Battery and Power Consumption of Pocket PCs

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Abstract—**Due to the increased functionality in today's portable devices, battery life and energy consumption continue to be a major concern for both designers and users. Unfortunately battery technology is not keeping pace with the energy requirements of these devices and therefore energy-efficient hardware design techniques, software optimization, energy management, and the design of efficient communication protocols continue to be explored by researches as viable means that would assist in the efficient use of the energy resources of these mobile devices. In this paper, using results obtained from a number of experiments, we investigate battery utilization and power consumption of two pocket PCs. Using benchmarks that are representative of typical workloads, and by varying the operating conditions of these devices we were able to explore the impact of a number of features available in these devices on battery life and the power consumed. Characterizing the consumption of these devices provides a platform for further research and contribute to the design of improved and energy-efficient future mobile computing devices.**

Index Terms —**portable devices, battery life, power consumption.**

I. Introduction

Mobile devices are increasingly becoming an integral part of our daily life contributing to an ever growing ubiquitous computing environment. Hence, users will continue to expect more functionality from these devices. Enhanced features and the complex operations performed by these portable devices are rapidly draining their limited system energy budget. Battery lifetime is perhaps one of the most important characteristics of a portable computer. For many users, doubling the battery lifetime may be far more important than doubling the clock frequency. A main concern is the fact that improvements in battery capacity have not kept pace with the improvements in microelectronics technology [1]. Reducing power consumption and prolonging battery-life is a major concern for designers. Battery capacity grows very slowly, about 5 to 10% every year, which is not adequate when we take into consideration the energy demand of handheld devices [2]. An understanding of the power consumption behavior of these devices and the impact of the different operating modes and scenarios on battery life is critical for the design of energy efficient devices.

In [3], an attempt was made to study the power usage of an IBM ThinkPad R40 laptop. The authors run a set of experiments to measure the power consumption of various key components such as CPU, hard disk and display. Energy consumption characterization in handheld devices for popular GUI platforms from the hardware, software, and application perspectives was discussed in [4]. Such characterization provides a basis for further research on GUI energy optimization. The power consumption of videos encoded using various codec standards and played on handheld devices was presented in [2]. Experiments were performed to explore the effects of the choice of codec standards, file formats, and encoding parameters on power consumed. Since the incorporation of 3D graphics in handhelds poses several serious challenges to the hardware designer, an analysis of the power consumption of mobile 3D graphics pipelines and the effects of various 3D graphics factors such as resolution, frame rate, level of detail, lighting and texture maps on power consumption was presented in [5].

In recent years and improve the energy budget usage of portable units, several energy management techniques have been investigated at different levels of system design – starting from silicon at the bottom to application design at the top, with communication protocols and operating system in between [6 – 9]. The primary objective of these techniques was to find means and methods to reduce the power consumption of mobile devices and extend the battery life time.

Therefore and in view of the slow battery capacity growth, it is becoming increasingly important to develop techniques to achieve high energy efficiency for handheld mobile devices. Designers must strive to maximize the amount of service work that the system can accomplish taking into consideration today's battery capacity constraints. An analysis of the power consumption requirements and an understanding of battery performance as the only energy source in these devices is essential, and offers both users and designers critical information that would assist in efficient system usage and in bringing to the market energy-efficient designs.

Initial and partial results of the work presented here were presented at APCCS [10]. In this paper an expanded and elaborate version of this work is presented. The aim is to experiment with two portable devices, namely the Compaq iPAQ 3950 and the HP iPAQ Rx3715 and assess their battery utilization as well as power consumption characteristics. The methodology used in this work is applicable to most handheld devices.

The rest of the paper is organized as follows: section 2 describes the experiment environment and the experimental setup as well the theoretical framework that forms the basis for the measurements taken. The various loads or benchmark software used is discussed in section

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3. Experimental results are presented in section 4. The paper is concluded in section 5.

II. EXPERIMENT ENVIRONMENT

The methodology used and the procedural steps taken to collect data that reflects battery usage, and the consumption characteristics are described in the following subsections.

A. *Experimental Setting*

The experimental setup or testbed consisted of the following components: the pocket PCs, the measurement apparatus and the software or benchmarks to be run to gauge the consumption. The setup is shown in Figure 1.

