802.11, Power Management, and Energy implications on smartphones

Shravan Rayanchu

Smartphones

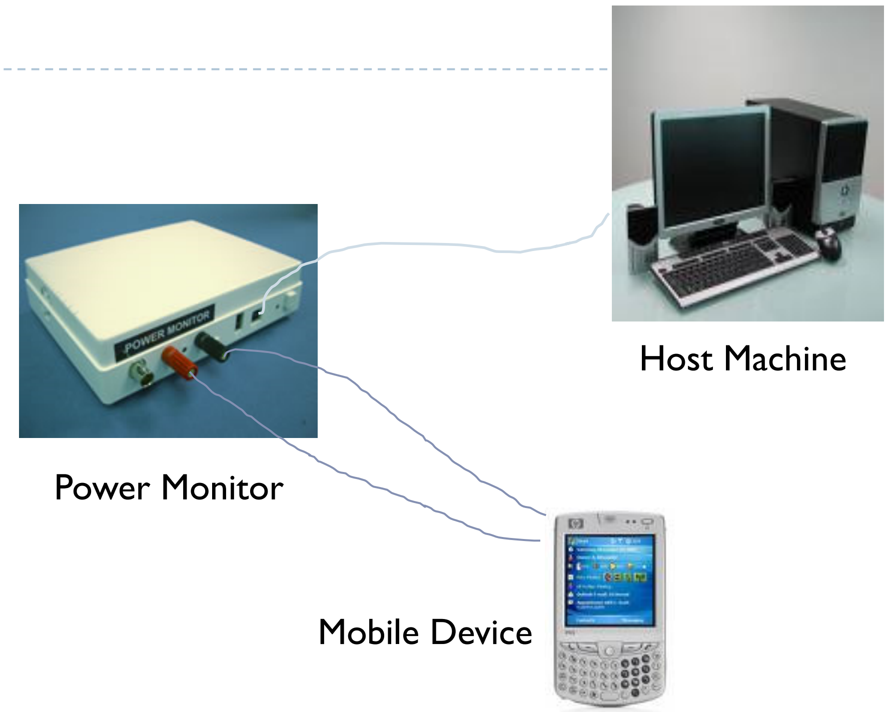
- Data connection options:
  - 3G / WiFi
- Which one should we use?
  - 3G speeds: Advertized 2 – 14 Mbps (shared)
    - *“ **<u>Downlink</u>** — Between 700 Kbps and 1.7 Mbps, **<u>Uplink</u>** — Between 500 Kbps and 1.2 Mbps”* (AT&T Media Newsroom)
  - WiFi speeds
    - 11a/g : up to 54 Mbps, 11n: up to 600 Mbps
  - What a

6.5 hrs **4 hrs** **5.5 hrs** **4 hrs** **4hrs**

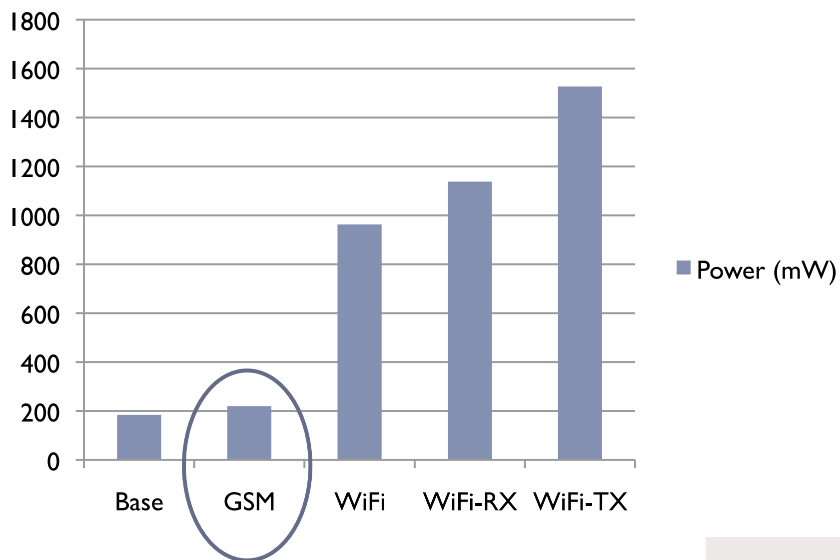
How much energy does WiFi consume?

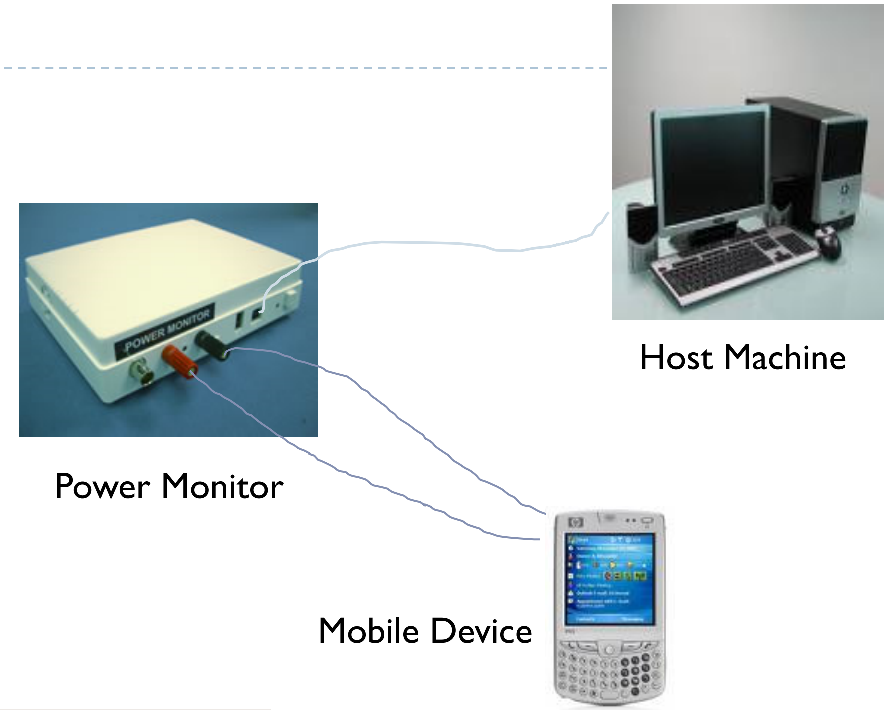
- Profiling Experiments
- CPU: 104 MHz
- TX/RX : 1 Mbps PHY

- HP iPAQ 6965



How much energy does WiFi consume?





WiFi-off: 184 mW
WiFi-on: 963 mW

Turning on WiFi interface increases power consumption by 5 times!

Ex: HTC Tilt 8900 (base: 155-475 mW , w/ WiFi: 1120 mW)

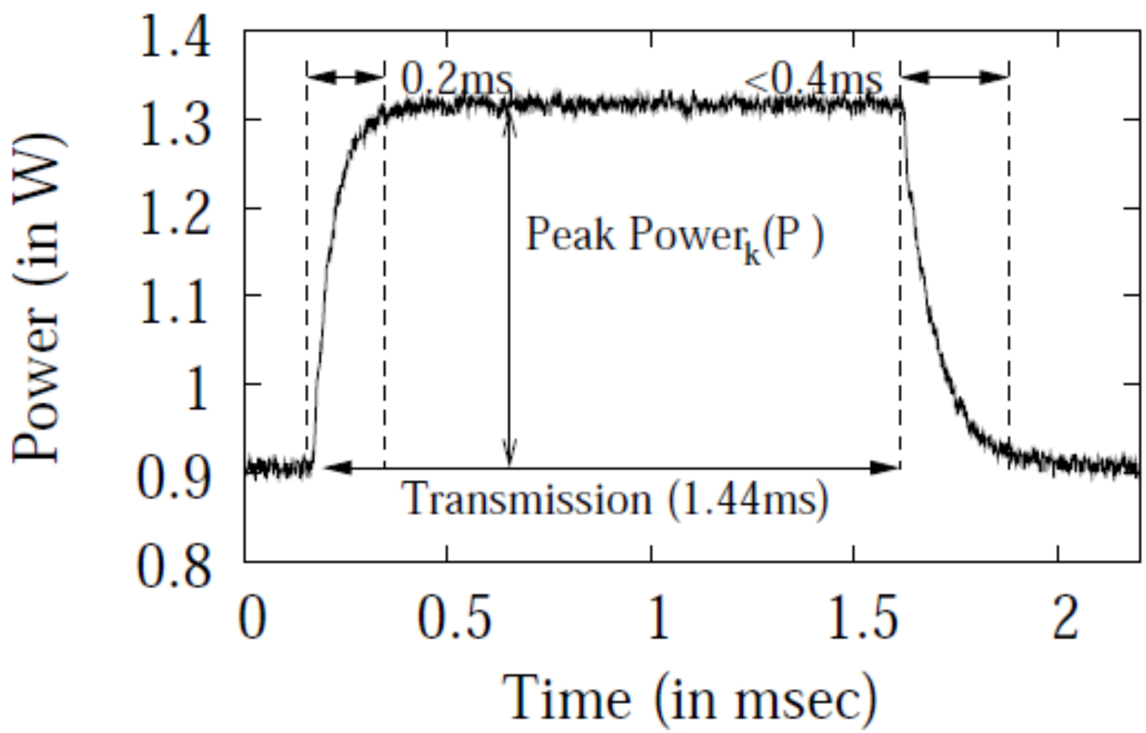
Designing a Wireless Network for Energy Efficiency

- Association
    - Currently clients pick an AP with best signal strength
    - More control to AP:
        - Load on AP / Channel free time / No. of clients / data rate

