Minimizing Energy for Wireless Web Access with Bounded Slowdown

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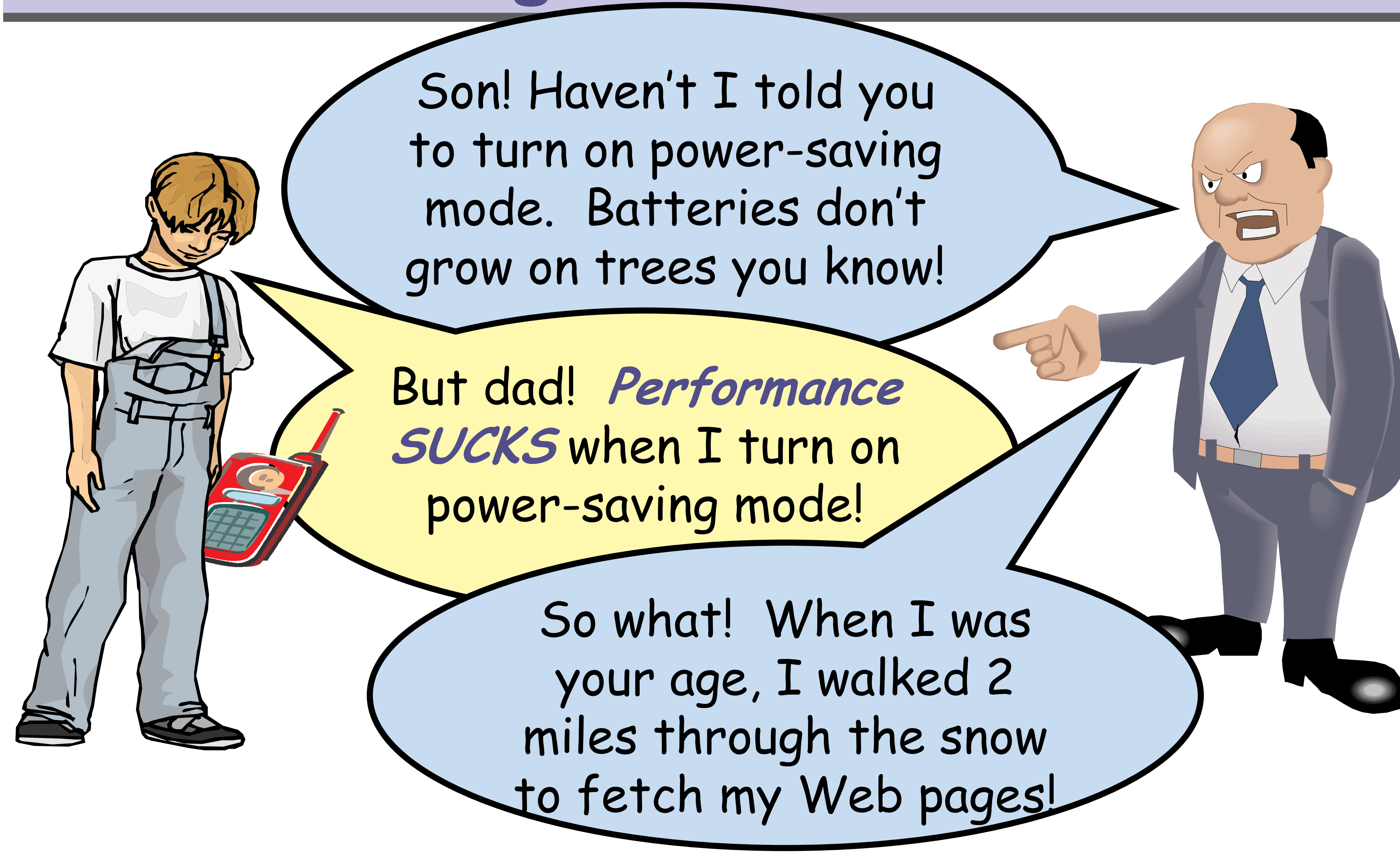
Mobile Device Energy Consumption

- **Energy is important resource in mobile systems**
- **Wireless network access can quickly drain a mobile device's batteries**
- **Energy-saving methods trade-off *performance* for *energy***
  - ***For example, the IEEE 802.11 Wireless LAN Power-Saving Mode (PSM)***
- **Understanding the trade-offs can give a principled way for designing energy-saving protocols**

