An Analysis of Power Consumption in a Smartphone

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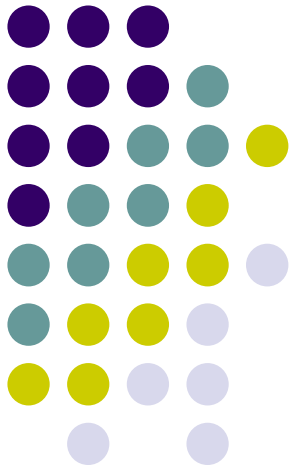
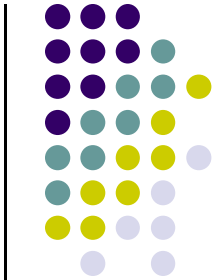
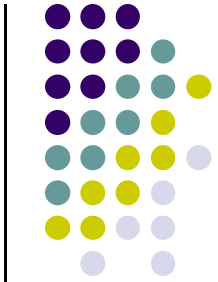


Introduction



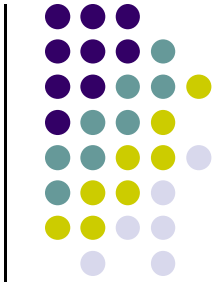
- Energy efficiency of the smartphones is very important, which needs a effective energy management.
- The core requirement for the energy efficient management is a good understanding of *where* and *how* the energy is used.
- This paper presents a detailed analysis of the power consumption of a recent mobile phone, the Openmoko Neo Freerunner.

Related Work



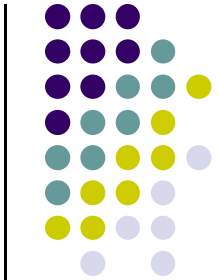
- Mahesri and Vardhan analyzed the power consumption on a laptop. Their conclusion is the CPU and display are the main consumer.
- Bircher and John looked at component power estimation using modeling techniques.
- Later, Bircher and John measure the power consumption of the CPU, RAM under a number of workload.
- Sagahyroon used a similar method to analyze the power consumption on a handed PC.

Methodology



- The approach is to measure the component level power consumption on a real hardware.
- Three elements: the device-under-test (DuT), a hardware data acquisition (DAQ) system and a host computer.
- Experimental Setup: Insert sense resistors on the power supply rails of the relevant components to measure the voltage drop with a know resistance.
- Software: the Android 1.5 (Freerunner) + the power-data collection software (the host computer) to collect raw data from DAQ.

Device under test & Benchmarks



- Openmoko Neo Freerunner mobile phone, the HTC Dream (G1) and Google Nexus One (N1).
- Freerunner hardware specifications.

Component	Specification
SoC	Samsung S3C2442
CPU	ARM 920T @ 400 MHz
RAM	128 MiB SDRAM
Flash	256 MiB NAND
Cellular radio	TI Calypso GSM+GPRS
GPS	u-blox ANTARIS 4
Graphics	Smedia Glamo 3362
LCD	Topploy 480 × 640
SD Card	SanDisk 2 GB
Bluetooth	Delta DFBM-CS320
WiFi	Accton 3236AQ
Audio codec	Wolfson WM8753
Audio amplifier	National Semiconductor LM4853
Power controller	NXP PCF50633
Battery	1200 mAh, 3.7 V Li-Ion

- Two types of benchmarks:
  - The first series of micro-benchmarks to independently characterize Components of the system.
  - The second series of micro-benchmarks based on real usage scenarios.

Baseline cases

- Suspended device: the state when the phone is not used. The processor performs a low level of activity but the phone still connects to the network, receive calls and SMS messages…
- Idle device: the device is fully awake but no applications are active with the backlight turned off.