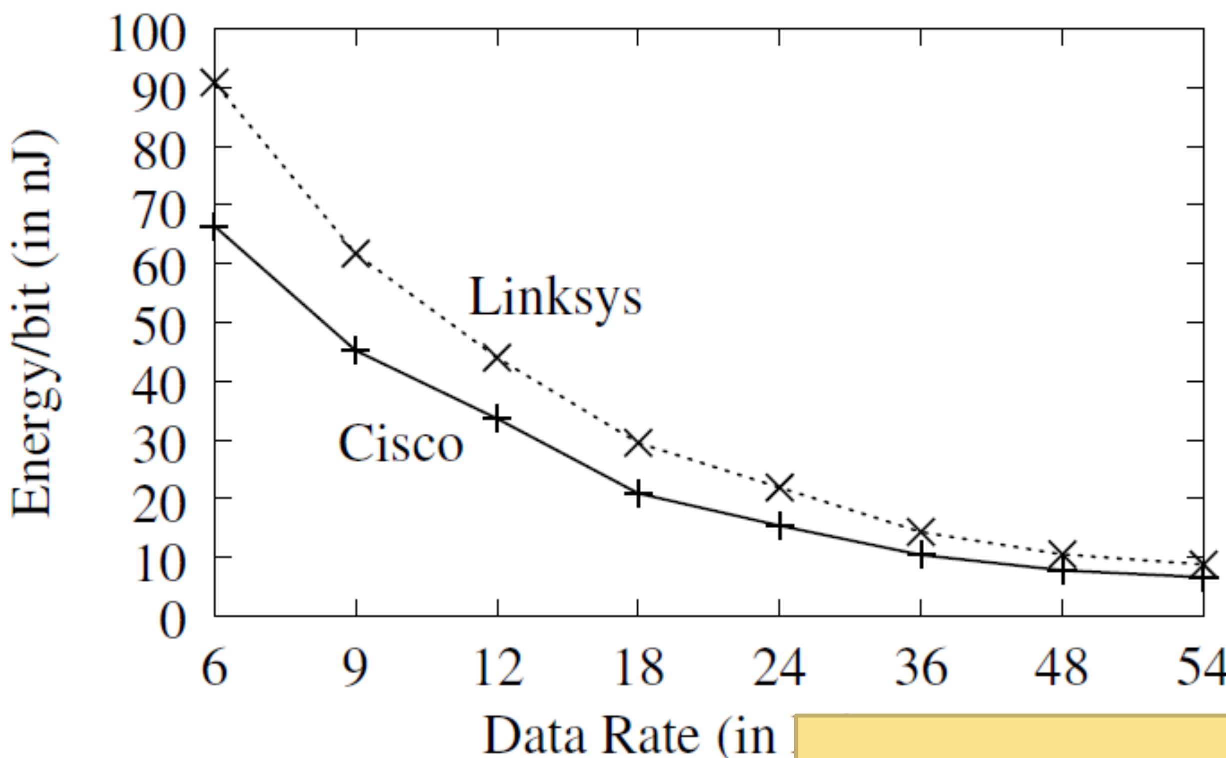
- How do wireless parameters effect the energy consumption?
    - Channel Load
    - Data rate
    - Losses
    - Channel width

Cost of a packet transmission

- Data : 1064 byte packet, Cisco wireless card



Impact of Data Rate



18/12 = 50% lesser energy!

- Associate to AP1 or AP2 ?
  - AP1 uses a fixed rate of 12 Mbps, AP2 uses 18 Mbps

Impact of Loss rates

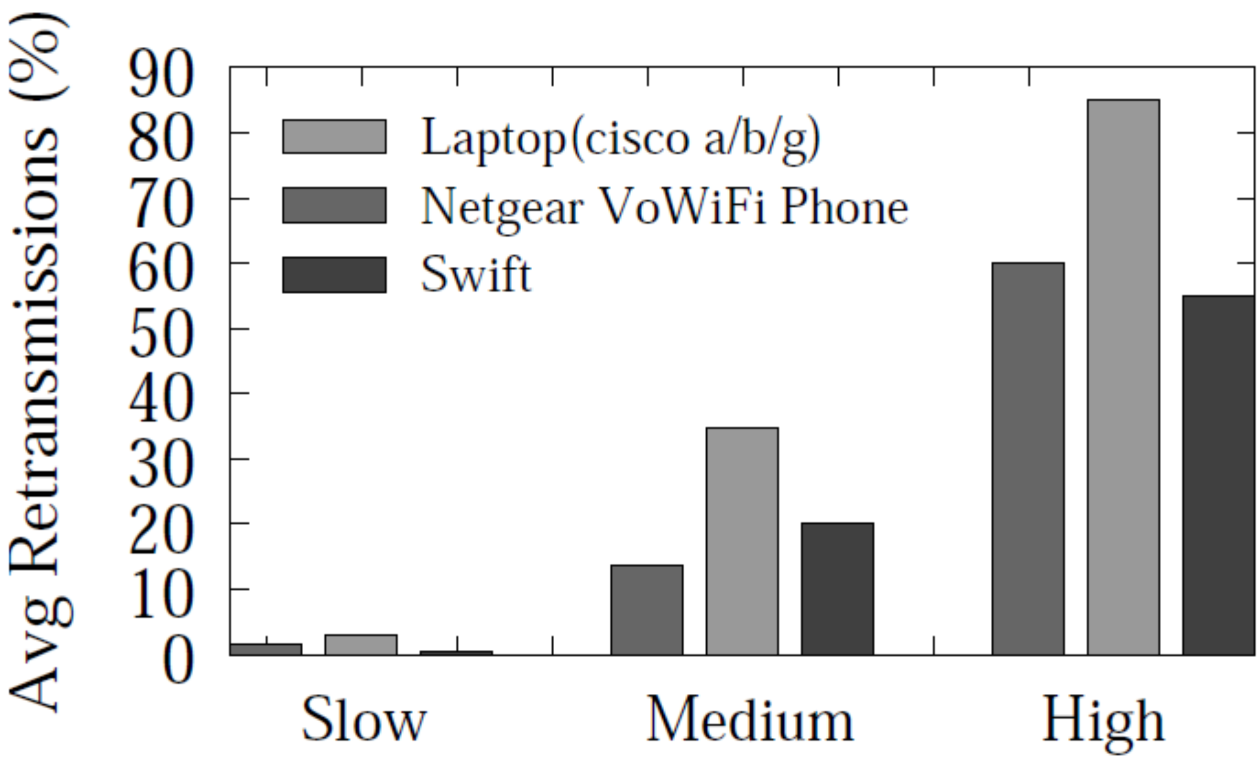
- AP1 : 12 Mbps, loss rate = 0%
- AP2 : 18 Mbps, loss rate = 40%

- TX time for AP1 → p/12 = 0.08333p
- TX time for AP2 → p/18 * 1/0.6 = 0.092p

10% more energy at 18 Mbps!

Impact of Mobility

- Imperfect rate adaptation during high mobility → losses



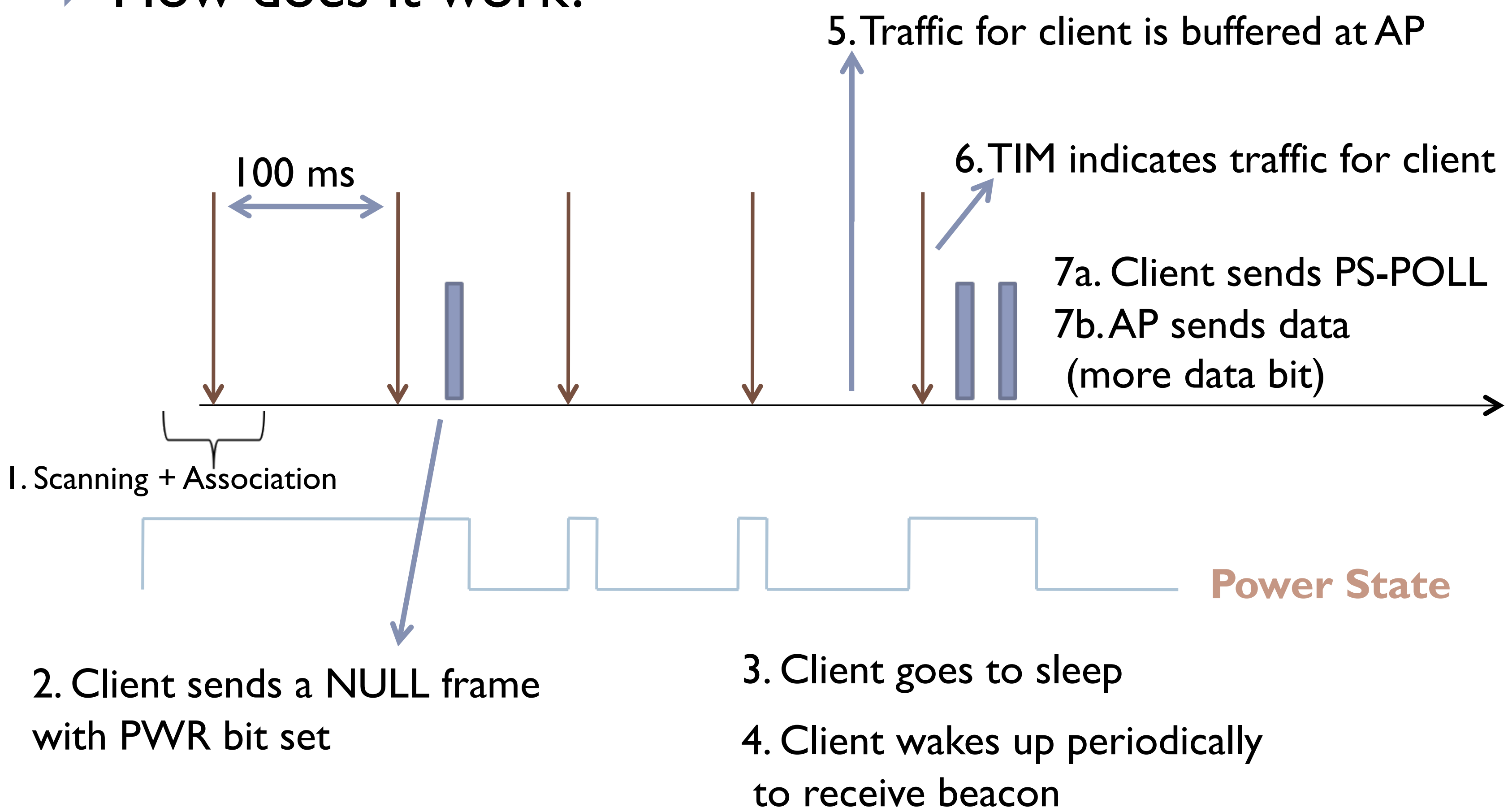
WiFi Power Management

- What can we do to save power?
  - Switch off the radio?
  - Low power state ~ power consumed is as low as being off

- Let us design a power management protocol
  - Sleep: Inform the AP
    - Save the state (Association info)
  - When should the client wake up?
    - Upload traffic ?
    - Download traffic?
      - AP has to inform the client – how? (Client wakes up periodically)
      - Client has to inform the AP that it is awake ..

