is gated by sampling rate

Compressive Sensing

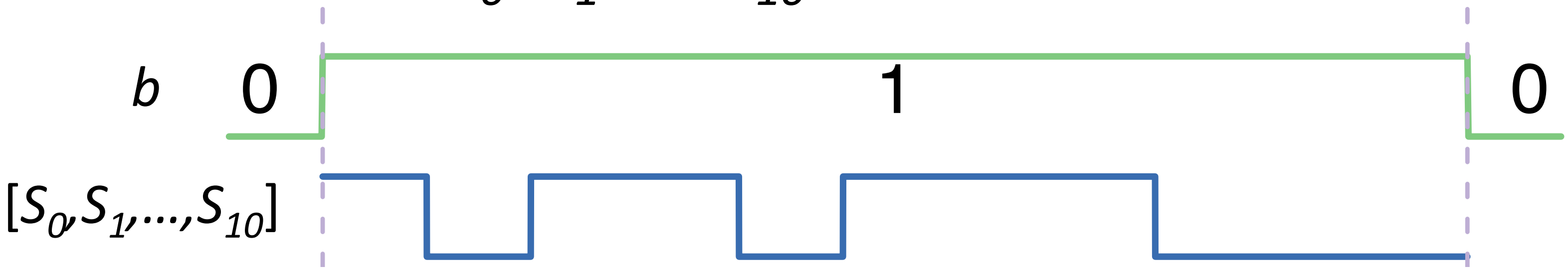
- Recent advances in compressive sensing allow us to cheat when information rate << signaling rate

- Tropp *et al.* showed how to decode such sparse signal with much lower sampling rates [TIT 2010]

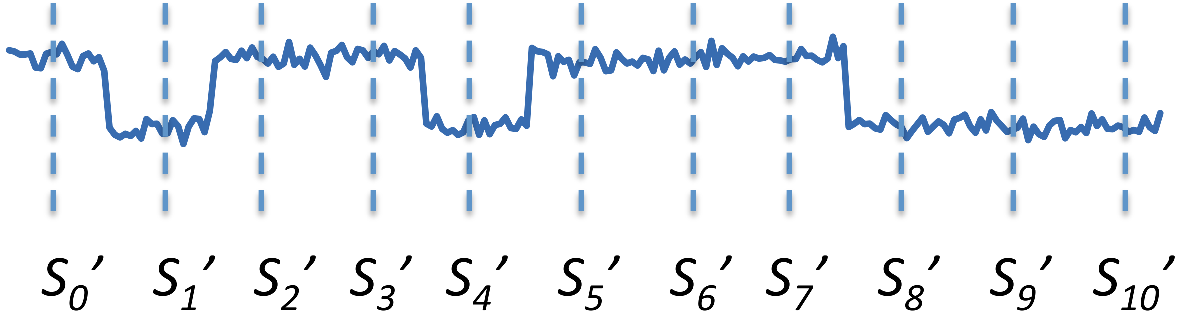
- Observation: Shares great degree of similarity with Direct-sequence Spread Spectrum (DSSS) used in WiFi (when operating at 1/2 Mbps)!

DSSS Encoding

- Sender: information bit (*b*) → 11-chip barker sequences [S_0, S_1, …, S_{10}]