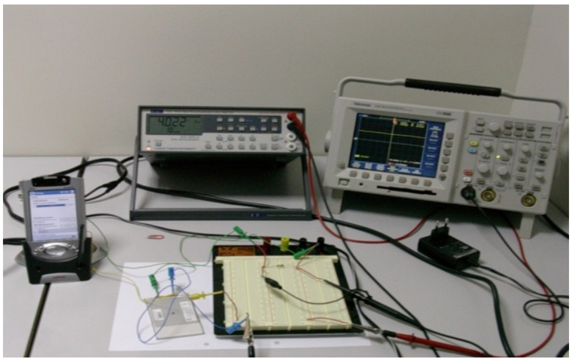

Figure 1. Experimental Setup

The Compaq iPAQ 3950 unit uses an Intel XScale processor. The speed is 400MHz and RAM is 64MB. It comes with an SD/MMC slot for extra memory. It has a transflective TFT display. Audio capabilities include microphone, speaker and a headphone jack. The only mode of wireless communication is through infrared. The operating system used is Windows Pocket PC.

The HP iPAQ Rx3715 unit uses a Samsung 2440 Processor. The speed is 400MHz and 152 MB of memory is available to the user. It also has a SD memory card support for any extra memory if required. The display is a 3.5 inch transflective color QVGA, 240 X 320 pixels, 64K color support. The backlight can be modified so as to change its brightness. For audio capabilities there is an integrated microphone, speaker, 3.5 mm stereo headphone jack, MP3 stereo through audio jack. The communication features include Infrared with a data transfer speed up to 115.2 Kbps, Bluetooth with a 10 meter range and WiFi capabilities. The Operating system used by it is Windows CE.

We used as well a Tektronix TDS 3032 Digital Phosphor Oscilloscope. It has two channels, a bandwidth of 300MHz, and maximum sample rate of 2.5GS/s. It has the capability of acquiring a maximum of 10,000 points waveforms to capture horizontal detail. The signal processing features include averaging the input signal to remove the uncorrelated noise and improve the measurement accuracy. If the signal appears noisy, the waveform intensity knob could be increased to see the noise more easily. The display features include a color LCD and digital phosphor to clearly display intensity modulation in the signal. The oscilloscope also had a built-in floppy disk to store and retreive waveforms and setups. The waveforms could be saved as a picture, spreadsheet file, MathCAD or internal format.

To prevent overcharging of the battery due to a spike upon connecting the Pocket PC directly to the power source, a protection circuit is used. The circuit diagram is of the complete setup is shown in figure 2.

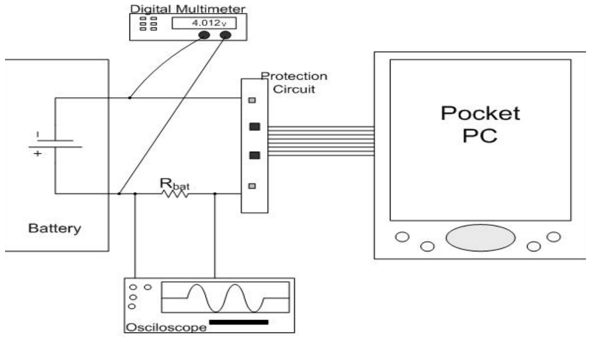

Figure 2. Circuit Diagram

In steady state, the power *P* of the pocket computer can be computed as follows:

$$P = V * I$$

Where V is the battery voltage and I is the current drawn by the computer. In this work, a digital multimeter was used to measure the voltage across the battery terminals. To measure the current, a small resistor R is positioned in series with the lithium battery. The voltage across the resistor V_R is sampled using the oscilloscope; using Kirchoff's law ($I = V_R/R$), we can compute the current drawn by the pocket computer. The instantaneous power is then computed by multiplying this current with the supply voltage. This is similar to the approach utilized in [11] to assess the power characteristics of the Itsy platform.

The oscilloscope was configured to perform a predefined number (*N)* of measurements while calculating the voltage across the battery. In our case, we set *N* at 500. At the end of every acquisition which is a set of *N* measurements the average is calculated.

For a total of N measurements taken Δ units of time apart, an estimate of the average power is computed using the following equation:

$$\mathbf{P_{AVG}} = 1/N \ \Sigma_i^N \ P(i)$$

III. SOFTWARE BENCHMARKS

In this work we experimented with a variety of workloads representing a wide range of tasks and at the same time capable of stressing different components within the PC. The applications used include:

A. *The Pocket PC Benchmark v1.02*

The application [12] tests the Pocket PC from different points of view such as calculations and heap management performance. It can execute three types of benchmarks, namely, CPU Benchmark, Graphics Benchmark and Flat File Benchmark. The benchmarks can be executed on a loop count from 1 to 1000. The advantage of this software was that we were able to execute these benchmarks on a loop of 1000 till the battery is drained. A brief description of each benchmark is provided below.