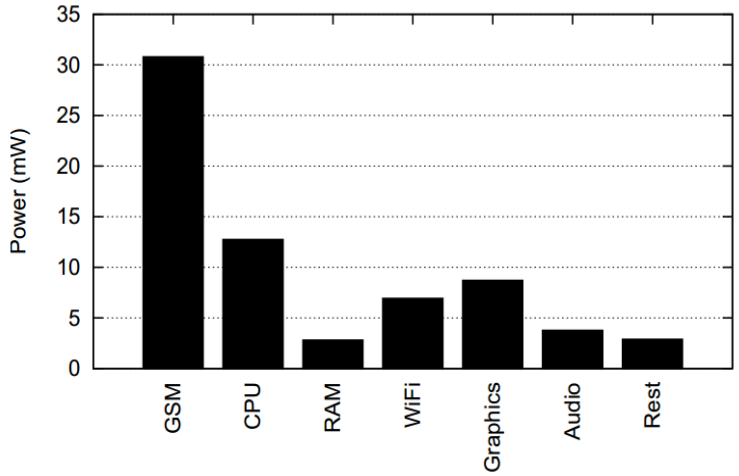


Figure 2: Power breakdown in the suspended state. The aggregate power consumed is 68.6 mW.

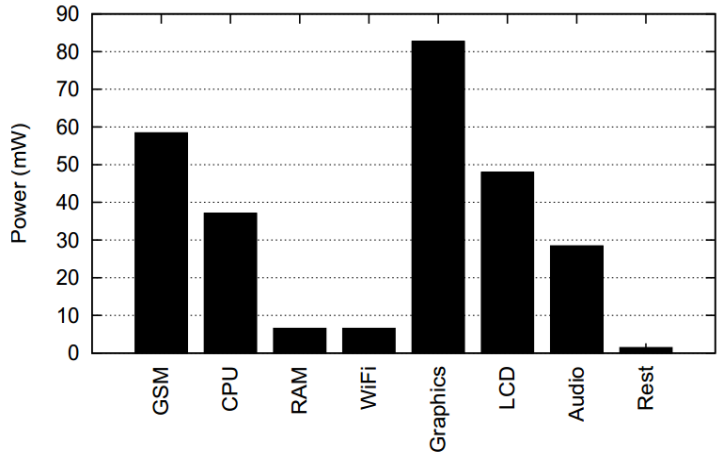


Figure 3: Average power consumption while in the idle state with backlight off. Aggregate power is 268.8 mW.

Micro-benchmarks

- CPU and RAM
  - Run a subset of the SPEC CPU2000 suite: equake, vpr, gzip, crafty and mcf.
  - For each of the benchmarks, the average CPU and RAM power are measured at fixed core frequencies of 100 MHz and 400 MHz.

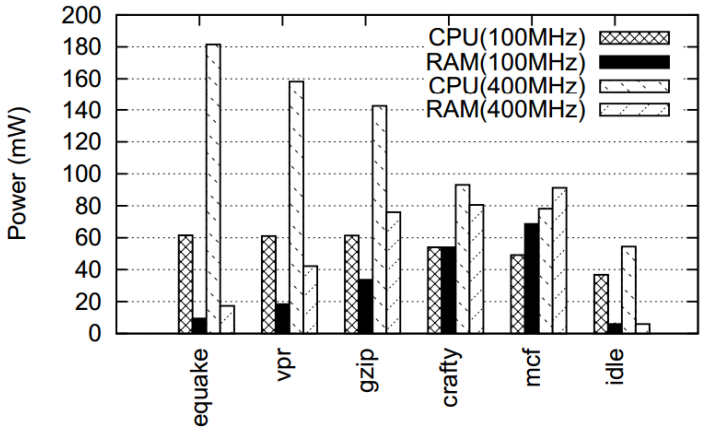


Figure 5: CPU and RAM power when running SPEC CPU2000 micro-benchmarks, sorted by CPU power.

Benchmark	Performance	Power	Energy
equake	26 %	36 %	135 %
vpr	31 %	40 %	125 %
gzip	38 %	43 %	112 %
crafty	63 %	62 %	100 %
mcf	74 %	69 %	93 %
idle	-	71 %	-

Table 3: SPEC CPU2000 performance, power and energy of 100 MHz relative to 400 MHz. Both CPU and RAM power/energy are included.