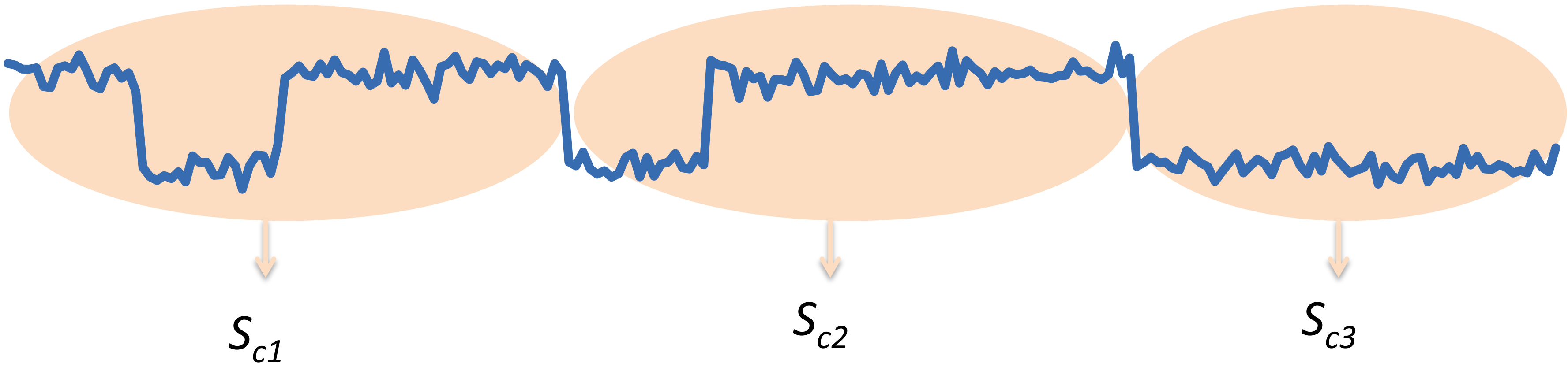


- Receiver: 11 sampled sequences [S_0', S_1', …, S_{10}'] → *b*



Compressive Decoding

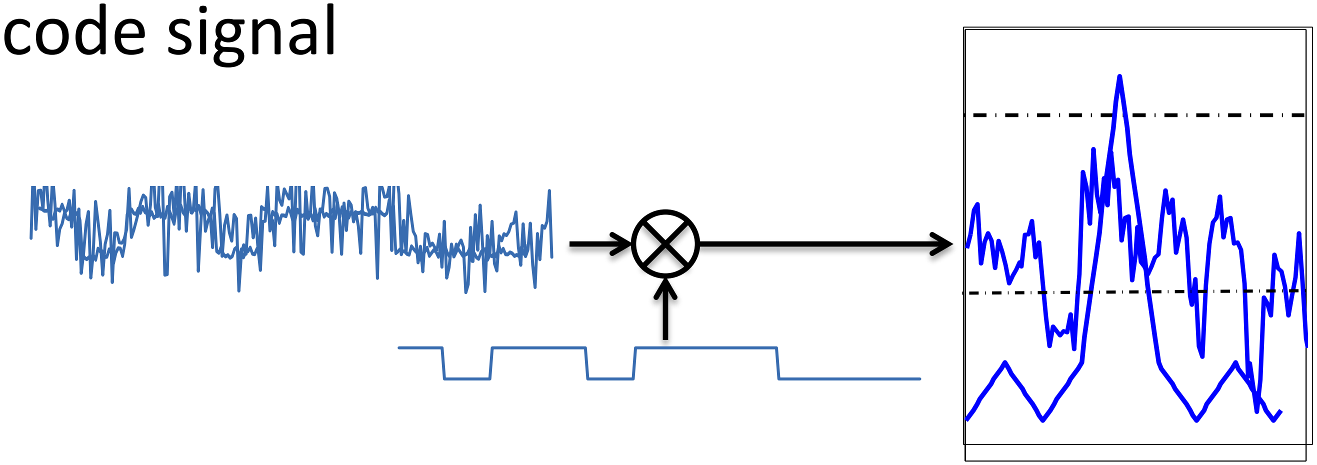
- Much redundancy in signal → opportunity for compressive sensing
- SloMo receiver: combinations of the 11-chip sequences (in analog domain) and <11 samples are sufficient
  - e.g., 3 samples [S_{c1}, S_{c2}, S_{c3}] → *b*



How about Transmission?

- Standard WiFi radio expects regular WiFi signal

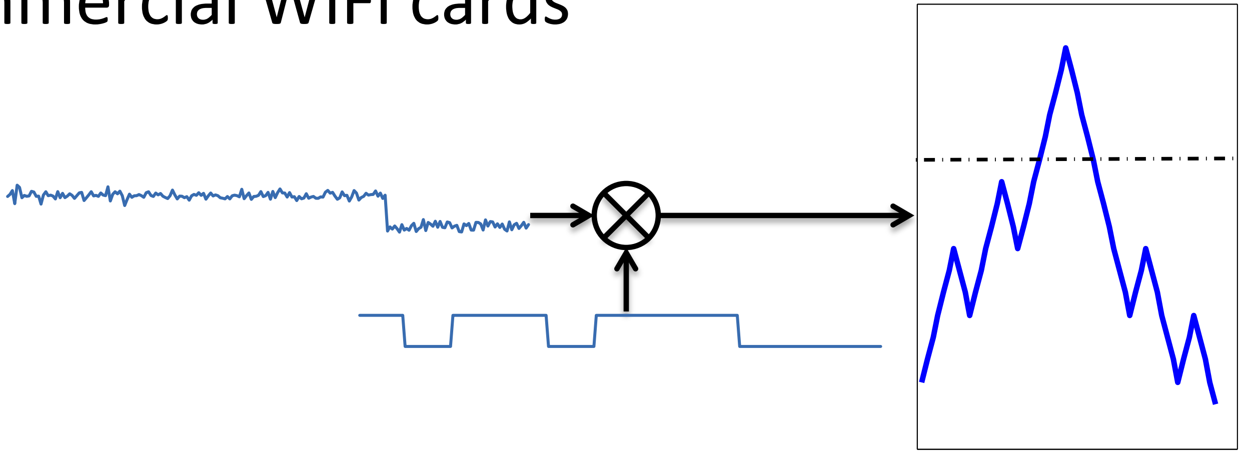
- Allows receiver to: (a) lock on to the signal; (b) decode signal