CPU Benchmark -

The CPU benchmark includes the following variations:

Integer arithmetic

The basic four integer arithmetic operations are addition, subtraction, multiplication, and division. Arithmetic operations can be signed or unsigned.

Heap Management

Applications allocate and manipulate memory primarily in their application heap. Space in the application heap is allocated and released on demand. When the blocks in the heap are free to move, the Memory Manager can often reorganize the heap to free space when necessary to fulfill a memory-allocation request. In some cases, however, blocks in the heap cannot move. In these cases, you need to pay close attention to memory allocation and management to avoid fragmenting the heap and running out of memory .

Floating Point Arithmetic

Arithmetic operations on floating point numbers consist of addition, subtraction, multiplication and division.

Graphics Benchmark -

The Graphics Benchmark runs Graphics Device Interface (GDI) applications so as to mimic the Standard graphics functions provided by Windows.

Flat File Benchmark -

The Flat File benchmark helps us study two important aspects of the memory which are file reading and file writing to Pocket PC's internal memory.

B. *The Spb Benchmark 1.0*

The Spb Benchmarks [13] is one of standard benchmarks which are used in Pocket PC power consumption analysis. It offers a variety of tests such as:

- Processor speed
- Memory Bus speed
- Screen and graphics speed
- Battery lifetime
- Storage card read/write speed

Using this software tests can vary from the most economical with no backlight, zero utilization to the most power consuming maximum backlight, video playback. Each single battery test is carried out for the whole battery lifetime period .

Finally, the XCPUScalar software is used to dynamically change the processor speed of the Pocket PC; it unlocks processor dynamic scaling capabilities [14]. We used this application to vary the frequency of the Pocket PCs between 100Mhz to 500MHz to study the effect of the change in frequency on power consumption.

IV. EXPERIMENTAL RESULTS

Using a series of experiments, we run the benchmarks described above using different scenarios and modes of operation to understand effect on battery life and power consumption of the devices. A brief description of each experiment is provided below:

Experiment 1 - We measured the battery consumption when the Pocket PC was idle at normal frequency i.e. 400 MHz and the display brightness was set to maximum.

Experiment 2 - This experiment was performed using one of the battery tests in the SPB benchmark suite. It we played the MP3 with the display off at 400 MHz .

Experiment 3 - In this experiment, MP3 was played at 400 MHz and the display brightness was set to maximum.

Experiment 4 - MP3 is played at the Pocket PCs normal frequency and the display brightness was set to 50%.

Experiment 5 - In this experiment we used the SPB benchmark suite. The battery test that we used periodically opened Pocket Word, loaded a document and closed Pocket Word and the display brightness was set to maximum level. The frequency was set at 400 MHz.

Experiment 6 - In this experiment, we used the CE performance benchmark which executed 1000 loops of CPU intensive operation. The display brightness was set to 0% and the processor frequency was at 400 MHz.

Experiment 7 - In this experiment, MP3 was played at 500 MHz and the display brightness was set to maximum. Also the speaker volume was set to the highest level.

Experiment 8 - In this experiment, MP3 was played at 300 MHz and the display brightness was set to maximum. Also the speaker volume was set to the highest level.

Experiment 9 - In this experiment, MP3 was played at 100 MHz and the display brightness was set to maximum. Also the speaker volume was set to the highest level.

Experiment 10 - In this experiment, we used the 'Pocket PC Benchmark' which executed 1000 loops of CPU intensive operation. The display brightness was set to 0% and the processor frequency was at 500 MHz.

Experiment 11 - In this experiment, we used the CPU benchmark which executed 1000 loops of CPU intensive operation. The display brightness was set to 0% and the processor frequency was at 100 MHz.

Experiment 12 - MP3 was played at 500 MHz and the display brightness was set to 50%.

Experiment 13 - MP3 was played at 100 MHz and the display brightness was set to 50%.

Experiment 14 - In this experiment we used the SPB benchmark suite. The battery test that we used periodically opened Pocket Word, loaded a document and closed Pocket Word and the display brightness was set to maximum level. The frequency was set at 500 MHz.

Experiment 15 - In this experiment we used the SPB benchmark suite. The battery test that we used periodically opened Pocket Word, loaded a document and closed Pocket Word and the display brightness was set to maximum level. The frequency was set at 100 MHz.

Experiment 16 - In this experiment, we used the 'Pocket PC Benchmark' which executed 1000 loops of Flat File operations. It starts off by performing 1000 file write operations and then 1000 loops of file read operations. We executed this benchmark at 100MHz and the Pocket PC display Brightness was set to 0%.

