Reliable and Energy Aware Next Generation Operating Systems

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***Abstract* - As our technology becomes more and more advanced, we must acknowledge the tradeoffs that come with each supposed "improvement". In some areas of OS (operating systems) we are already doing this. Take modern computing, for example. Modern operating systems already have procedures in place that allow them to monitor things such as the CPU (central processing unit), memory usage, storage, etc. We already know the impact that these things have on computers, and because of this our operating systems are designed to handle any potential issues that arise. Another resource that needs to be accounted for is energy usage, or power consumption. The amount of energy that a system is often overlooked, but still extremely important. This research paper will seek to outline the effects that rising power consumption will have on our technology as products become more and more advanced, as well as discuss ways that the coming generations of operating systems can minimize the impact.**

Index Terms - Operating System (OS), CPU (central processing unit)

I. Introduction

Before we dive into ways that we can account for rising energy usage by our products, we must first look at how energy requirements can vary between circumstances. One contributor to these requirements is the purpose of use. Your personal computer at home does not require the same resources as a workstation at a large technical company. Another contributing factor is the energy source. Assuming both of the computers mentioned above are desktops, they draw power from an outlet that they are plugged into, but what about a mobile device? Now we have switched the source from the outlet to a battery, introducing a whole slew of other factors to be concerned with. Battery size and the expected duration of use are two such factors that go hand in hand. Take for example, mobile phones. We have come to expect our mobile phones to last us all day (at least), but there are very clear and obvious size constraints for a battery in a device that we carry around in our pockets all day [1]. Increasing the physical size of the battery is simply not an option in this scenario, so instead *efficiency* is the core focus of innovation.

Efficiency is at the heart of this discussion. As manufacturers deal with constraints when it comes to the source of power for their products, they must look to other means of achieving their goals. Creating a more efficient application or operating system allows for reallocation of resources away from strictly providing power to a system, and rather to areas that give us as consumers more tangible benefits. Another thing to consider is cost. Sure, you could always add more power to a system in order to meet your thresholds, but the price on this could add up in a hurry. A better, more **efficient**, way to get the power you need? Decrease the usage of the operating system or an application in use, and utilize those saved resources wherever else they may be needed.

REFERENCES

[1] (*Accounting and control of power consumption in energy-aware operating systems, 2003*)

[2] (*Every Joule is Precious: The Case for Revisiting Operating System Design for Energy Efficiency, 2000*)

[3] (*Energy-aware adaptation for mobile applications, 1999*)

[4] *(Proactive Energy-Aware Computer, 2017)*

[5] *(EFLECT: Porting Energy-Aware Application to Shared Environments, 2022)*

[6] *(Energy Efficient Mobile Operating Systems, 2013)*

[7] *(A Hybrid Model for Reliability Aware and Energy-Efficiency in Multicore Systems, 2021)*

[8] *(Predictive Energy-Aware Routing Solution for Industrial IoT Evaluated on a WSN Hardware Platform, 2022)*

[9] *(Power Management Techniques in Smartphones Operating Systems, 2012)*

[10] *(An energy-aware virtual machines consolidation method for cloud computing: Simulation and verification, 2021)*

Literature Review

[1]

a. *Accounting and control of power consumption in energy-aware operating systems* takes a look into the process of resource accounting and its associated models that aim to charge the responsible parties for resource usage. However, we are more interested in a subset of this paper regarding the energy-aware resource model. The energy-aware resource model uses resource throttling through a hierarchical system. The OS gains knowledge on the consumption of resources and then proceeds to throttle rates and introduce limits for energy consumption.
b. The energy-aware resource model is a rather simple system which gives a lot of freedom to the OS, while also being secure and efficient. Automation of this task is easy on the scheduler as it can ignore individual resource limits as long as it stays within global limits. It also takes into account both direct and indirect consumption of resources, all of which is used in the accounting process to apportion proper resource usage costs to the responsible party.
c. This technique only takes into account energy consumption and usage time of the main processor. It is limited in the sense that there are more metrics that can be added to improve the resource analysis done by the energy-aware resource model. There is also room for performance improvements as this system requires frequent and rather costly calculations of energy consumption.

[2]

a. *Every Joule is Precious: The Case for Revisiting Operating System Design for Energy Efficiency* proposes a full rework of operating system design, focusing on energy efficiency as opposed to the typical maximizing of performance. This system takes a top-down approach, granting power to high level components over the manipulation of resource control and energy usage.
b. There are many energy efficient techniques that currently exist that are either not widely used, or not implemented concurrently with others. These techniques, combined with a redesign of operating systems to prioritize energy efficiency, will have significant impacts on the future uses and structure of the operating system, especially in battery-operated wireless and mobile devices.
c. Operating systems are in charge of allocating resources. This is typically done by analyzing the processes and scheduling based on fairness and performance. When the operating system is redesigned to be energy-minded, this calculation changes and can skew the priority of how tasks are scheduled in a way that doesn't make sense for how an operating system is designed to run.