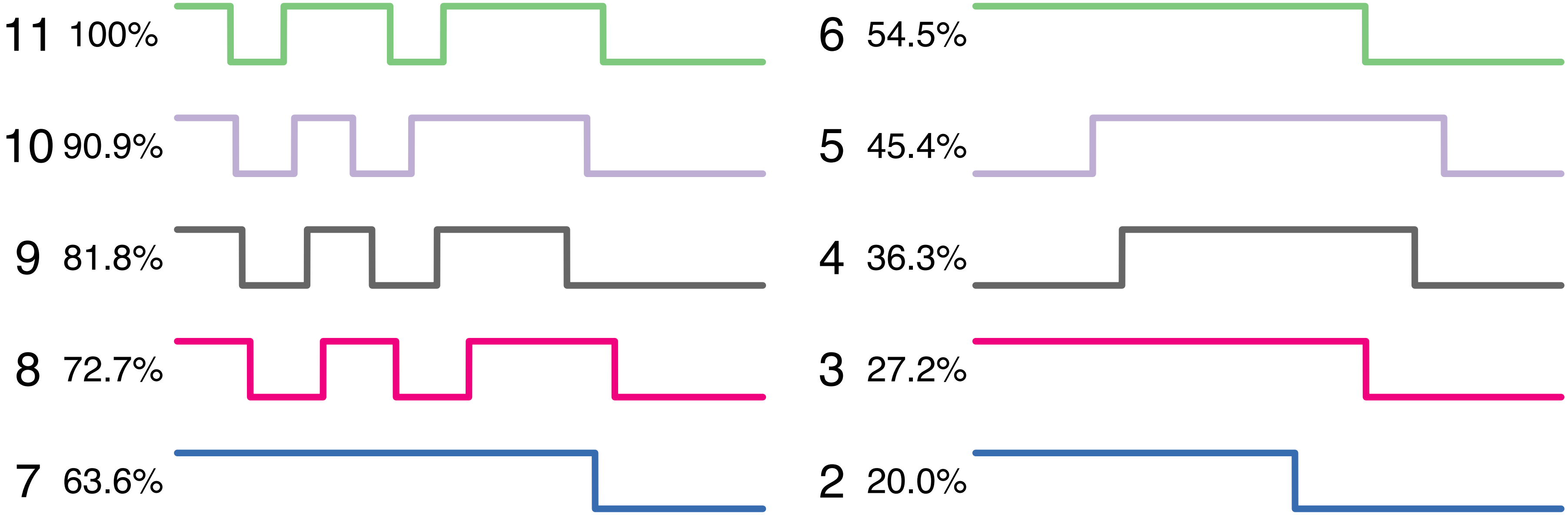
- Downclocked transmission:
  - shorter sequences per bit (<11 chips)
  - challenge: may not be recognized

SloMo Transmitter

- Approximate the 11-chip Barker sequences used in WiFi standard with shorter sequences
- Leverage the large headroom in DSSS decoding on commercial WiFi cards



Barker-like sequences



11 100%

10 90.9%

9 81.8%

8 72.7%

7 63.6%

6 54.5%

5 45.4%

4 36.3%

3 27.2%

2 20.0%

High downclocking rate fidelity

SloMo Micro-benchmarks

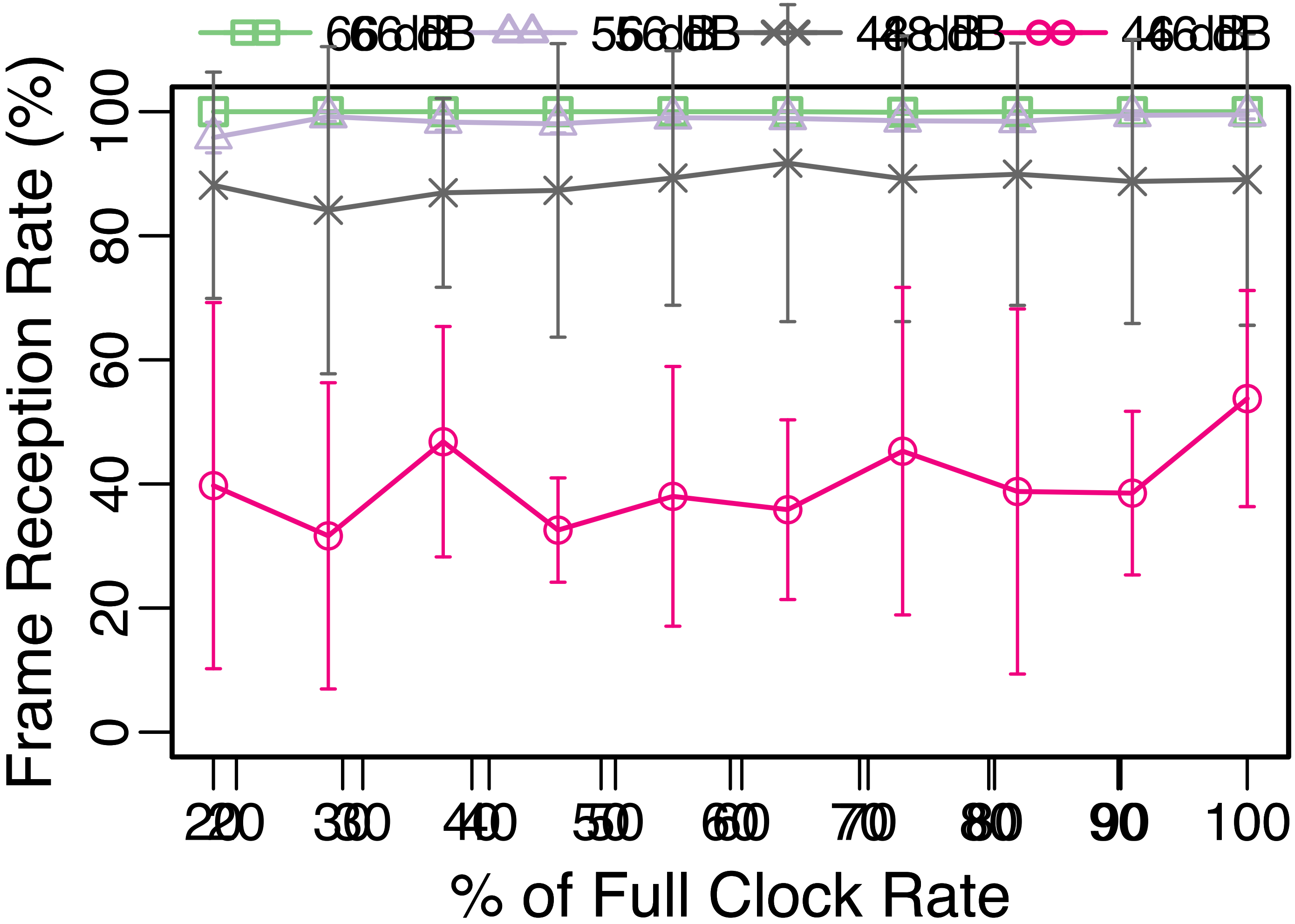
- Implemented on Microsoft SORA platform