Micro-benchmarks

- Flash storage
  - Two types of flash memory: 256 MiB of internal NAND flash and an external micro Secure Digital card slot.
  - Use the Linux dd program to perform streaming reads and writes. For reads, a 64 MiB file is used. For writes, 8MiB of random data was written.

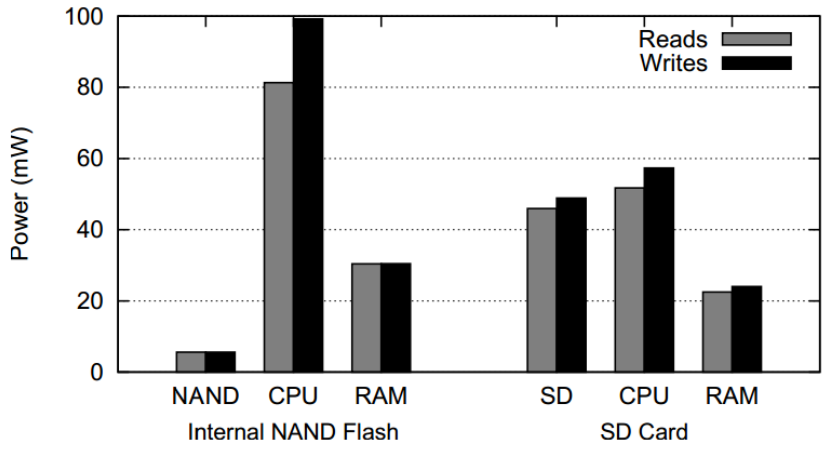


Figure 6: SD, NAND, CPU and RAM power for flash storage read and write benchmarks.

Metric	NAND	SD
Idle (mW)	0.4	1.4
Read		
throughput (MiB/s)	4.85	2.36
efficiency (MiB/J)	65.0	31.0
Write		
throughput (KiB/s)	927.1	298.1
efficiency (MiB/J)	10.0	5.2

Table 4: Flash storage power and performance.

Micro-benchmarks

- Network
  - The two main networking components: WiFi and GPRS.
  - Download a file via HTTP using wget. The files were 15 MiB for WiFi and 50 KiB for GPRS. 10 iterations of the benchmark.

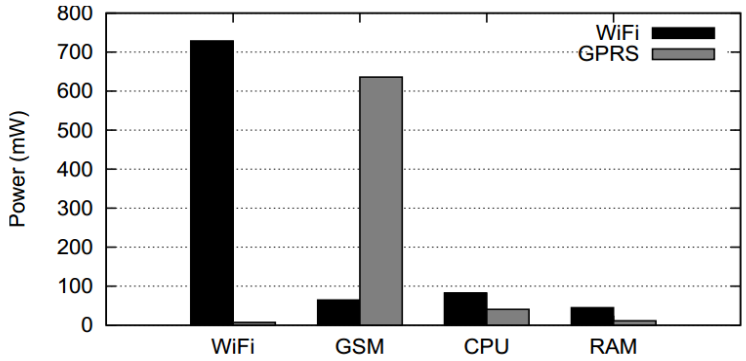


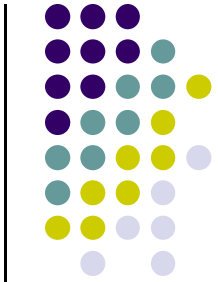
Figure 7: Power consumption of WiFi and GSM modems, CPU, and RAM for the network micro-benchmark.

State	Power (mW)
Enabled (internal antenna)	$143.1 \pm 0.05\,\%$
Enabled (external antenna)	$166.1 \pm 0.04\,\%$
Disabled	0.0

Table 5: GPS energy consumption.

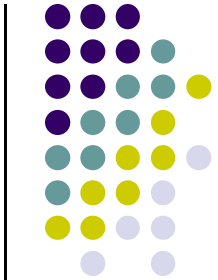
- GPS
  - Enable the module and ran the GPSStatus2 Android application.