Motivation:
Web browsing is slow with 802.11 PSM



- **Users complain about performance degradation**

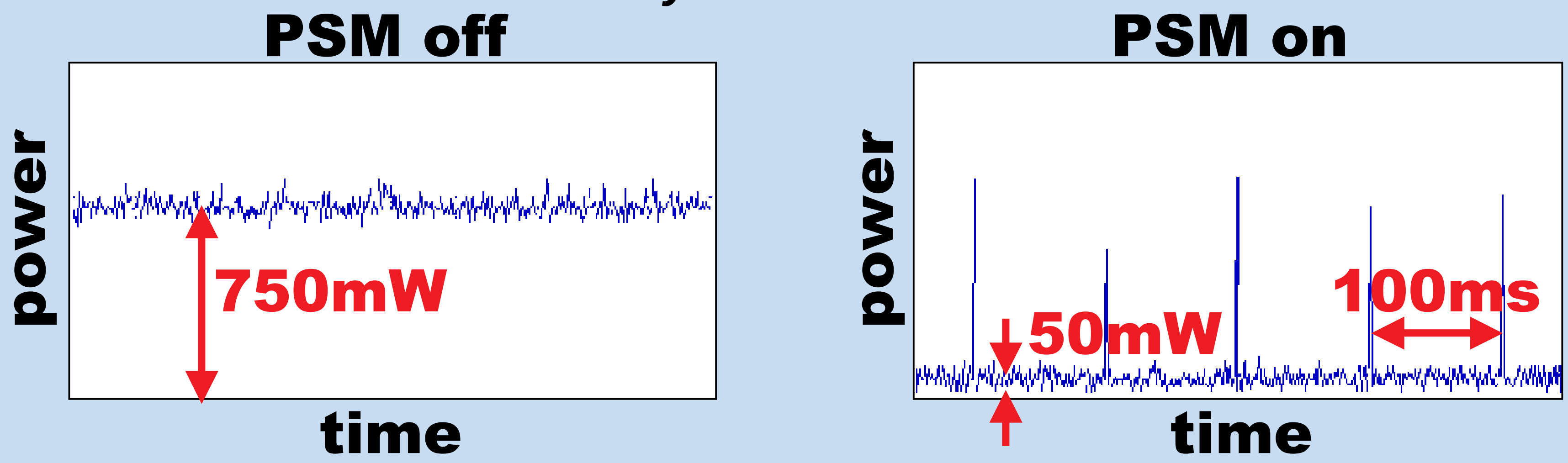
Outline

- Power-Saving Modes
  - Operation of 802.11 (PSM-static)
- Performance of PSM-static
- Energy usage of PSM-static
- Bounded-Slowdown (BSD) Protocol
- Results: Performance and Energy of BSD
- Conclusion