- Entirely backwards compatible

- Requires NO modification at AP

- Works on any 802.11b/g/n/ac devices @1-2 Mbps

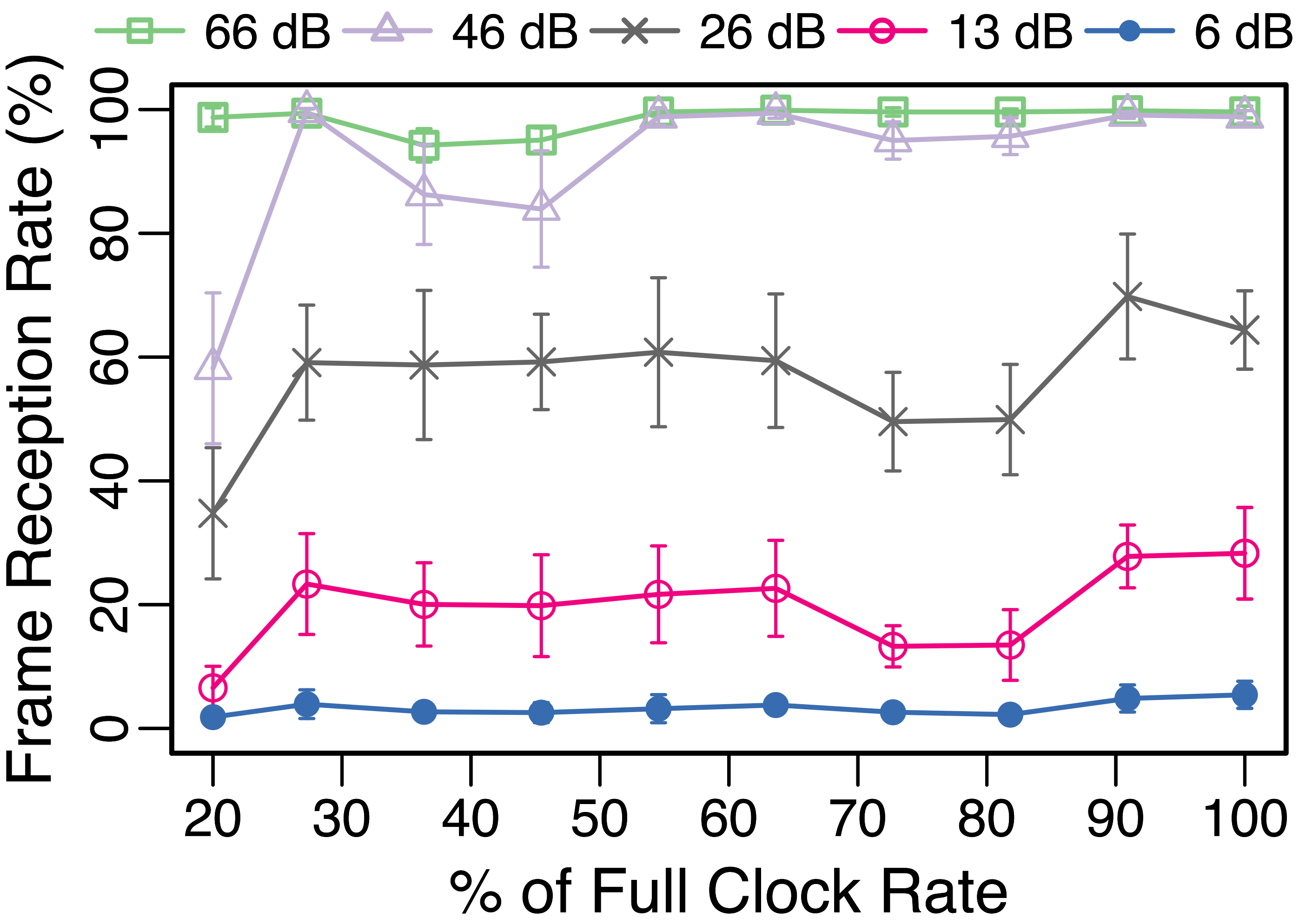
Downclocked Rx (WiFi→SloMo)



Baseline: standard WiFi implementation(@100% clock rate)

4 SNR values: 66dB, 56dB, 48dB, 46dB; 1000-bytes UDP packets

Downclocked Tx (SloMo→WiFi)