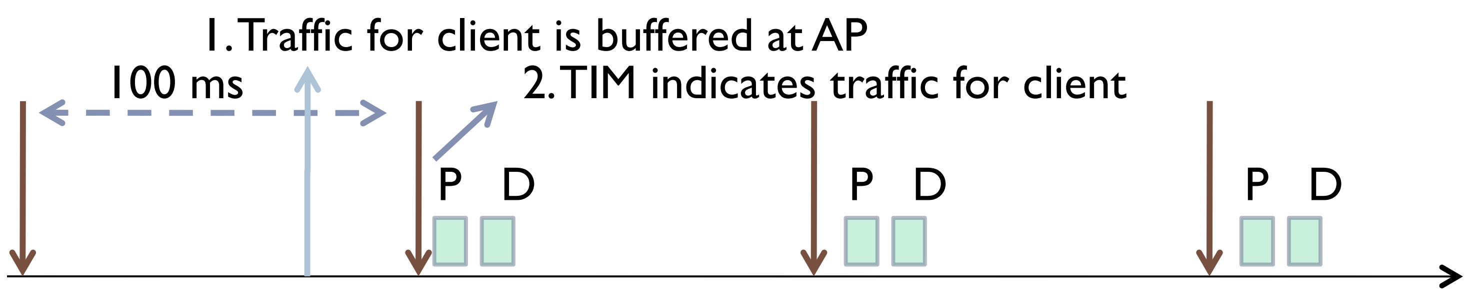
IEEE 802.11 PSM

- How does it work?



IEEE 802.11 PSM

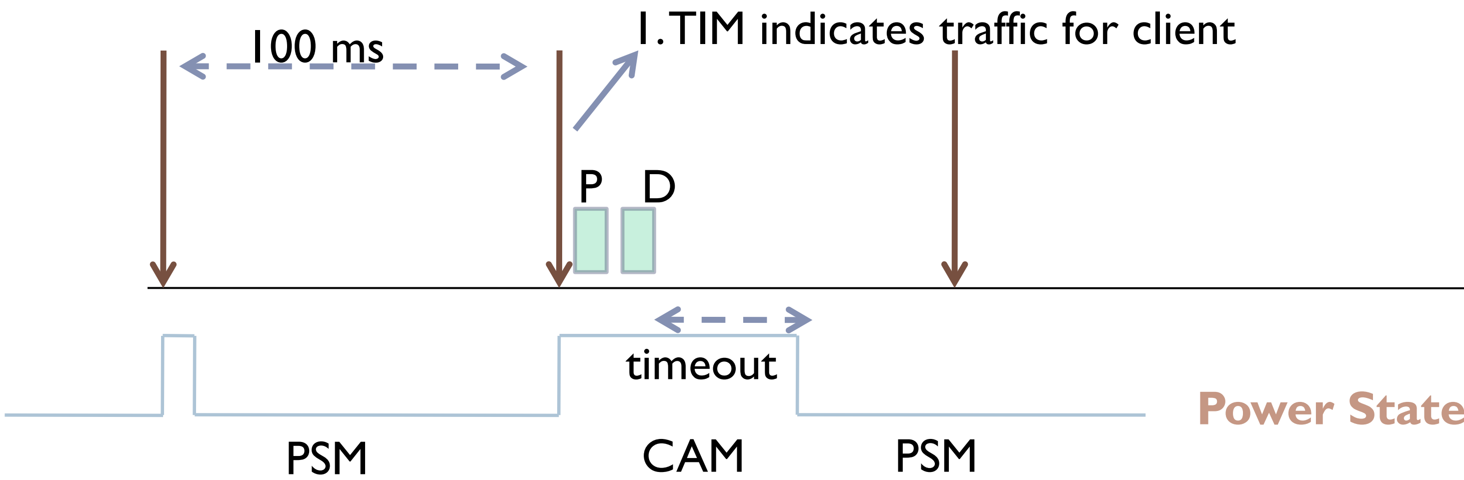
- PSM Static
  - What are the benefits of PSM?
  - Can PSM static be harmful?
    - Increased latency! (Max latency tolerable ?)



- One PS-POLL for every data packet!
  - Energy = RX (data) + TX(PS-POLL)

- PSM Adaptive:
  - PSM + CAM
  - CAM → PSM: time out (how much?)
  - PSM → CAM: TIM bit, threshold packets etc.

Adaptive PSM



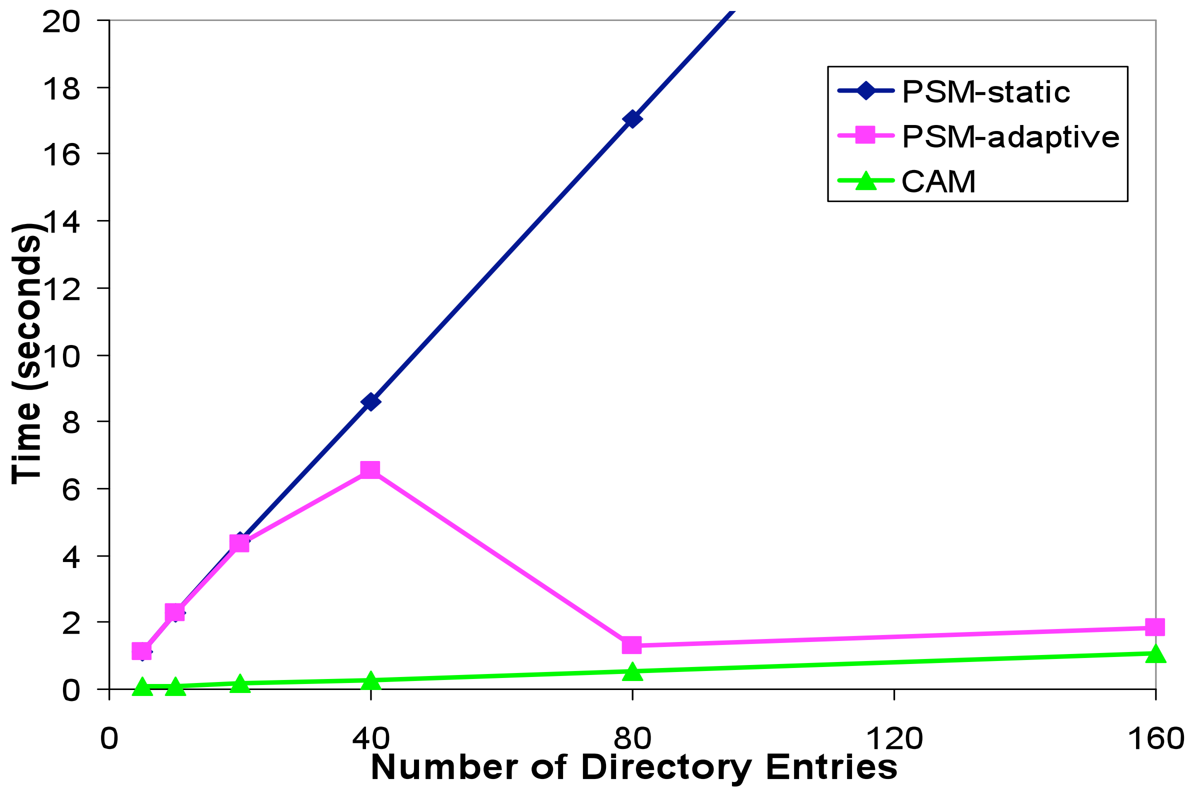
- Timeout
  - **Longer → more energy, but lesser latency for subsequent packets**

Research paper

- Self-Tuning Wireless Network Power Management
  - Manish Anand et. al, Mobicom'03

Effect of Power Management on NFS

Time to list a directory on handheld with Cisco 350 card



PSM-static:

- **16-32x slower**
- **17x more energy**

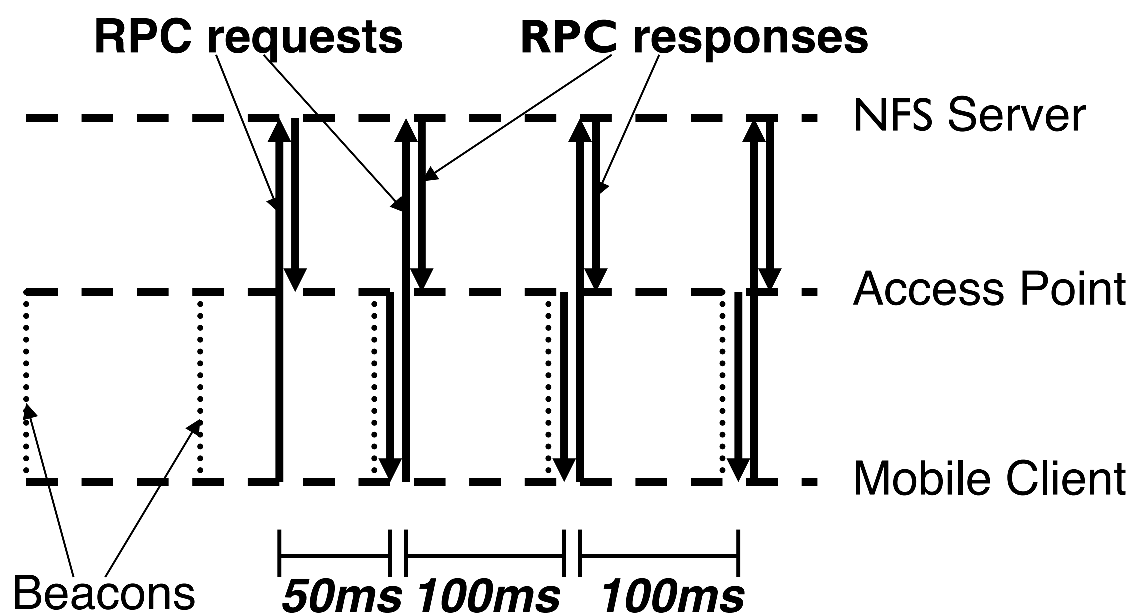
PSM-adaptive:

- **up to 26x slower (small dirs)**
- **12x more energy**

Problem : RPCs issued sequentially, each RPC is small Insufficient traffic for PSM-adaptive to trigger a switch to CAM

What's Going On?

NFS issues RPCs one at a time …..