Experiment 17 - In this experiment, we used the 'Pocket PC Benchmark' which executed 1000 loops of Graphic operation. We set the display brightness to 100%, the frequency was set to 400MHz and executed 1000 loops of graphic operations.

Experiment 18 - In this experiment, we used the 'Pocket PC Benchmark' which executed 1000 loops of Flat File operations. It starts off by performing 1000 file write operations and then 1000 loops of file read operations. We executed this benchmark at 500MHz and the Pocket PC display Brightness was set to 0%.

Experiment 19 - In this experiment, we used the 'Pocket PC Benchmark' which executed 1000 loops of Graphic operation. For the experiment, we set the display brightness to 100%, the frequency was set to 100MHz and executed 1000 loops of graphic operations.

Experiment 20 - In this experiment, we used the 'Pocket PC Benchmark' which executed 1000 loops of Graphic operation. We set the display brightness to 100%, the frequency was set to 500MHz and executed 1000 loops of graphic operations.

Experiment 21 - In this experiment we used the SPB benchmark suite. This benchmark measures the battery lifetime when a video clip is played with media player and the screen backlight was set to maximum. The frequency the Pocket PC was set to was 400MHz.

Experiment 22 - In this experiment, we used the 'Pocket PC Benchmark' which executed 1000 loops of Flat File operations. It starts off by performing 1000 file write operations and then 1000 loops of file read operations. We executed this benchmark at 400MHz and the Pocket PC display Brightness was set to 0%.

Experiment 23 - In this experiment, we kept the Bluetooth ON to study its battery consumption characteristics when its at idle. We used the RX3715 and the frequency was set to the Pocket PC's default frequency which is 400 MHz.

Experiment 24 - In this experiment we used the SPB benchmark suite on the RX3715. This benchmark measures the battery lifetime when a video clip is played with media player and the screen backlight was set to maximum. The frequency the Pocket PC was set to was 400MHz.

Experiment 25 - In this experiment, we left the WiFi adapter ON idle. We used the RX3715 and the frequency was 400 MHz.

Experiment 26 - In this experiment, we used the WiFi adapter to access the internet through the Internet Explorer. We used the RX3715 and the frequency was 400 MHz.

Experiment 27 - In this experiment, we used the Bluetooth to receive files from another Bluetooth device. We used the RX3715 and the frequency was 400 MHz.

Next, we discuss the outcomes and the observations made based on the measurements from these experiments.

Figures 3 through 10 are graphs showing battery discharge versus time when the device is operated under different conditions. For example, for the iPAQ 3950, comparing the results depicted in figures 3 and 4, it is evident that by simply reducing the display brightness to about 50% of the maximum possible, we were able to extend battery life by approximately 50%. The graph of figure 5 clearly shows increasing the frequency of operation in this case comes at a price. When the pocket PC was operated at the lowest frequency (100 Mhz) the battery lasted the longest, however, execution pace was much slower. Operating the device at 500 Mhz drained the battery before even reaching the floating point arithmetic part of the benchmark.