[3]

a. *Energy-aware adaptation for mobile applications* focuses on the educated balance between efficiency/battery life and performance/quality. The system in question closely monitors the energy supply and demand of the application and makes "the correct tradeoff between energy conservation and application quality."
b. The energy-aware analysis of the system's consumption and allocation of resources is capable of dynamically improving battery life by a magnitude in the range of 30-50% with little to no changes in the structure and design of the operating system. As with all of the solutions proposed in the papers studied in this literature review, there is no end-all solution that exists for the energy concerns in operating systems. However, it is probable that some version of a dynamic tradeoff system like this will be prevalent in the majority of energy aware systems to come due to its impeccable budgeting of resources.
c. The only significant downside to an approach like this is the necessary detriment to the user's experience. The whole design aims to save battery life at the cost of performance, but at what point do we draw the line? How is the balance found between the two and can we design it in a way that allows it to be adjusted in times where performance becomes a priority over the preservation of battery?

[4]

A. *Proactive Energy-Aware Computing* proposes a tool (HEAL) that would allow the software and hardware to communicate and dynamically inform how much energy is being demanded by a particular process.
B. The positives of this technique is clear in that it informs the user of the machine just how much energy a particular resource is taking up. With this knowledge, the user can determine better, more efficient ways to run their machine. Another big use of this technology would be that designers of software can get a much better gauge of the energy their products demand, and potentially take steps to reduce it.
C. The only negative I could really think of about this technique would be that it would take resources in order to utilize this tool that could potentially be used elsewhere, but I think this would only be an issue for machines that are really pushed to their limits already.

[5]

A. *EFLECT: Porting Energy-Aware Applications to Shared Environments* proposes an interesting way to discover just how much energy an application is using. This paper mentions that one glaring issue with a lot of energy aware programs is that one may unintentionally observe the energy consumption of *another* energy aware application. To solve this, *EFLECT* is a tool that can prevent this from happening by sending these apps to a shared environment without affecting the OS.
B. The positive to this kind of tool is that it gives the user a bit more confidence in the information they are receiving. Applications being energy aware does not mean much if there is a real possibility that the data being reported is off. EFLECT aims to solve this problem while still maintaining the integrity of the operating system.
C. The main negative of this system is the time and storage that using this tool would require. I am not sure this is something that you would want constantly running on your machine, rather you may want to use it for a bit to get a baseline of the energy consumption numbers, then go back to using things as usual.

[6]

A. *Energy Efficient Mobile Operating Systems* not only discusses the importance of managing energy consumption, but also performs multiple experiments as to how it can be decreased. A new technique, GRACE-1, was proposed that would allow computers to operate efficiently while still maximizing quality. In the experiments that were conducted the total energy consumption of the test laptop decreased by up to 31.4%.

B. The positives introduced in this paper are a real ability to actively decrease energy consumption. Techniques discussed up to this point mostly involve monitoring it, but GRACE-1 was able to actually lower the cost.

C. The only negative that I can see to this technique is that while GRACE-1 does strike a balance between efficient energy use and quality, there is still performance being left on the table. Those that like to run their machines at the absolute highest performance settings may not like this solution.

[7]

A. A Hybrid Model for Reliability Aware and Energy-Efficiency in Multicore Systems discusses a technology, Dynamic Voltage/Frequency Scaling (DV/FS), that allows cores of a machine to operate at different frequencies in order to conserve energy in some cores while maximizing overall performance. This technique works by detecting when a device is idle in order to decrease the frequency and increase energy efficiency. Another technique, Dynamic Power Management (DPM), is also mentioned. DPM relies on calculating the point at which a core goes into sleep mode in order to decrease the current leakage, which in turn decreases overall consumption. The paper suggests a hybrid model of these two techniques, where DV/FS would be used to determine the optimal frequency of each core, but utilizing a dynamic programming (DP) approach.

B. The upside to the hybrid technique is that we are still optimizing the frequency of each core, but gaining the speed benefits of dynamic programming. Overall, this will result in a more energy efficient design, while not sacrificing speed and performance.

C. I do not believe this model has any true downsides for the regular user. The data shows very good results when it comes to energy consumption, and even machines requiring more and more power will benefit as the DV/FS calculation will account for that.

