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Minimizing Power Consumption by Personal Computers: A Technical Survey

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Abstract— Recently, the demand of "Green Computing", which represents an environmentally responsible way of reducing power consumption, and involves various environmental issues such as waste management and greenhouse gases is increasing explosively. We have laid great emphasis on the need to minimize power consumption and heat dissipation by computer systems, as well as the requirement for changing the current power scheme options in their operating systems (OS). In this paper, we have provided a comprehensive technical review of the existing, though challenging, work on minimizing power consumption by computer systems, by utilizing various approaches, and emphasized on the software approach by making use of dynamic power management as it is used by most of the OSs in their power scheme configurations, seeking a better understanding of the power management schemes and current issues, and future directions in this field. Herein, we review the various approaches and techniques, including hardware, software, the central processing unit (CPU) usage and algorithmic approaches for power economy. On the basis of analysis and observations, we found that this area still requires a lot of work, and needs to be focused towards some new intelligent approaches so that human inactivity periods for computer systems could be reduced intelligently.

Index Terms— CPU Usage; Dynamic Power Management; Operating Systems; Personal Computers; Power Consumption

I. Introduction

We cannot escape the fact that the world is becoming more and more dependent upon the use of information and communication technology (ICT), and that personal computers (PC) are one of the means. All over the world, PCs are being increasingly used right from kids to professionals in the course of their everyday lives, and this shows why we see such a phenomenal growth in sales of PCs over the last few years. There are basically two major reasons behind this: 1) technology is becoming cheaper with each passing day, and 2) people are getting more and more addicted to these ICT products. But the offshoot in getting used to these technologies are the innumerable other adverse effects caused to our environment, health and economy. From Figure 1, it can be clearly seen that PCs occupy the largest share among the several available ICT products in the market, thus, making them also responsible for the high quantum of power consumption [1]. Consequently, this surge in power consumption leads to a greater demand for power production by most of the developing countries, as their existing power production is insufficient to meet their citizens' demands, and they have to face a number of power cuts and load-shedding situations in order to maintain a fair balance between demand and supply.

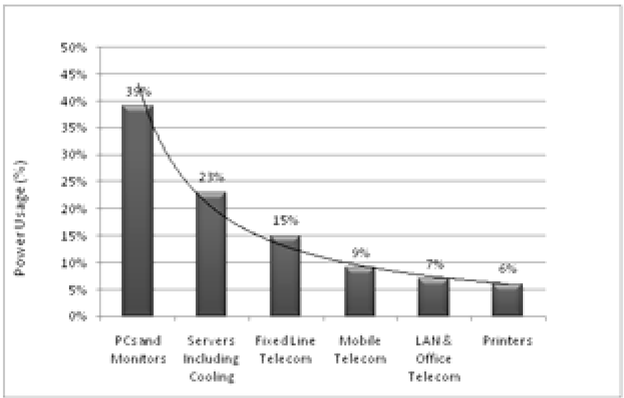

Fig.1: Power usage by ICT devices [1]

This survey is concerned with minimizing power consumption by PCs. In recent studies, it has been found that there is a great need to modify the Windows power scheme, so that power consumption could be minimized. Therefore, this is the area of study on which one can focus; the objective being to reduce power dissipation. The motive behind this research on minimizing power consumption by PCs derives from a human tendency to leave the computer system running in between jobs, and as to when work is likely to be resumed is not at all predictable. The running computer system consumes electricity, and it is estimated that a typical desktop PC with a 17-inch flat-panel LCD monitor requires about 65–100 watts for the computer, and 35 watts for the monitor. If left on 24×7 for one year, this system will consume 874 kilowatt hours of electricity – enough to release 341 kg of carbon dioxide into the atmosphere, and can also be equated to driving 1312 km in an average car [2]. On the other hand, by turning off this computer system *when not in use* (i.e., lunch times, weekends, during meetings) *for one year*, one can save as much energy as it takes to wash 464 loads of washing, or to run your microwave 24 hours a day for one week [3]. Even the various options used by the power scheme in the OS are not sufficient to save power, for example, screen savers are actually power wasters because when the screen saver kicks in, more power is consumed by the hard disk drive (HDD), CPU and monitor [4]. According to a study performed by IST at the University of Waterloo, for a Pentium 4, 1.7 GHz machine without the monitor, it was found that during the system boot-up, power requirement is close to 110 watts; in idle mode, it uses close to 60 watts; and in full power-saving mode, with no hard disk spin and the machine in sleep mode, power consumption is close 35 watts [5].