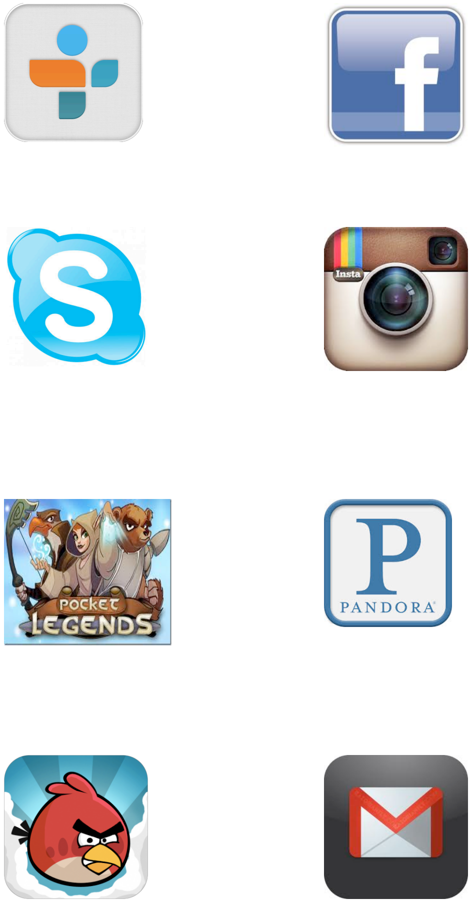


Baseline: standard WiFi implementation(@100% clock rate)

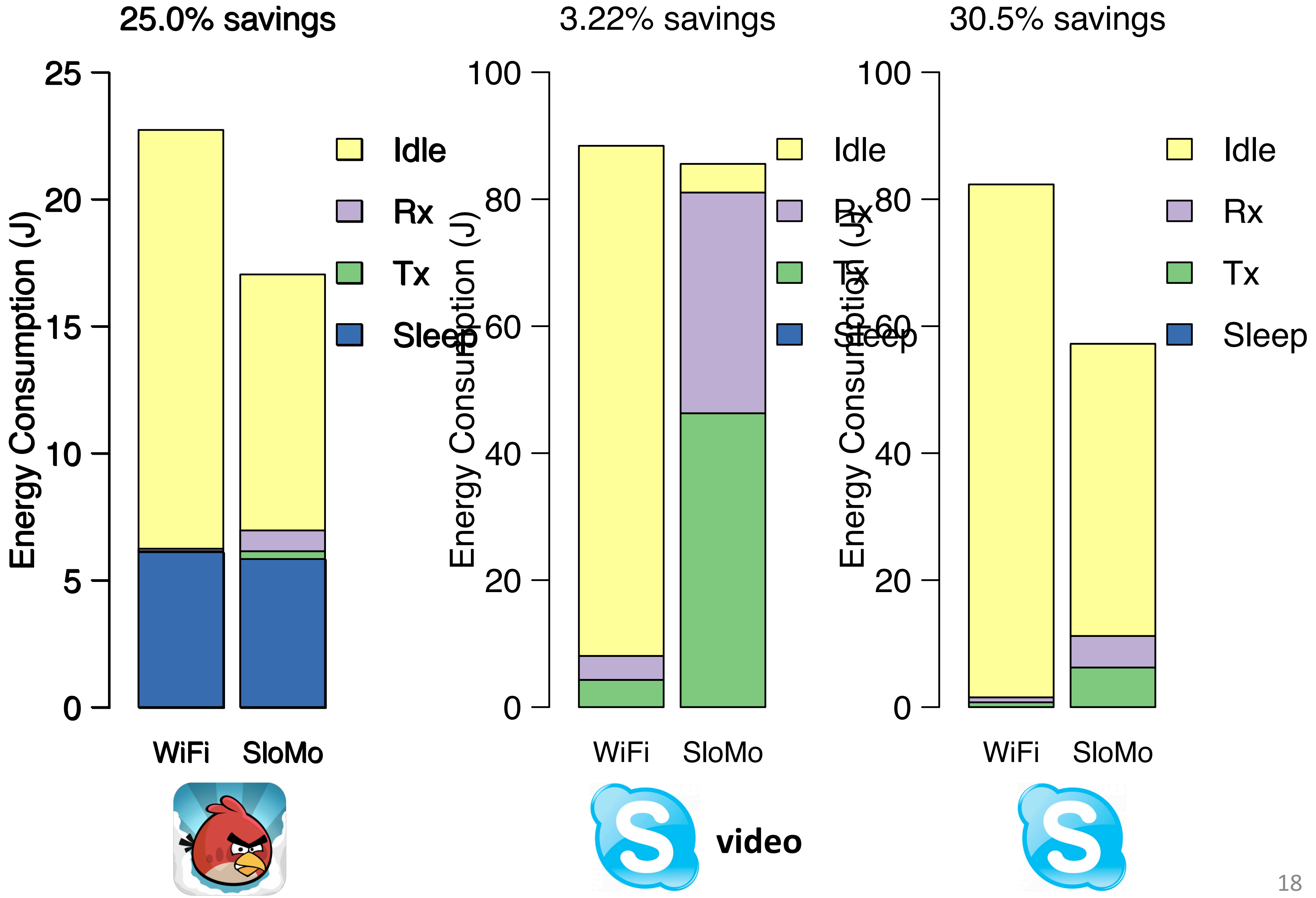
5 SNR values: 66dB, 46dB, 26dB, 13dB, 6dB; 1000-bytes UDP packets