- Get file listing
- Issues 2 RPCs (lookup, getattr for each file)
- Each RPC delayed 100ms **– cumulative delay is large**
  - – Affects apps with **sequential request/response** pairs

Applications:

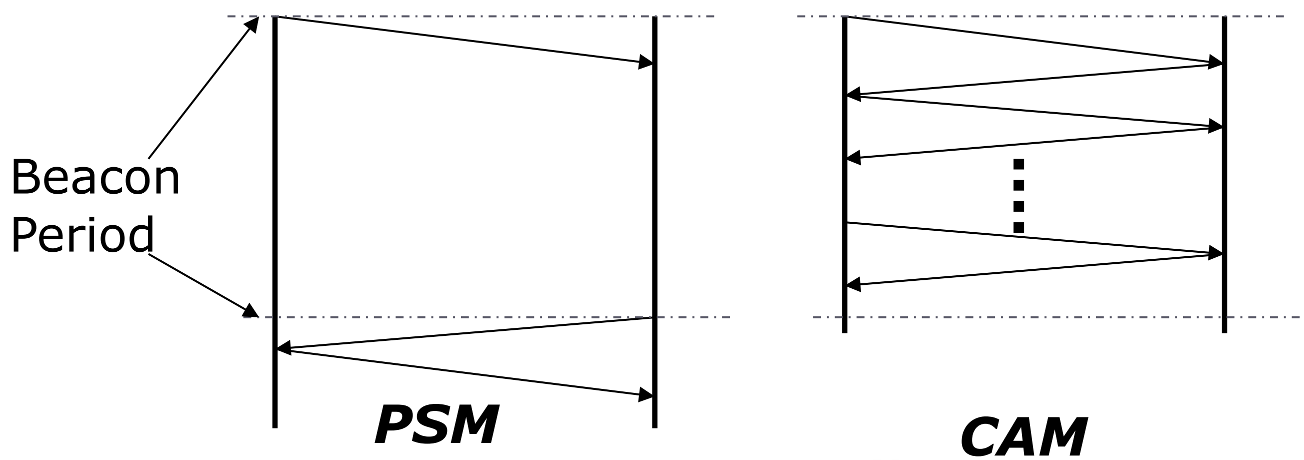
- Low latency / Foreground
  - CAM is better
- Think time, Background
  - PSM useful
- Untuned power management during interactive episodes dominates the benefits realized during idle periods.

STPM: Overview

- "One size fits all" approach – does not work!
- Self tuning power management
  - Characteristics of network interface, mobile computer
    - Time & energy costs of switching power modes, Base power usage
  - Intent and access patterns of applications
    - Latency, transfer size etc
    - API to disclose hints about interface usage

Know Application Intent

Application: NFS File access

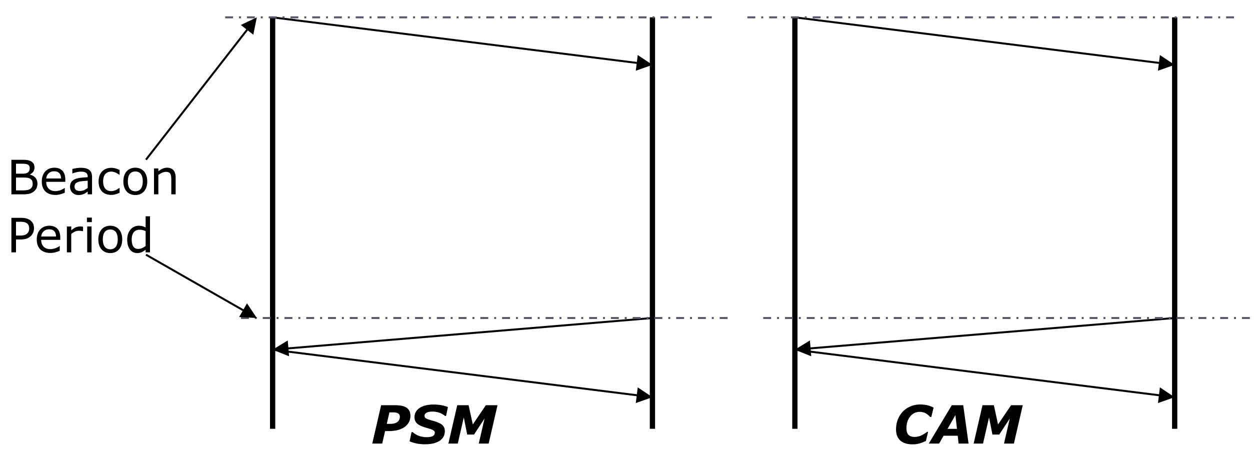


- Not enough network traffic to switch to CAM
- **Data rate is dependent on the power management**

Best Policy: Use CAM during activity period

Know Application Intent

- Application: Stock Ticker that is receiving 10 packets per second



- **Data rate is not dependent on power management**
- STPM allows **applications** to disclose **hints** about
  - **When** data transfer are occurring
  - **How much** data will be transferred (optional)
  - **Max delay** on incoming packets
- Best Policy: Use PSM

Power Modes: to switch or not to switch?

	Cisco Aironet 350		Orinoco Silver	
	Time	Energy	Time	Energy
PSM to CAM	0.40 s	0.51 J	0.23 s	0.24 J
CAM to PSM	0.41 s	0.53 J	0.26 s	0.31 J
Disable	0.00 s	0.00 J	N/A	N/A
Enable	0.39 s	0.51 J	N/A	N/A

- Transition incurs cost : time, energy
- Measuring transition time
  - Initiation transition, immediately perform a *ping*
- Short RPC: transition cost > latency reduction achieved in CAM
- **Break even size**: For transfer greater than this, performance benefit of CAM > transition cost

Proactive Vs Reactive

- Transition cost of changing power mode: 200 -600 ms.

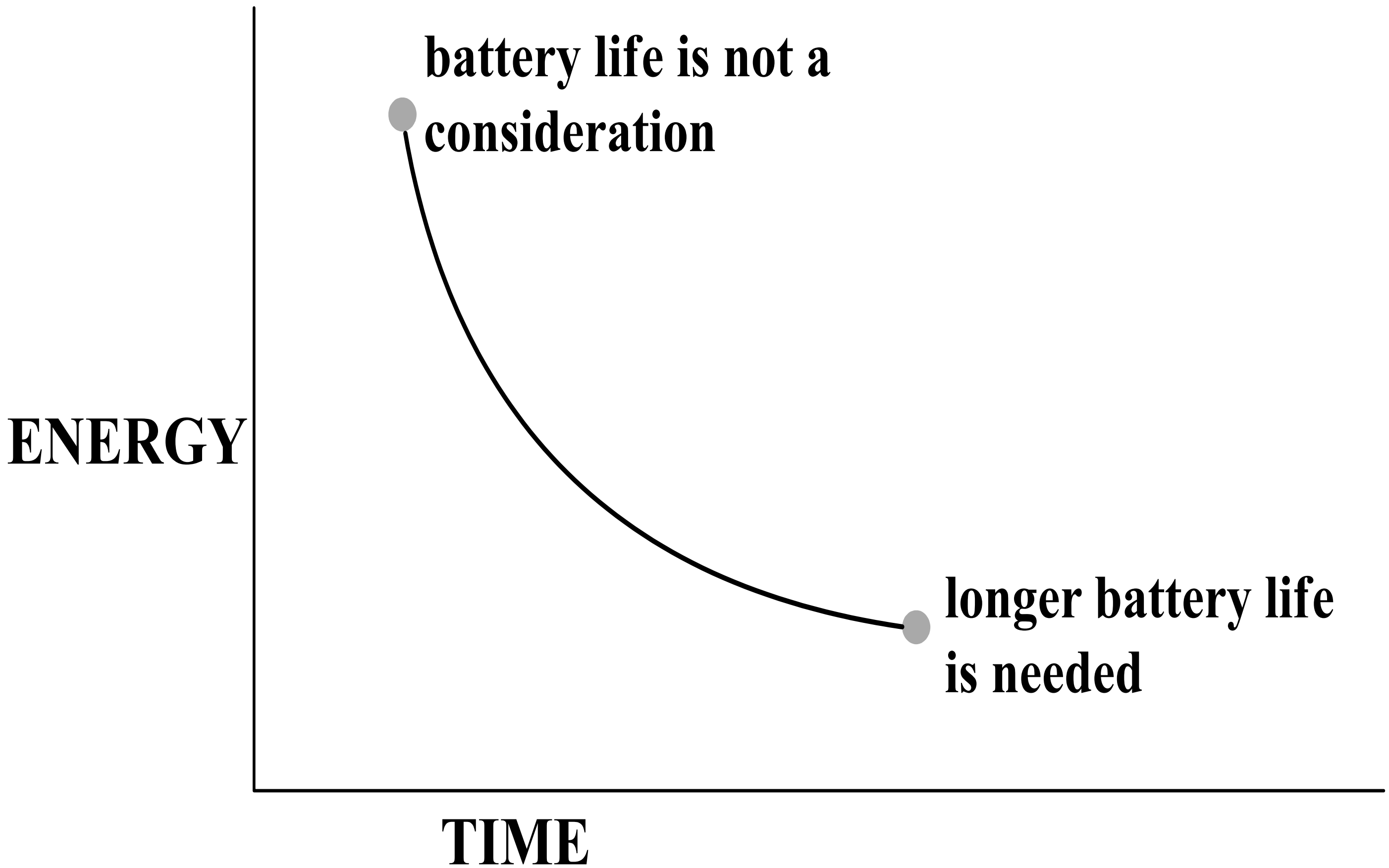
- Large transfers: **use a reactive strategy**
  - If transfer large enough, should switch to CAM
  - **Break even point** depends on card characteristics (supported data rates, transition cost)
  - STPM calculates this dynamically

- Many applications (like NFS) only make short transfers: **be proactive**
  - Benefit of being in CAM small for each transfer
  - But if many transfers, can amortize transition cost
  - **Need foreknowledge**: Build empirical distribution of n/w transfers
  - Switches to CAM when it predicts many transfers likely in future

Respect the Critical Path

- Many applications are latency sensitive
  - NFS file accesses
  - Interactive applications
  - **Performance and Energy critical**
- Other applications are less sensitive to latency
  - Prefetching, asynchronous write back (Coda DFS)
  - Multimedia applications (with client buffering)
  - **Only energy conservation critical**
- Applications disclose the nature of transfer: **foreground** or **background**

