Electronics and Software Solutions for Real-Time Power Management in Handheld & Wireless Devices

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...A Better Title...

How to Make Gadgets That Run Longer!

Why?

- For the soldier in a forward or sensitive area, extending a device's battery life has the potential to...
  - ...greatly improve mission effectiveness
  - ...make new mission scenarios possible

Example Gadgets

- PDAs
- Smart sensors
- Wearable computers
- Cell phones
- Smart phones
- Wireless radios
- Autonomous robots
- Tablet computers

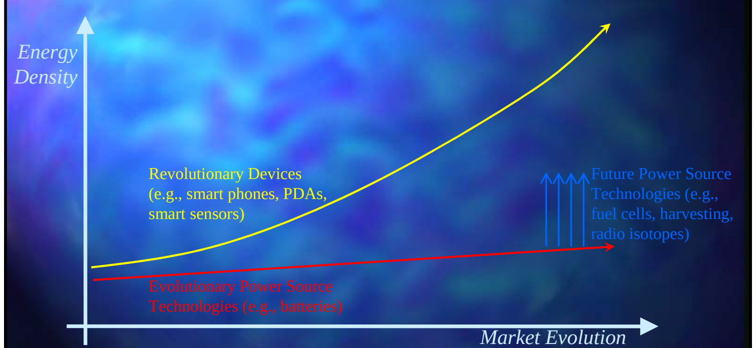
Overview

- "Device" Power Management Defined
- Why Device Power Management
- Example Device Power Management Technologies
  - Power Mode Basics
  - Energy Sharing
  - Performance Adjustment
- Summary and Future Prospects

"Device" Power Management Defined

- Definition:
  – the intelligent supervision and manipulation of energy sources and loads in mobile/handheld devices, so as to extend usable life **without affecting perceived performance**
- Why?
  – Because improvements in batteries (energy sources) are not keeping up with the requirements of devices (energy loads)

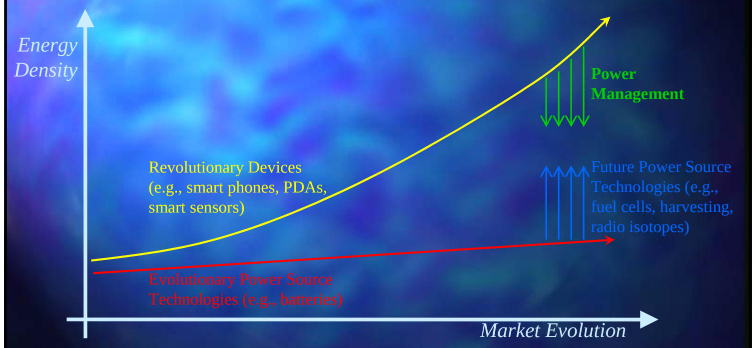
Why Device Power Management?



Why Device Power Management?

- Battery innovations are proceeding at a slow rate
  - Li-Ion battery energy density has doubled, but it has taken a decade
- Fuel cells are years away
  - "Micro" fuel cells are being introduced
  - Initial "micro" market is augmenting rechargeable batteries
  - Consumer electronics manufacturers are developing fuel cells for laptop computers, but a study by ABI Research estimates that only 10-15% of laptops will use fuel cells by 2012
- Alternative power source technologies, such as power harvesting, thin films, and radio isotopes are still futuristic

Why Device Power Management?



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Power Management – The Good News

- Device power management is a growing business
  - Battery life sells! – the longer the better
  - Size sells! – the smaller the better
- Major semiconductor and system software vendors are pushing to make their products more energy-aware
- Major hardware/software development tools suppliers are incorporating features to allow designers to better manage and limit energy consumption
- Results at the component "silicon" level:
  - Greater integration of computing and peripherals (Systems-On-Chip)
  - Handling of leakage current (smaller fabrication geometries)
  - Use of power islands to make energy control more granular
  - Provision for power modes in CPU hardware and OS software
  - Highly integrated digitally controllable power supplies

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Power Management – The Challenge

- These innovations at the semiconductor and system software level must be orchestrated into gadget designs
  - How a component's power management features are used is highly dependent on the system design of the device itself
  - Many items impact how components are combined into a complete device design
    - Feature requirements
    - Usage scenarios

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Example Scenarios

- Smart Sensor
  - Remote operation for extended periods of time
  - Takes and analyzes measurements at sparse intervals
  - Communicates alarms and other data as appropriate
  - Draws 1-1000 milli-Watts, depending on operational mode
- Smartphone
  - Provides wireless communications services
  - Allows recording/playback of multimedia
  - Keeps track of vital personal and professional information
  - Draws 5-2500 milli-Watts, depending on operational mode

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Device Power Management Technologies

- Power Mode Basics
  - Intelligent Waiting
  - Event Reduction
  - Intelligent Shutdown
- Energy Sharing
  - Load Distribution Networks
  - Hybrid Energy Sources
- Performance Adjustment
  - Clock & Voltage Scaling

Power Mode Basics

- Most CPUs for wireless devices incorporate multiple operational modes, such as Run, Idle, and Sleep
- These modes must be applied intelligently by the hardware/software designers of a device, so as to ensure maximum battery life
- Proper application of power modes can increase battery life dramatically

Intelligent Waiting

- Idling a CPU when waiting for an event reduces energy consumption without affecting performance
  - "Run" mode energy consumption can be more than twice that of "Idle" mode energy consumption, so maximizing Idle time positively affects battery life
  - Examples: in between touchscreen inputs; in between wireless packets
  - CPUs and operating systems support Idle and other modes
  - Proper use of Idle places an additional burden on the software developer
    - Never "spin" and avoid polling if at all possible