[8]

A. A reality for all computing is the interaction of a machine, or various machines, over wireless networks. *Predictive Energy-Aware Routing Solution for Industrial IoT Evaluated on a WSN Hardware Platform* dives into how to ensure that network systems are reliable, safe, and efficient in both cost and energy consumption. It does this utilizing a technique called Predictive-Energy Aware Routing (PEAR). The PEAR system takes into account routing balance and profiling in order to have predictable energy consumption. With this prediction, PEAR can reduce overconsumption and increase the lifetime of network clusters.

B. The positives here are fairly straightforward, PEAR enables wireless networks to not only be aware of energy consumption, but increase their average lifetimes.

C. I cannot think of any negatives to this approach. Being energy aware is one thing, but having the ability to actually *decrease* consumption and ensure higher uptimes/network reliability is an extremely useful tool to deploy.

[9]

A. Power Management Techniques in Smartphones Operating Systems explores, as the title suggests, ways to manage energy efficiency in smartphones. Thus far, most of the techniques that have been explored in the papers are in reference to computer operating systems, but in today’s world it is just as important to look at mobile OS. Multiple techniques are mentioned, but the one that I found most enticing is what I will be calling the “mobile hybrid”, as the article itself does not refer to it in any specific way. This model focuses on collaboration between the operating system and the applications that are being run on it in order to reduce the phone's power consumption.

B. Upsides to this technique are that all resources in the mobile device are being monitored, and the most optimal solution can be reached. In other techniques mentioned within the article, such as *Chameleon*, the monitoring is not able to consider things such as resource consumption from applications, only the operating system itself.

C. Downsides to this technique are that the operating system must have knowledge of the applications' energy requirements and the amount of energy available until the device can be charged again.

[10]

A. *An energy-aware virtual machines consolidation method for cloud computing*, dives into optimizing energy efficiency for virtual machines utilizing a technique known as *virtual machine consolidation*. This paper reports specifically on an energy aware version of this technique, EVMC. This technique optimizes the energy consumption of the overall cloud system that the virtual machines are a part of, while maintaining the services that make cloud computing so vital.

B. The positives of a technique such as EVMC is that it creates a more energy efficient environment by decreasing the number of active physical machines as well as the migration of virtual machines.

C. Downsides could include the level of effort involved in creating such a system, as it does utilize a machine learning method known as *support vector machine*.

TABLE 1
SUMMARY OF ENERGY PROTOCOLS & TECHNIQUES

#	Protocol/ Technique	U	D	R	E	DP	NW	CC	Conclusion
1	HEAL[4]	Y	Y	N	N	N	N	N	Good - Informs on energy consumption but does nothing to confirm that information is coming from the right place
2	EFLECT[5]	Y	Y	Y	N	N	N	N	Best - When it comes to strictly getting information, this is the best option. Moving the applications to shared environments provides a level of reliability that other options cannot compete with.
3	GRACE-1[6]	Y	N	N	Y	N	N	N	Poor - Though it is nice to be able to decrease energy consumption, the loss of performance paired with lack of other features for monitoring makes this a less than ideal option.
4	DV/FS[7]	N	Y	Y	Y	N	N	N	Good - The DV/FS approach is a good option as it does optimize each core in the machine such that it does not have much, if any, energy leakage. This results in a machine that is not sacrificing performance while ensuring maximum efficiency. The only downside to this technique is the speed of the calculation.
5	DPM[7]	N	Y	N	Y	Y	N	N	Good - DPM is a solid option as it shuts down inactive cores on a machine in a dynamic fashion. Where this differs from DV/FS is that it completely shuts down the cores as opposed to reducing frequency.
6	Hybrid of DV/FS & DPM[7]	N	Y	Y	Y	Y	N	N	Best - I believe this is the best solution as it combines the upsides of both DV/FS and DPM, while eliminating their negatives. Rather than shutting down cores, this approach still simply reduces frequency/voltage, but the hybrid model does this dynamically.
7	PEAR[8]	Y	N	Y	Y	N	Y	N	Best - As a networking solution, PEAR ensures not only energy efficiency but network reliability with little to no downside.
8	Mobile Hybrid[9]	Y	Y	N	Y	N	N	N	Good - Though this technique does have its downsides, it is a reliable way to reduce power consumption in the mobile device while still maintaining an acceptable level of performance.
9	EVMC[10]	N	Y	N	Y	Y	N	Y	Best - This technique is extremely valuable as it considers the case of virtual machines in the cloud.

U - Informs energy usage | D - Dynamic energy analysis | R - Extra effort to improve reliability |
E - Improves energy efficiency | DP - Dynamic Programming | NW - Networking | CC - Cloud Computing