Embrace Performance/Energy Tradeoff

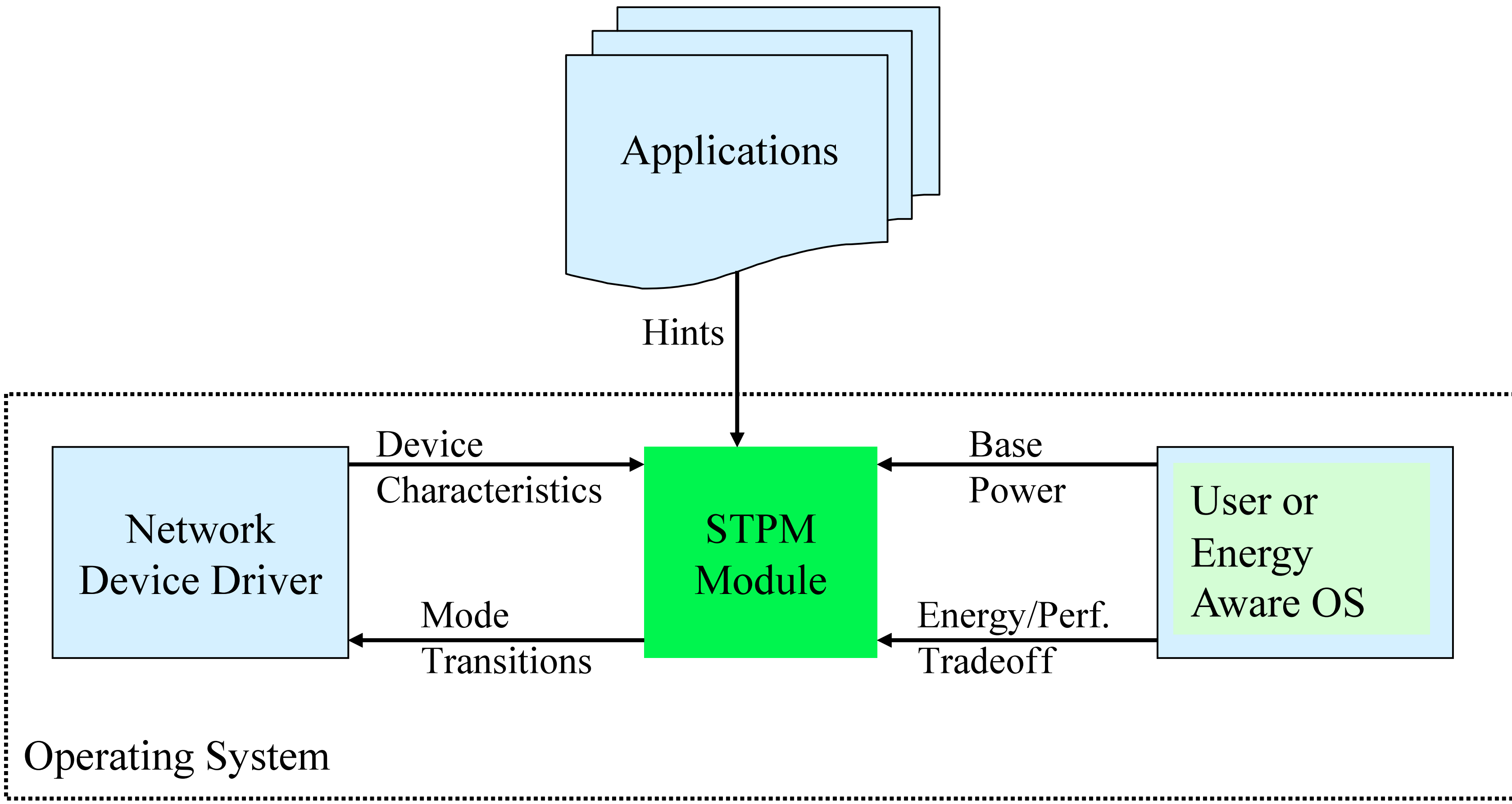


- Trade off: Energy Vs Performance
- STPM lets user specify relative priorities using a **tunable knob**

Adapt to the operating environment

- Must consider base power of the mobile computer
- Consider mode that reduces network power from 2W to 1W
  - Delays interactive application by 10%
- On handheld with base power of 2 Watts:
  - Reduces power 25% (from 4W to 3W)
  - Energy reduced 17.5% (still pretty good)
- On laptop with base power of 15 Watts:
  - Reduces power by only 5.9%
  - Increases energy usage by 3.5%
  - **Battery lasts longer, user gets less work done**

STPM Architecture



STPM: API

- TransferHintBegin:
  - Foreground / Background
  - Expected transfer size (default: small)
- ListenHintBegin:
  - Max. delay application is willing to tolerate
- HintEnd
  - Removes hints when application terminates
- SetKnob,
  - 0 to 100 (min, max performance)
- SetBasePower

Network Power Costs

Card Mode	Cisco Aironet 350	Orinoco Silver
$P_{disabled}$	0.24 W	N/A
P_{PSM_idle}	0.39 W	0.19 W
P_{PSM_recv}	1.42 W	2.22 W
P_{PSM_send}	2.48 W	2.70 W
P_{CAM_idle}	1.41 W	1.21 W
P_{CAM_recv}	2.61 W	2.25 W
P_{CAM_send}	3.69 W	2.67 W

Using Digital Multimeter, measure the power drawn by mobile computer

- w/o network card (gives **base** power)
- with card (**Tx, Rx, Idle, disabled**)

Transition to CAM

STPM switches from PSM to CAM when:

- Case 1: Application specifies **max delay < beacon period**

- Case 2: Disclosed **transfer size > break-even size**

Expected time to perform transfer:

$$T = L + B_s/DR_s + B_r/DR_r$$

Transition to CAM

- Expected energy to perform transfer

$$E = L \times (P_i + P_b) + B_s/DR_s \times (P_s + P_b) + B_r/DR_r \times (P_r + P_b)$$

- Switch from PSM to CAM if

$$1.\ \mathrm{T}_{CAM} + \mathrm{T}_{transition} < \mathrm{T}_{PSM}$$

$$2.\ \mathrm{E}_{CAM} + \mathrm{E}_{transition} < \mathrm{E}_{PSM}$$

Conflicting Cases: Use **knob** to resolve

$$C = (\mathrm{T}) \times knob + (\mathrm{E}) \times (100 - knob)$$

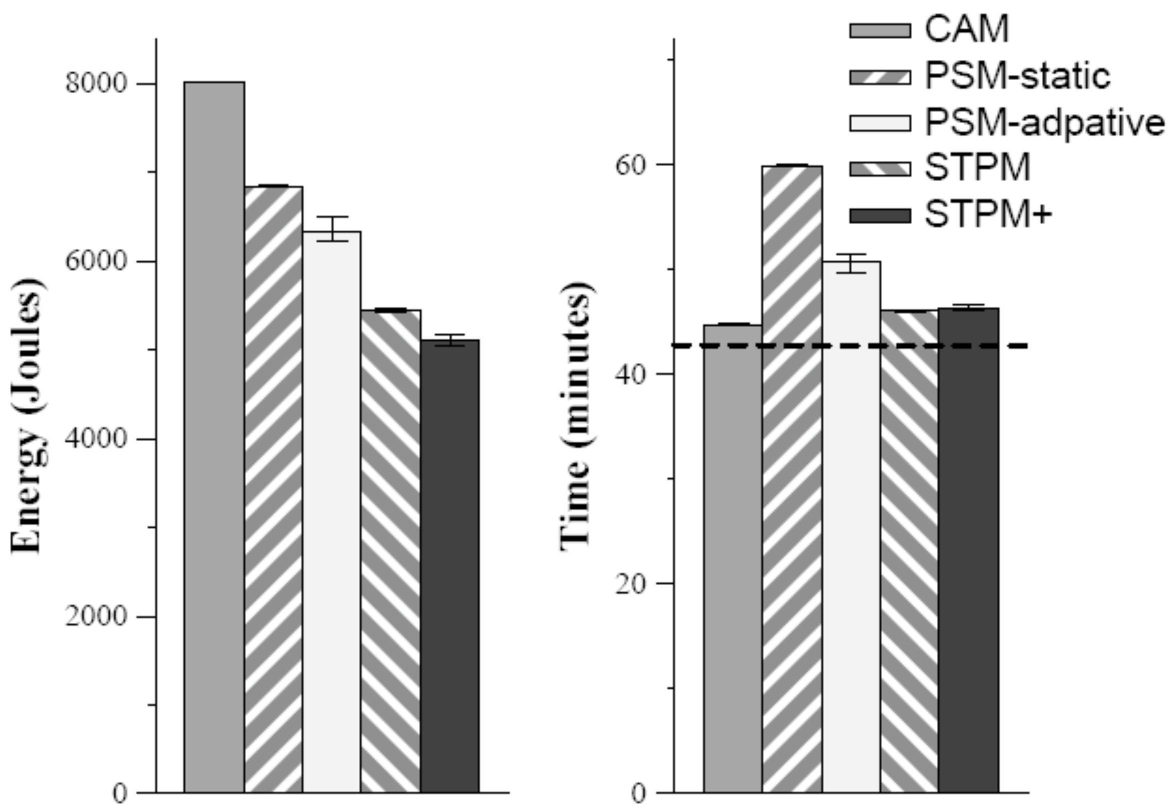
Transition to CAM

- Case 3: Many **forthcoming transfers** are likely

- **Run**: Transfers closely correlated in time
- **Run Length**: Number of Transfers
- To predict forthcoming transfers STPM generates an empirical distribution of run lengths

Results: CODA on handheld

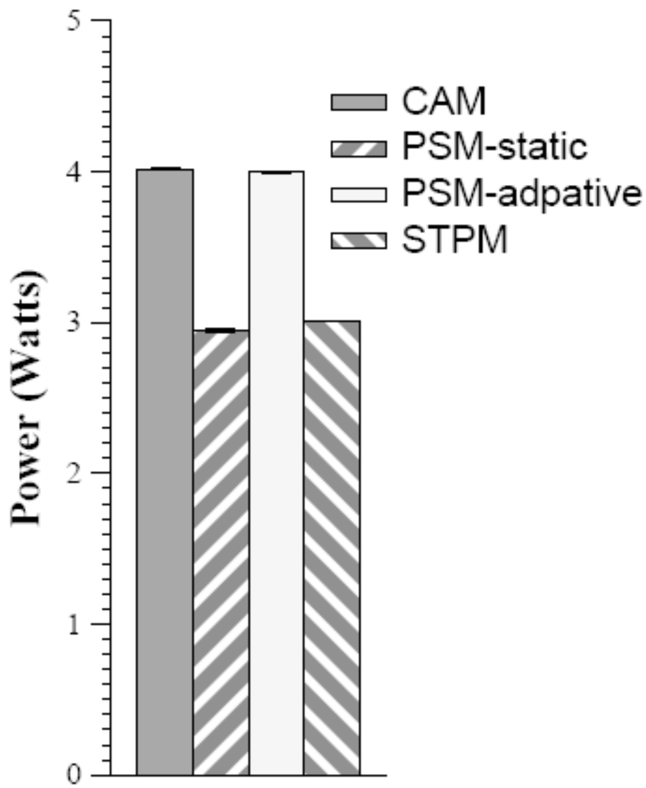
Workload: 45 minute interactive software development activity



- CAM: best performance, max energy
- PSM-st: reduces energy, bad performance
  (15 extra mins)
- PSM-adp > PSM-st
- Dashed: Think Time
  STPM Near Optimal

STPM: 21% less energy, 80% less time than 802.11b power mgmt.