Usage Scenarios



- Audio playback
  - The sample music is a 12.3 MiB, 537-sec stereo 44.1 kHz MP3 with the output to a pair of stereo headphones.
  - GSM is included and audio file is stored on the SD card.
- Video playback
  - Use a 5 minutes, 12.3 MiB H.263-encoded video clip (no sound) and played with Android's camera application.
- Text messaging
  - The process consists of loading the contacts application and selecting a contact, typing and sending a 55-character message, then returned to the home screen.

Usage Scenarios



- Phone call
  - Making a GSM phone call: loading the dialer application, dialing a number and making a 57-sec call.
- Emailing
  - Use Android email application. The workload consists of opening the email application, downloading and reading 5 emails and replying to 2 of them.
- Web browsing
  - Measure the power consumption of a web-browsing workload using both GPRS and WiFi connections. The benchmark ran for a total of 490 seconds and consists of loading the browser application, selecting a bookmarked web site and browsing several pages.

Usage Scenarios

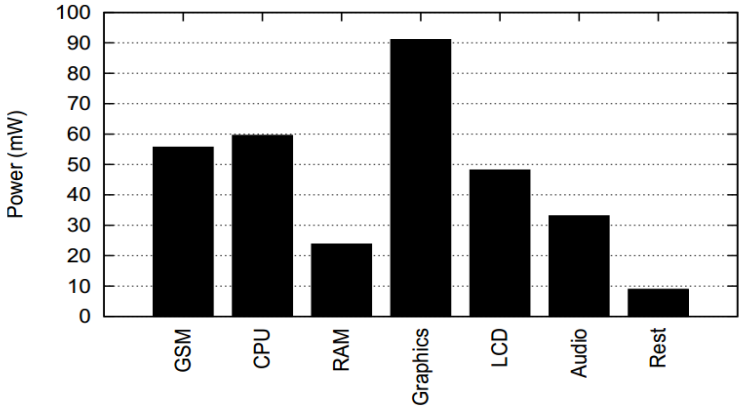


Figure 8: Audio playback power breakdown. Aggregate power consumed is 320.0 mW.

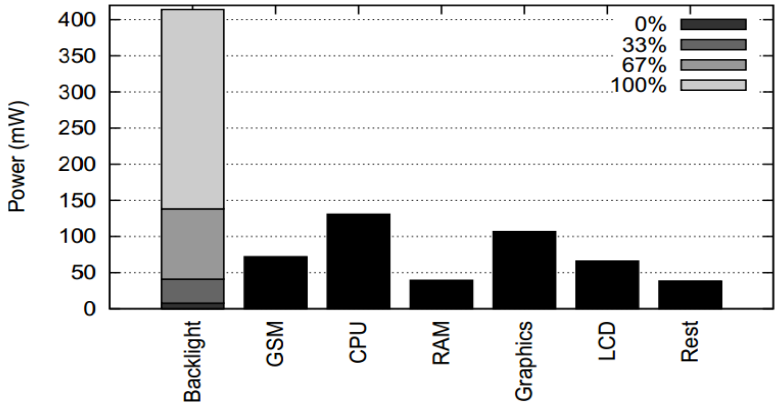


Figure 9: Video playback power breakdown. Aggregate power excluding backlight is 453.5 mW.

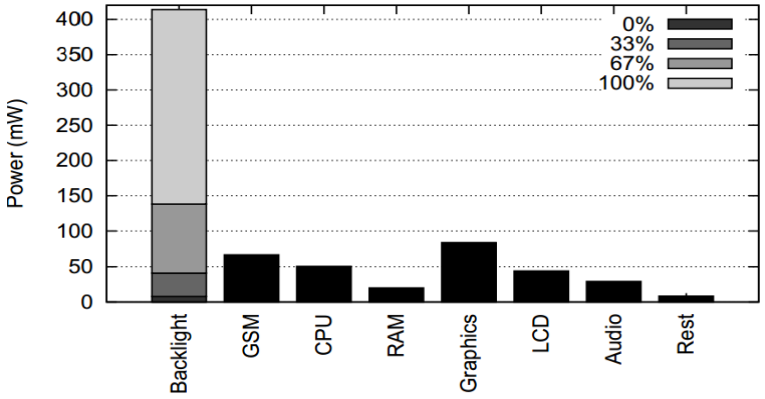


Figure 10: Power breakdown for sending an SMS. Aggregate power consumed is 302.2 mW, excluding backlight.

