B.1 Increasing the Lifetime of Batteries

- Improvement of the efficiency of energy consuming components
  - CPU: clock/voltage scaling
  - Energy-aware virtual memory & garbage collection
    - adjust memory allocation to reference patterns in multi-bank systems
  - Energy-aware I/O (disk, WLAN)
    - shutdown policies, variable rotation speed/transfer rate, ...
  - TFT display power management
    - variable dot clock
    - reduced pixel color intensity of the background
    - brightness & contrast enhancement & backlight dimming
  - Hibernation (suspend to disk)
B.1 Increasing the Lifetime of Batteries

- Improvement of the battery efficiency (rate capacity/recovery effect)
  - Battery-aware task & I/O scheduling (load smoothing)
  - Battery-aware dynamic clock/voltage scaling

- Scheduling with respect to an energy budget
  - Guarantee of a defined active time for mission critical operations

B.2 Limiting Peak Power

- Peak power consumption may not exceed limits
  - Battery/UPS power
  - Solar power
  - Power over Ethernet (e.g., PoE with 48VDC@45W)
  - Power as contracted with utilities

→ How to guarantee mission critical services?
B.3 Thermal Management

- Temperature may not exceed limits ($T_{\text{skin}} < 55 \, ^{\circ}\text{C}$, $T_{\text{chip}} < 75 \, ^{\circ}\text{C}$)
  - Increased reliability of devices without fans
  - Reducing the noise of fans
  - Compact package size
- Reducing cost of floor space in high density data centers (700-2000 W/m$^2$)
- Safe operation in case of cooling failure
  - Power/temperature estimation
  - Thermal response mechanism
  - Service specific power throttling policy
  - Distributed thermal management
    - Temperature modeling and estimation
    - Load balancing (load assignment/migration) and throttling

B.4 Energy Accounting and Billing
B.5 The Need for Energy Characterization

- Power Management has to decide
  - When
  - Where
  - How fast
  - Under which environmental conditions
  - At which price for power and cooling

any activity in the system is allowed to take place.

- The energy-related behavior of the system is the basis of all power-management decisions.

- If we cannot predict the behavior of the system off-line, we have to observe the system.

→ The Case for On-Line Energy Characterization