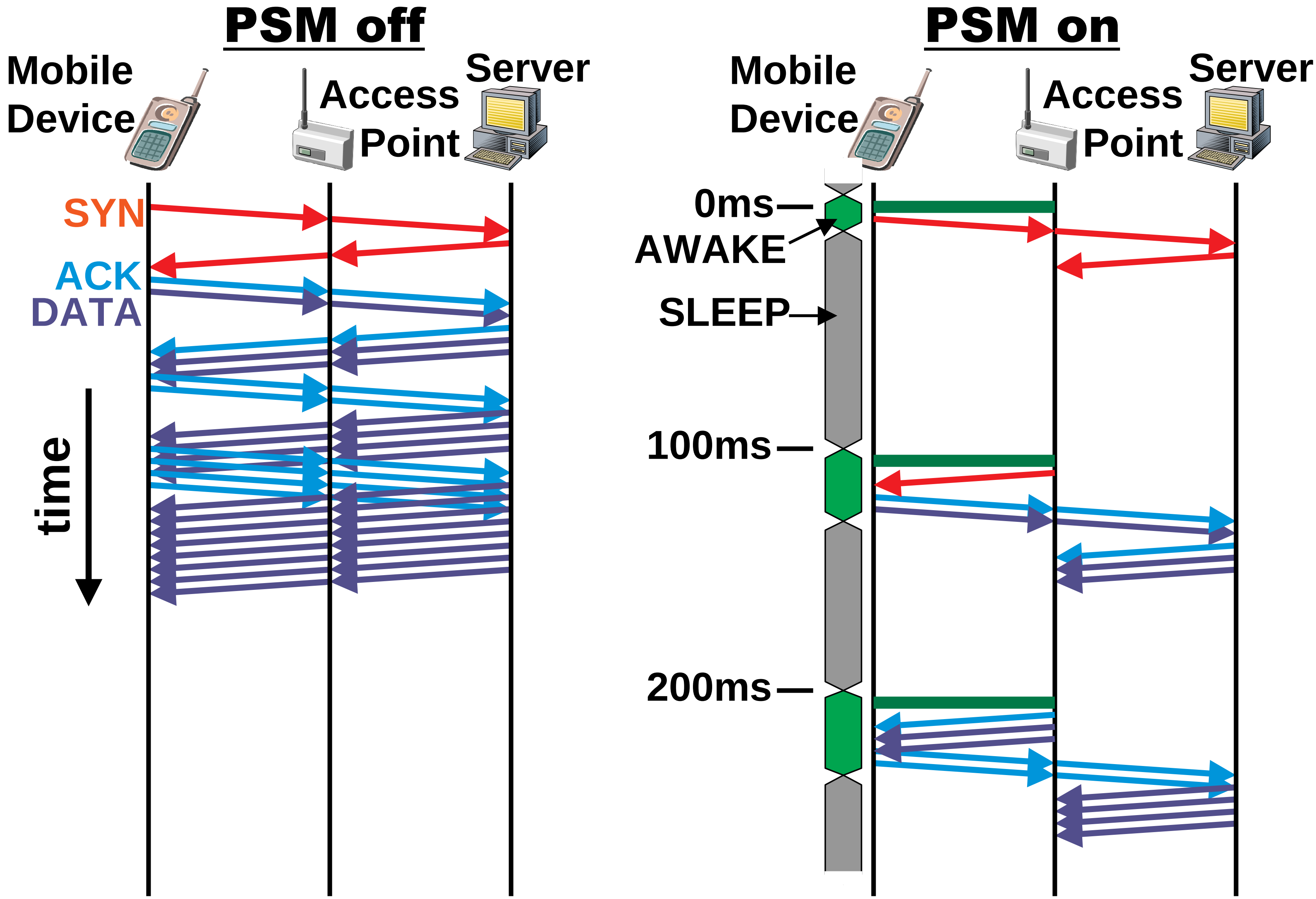
Wireless Interface Power-Saving

- **AWAKE: high power consumption, even if idle**
- **SLEEP: low power consumption, but can't communicate**
- **Basic PSM strategy: Sleep to save energy, periodically wake to check for pending data**
  - **PSM protocol: when to sleep and when to wake?**
- **A *PSM-static* protocol has a regular, unchanging, sleep/wake cycle while the network is inactive (e.g. 802.11)**

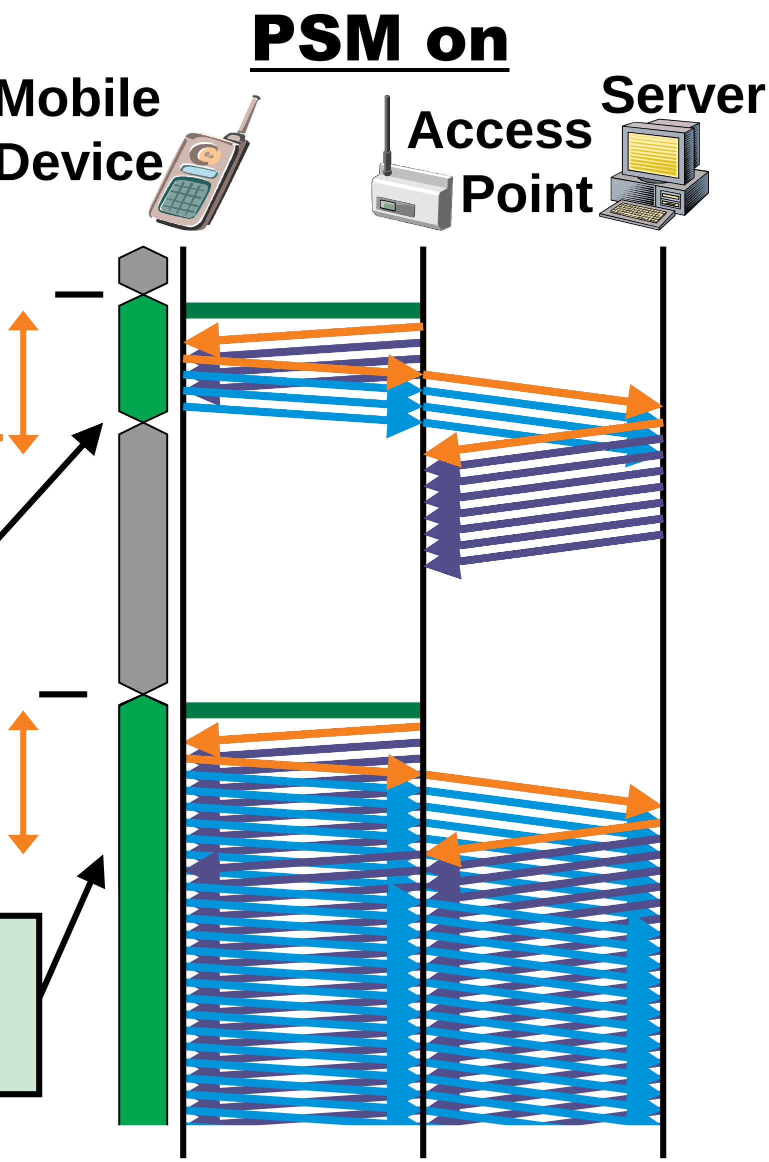
Measurements of Enterasys Networks RoamAbout 802.11 NIC



