Energy Estimation of Peripheral Devices in Embedded Systems

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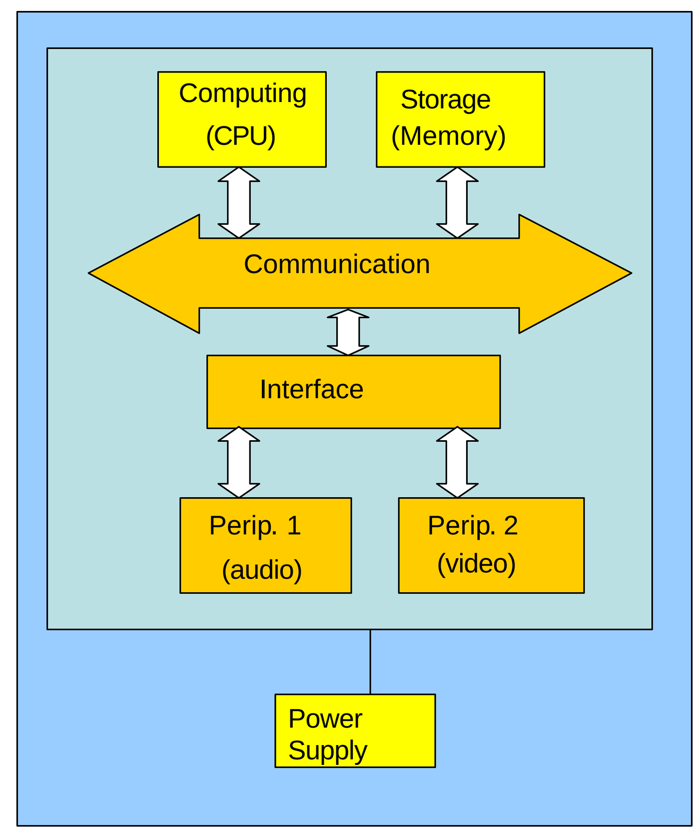
Motivation

- Embedded Systems
  - Faster
  - Powerful
  - Longer
- Increase in energy consumption
- Peripheral Devices
  - Audio, video, wireless links …
  - 60 % of system energy consumption
- Energy Optimization
  - Datasheet values
  - Prototype
  - Simulator
- Proposal: An cycle-accurate energy simulator including peripheral devices

Cycle-Accurate Energy Simulator

- Devices
  - Computing
  - Storage
  - Interface
  - Peripheral
  - Power supply
- Communication
  - Address bus
  - Data bus
- Each Device
  - Energy model per operation mode
- Total energy consumption

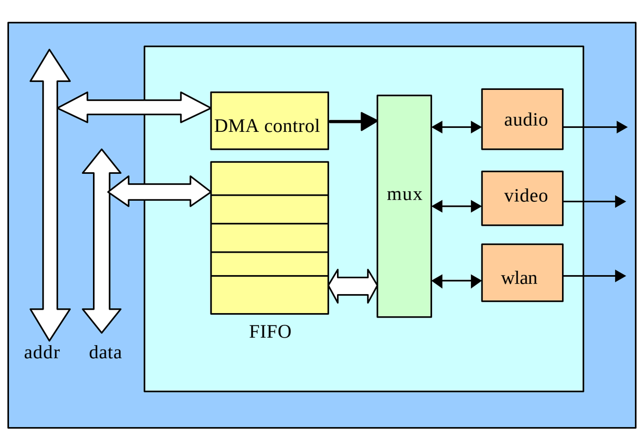
$$E_{Cycle} = E_{Computing} + E_{Storage} + E_{Power} + E_{Interface} + E_{Peripheral}$$



- ARMulator v1.1
  - Performance simulator
  - ARM processors
  - Modular simulator
- Previous Work
  - Computing
  - Storage
  - Power supply
- Communication Protocols
  - Polling-based
  - Interrupt-based
  - DMA

Interface Device

- I/O controller
  - Type
    - Coprocessor
    - FPGA
    - ASIC
    - Nonexistent
  - Operation modes
    - Active
    - Idle



  - Equivalent Capacitance $C_{coproc,state} = \frac{I_{coproc,state}}{V_{dd,coproc} * f_{coproc}}$
  - Energy Consumption $E_{coproc,state} = \frac{C_{coproc,state} * V^2_{dd,coproc}}{N_{coproc}}$