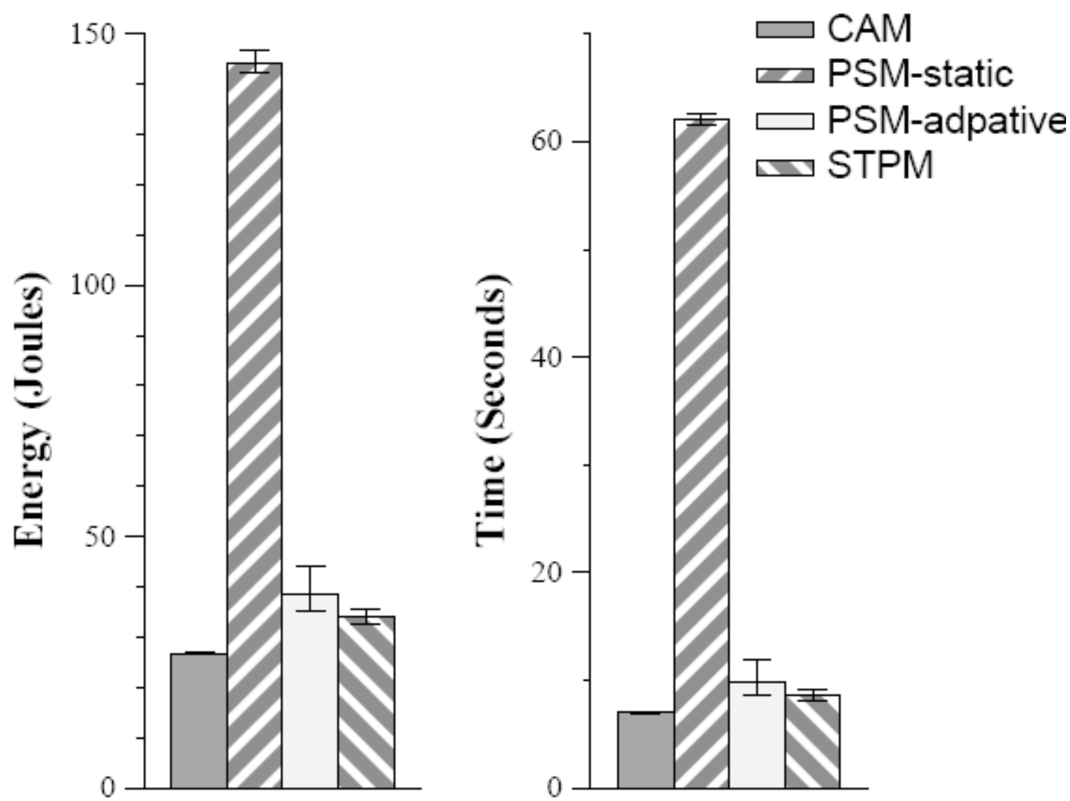
Results: Xmms



- Client buffering determines if power management can be used
- STPM
  - 25% less power than CAM
  - 2% more energy than PSM-st
  - No audio packets dropped
- PSM-adaptive performs badly
  - Assumes latency is critical

Workload: 128Kb/s streaming MP3 audio from an Internet server

Results: remote X



- CAM: best performance, least energy
- PSM-st:

  increases time, energy!
- CAM is 25% faster than STPM and needs 28% less energy
- Think Time matters

Research Paper

- NAPman: Network Assisted Power Management for WiFi Devices
  - Eric Rozner et. al, MobiSys 2010
  - Revisiting PSM
  - Effect of "background" traffic on PSM clients

Effect of background traffic

Experiment Setup

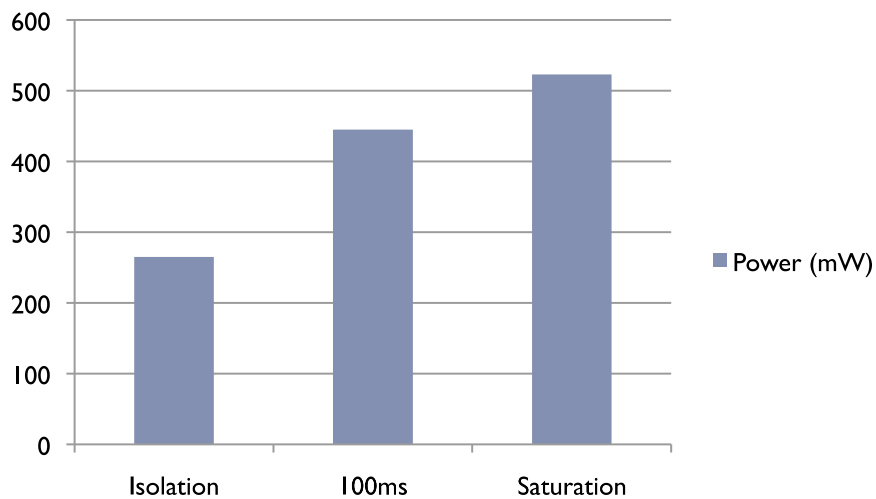
Linksys WRT54GL AP
2 HP iPAQ clients

Auto-rate algorithm at AP
Packet size:1440 bytes
PSM-adaptive: 30ms timeout, RX thresh: 10

1. PSM client (near)
   - 11 Mbps PHY
   - Periodic traffic: one packet every 100ms
2. CAM client (far)
   - 1 Mbps PHY
   - Traffic :
     1. Periodic (one packet/100ms)
     2. Saturated

Effect of background traffic

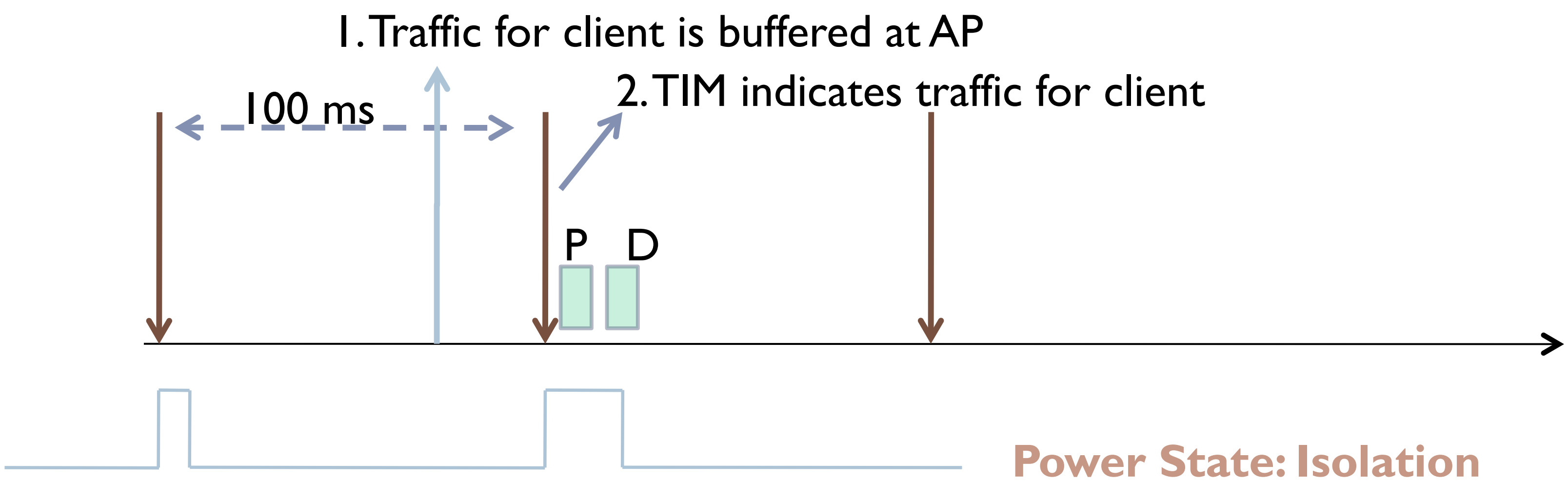
- Total packets: 1000 (~ 100 sec)



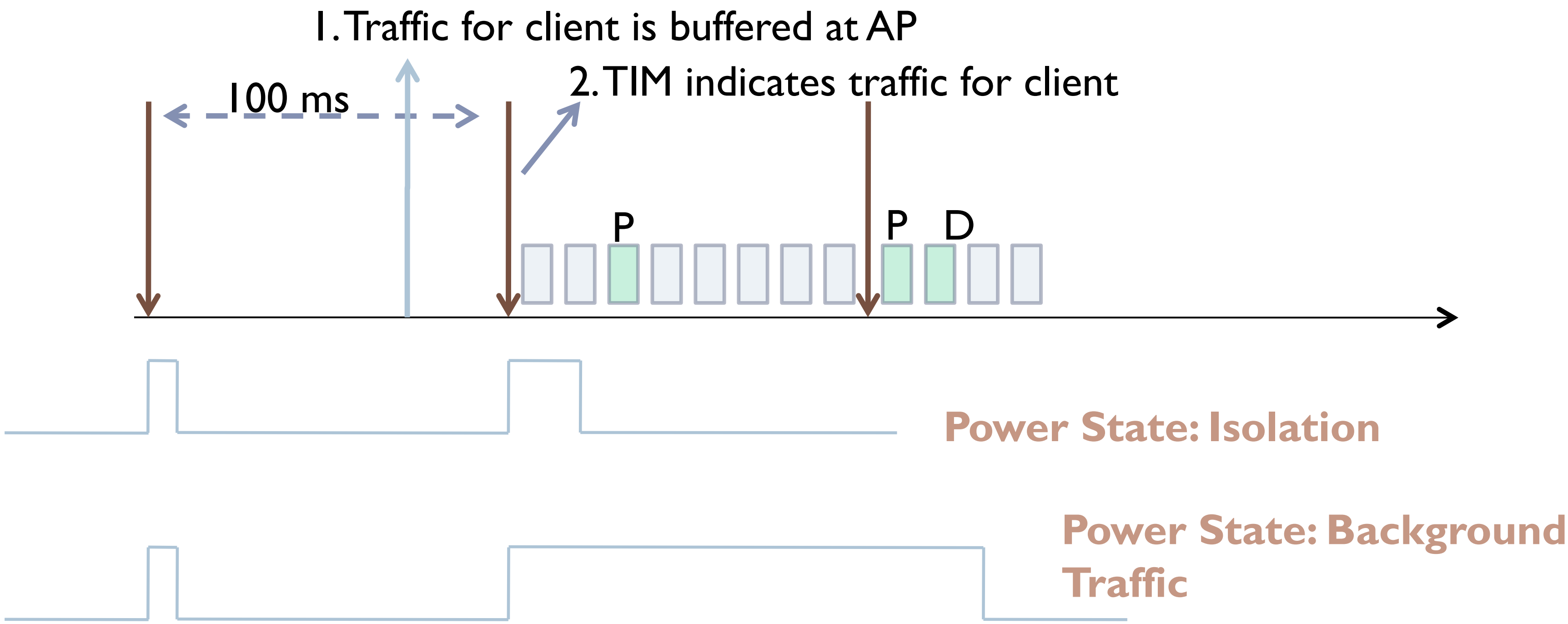
~ 2X more energy!!