Moreover, this running system is also not good for our environment because of its continuous heat dissipation, and it is found that in the last 250 years, the carbon dioxide in the earth's atmosphere has increased by 30% due to human activity, and 50% of that increase has occurred in the last 50 years in which PCs and monitors account for over one-third of IT power consumption and CO_2 emissions, and sadly, the power management tools are not active on 90% of desktop PCs [6]. According to the US Environmental Protection Agency's Energy Star, the program estimates that activating the power management in a PC can result in cost savings of as much as $100 per computer, and this is a significant figure when multiplied by the number of computers in a typical organization. Power management tactics can save energy and help to protect the environment [7]. In a recent Microsoft Developers Network (MSDN) blog [8] from the Windows engineering team of Microsoft, they have emphasized the need to minimize the power consumption of your PC. They also said that this is an area of significant innovation for Windows 8 PCs.

This paper is organized into six various sections and subsections for addressing the issue of minimizing power consumption by PCs. In Section II, we present the current market scenario for popular OSs used by people, and discuss the power management schemes of the Windows OS and compare these schemes with two different versions of the same OS. Section III discusses about the major drawbacks of available power schemes in the OS. In this section, we present the two different user scenarios for using the computer system, and discuss how these time-out-based approaches used by these power schemes are insufficient to handle the problem of high power consumption. Section IV presents a detailed survey for measuring power consumption using hardware, software, minimizing CPU usage, and various algorithmic approaches. Section V discusses about the challenges and directions for implementing the various approaches to minimize power consumption, as shown in the previous section. For future guidance, in this section, we propose that some intelligent methods should be used with these approaches, so that power saving could be done effectively. Finally, Section VI concludes this work, and recommends that the Windows power schemes are not sufficient enough to minimize power consumption, and the time-out approach used by them must be replaced with some novel intelligent techniques.

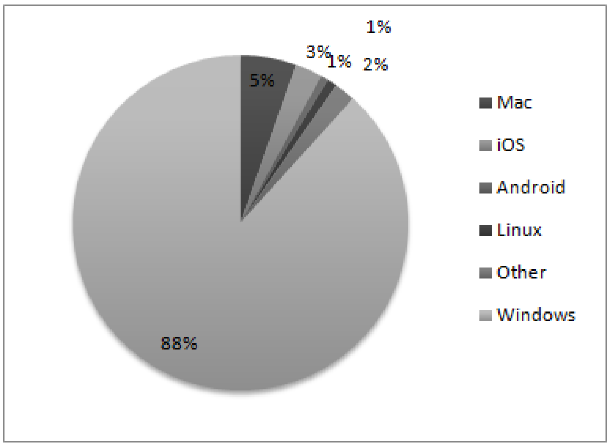

Fig.2: Market share of various operating systems

II. Power Management in PCs

Keeping the above major problem in focus, various organizations, including hardware and software industries, have started designing their products in such a way that they will consume less power and emit less heat to keep the environment green.

However, according to various quarterly results [9] as shown in Figure 2, it is found that Microsoft Windows still leads the market with a market share of around 88–90% among the other key players like Linux, Mac OS, and Android. Thus, from this we can conclude that the Windows OS is one of the most popular, and people still prefer to work with it.