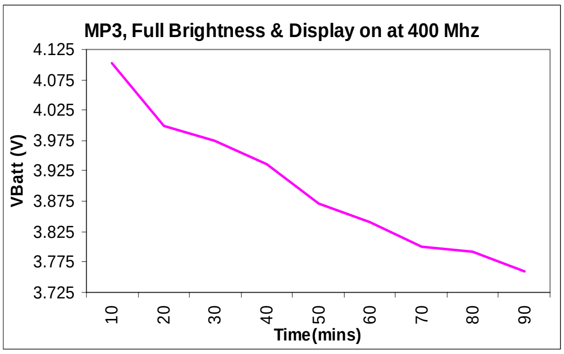

Figure 3. MP3, Full Brightness & Display on at 400MHz

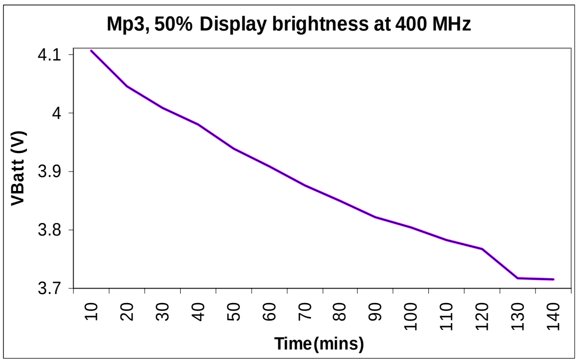

Figure 4. MP3, 50% Brightness at 400 MHz

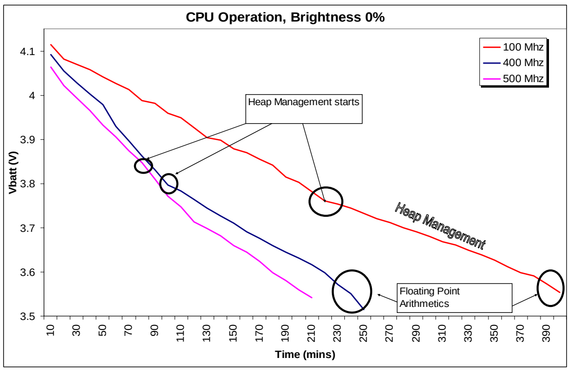

Figure 5. CPU Operation, 0% Brightness at varying frequencies

In figure 6 the SbP benchmark periodically opens "pocket work", loads a document and closes "pocket word" emulating typical pocket PC usage. We kept the brightness at the maximum level and varied the frequency. Operating the device at 400 Mhz yielded optimum results for executing a standard utility, in this case, the 'word application'.

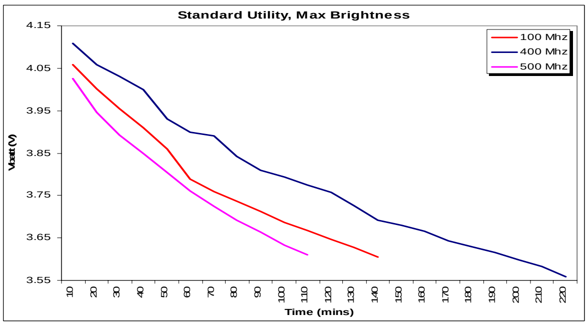

Figure 6. Standard Utility, 100% Brightness at varying frequencies

In figure 7 we used the Flat File bench mark to first write files to the internal memory of the PC, then read the files from internal memory. When writing files to internal memory at 100 MHz and 400MHz battery consumption rate was almost the same, additionally, the same number of jobs is performed in both cases. However, reading files at 400MHz was a better option because it took less power and more time to consume the battery. The beginning of the reading of the files phase has been indicated by circles in Figure 7.

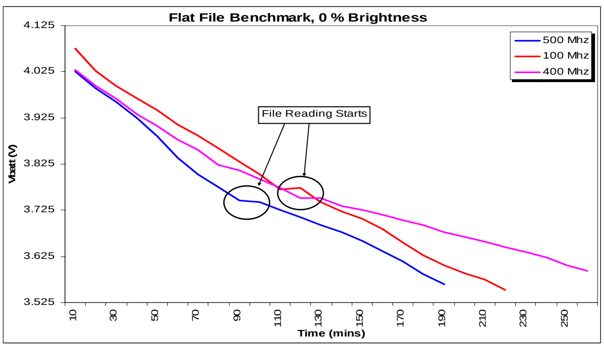

Figure 7. Flat File, 0% Brightness at varying frequencies

Figure 8 depicts the results obtained when we experimented with the WiFi in browsing the net, and using Bluetooth in transferring files from another Bluetooth-enabled device. The graphs are combined for space saving purposes; however, the two protocols are clearly used differently. As expected, Bluetooth has lower power consumption requirements.

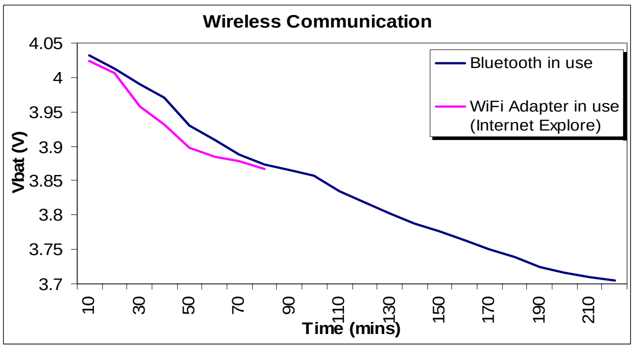

Figure 8. Wireless Communication

Audio performance at 400 Mhz but with different operating scenarios for the display of the device is reflected in figure 9. We can see a very clear difference in how long the battery will last when the display is on and when it is turned off. If the user plays the MP3 with the display off rather than having the display on with only 50% display brightness, he/she would save about 93.568 mW of power. The Pocket PC would run for an additional 4 hours when the display is off.