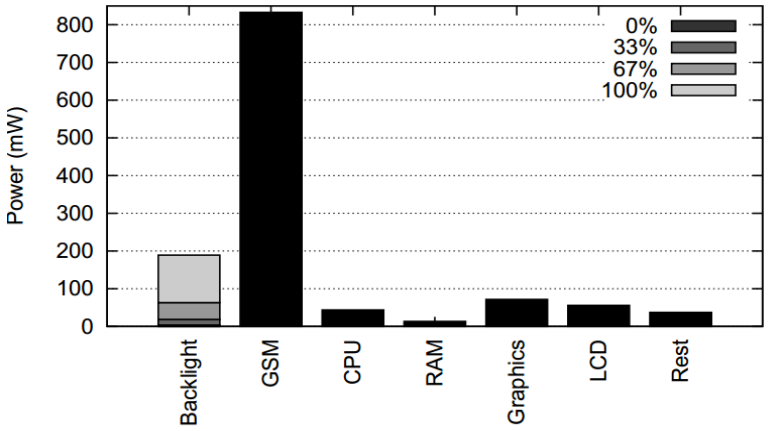


Figure 11: GSM phone call average power. Excluding backlight, the aggregate power is 1054.3 mW.

Usage Scenarios

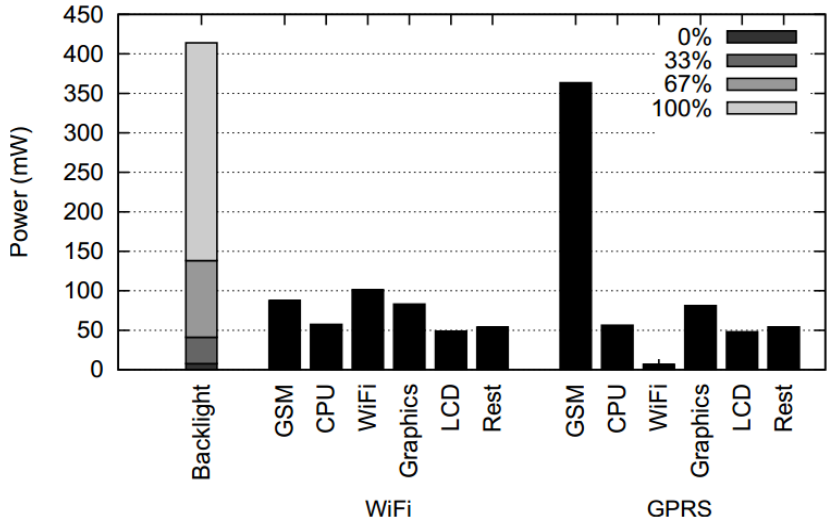


Figure 12: Power consumption for the email macro-benchmark. Aggregate power consumption (excluding backlight) is 610.0 mW over GPRS, and 432.4 mW for WiFi.