Apps WiFi Energy Evaluation

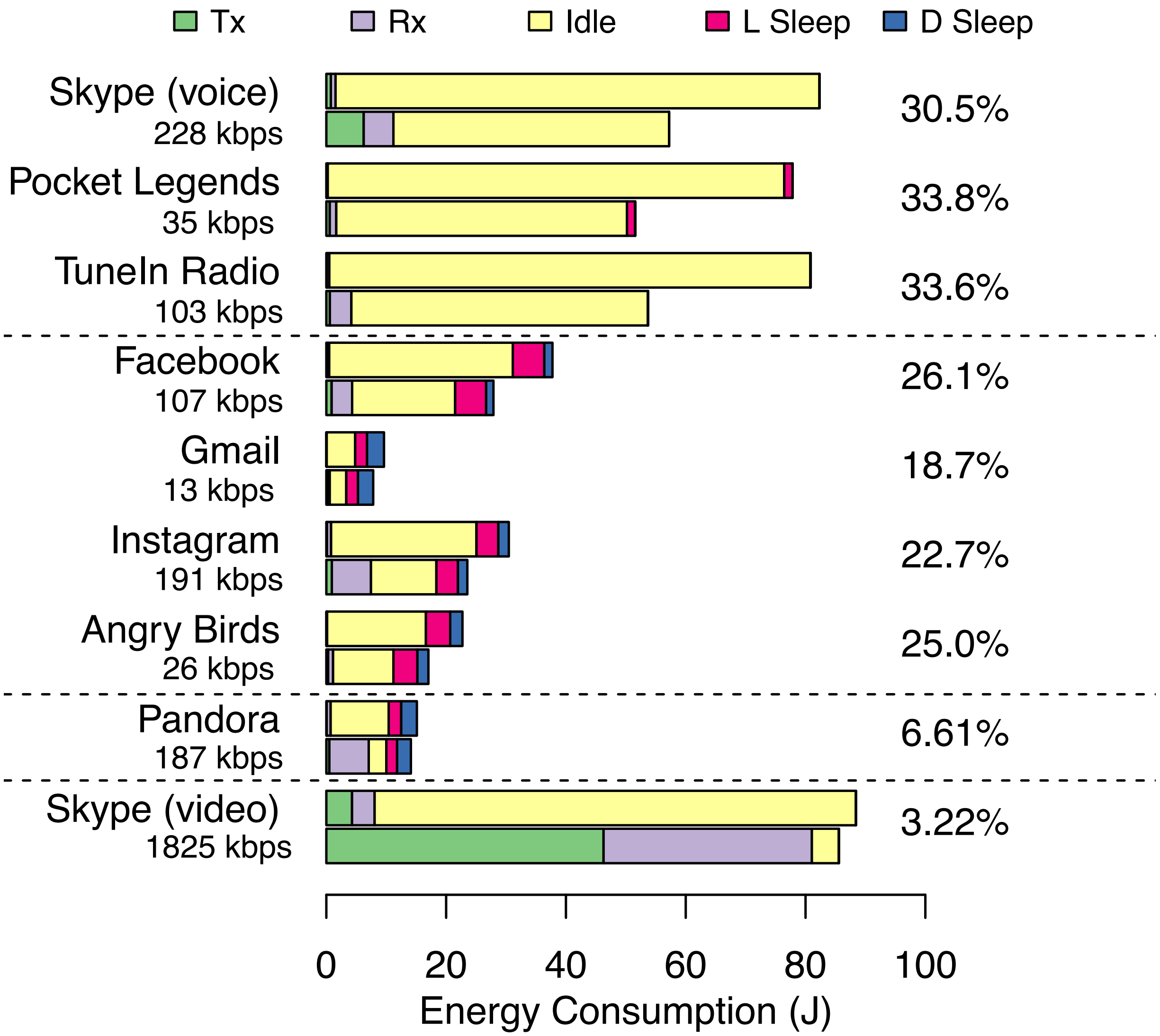
- Trace based energy evaluation
  - power model based on real measurements [Manweiler *et al.* MobiSys 2011]
- 8 popular smartphone apps
  - each app > 1 M downloads
- Collect 200s of real WiFi packet traces
  - Google Nexus S and iPhone 4S