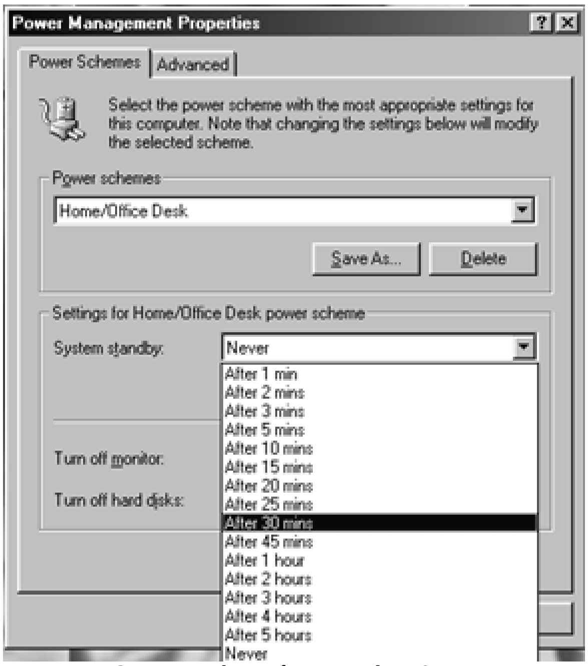

Fig.3: Power scheme from Windows 95 to XP

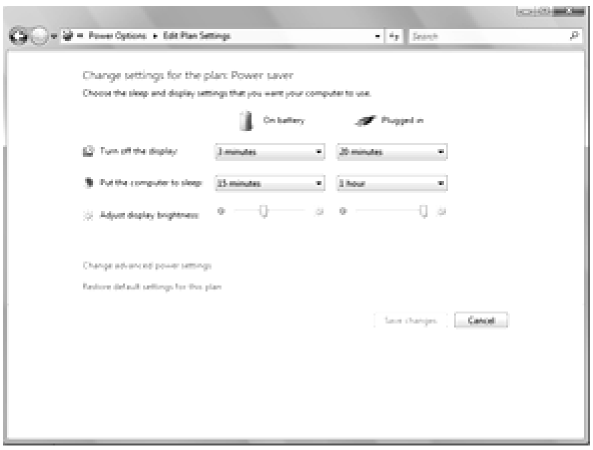

Fig.4: Power scheme of Windows Vista & Windows 7

When we see the power scheme options of this popular OS, as shown in Figures 3 and 4 where, Figure 3 shows the available power options from Windows 95 to XP, and Figure 4 shows the available power options for Windows Vista and 7. If we compare both the scenarios of Figures 3 and 4, then in these power schemes, we see that various options are available for power management that address the issue of human inactivity, using which a PC can enter automatically into the sleep mode, standby mode, HDD turn off, monitor turn off or switching it to hibernate. This is shown in Figure 5. The various states shown in Figure 5 completely depend upon the default settings or end-user configuration settings. Another interesting fact that can find from Figures 3 and 4 are that the option to turn off the HDD after a certain period of time, which is available in Figure 3, is no longer available in Figure 4. This shows that the organization has started thinking seriously about the issue of power consumption by the computer systems.

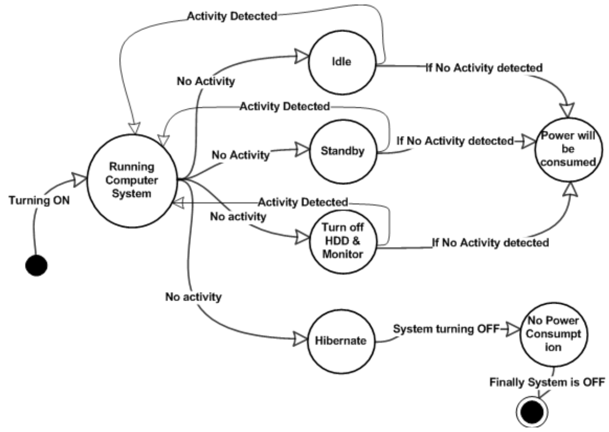

Fig.5: State transition diagram shows various states of a computer system with and with-out power consumption