PSM-Static Impact on TCP (initial RTTs)



PSM-Static Impact on TCP (steady state)



Time to send buffered window

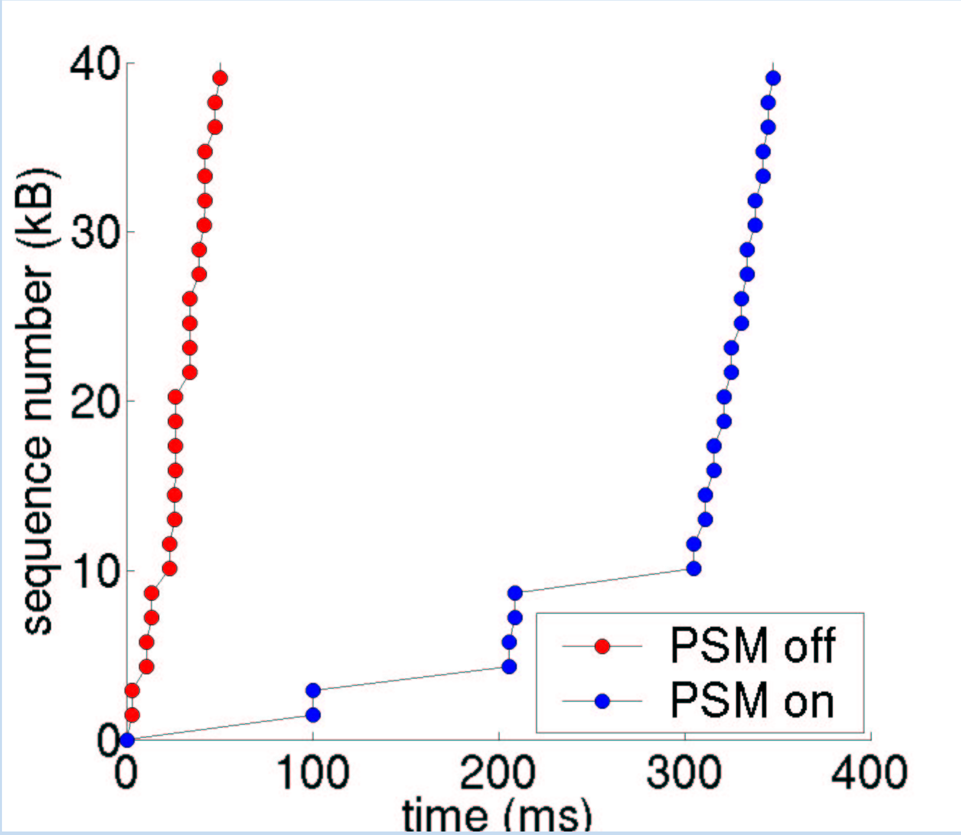
Server RTT

window < BW•RTT
Network interface sleeps

window > BW•RTT
Network interface stays awake

PSM-static Overall Impact on TCP

Measured TCP Performance



The transmission of each TCP window takes 100ms until the window size grows to the product of the wireless link bandwidth and the server RTT

Performance Inversion

- **PSM-static and TCP can have strange *emergent interactions***
- **TCP may achieve *higher throughput* over a *lower bandwidth* PSM-static link!**
- **How? A wireless link with a smaller bandwidth delay product will become saturated sooner and prevent the network interface from going to sleep**
- **See paper for details**

Web Browsing is Slow with PSM-static

- **Web browsing typically consists of small TCP data transfers**
  - **RTTs are a critical determinant of performance**
- **PSM-static slows the initial RTTs to 100ms**
  - **Slowdown is worse for fast server connections**
  - **Many popular Internet sites have RTTs less than 30ms (due to increasing deployment of Web CDNs, proxies, caches, etc.)**
- **For a server RTT of 20ms, the average Web page retrieval slowdown is 2.4x**