NAPman

- Basic PSM problem and solution

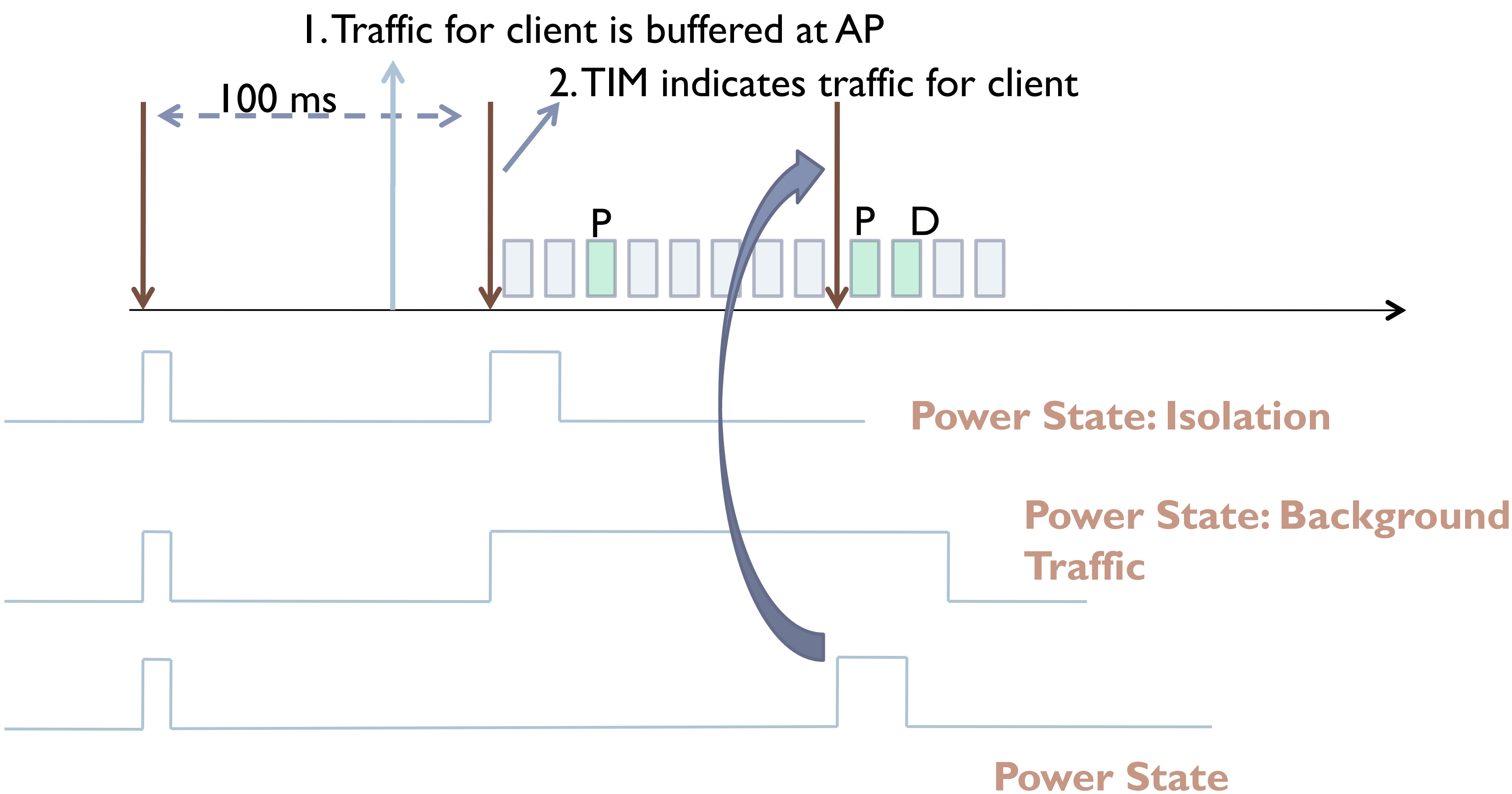


NAPman



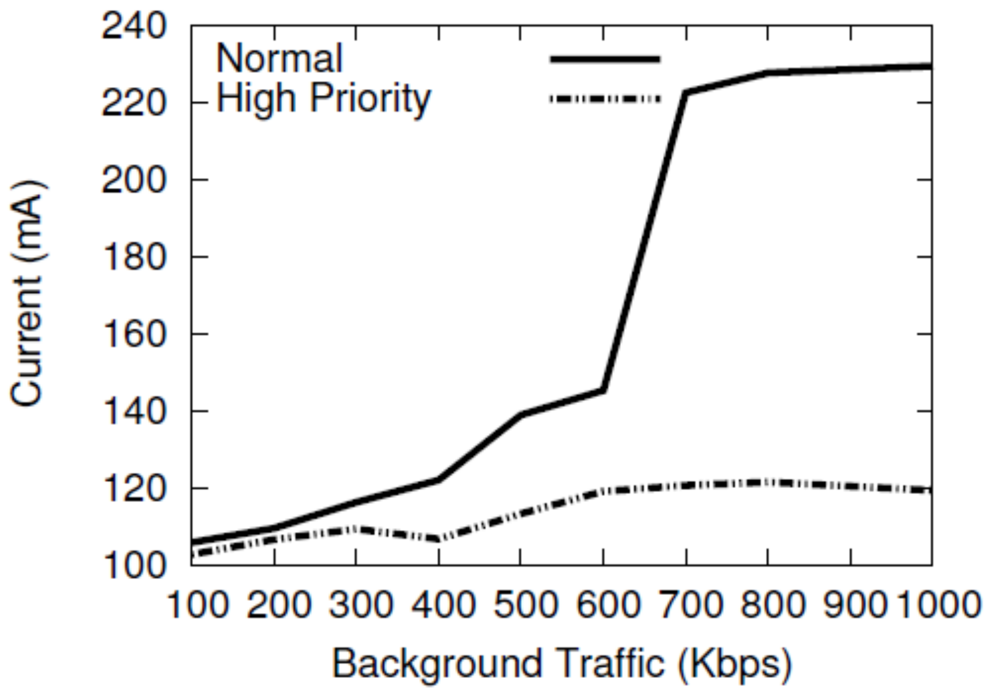
1. Traffic for client is buffered at AP
2. TIM indicates traffic for client
100 ms
P
P
D
Power State: Isolation
Power State: Background Traffic