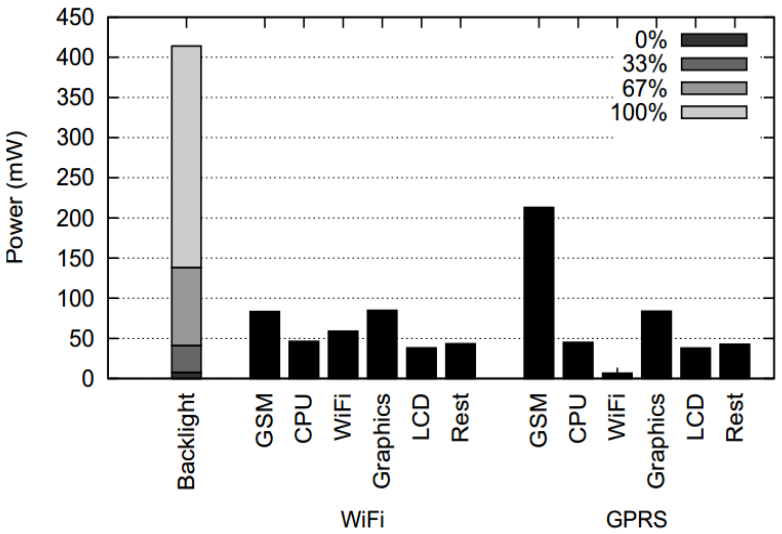
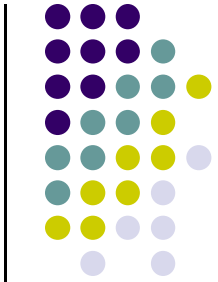


Figure 13: Web browsing average power over WiFi and GPRS. Aggregate power consumption is 352.8 mW for WiFi, and 429.0 mW for GPRS, excluding backlight.

The HTC Dream (G1) and the Google Nexus One (N1)



- 246 MHz and 384 MHz on the G1, 245 MHz and 998 MHz on the N1.

	G1	N1
SoC	Qualcomm MSM7201	Qualcomm QSD 8250
CPU	ARM 11 @ 528 MHz	ARMv7 @ 1 GHz
RAM	192 MiB	512 MiB
Display	3.2" TFT, 320x480	3.7" OLED, 480x800
Radio	UMTS+HSPA	UMTS+HSPA
OS	Android 1.6	Android 2.1
Kernel	Linux 2.6.29	Linux 2.6.29

Table 6: G1 and Nexus One specifications.

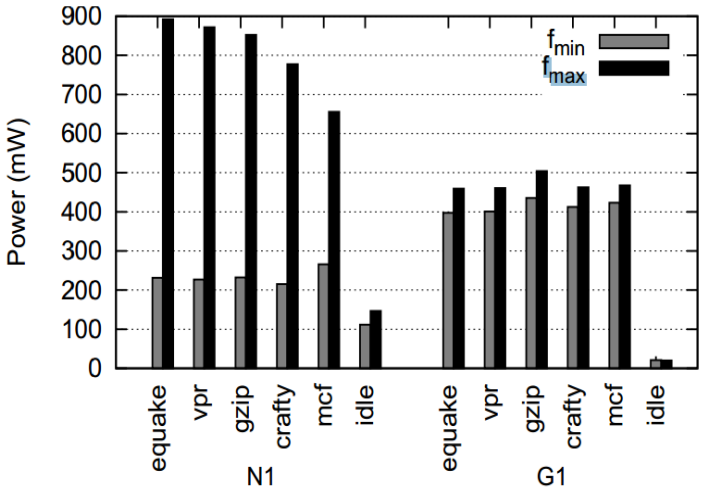
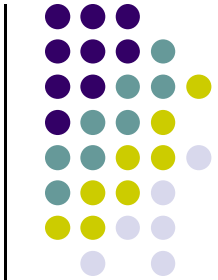


Figure 15: N1 and G1 system power for SPEC CPU2000 benchmarks.

Benchmarks



- Bluetooth
  - Re-Ran the audio benchmark on the G1 with the audio output to a Bluetooth stereo headset.

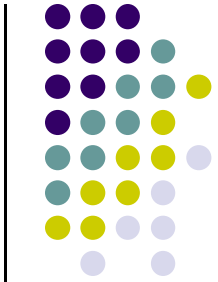
Benchmark	Power (mW)	
	Total	Bluetooth
Audio baseline	459.7	-
Bluetooth (near)	495.7	36.0
Bluetooth (far)	504.7	44.9

Table 8: G1 Bluetooth power under the audio benchmark.