PSM-static Does Not Save Enough Energy

- **Client workloads are bursty**
- **99% of the total inactive time is spent in intervals lasting longer than 1 second (see paper)**
- **During long idle periods, waking up to receive a beacon every 100ms is inefficient**
  - **Percentage of idle energy spent listening to beacons:**

Enterasys RoamAbout	23%	*Used in our paper*
ORiNOCO PC Gold	35%	*Based on data in:*
Cisco AIR-PCM350	84%	*[Shih, MOBICOM 2002]*

- **Longer sleep times enable deeper sleep modes**
  - **Basic tradeoff between reducing power and wakeup cost**
  - **Current cards are optimized for 100ms sleep intervals**

The PSM-static Dilemma

Compromise between performance and energy

If PSM-static is *too coarse-grained*, it harms performance by delaying network data

If PSM-static is *too fine-grained*, it wastes energy by waking unnecessarily

Solution: dynamically adapt to network activity to maintain performance while minimizing energy

- ***Stay awake*** **to avoid delaying very fast RTTs**
- ***Back off*** **(listen to fewer beacons) while idle**

PSM Problem Statement

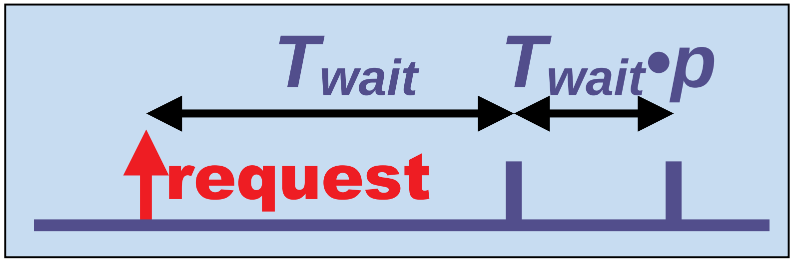
Find a protocol that minimizes energy consumption while guaranteeing that RTTs do not increase by more than a given percentage *p*

- **Minimize energy assuming simple power model (sleep/wake/listen)**
- **Must operate solely at the link layer with no higher-layer knowledge**
  - **Assume any data sent by mobile device is a request, and no correspondence between send and receive data**
  - **Benefit: works even when network interface is shared**
- **Only applies to request/response traffic**

Bounding Slowdown with Minimum Energy (Idealized)

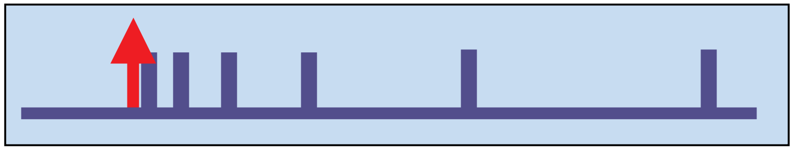
Bounded Slowdown Property:

If T_{wait} has elapsed since a request was sent, the network interface can sleep for a duration up to $T_{wait} \cdot p$ while bounding the RTT slowdown to (1+p)



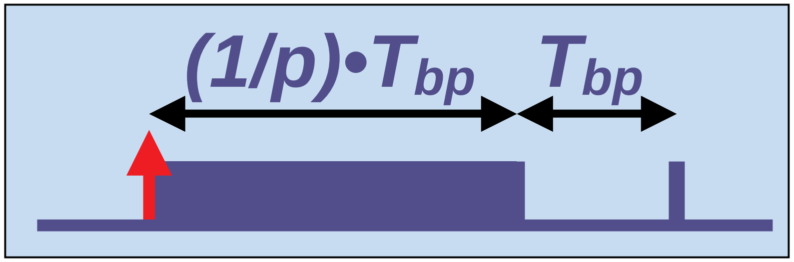
Idealized protocol:

- **To minimize energy: sleep as much as possible**
- **To bound slowdown: wakeup to check for response data as governed by above property**