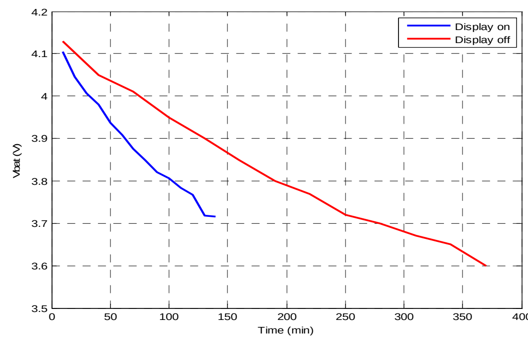

Figure 9. MP3 played at 400MHz

Figure 10 shows the power consumed when the MP3 player is on while the backlight is set to full brightness. The frequency of operation was varied and the power consumed shows that an optimum performance was reached when the device is operated at 400 Mhz.

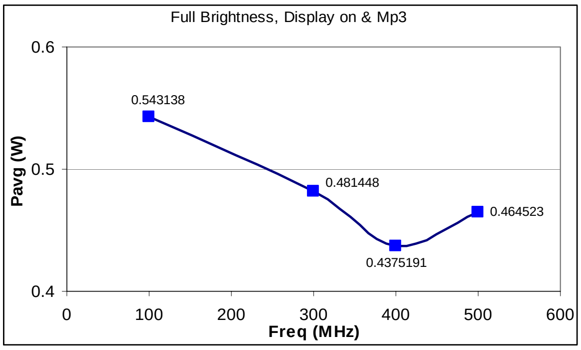

Figure 10. MP3, 100% Brightness at varying frequencies

Tables 1 provides a summary of the various measurements for the iPAQ 3950 unit, and figure 11 is a chart showing its average power consumption when subjected to different operating conditions. Table 2 and figure 12 summarize the results for the HP iPAQ RX3715. Upon examining figure 11, the reader can make interesting observations; for example, operating the device at a slow frequency (in this case 100 Mhz) had an impact only when we consider CPU intensive and graphics operations. On the other hand, for the standard utility test running the device at 400Mhz yielded better results. Operating the device at the 500Mhz did not have a positive impact in most cases.

Benchmark	***Frequency***	***P avg***	***Lifetime***	***Capacity***
	MHz	mW	[Hours]	[mW.h]
Full Brightness & Idle	400	394.218	4.33	1706.966
No display & Mp3	400	177.874	6.33	1125.942
Full Brightness, Display on & Mp3	100	543.138	1.5	814.707
Full Brightness, Display on & Mp3	300	481.448	1.16	558.480
Full Brightness, Display on & Mp3	400	437.519	1.5	656.279
Full Brightness, Display on & Mp3	500	464.523	0.66	306.585
50% Brightness, Display on & Mp3	100	345.041	3	1035.123
50% Brightness, Display on & Mp3	400	271.441	2.33	632.458
50% Brightness, Display on & Mp3	500	349.362	1.83	639.332
Max Brightness & Standard Utility	100	400.955	2.33	934.225
Max Brightness & Standard Utility	400	323.607	3.66	1184.402
Max Brightness & Standard Utility	500	551.299	1.83	1008.877
CPU Operations	100	206.832	7	1447.824
CPU Operations	400	309.436	4.16	1287.254
CPU Operations	500	370.856	3.5	1297.996
Graphics	100	388.793	2.33	905.887
Graphics	400	542.169	1.66	900.001
Graphics	500	547.174	1.33	727.741
0% brightness Flat File Benchmark	100	299.804	5	1499.020
0% brightness Flat File Benchmark	500	328.622	3.16	1038.446

Table 1: Average power and battery life time of the iPAQ 3950. The third column is the total power averaged over a complete battery discharge. The forth column is the average battery lifetime. The fifth is the effective battery capacity (power-lifetime product)

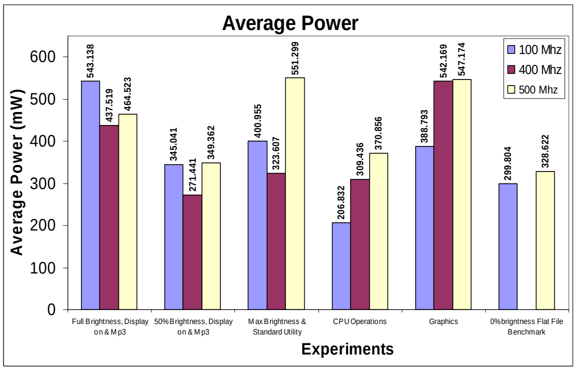

Figure 11. Average Power for iPAQ 3950 using different operating conditions and frequencies

Figure 11 shows the consumption of the HP iPAQ 3950 at 400 Mhz. Two consuming and battery-exhausting scenarios were observed on video play back and WiFi utilization, while the display brightness is set to its maximum. However, the capacity was relatively better in the case of the video playback experiment.