Apps Energy Saving

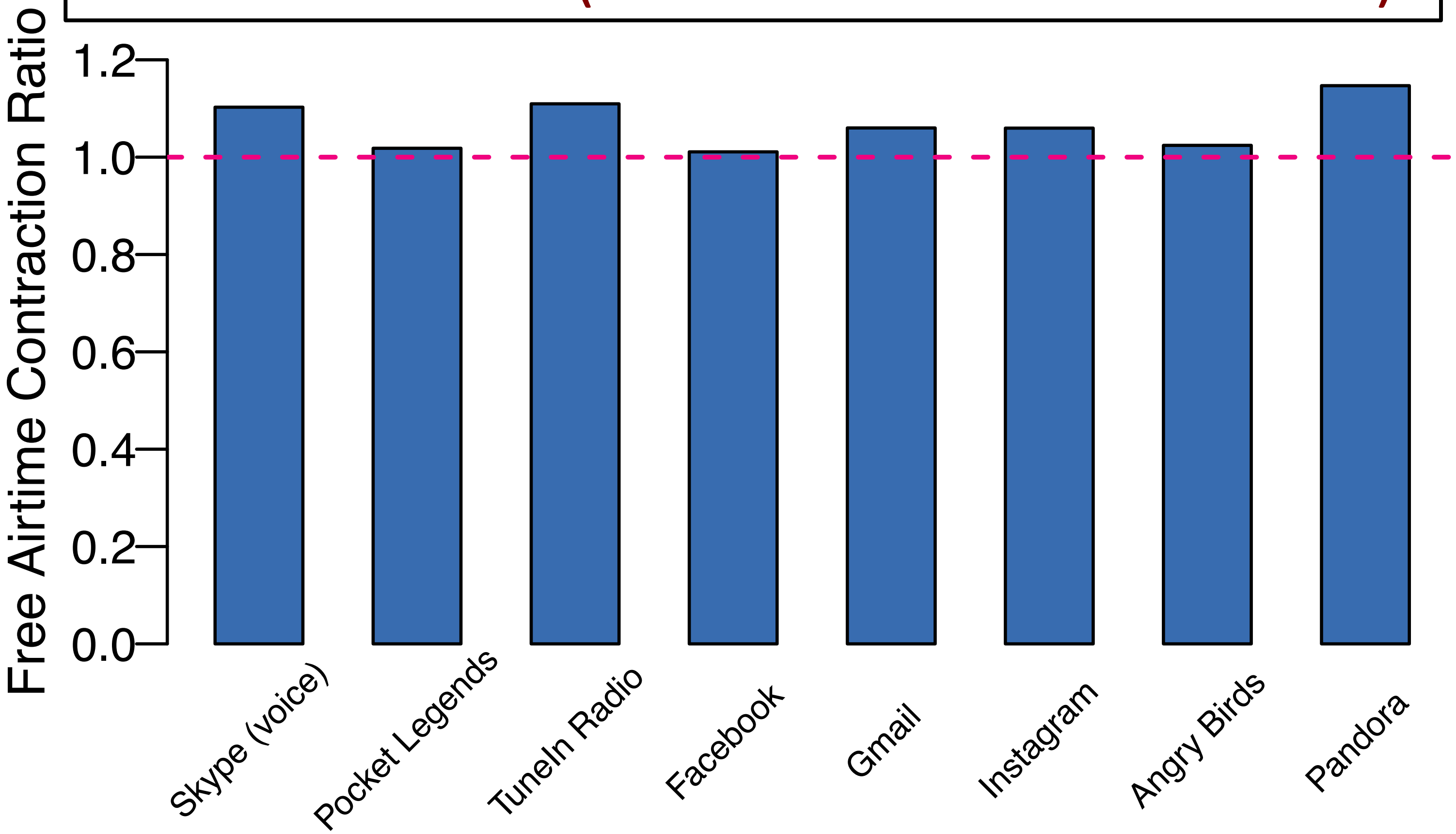


Apps Energy Saving (all)



Small Time Penalty Paid

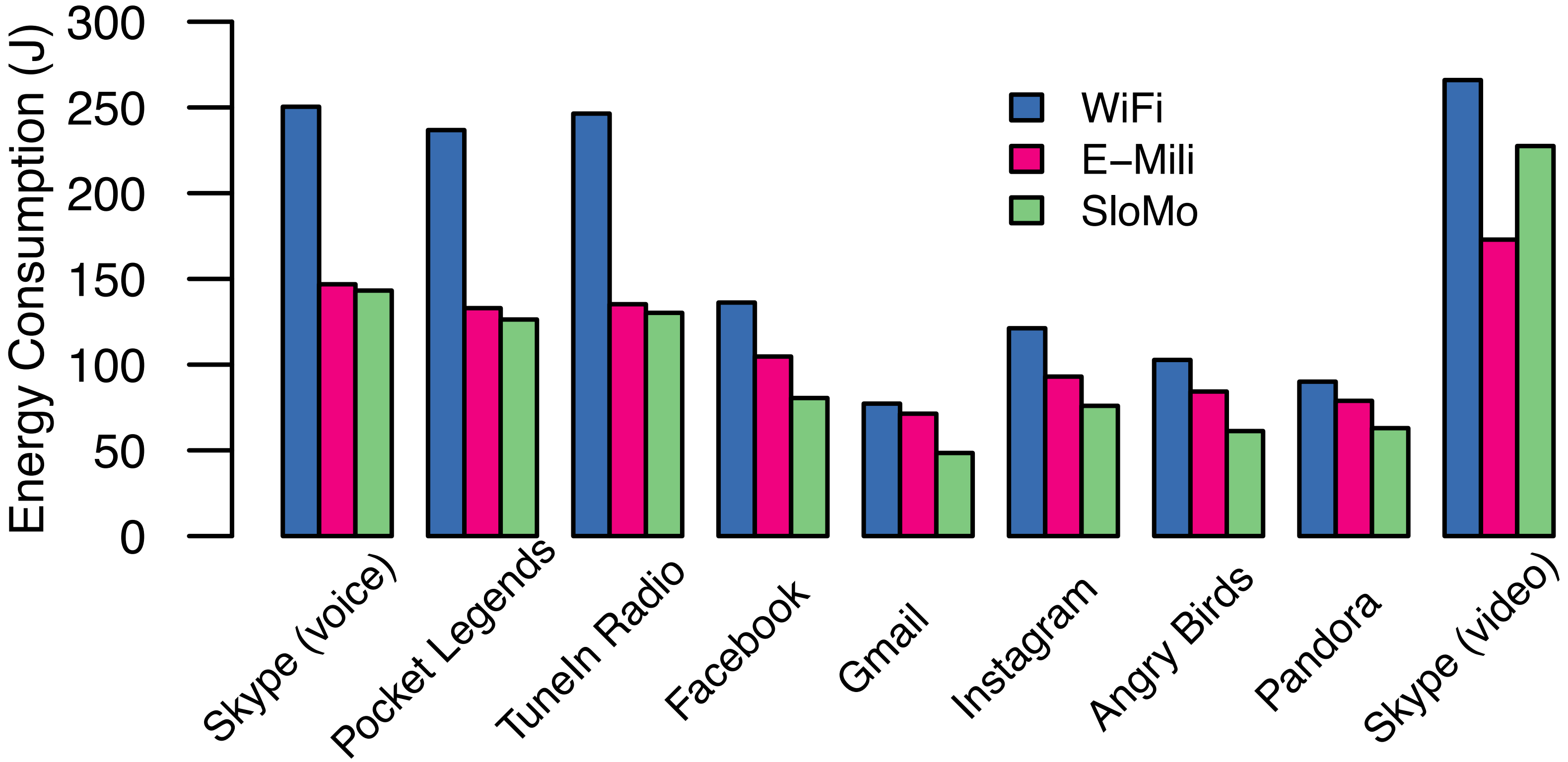
Max ratio: 1.15 (or <13% additional airtime)