NAPman



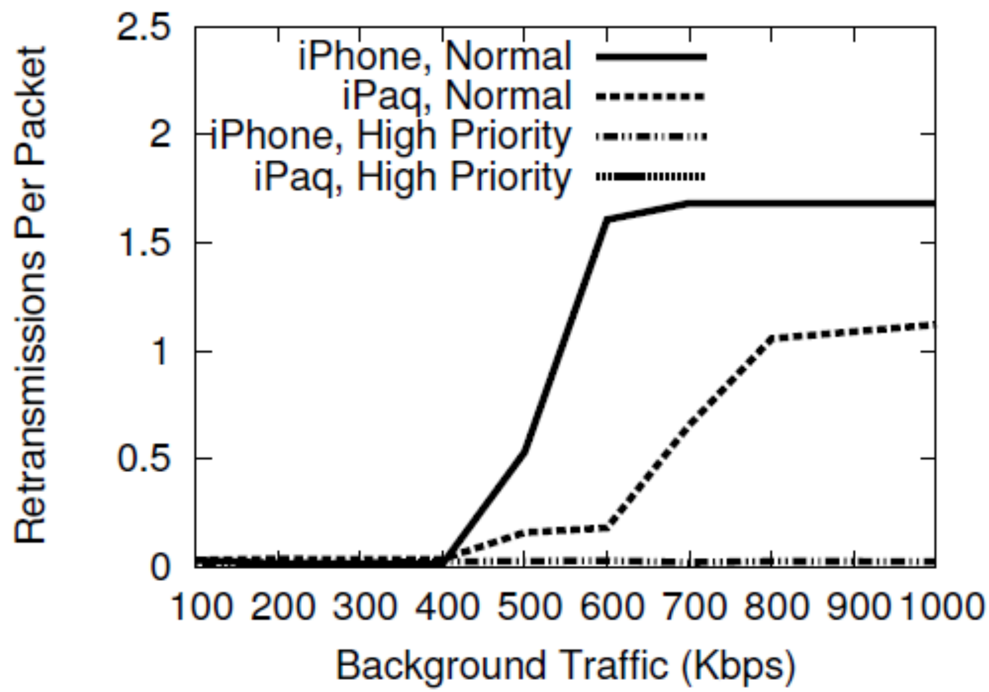
Notify the client at the right time

Priority queuing



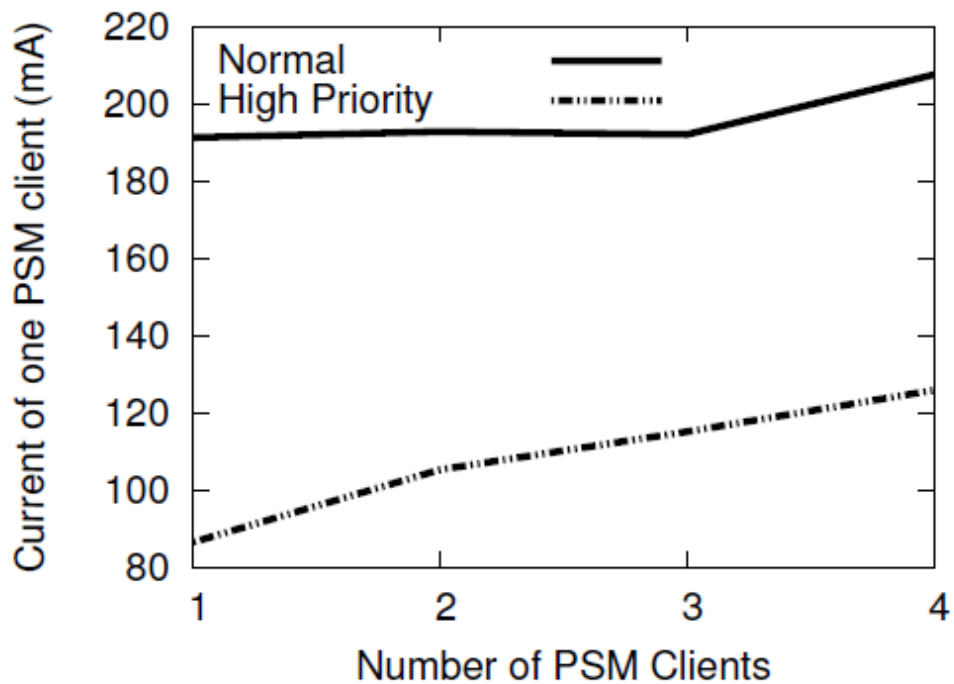
- AP sets the TIM bit
- On receiving PS-POLL, the data packet is scheduled using a higher priority queue
- PSM client immediately receives the packet and then goes to sleep

Priority queuing



- Increased retransmissions → reduced capacity!
- Priority queuing can resolve the issue
- Problems – (i) Fairness (ii) Multiple PSM clients

Multiple PSM clients create a problem ..



- Multiple PSM clients can nullify the effect of priority queuing

Questions?

Transition to CAM

- Expected time to perform nth transfer

$$T_n = \sum_{i=1}^{n-1} L_{PSM} \times P(r \geq i) + \sum_{i=n}^{1024} L_{CAM} \times P(r \geq i) + T_{TC} \times P(r \geq n)$$

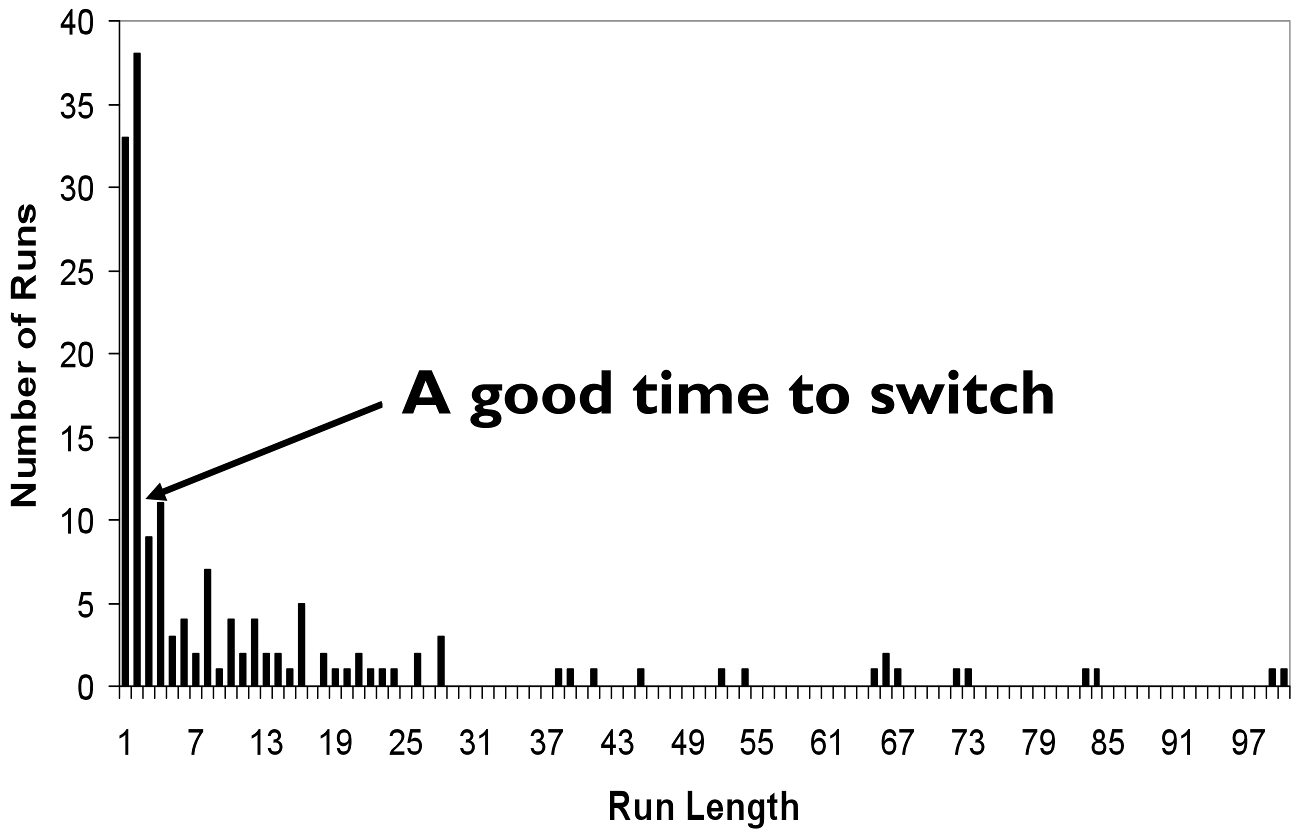
$P(r \geq n)$ is the probability that *length of run* $\geq n$

Transition to CAM

$$E_n = \sum_{i=1}^{n-1} L_{PSM} \times (P_{PSM(idle)} + P_{base}) \times P(r \geq i)$$
$$+ \sum_{i=n}^{1024} L_{CAM} \times (P_{CAM(idle)} + P_{base}) \times P(r \geq i)$$
$$+ (E_{TC} + (T_{TC} \times P_{base})) \times P(r \geq n)$$

$$C_n = (T_n / T_{mean}) \times knob + (E_n / E_{mean}) \times (100 - knob)$$

Intuition: Using the Run-Length History



Switch when expected # of transfers remaining in run is high

Evaluation

Client: iPAQ handheld with Cisco 350 wireless card

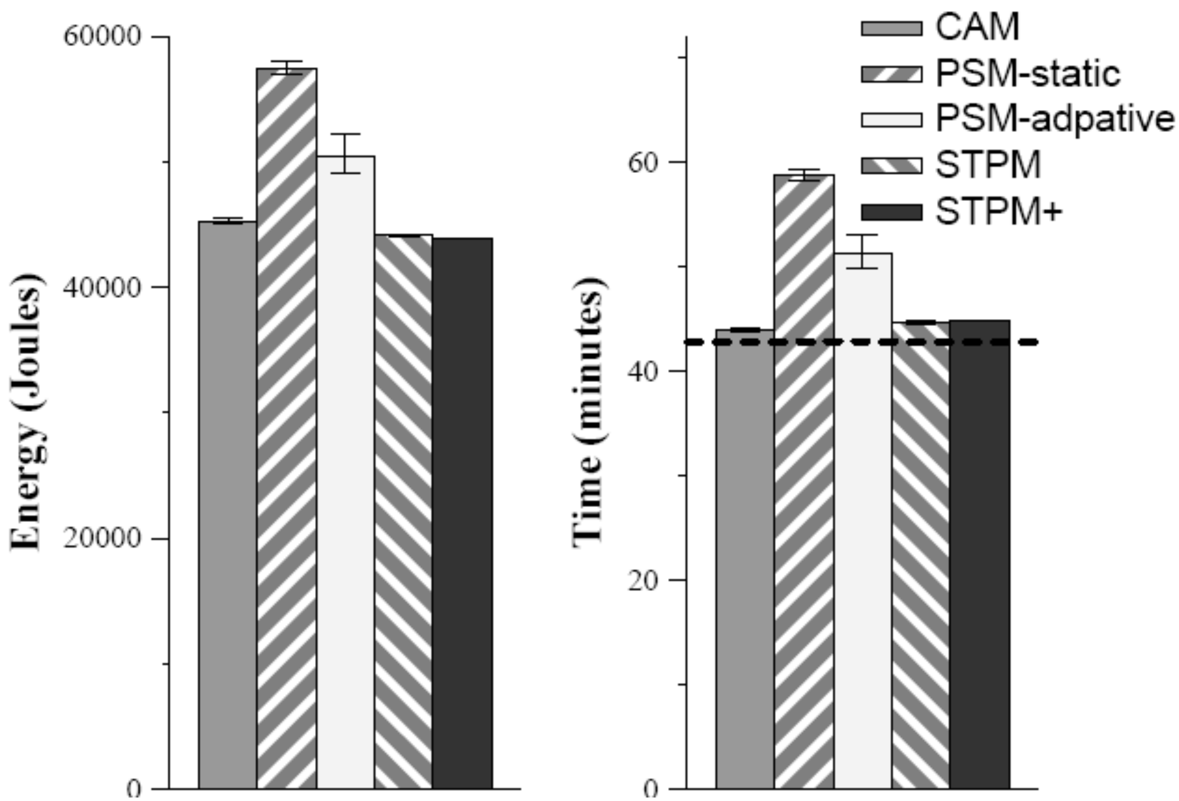
Evaluate STPM vs. CAM, PSM-static, and PSM-adaptive:

- NFS distributed file system
- Coda distributed file system (file access, asynch writes)
- XMMS streaming audio (streaming data, buffering)
- Remote X (thin client display)

Run DFSTrace tool generate access stats for STPM

- Use Mummert's file system trace (SOSP '95)
- File system operations (e.g. create, open, close)
- Captures interactive software development

Results: CODA on laptop



- CAM: good performance, max energy
- PSM-st, PSM-adp:

  increase energy!

STPM: 2.6% less energy, 15% more time than CAM