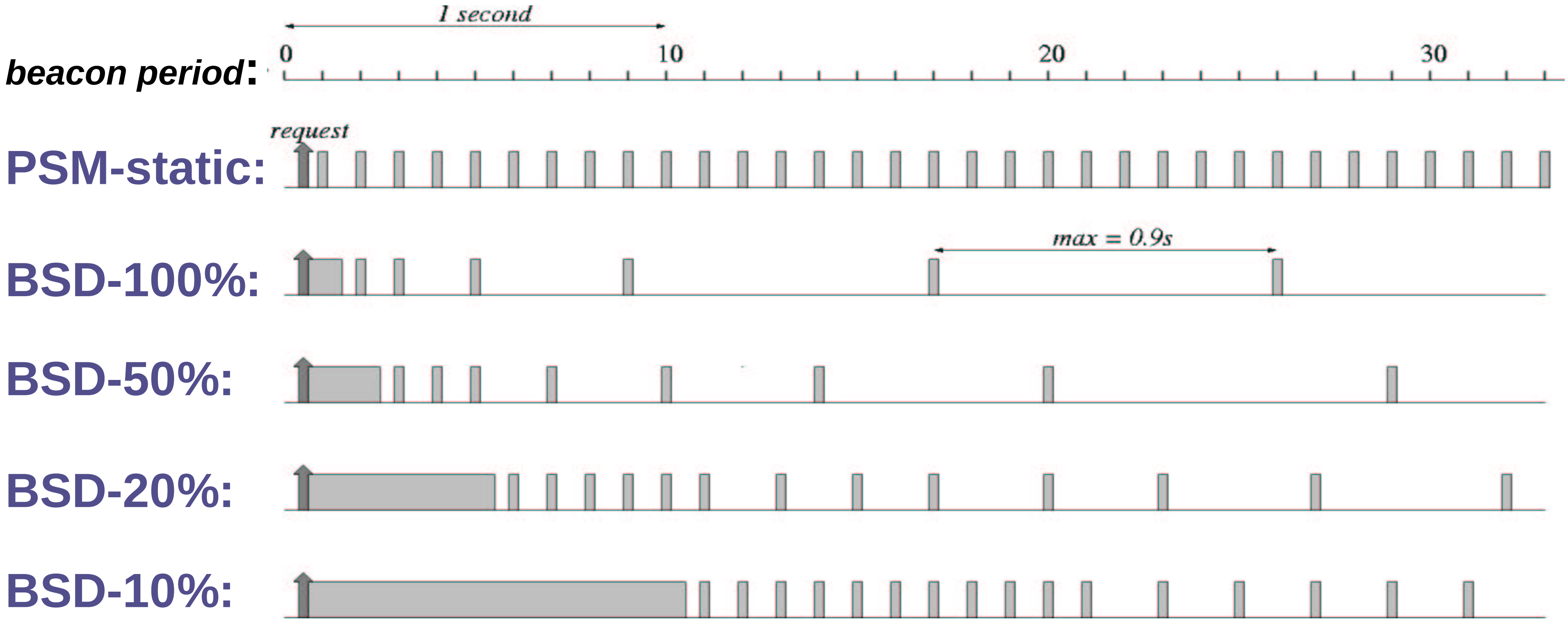


Synchronization

- Mobile device and AP should be synchronized with a fixed beacon period (T_{bp})
- May delay response by one beacon period during first sleep interval
- To bound slowdown, initially stay awake for $1/p$ beacon periods
- Round sleep intervals down to a multiple of T_{bp}
- Requires minimal changes to 802.11



Bounded-Slowdown (BSD) Protocol



- **Parameterized BSD protocol exposes trade-off between performance and energy**
- **Compared to PSM-static: awake energy increases, listen energy decreases**