Audio Peripheral

- Audio Interface
  - Data Conversion
  - Operation Modes
    - Standby
    - Digital to analog
    - Analog to digital
  - Equivalent Capacitance

$$C_{audio,state} = \frac{I_{audio,state}}{V_{dd,audio} * f_{audio}}$$

  - Energy Consumption

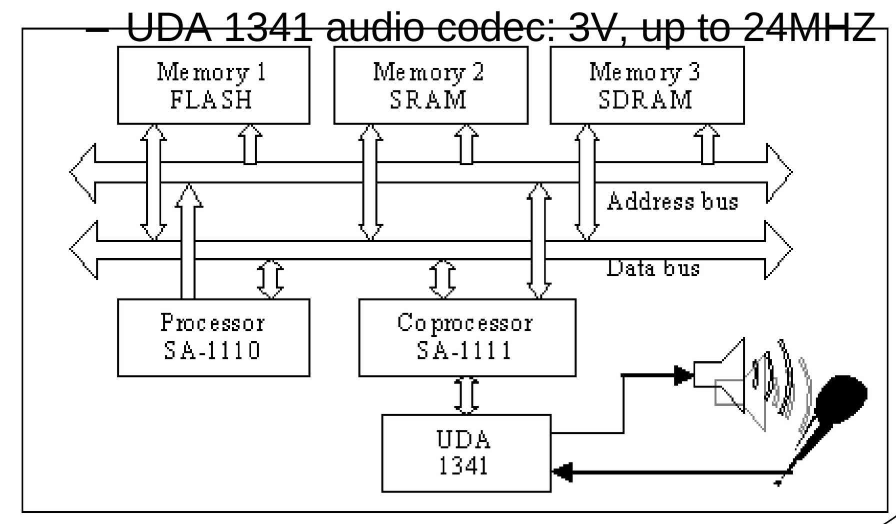
$$E_{aud,mod} = \frac{C_{aud,mod} * V^2_{dd,audio}}{N_{audio}}$$

- Audio Device
  - Analog Device
  - Parallel RC circuit
  - Single operation mode
  - Energy consumption

$$E_{dev} = \frac{V^2_{sample}}{R_{dev} * f_{simulator}} + C_{dev} * V_{sample} * \Delta V$$

Architecture

- SmartBadge IV
  - SA-1110 processor 200MHz
  - Memory
    - FLASH: 4MB, 5MHz
    - SRAM: 2MB, 70ns access time
    - SDRAM: 64MB, 100MHz
  - SA-1111 coprocessor: 3.6864 external clock
  - UDA 1341 audio codec: 3V, up to 24MHZ



Audio Device Driver

- Polling-based
  - Status check of I/0 buffer status
    - 96% of the energy
  - Actual data transfer
    - 3% of the energy

Routine	Energy %
check_fifo	96.29
to_fifo	1.30
from_fifo	1.29
main	0.29
flsbuf	0.02

- Interrupt-based
  - DMA-supported
    - Direct transfer between memory and the device
    - CPU in sleep mode
  - Actual data transfer
    - 99% of the energy

Routine	Energy %
dma_transfer	98.78
flsbuf	0.49
fprintf	0.11
freopen	0.06
fputc	0.04

MP3 Audio Decoder

- Tested with both audio drivers
- 5 second audio sample is used
- Sample is decoded and played
- 44% total system energy consumption reduction with interrupt-based device driver

Audio driver	Polling-based		DMA-based		
	Energy (J)	%	Energy (J)	%	% diff.
Proc.	2.59	18.43	0.86	10.95	66.74
Mem.	3.30	23.47	1.27	16.15	61.49
SA1111	1.06	7.55	0.93	11.81	12.44
Sys. Bus	0.02	0.16	0.01	0.19	36.18
Audio D.	3.25	23.09	3.25	41.33	-0.20
DC_DC	0.76	5.42	0.54	6.84	29.26
Battery loss	3.08	21.89	1.00	12.73	67.45
System	14.06		7.87		44.03

Future Work

- Modeling of video peripheral devices
- Modeling of wireless communication peripheral devices
- Modeling of sensor peripheral devices
- Integrating multiple models in one framework

Conclusion

- Importance of Energy Optimization
- Effects of peripheral devices on energy optimization
- Cycle-accurate energy simulation
- Audio Driver Optimization
  - 44 % energy reduction