

B The Playground for Power Management

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 ($T_{\text{skin}} < 55\text{ °C}$, $T_{\text{chip}} < 75\text{ °C}$)
 - ◆ Increased reliability of devices without fans
 - ◆ Reducing the noise of fans
 - ◆ Compact package size
 - ◆ Reducing cost of floor space in high density data centers ($700\text{-}2000\text{ W/m}^2$)
 - ◆ 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