Benchmark	Frequency	P avg	Lifetime	Capacity
	MHz	mW	[Hours]	[mW.h]
Bluetooth idle, Full brightness	400	191.452	8.64	1654.149
Video Playback, Full brightness	400	347.930	1.33	462.747
WiFi Adapter on idle, 0% brightness	400	93.399	10	933.993
WiFi Adapter in use(IE), Max brightness	400	289.197	1.33	384.633
Bluetooth, Max Brightness (receive)	400	232.281	3.66	850.148

Table 2. Average power and battery lifetime of the iPAQ RX3715. The third column is the total power averaged over a complete battery discharge. The forth column is the average battery lifetime. The fifth is the effective battery capacity (power-lifetime product).

V. ANALYSIS

From the results of experiments performed in this work, it is obvious that there are wide variations in battery life time depending on parameters such as frequency, degree of brightness of displays, the requirements of the application running, etc. For example, results summarized in Table 1 Show that operating the MP3 player with a CPU frequency of 400 Mhz, but with the display brightness reduced to 50% there is some savings in battery life (approximately

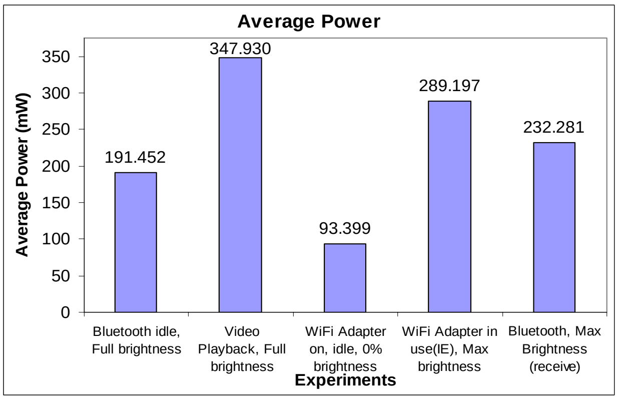

Figure 12. Average Power for iPAQ RX3715 using different operating conditions

15%). At 100 Mhz with the display brightness reduced to approximately 50% from the maximum possible had the effect of doubling the battery life time; power consumption has been reduced by about 36%. Hence, frequency scaling has contributed to a reduction in power consumption and in an extension to battery life. Furthermore, these results indicate that backlight dimming techniques can lead to a substantial increase in battery life, and the use of energy-adaptive display systems enhances the life-time span of the handheld device. These displays can adapt their power consumption based on the contents being displayed on the screen and the area of interest to the user.

Table 1 results also show that energy demands of CPU intensive operations may vary over a wide range. A possible technique that is increasingly being used to reduce CPU power consumption is Dynamic-Voltage and Frequency Scaling or DVFS. Power consumption of CPUs (implemented in CMOS) varies linearly with the frequency and quadratically with the supply voltage and therefore reducing either should lead to a reduction in power consumption. Designers, however, should pay close attention to the inherent tradeoff when using this technique; by reducing the frequency at which the CPU operates, a specific operation will consume less power but may take longer to complete. Although reducing the frequency alone will reduce the average power used by the CPU over that period of time, it may not deliver a reduction in energy consumption overall, because the power savings are linearly dependent on the increased time. While greater energy reductions can be obtained with slower clocks and lower voltages, operations will t ake longer; this exposes a fundamental tradeoff between energy and delay [15]. A graph showing battery-life time changes with frequency for the CPU benchmarks used in this work is provided in figure 13.

It is evident that an increase in frequency has led to a corresponding increase in power consumption and a reduction in battery-life time.

Recent work [16] reported that reducing CPU frequency may not always reduce the energy consumption and that the lowest energy consumption appears at some operating frequency other than the lowest one supported by the processor. In [17], Ikenaga,

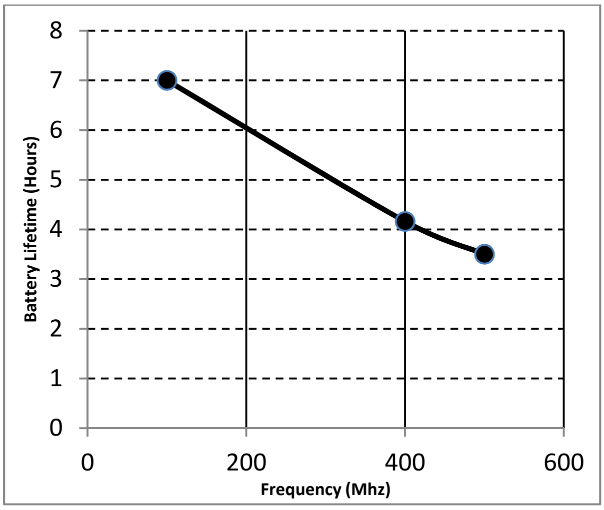

Figure 13. Battery-life Time for CPU operations

defines an MEP (Minimum Energy Point) for mobile devices, such that when operational frequencies are lower than that of the MEP, at which the supply voltage is optimum, energy consumption increases with decreases in operational frequency. In [18], it is argued that to determine an optimal CPU speed-setting, total system power including main memory and battery characteristics must be included and not to consider CPU-power only by itself. A discussion of various DVFS algorithms can be found in [16].