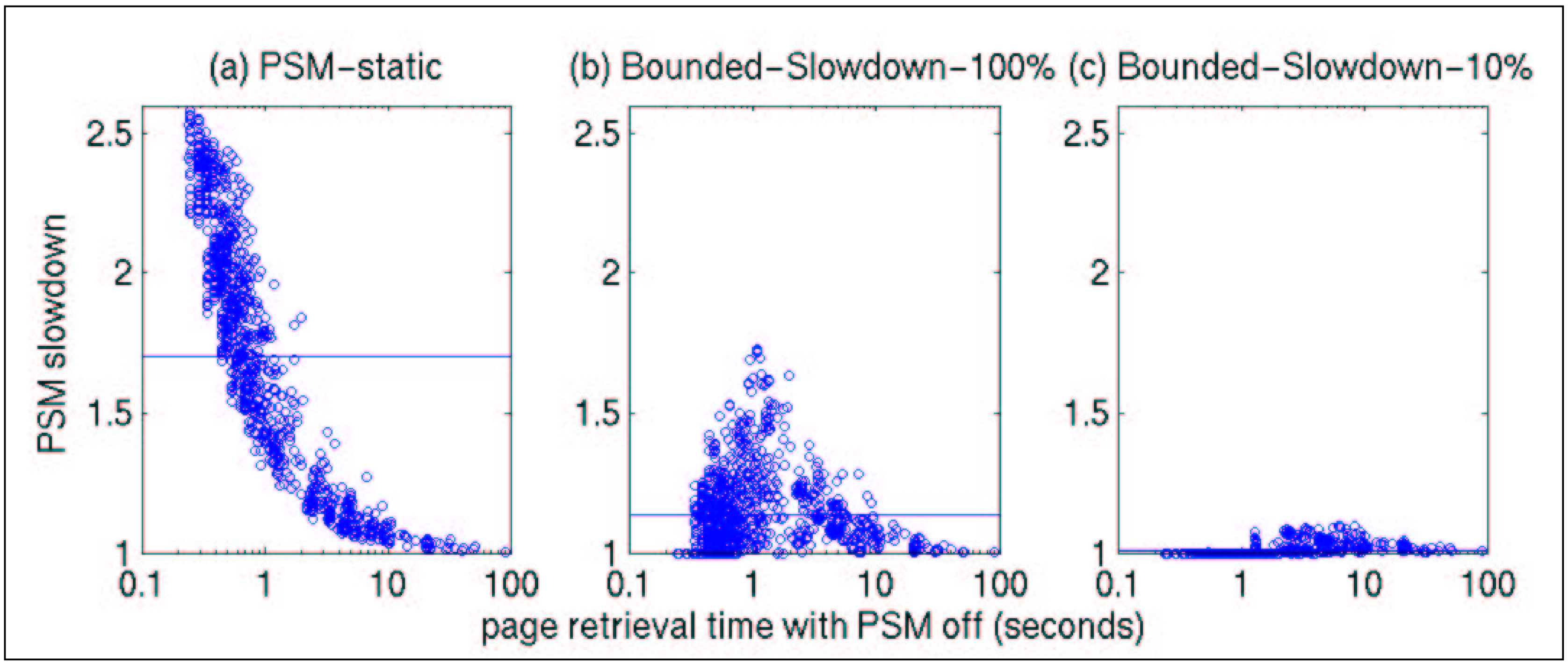
Simulation Methodology

- **ns-2 used to model mobile client communicating with AP over wireless link**
- **Web traffic generator with randomized parameters based on empirical data**
  - **Includes: request length, response length, number of embedded images, server response time, user think time**
- **Limitation: single server with fixed bandwidth and RTT**
  - **Server RTT is fixed, but server response time varies**
  - **Evaluated various server RTTs**
- **Simple energy model: awake power, sleep power, listen energy**

