**Statistical Analysis of Processor Frequency Scaling Algorithms**

Recently can be observed a growth in mobile device sales, including smartphones and tablets, with its high quantity and diversity of hardware and software models, it put on focus the fragmentation problem. Batteries with low capacity are constraints in design of embedded systems. The increase of features highlighted the need for greater capacity in mobile batteries to provide an extended time of use.

This work proposes an environment for simultaneously execute tests on mobile devices with support for energy analysis.

Two major technology smartphones were used to evaluate the proposed environment. Experiments to provide energy efficiency optimizations in mobile processor frequency scaling were conducted. From the analysis made in the environment, techniques using DVFS that allowed energy savings of up to 25\% were created.

Recientemente se observa un crecimiento en las ventas de dispositivos móviles, incluyendo teléfonos inteligentes y tabletas, con su gran cantidad y diversidad de modelos de hardware y software, que puso el foco del problema de la fragmentación.

Problema

Las baterías con baja capacidad son las limitaciones en el diseño de sistemas embebidos. El aumento de las características de relieve la necesidad de una mayor capacidad de las baterías de móviles para proporcionar un largo tiempo de uso.

Objetivo

Este trabajo propone un entorno para ejecutar simultáneamente pruebas en los dispositivos móviles con soporte para análisis de energía.

Método

Dos de los principales teléfonos inteligentes de tecnología se utilizaron para evaluar el entorno propuesto. Los experimentos para proporcionar optimizaciones de eficiencia energética en móvil escalado de frecuencia de procesador se llevaron a cabo.

Resultado

A partir del análisis realizado en el medio ambiente, se han creado técnicas que utilizan DVFS que permitieron un ahorro energético de hasta un 25 \%.

**Introduction**

Devices such as smartphones and tablets that use the Android operating system grew surprisingly, increasing from 200.000 activated per day in 2010 to 1.5 million devices activated per day in 2013 and actually is the platform with more active devices \cite{statista2014}. This growth can be explained by the amount of features that are aggregated to smartphones and tablets each year, reducing costs of equipment and the variety of options that encompass the various user profiles, from simple and inexpensive to more complex solutions.

The need to prolong the use of devices, the strong growth of mobile devices and Android operating system, the breakthrough in the development of multicore processors, it becomes necessary to develop techniques that reduce the energy consumption of these devices to increase its time of use. This is a concern of most mobile devices design, among these are smartphones and tablets.

Devices with more features require more processing power and consequently more energy dissipation. This processing power is measured by the amount of processors and cores and the clock frequency of each core of the processor. For developing techniques that allow energy efficiency it is necessary to understand the problem addressed and the characterization of their energy spent on mobile.

El objetivo de este trabajo es definir una metodología para el análisis estadístico del consumo de energía de los dispositivos móviles en entornos integrados (software y hardwerd). La caracterización de los dispositivos a partir de esta metodología sería un paso fundamental en el desarrollo de nuevas técnicas para reducir el consumo de energía en los dispositivos móviles.

The remainder of this paper is organized as follows:

\subsection{Linux and Android Governors}

The Linux operating system uses governors for operational control system. Governors are regulatory modules of the Linux kernel that communicate with the hardware. The main function is to regulate the operating frequencies of the processor cores. The Android OS is based on Linux kernel and also uses governors. There governors that focus on performance, while others, in energy savings. This choice must be made according to user usage profile \cite{vpallipadi2006}.

Performance and energy spent minimization are opposite variables. When improve one, worse another. It is necessary to balance these variables to provide the user a better user experience. The governors more used in Linux operating system are: OnDemand, Performance and PowerSave. For Android operating system has that ones used in Linux with others adapted for mobile devices, such as Interactive, PegasusQ, UserSpace, among others.

\subsection{Techniques to Reduce Energy Consumption}

Several techniques that reduce energy consumption in mobile devices are available in literature. You can perform energy optimizations in several areas, such as data transmission: choose intelligently and in runtime which data network is better to use, Wifi or mobile networks (2G / 3G / 4G) \cite{gperrucci2009}, decreased downtime at the end of data transmissions, this technique is called fast dormancy \cite{fxu2013}, grouping data packets and send by bursts (batching) \cite{rpalit2012} \cite{jhuang2012}, decouple processing the transmission of data \cite{fxu2013}, processing off-load to the cloud, Dynamic Voltage and Frequency Scaling (DVFS) \cite{asilvafilho2012}, among others.