Event Reduction

- Reducing the number of events/interrupts allows the CPU to spend more time in Idle, without necessarily affecting performance
  - Most embedded operating systems now implement intelligent time-slicing
    - Software developers need to understand their software's process/thread structure and adjust accordingly
  - Direct memory access (DMA) is a well-known feature that takes on new meaning in wireless devices, because it allows the number of events to be reduced, thereby increasing Idle time and consequently battery life

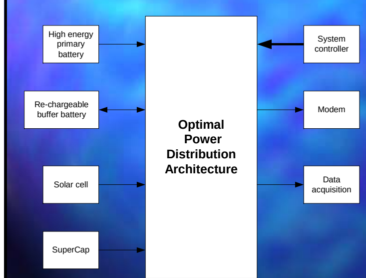
Intelligent Shutdown

- Many wireless devices never completely power off. Instead, they "suspend", and then "resume"
- Often, these devices will maintain their memory contents, while suspended in "Sleep" mode
- This feature allows immediate resumption on power-up, eliminating power-hungry bootup procedures
  - The end user application, whether for a smart sensor or smartphone, is right back where it was when power was turned off
  - Operating systems support this feature, but there is typically lots of tweaking for a specific device, depending on the device's unique features

Energy Sharing

- Devices have multiple internal loads with differing characteristics
- Different batteries have operational features that define how well they handle different types of loads
- Correct matching of batteries to loads can increase a device's operational life and lengthen a rechargeable battery's life

Load Distribution Networks



- Load distribution networks direct the flow of energy from multiple sources to multiple loads
- The goal is to "match" source and load characteristics

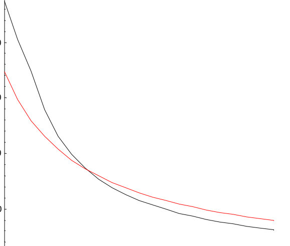
Selecting Multiple Power Sources

- To achieve the most efficient release of energy, an energy source must operate as close to it's optimal regime as possible
  - Batteries are non-linear and provide optimum energy release only in a very narrow range of operation (supply current, temperature, etc.)
  - Run/Idle modes create highly variable peak-to-average power and energy consumption
  - A single energy source is not efficient for all modes

Combination Energy Sources

- A combination energy source incorporates multiple sources and hardware/software to distribute energy from the sources in real-time as a function of load changes
  - Devices with widely variable power modes – such as smart sensors – can benefit greatly from properly managed hybrid sources

Combination Energy Sources



- The graph shows a standard battery source (red) and a combination source (black)
- At a 1% run/idle duty cycle, the combination source (with appropriate intelligence) increases battery life by 20%, **without altering volume or weight**

Device Performance Adjustment

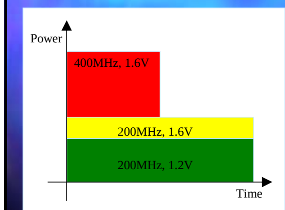
- A device's software tasks have varying performance requirements
- Most of today's CPUs for wireless devices can operate at different clock frequencies
- Proper adjustment of clock frequency can greatly impact battery life
- This is an area of significant business interest right now

Clock & Voltage Scaling

- The internal performance level of a CPU core is directly proportional to its clock frequency
- The power consumed by a CPU core is directly proportional to its clock frequency
- The power consumed by a CPU core is directly proportional to the square of its supply voltage

- $P = K * F * V^2$

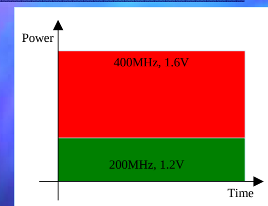
Clock & Voltage Scaling



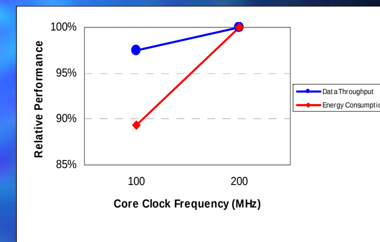
Energy is the area under the curve

- Reducing a CPU's clock frequency by 50% without reducing voltage cuts power consumption for the core by about 50%
- However, because internal performance is reduced by 50%, a task can take twice as long
- The result is that energy consumption is approximately the same
- However, if voltage is dropped too, overall energy consumption is reduced
- Basis for "just-in-time" algorithm (reduce Idle time)

Clock & Voltage Scaling



Task completes in same amount of time, regardless of clock frequency



- Certain tasks are independent of the CPU's clock frequency
- "Saturation" algorithms reduce clock frequency and voltage, even when the CPU is executing
- Saturation algorithms identify periods when performance is independent of clock frequency (e.g., wireless I/O and storage I/O)
  - Energy consumed during these scenarios can drop significantly, depending on activity

Summary

- Energy sources for devices are improving at a linear rate, while energy requirements for devices are increasing at an exponential rate
- Many silicon, software, and tools providers are now making their products energy-aware
- Innovations in system-wide power management technologies are now taking advantage of the energy-aware features of new components, thereby reducing the gap between energy sources and energy loads

The Future of Power Management

- More intelligence in clock and voltage adjustment and power distribution
- Asynchronous circuits
- More advanced power modes and power islands
- Dynamic incremental adjustments to internal silicon device properties, to account for manufacturing differences, temperature variations, etc.