From the graphics benchmark results of Table 1, it is evident there continuous to be a disparity between the energy requirements to produce quality graphics on handheld devices, and the energy available from today's batteries. A major improvement in this area is the introduction of low-power graphics processor (GPU). In [5], a quantitative analysis of workload variations and imbalances of different stages of a mobile 3D graphics pipeline, and the potential for DVFS based power savings is presented. The paper claims that using history-based DVFS strategies can achieve energy savings of up to 50%. A technique to reduce the dynamic power consumption component of a GPU by reducing the precision of its arithmetic operations was discussed in [19]. The recently introduced Tegra 2 mobile processor [20] from NVDIA promises outstanding graphics performance on mobile units. There are no studies available yet in the published literature documenting energy efficiency of this processor.

In this work and using the Flat File benchmark, device memory is subjected to continuous writing and reading operations. In memory banks, power loss can be static or dynamic. Static power loss is technology and processing dependent, while dynamic loss occurs on each instruction or data memory access. That is, energy dissipation is proportional to the amount of data or code being transferred. A reduction in power consumption can be achieved by using code optimization and data compression techniques. Additionally, the use of new memory designs such as CellularRAM and MobileRAM is expected to result in power savings in future handheld devices. CelluarRam is a pseudo SRAM that permits selfrefresh and recharged operations inherent in DRAM technology while providing lower standby and operating currents and lower consumption. In MobileRam an on-chip temperature sensor is used to automatically senses the temperature and choose the most efficient (in terms of power) memory refresh rate [21].

From Table 2, video playback and wi-fi usage are evidently issues of concern to designers when we consider battery utilization. Video decoding has demanding and complex computational requirements and contributes to rapid battery drainage. In [22], it was shown that for handheld devices, increasing resolution cost higher energy needs and often not justified, whereas increasing bit rate gives better picture quality without inducing too much energy consumption.

Since displays are power hungry, an adaptive middleware based approach to optimize backlight power consumption for mobile handheld devices when playing video without compromising quality was discussed in [23].

WiFi radios have a high wakeup and connection maintenance energy, but low energy per bit transmission cost and high bandwidth. Reducing energy consumption is achieved by spending as much time as possible in low power states or power saving modes [24].

Finally, battery-life concerns cannot be addressed without the battery itself as a device being the focus of research at some level. In [1], the authors propose an analytical battery model which can be used for battery life estimation. The model allows designers to predict time-to-failure for a given load and provides a cost metric for life-time optimization algorithms. To our knowledge, this is one of the very few reported work that describes an attempt towards a formal treatment of battery-aware task scheduling and voltage scaling based on a battery model.

VI. CONCLUSION

Portable computing devices continue to come to the market with more powerful processors, enhanced features and increased functionality, and hence, the energy requirements of these devices continue to increase. This increase in energy requirements is not accompanied by a corresponding improvement in battery technology. To develop sound energy management policies, to design energy-efficient units, and to educate the users of these devices in ways and means of prolonging the battery life an examination of their power consumption tendencies is critical.

The aim of this work was to study two battery-powered mobile devices and have an insight into their power consumption requirements and their battery discharge behavior. Through a series of experiments and using different benchmarks we obtained sets of data that highlights the dynamics and the factors that come into play when we discuss battery utilization and energy requirements. Results indicate that factors such as frequency, display brightness, benchmark characteristics, and wireless protocols used have a noticeable impact on battery-capacity and power. It is evident that features such as dynamic-voltage-frequency scaling, and usage of energy-adaptive displays are critical to optimizing battery life-time. A memory subsystem with a hierarchy that reduces the misses in cache and minimizes external reads and writes to external memory is of value as well. Wireless RF designs and protocols that allow for power savings mode will continue to contribute substantially to energy savings. Finally, we argue there is still a need for an energy-management approach to these devices that integrates optimization techniques stemming from cooperation of chip or hardware designers with the software engineers who write the operating systems, compilers, and the applications that run on them.

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