In DVFS technique is possible to reduce the operating frequency of the processor or the voltage to decrease the power expended. In some cases, performance is affected by the decrease in operating frequency, while in some cases it is irrelevant. The energy consumption is calculated using the formula of the instantaneous power. Power is proportional to the frequency and voltage squared \cite{mdomeika2008}.

\begin{equation}

\label{eq:dvfs}

p = cfv^{2} + p\_{\_{static}}

\end{equation}\\

\section{Database Selection}

We built our database from experimentation. Each experiment is composed of a set of trials, in each trial we analyse the impacts of application of some algorithm. Each algorithm do some combination in processor frequency scaling trying to minimize energy consumption, get better performance or both. We repeated each experiment 30 times and calculated statistics variables like mean and standard deviation of samples.

In the smartphone we have a lot of dynamic variables inside the operational systems like: GPS, Data Network (WiFi or Cellular network), Calls, Applications updates, Events and the Process from the operational system itself. All the components that can be disabled will be, all the others that is impossible to disable, we will try to minimize the impact in the output variable and control that impact. Experiments will run in smartphones: Samsung Galaxy S3 (GT-9305T) and Samsung Galaxy S4 (GT-I9505). The experiments combinations are in Table \ref{table:ExperimentTrials}. The S3-700 and S4-702 represents the frequency that obtained the minimum value of energy consumption, S3-1100 and S4-1134 are the near frequency of the mean energy consumption and S3-1400 and S4-1890 the frequency that reached the maximum energy consumption.

**Resultados**

Question

Data source

Processing

Analysis

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| Tabla XXX. Sumarize | | | | | | | | | |
|  | Min. | 1st Qu. | Mediam | Meia | Sd. | Var | 3er Qu. | Max. | N |
| PS | 238.00 | 242.13 | 244.45 | 244.70 | 3.64 | 13.26 | 246.47 | 252.20 | 30 |
| O | 223.33 | 237.70 | 240.57 | 240.69 | 6.22 | 38.72 | 244.14 | 257.51 | 30 |
| P | 186.36 | 198.72 | 199.32 | 201.25 | 5.18 | 26.83 | 202.40 | 208.22 | 30 |
| PQ | 188.94 | 200.75 | 202.45 | 201.32 | 4.60 | 21.18 | 203.46 | 208.20 | 30 |
| **700MHz** | **172.37** | **179.30** | **180.96** | **180.45** | **3.27** | **10.69** | **182.25** | **185.60** | **30** |
| **1100MHz** | **191.85** | **194.08** | **195.92** | **195.58** | **1.69** | **2.85** | **196.96** | **198.20** | **30** |
| 1400MHz | 226.20 | 227.51 | 229.04 | 229.74 | 2.68 | 7.18 | 231.85 | 234.50 | 30 |

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| --- |
| allboxplotgraph |
| Figura XXX. Box plot. |

Os gráfico Box-plot evidencia as diferenças existentes entre os algoritmos.

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| alldensitygraph |
| Figura XXXX. Gráfico de densidade aproximada. |

Analisis de kurtosis/skewness

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| --- | --- | --- | --- | --- | --- | --- | --- |
| Tabela XXX. Análises de kurtosis/skewness. | | | | | | | |
|  | PS | **O** | P | **PQ** | 700MHz | 1100MHz | **1400MHz** |
| kurtosis | 2.58 | **4.76** | 3.27 | **4.60** | 3.34 | 2.23 | **1.82** |
| skewness | 0.25 | **-0.10** | -1.04 | **-1.29** | -0.67 | -0.43 | **0.34** |

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| --- | --- | --- | --- | --- | --- |
|  | | | | | |
| pshistnorm | ohistnorm | | C:\Users\Pedro\AppData\Local\Microsoft\Windows\INetCache\Content.Word\phistnorm.png | | C:\Users\Pedro\AppData\Local\Microsoft\Windows\INetCache\Content.Word\pqhistnorm.png |
| PS | PQ | | P | | PQ |
| x700histnorm | | X1100MHzhistnorm | | C:\Users\Pedro\AppData\Local\Microsoft\Windows\INetCache\Content.Word\X1400MHzhistnorm.png | |
| 700MHz | | X1100MHz | | X1400Mz | |
|  | | | | | |

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| --- | --- | --- | --- | --- | --- |
|  | | | | | |
| spqqnorm | oqqnorm | | pqqnorm | | pqqqnorm |
| PS | PQ | | P | | PQ |
| X1100MHzqqnorm | | C:\Users\Pedro\AppData\Local\Microsoft\Windows\INetCache\Content.Word\X1400MHzqqnorm.png | |  | |
| 700MHz | | X1100MHz | | X1400Mz | |
|  | | | | | |