Benchmark	Average System Power (mW)		
	Freerunner	G1	N1
Suspend	103.2	26.6	24.9
Idle	333.7	161.2	333.9
Phone call	1135.4	822.4	746.8
Email (cell)	690.7	599.4	-
Email (WiFi)	505.6	349.2	-
Web (cell)	500.0	430.4	538.0
Web (WiFi)	430.4	270.6	412.2
Network (cell)	929.7	1016.4	825.9
Network (WiFi)	1053.7	1355.8	884.1
Video	558.8	568.3	526.3
Audio	419.0	459.7	322.4

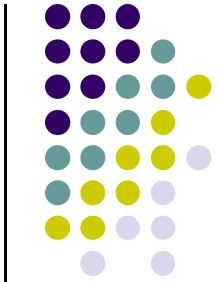
Table 9: Freerunner, G1 and N1 system power (excluding backlight) for a number of micro- and macro-benchmarks.

Analysis



- The GSM module consumes a great deal of both static and dynamic power.
- In all except the GSM-intensive benchmarks, the brightness of the backlight is the most critical factor.
- Overall, the static contribution to system power consumption is substantial.
- The RAM, audio and flash subsystems consistently show the lowest power consumption.

DVFS & Energy Model

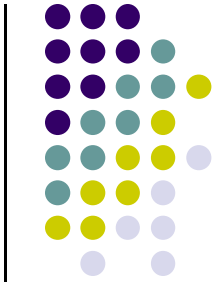


Benchmark	% Energy		
	Freerunner	G1	N1
equake	95.5	126.0	75.6
vpr	95.8	124.5	75.9
gzip	95.8	120.1	77.7
crafty	95.5	115.6	77.3
mcf	94.9	105.3	65.9

Table 11: SPEC CPU2000 percentage total system energy consumption of the minimum frequency compared with the maximum frequency, padded with idle power.

$$
\begin{aligned}
E_{\text{audio}}(t) &= 0.32W \times t \\
E_{\text{video}}(t) &= (0.45W + P_{\text{BL}}) \times t \\
E_{\text{sms}}(t) &= (0.3W + P_{\text{BL}}) \times t \\
E_{\text{call}}(t) &= 1.05W \times t \\
E_{\text{web}}(t) &= (0.43W + P_{\text{BL}}) \times t \\
E_{\text{email}}(t) &= (0.61W + P_{\text{BL}}) \times t
\end{aligned}
$$

Modeling usage patterns



- Suspend, Casual, Regular, Business and PMD (portable media device)

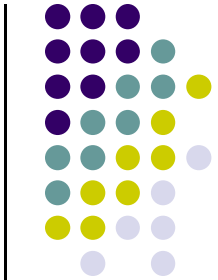
Workload	SMS	Video	Audio	Phone call	Web browsing	Email
Suspend	-	-	-	-	-	-
Casual	15	-	-	15	-	-
Regular	30	-	60	30	15	15
Business	30	-	-	60	30	60
PMD	-	60	180	-	-	-

Table 12: Usage patterns, showing total time for each activity in minutes.

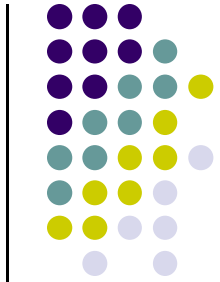
	Power (% of total)							Battery life
Workload	GSM	CPU	RAM	Graphics	LCD	Backlight	Rest	[hours]
Suspend	45	19	4	13	1	0	19	49
Casual	47	16	4	12	2	3	16	40
Regular	44	14	4	14	4	7	13	27
Business	51	11	3	11	4	11	10	21
PMD	31	19	5	17	6	6	14	29

Table 13: Daily energy use and battery life under a number of usage patterns.

Limitations



- Freerunner is older and lack of 3G cellular interface.
- The processor is based on ARMv4



Q&A
Thanks