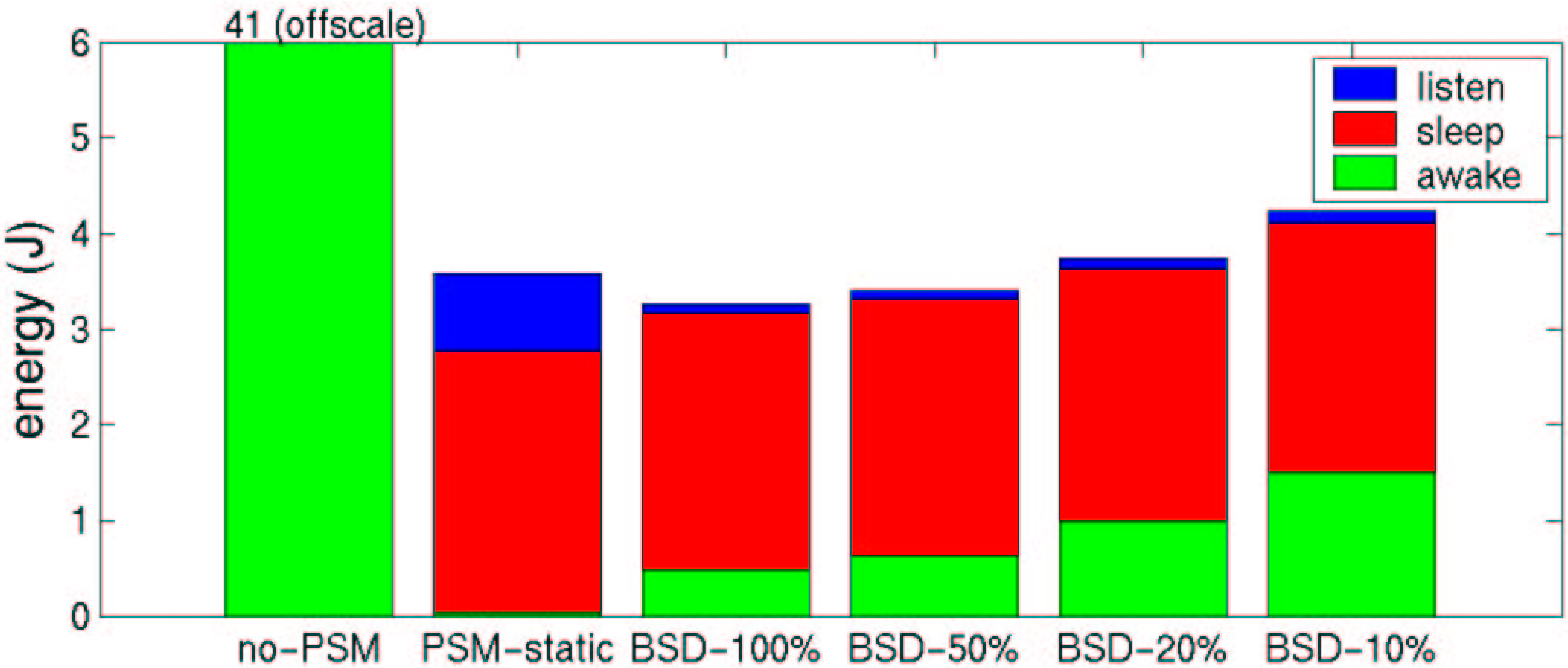
Web Browsing Performance

Average PSM Slowdown

	PSM-static	BSD-100%	BSD-10%
RTT=10ms	3.32	1.19	1.01
RTT=20ms	2.42	1.16	1.01
RTT=40ms	1.70	1.14	1.01
RTT=80ms	1.16	1.11	1.01

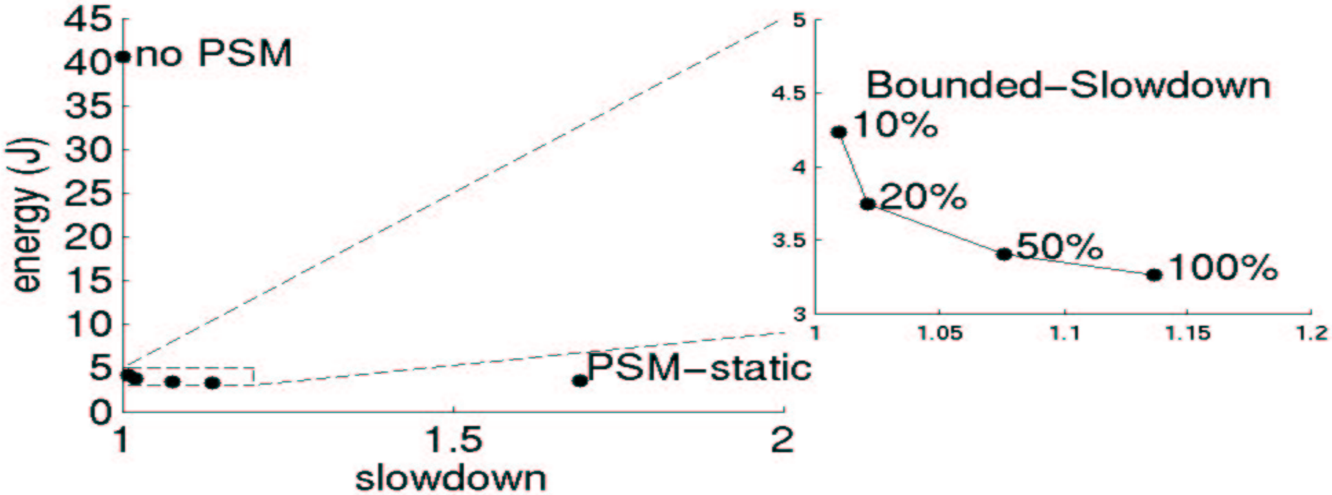


Web Browsing Energy



- BSD would have large energy savings for other cards: 25% for ORiNOCO PC Gold, and 70% for Cisco AIR-PCM350
- Sleep energy could be reduced by going into deeper sleep during long sleep intervals
- Shorter beacon-period can reduce awake energy (see paper)

Conclusion



- **PSM-static (the 802.11 PSM) drastically reduces Web browsing energy, but it also slows down Web page retrieval times substantially**
- **BSD dynamically adapts to network activity and uses the minimum energy necessary to guarantee that RTTs do not increase by more than a given percentage**
- **BSD exposes the energy/performance trade-off**
- **BSD can essentially eliminate the Web browsing slowdown while often using even less energy than PSM-Static**