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| --- | --- | --- | --- |
| Test Aderência | Shapiro-Wilk | Lilliefors | Anderson-Darling |
| PS | 0.6321 | 0.6164 | 0.658 |
| O | 0.2109 | 0.2101 | 0.19 |
| P | 0.0009075 | 0.0007678 | 3.791e-05 |
| PQ | 0.0008656 | 0.0009473 | 0.0002399 |
| 700MHz | 0.09014 | 0.195 | 0.09208 |
| 1100MHz | 0.1943 | 0.2782 | 0.1491 |
| 1400MHz | 0.02742 | 0.2689 | 0.05013 |

**Test no parametrico de friedman con post test de nemenyi**

H\_0: mu\_1 = mu\_2 = ... m\_n

H\_1: existe mu\_i != mu\_j; i!=j

> test\_friedman$tfriedman Friedman rank sum test

data: X

Friedman chi-squared = 168.51, df = 6, p-value < 2.2e-16

> test\_friedman$ptnemenyi

Pairwise comparisons using Nemenyi multiple comparison test

with q approximation for unreplicated blocked data

data: X

PS O P PQ X700MHz X1100MHz

O 0.99161 - - - - -

P 2.3e-08 1.6e-06 - - - -

PQ 2.0e-07 1.1e-05 0.99983 - - -

X700MHz 6.6e-14 6.2e-14 0.00095 0.00020 - -

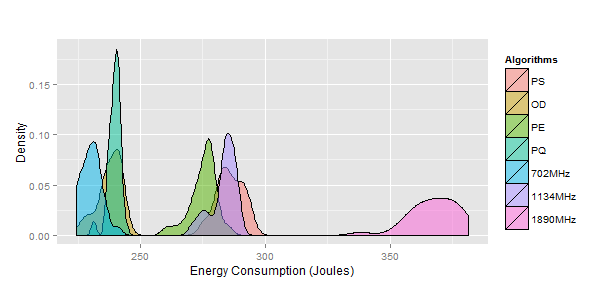
X1100MHz 1.7e-13 1.6e-11 0.55289 0.32245 0.25817 -

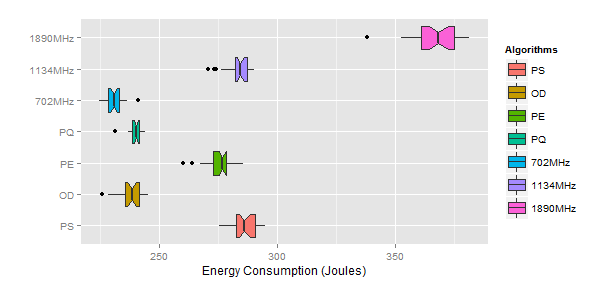
X1400MHz 0.06265 0.32245 0.02133 0.06265 6.5e-12 1.1e-05

P value adjustment method: none

S4

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Tabla XXX. Sumarize | | | | | | | | | |
|  | Min. | 1st Qu. | Mediam | Meia | Sd. | Var | 3er Qu. | Max. | N |
| PS | 275.3 | 282.3 | 285.9 | 285.8 | 5.185784 | 26.89236 | 290.4 | 294.6 | 30 |
| O | 225.5 | 235.3 | 238.2 | 237.7 | 4.829817 | 23.32713 | 241.3 | 245.0 | 30 |
| P | 260.1 | 272.7 | 276.7 | 275.1 | 5.295362 | 28.04086 | 278.3 | 285.5 | 30 |
| I | 231.3 | 238.3 | 240.0 | 239.6 | 2.389887 | 5.711561 | 241.2 | 244.0 | 30 |
| 702MHz | 224.5 | 228.0 | 230.6 | 230.5 | 3.97174 | 15.77472 | 232.8 | 241.0 | 30 |
| 1134MHz | 270.5 | 282.1 | 284.3 | 283.3 | 4.997017 | 24.97018 | 287.2 | 289.9 | 30 |
| 1890MHz | 338.2 | 361.0 | 368.2 | 367.4 | 9.678511 | 93.67358 | 375.1 | 381.5 | 30 |





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| Tabela XXX. Análises de kurtosis/skewness. | | | | | | | |
|  | PS | O | P | I | 702MHzMHz | 1134MHz | 1890MHz |
| kurtosis | 2.265748 | 3.050844 | 4.084406 | 6.021741 | 3.010252 | 3.266138 | 3.919491 |
| skewness | -0.1651545 | -0.8431631 | -0.8960374 | -1.272297 | 0.4522422 | -1.06603 | -0.8309137 |