$$\text{Airtime Contraction Ratio} = \frac{\text{Free Channel Airtime under Standard WiFi}}{\text{Free Channel Airtime under SloMo}}$$

Comparison with Existing Schemes

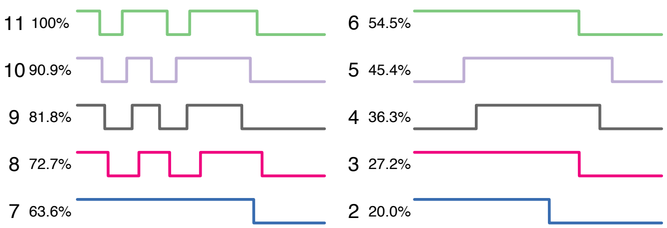
SloMo: 13% over E-Mili

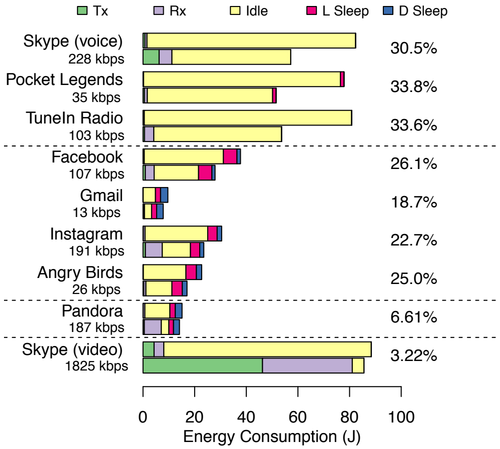


E-Mili [Zhang *et al.* Mobicom 2011]: re-design WiFi packet format to allow downclocked packet detection, revert to full rate for Tx/Rx

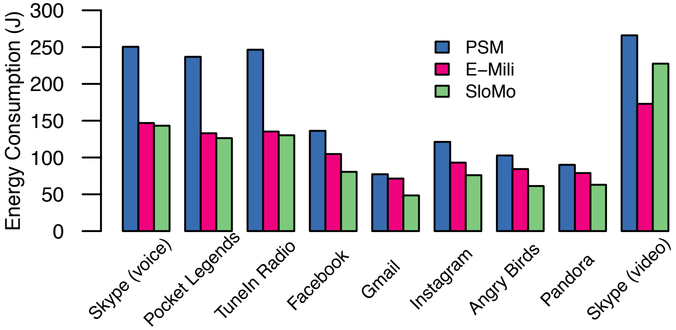
Downclocking WiFi with SloMo

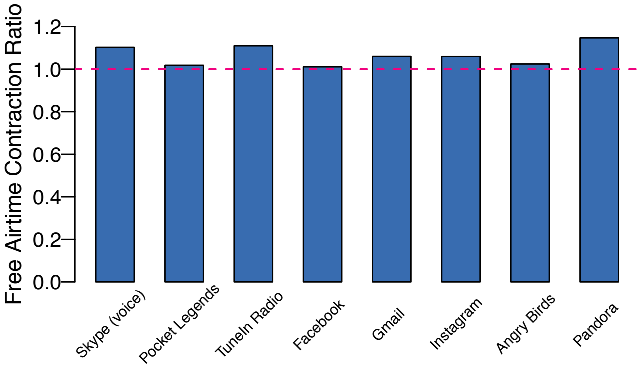
- Trades SNR for saving energy and enables downclocking in WiFi for all communication states
- Works on 11b/g/n/ac devices at 1/2 Mbps
- Fully backwards-compatible design saves up to 34% energy for popular smartphone apps





Thank you!





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