III. Major Drawback of Available Power Scheme in OS

As we have seen in Figures 3 and 4, a number of power-saving options are available in these schemes, but a big question that arises is: "Are they sufficient enough to save power?" The answer to this question is very clear and direct: "May be not." Because all these available options are totally based on time-out approaches, they consider the keyboard event and mouse event for switching back on the system's state in any of the options available in the power schemes. At present, the available power schemes in Microsoft Windows 95/XP/Vista or in any other OS is not sufficient enough for effective power management, or to save power completely and reduce heat dissipation by the PCs. This situation is described in the following two cases:

Case A:

The user of a PC selects the following settings in the power scheme available in the OS to save power:

Turn off monitor/display = After 45 min.
Turn off hard disks = After 45 min.
System standby/sleep = After 1 hour

The user of this system has to leave the system for some reason just after login into the system, and he came back to his system after 30 min or more and continues his work.

Case B:

The user of a PC selects the following settings in the power scheme available in the OS to save power:

Turn off monitor/display = After 10 min.
Turn off hard disks = After 10 min.
System standby/sleep = After 30 min.

The user of this system has to leave the system for some reason just after login into the system, and he came back to his system after 30 min. or more and continues his work.

In the above scenarios, though the users have configured the power schemes differently in both the cases, the power consumption of the computer system is very low in case B as compared with case A, though the inactivity period of the user is the same, that is, 30 min in both the cases. So, in spite of having the power scheme options in the OS we could not minimize the power consumption in case A. The one major reason for this could be that these power schemes are very much PC and peripheral oriented, and have nothing to do with the operator's behavior, which means that they are unable to say something about the operator's inactivity [10] period on the computer system. So, from the above cases we can easily find out that inactivity is the enemy of power consumption, and one cannot minimize it without predicting the inactivity period of the operator.

IV. Measuring Power Consumption

To reach at any solutions as stated in the above section, first, let us see the various methods available for measuring the power consumption of a PC and its various peripheral devices. Over a period of time, various techniques for measuring power consumption by PCs have been proposed. These techniques can be categorized into various categories, like hardware based approaches; software based approaches; minimizing the CPU usage; and by using algorithm based approaches. The work done by various groups of researchers on these different approaches are given in the following sections.

A. Hardware-based approaches

A lot of work for minimizing the power consumption of a computer system is done by using external hardware for monitoring the various activities of the system and the various devices attached to it. The work of software power consumption can be classified into three categories:

i. Using simulations
ii. Measurement-based estimation
iii. Direct measurement

In [11, 12], the authors have proposed a simulation-based power model using FAST simulator, and stated that traditional power models that were used with software simulators can directly benefit from this simulator.

A high-level view of FAST simulator is shown in Figure 6. The functional model (FM) implemented is software running on a general purpose processor, which could also be put in hardware for performance improvement. This simulator is able to tolerate the overhead communication between FM and Timing Model (TM). Another approach used by the authors in [13–17] presents the second category approach, that is, a measurement-based estimation, architecture of power measurement tool. They have used a National Instruments (NI) data acquisition card [13, 14] as it can measure 16 components simultaneously, or by using basic lab equipment [15–17] that measures the voltage and current of the system.

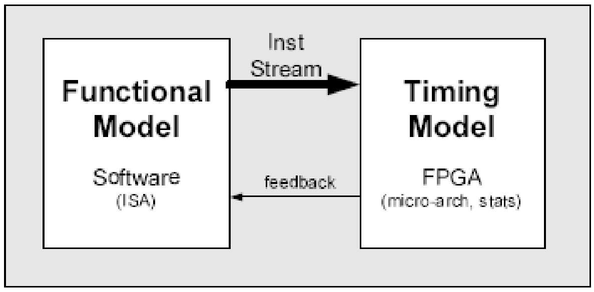

Fig 6: FAST Simulator.

For the third approach, direct measurement [18–23] is worked out by many researchers to minimize power consumption of the system. These authors have used various approaches, like data path scheduling, dynamic power profiling, dynamic power management, temperature on SoC (System on Chip) and dynamic voltage and frequency. All these approaches directly measure the power consumption. As we know, most of the OSs correlates the power consumption with the CPU, so most of the direct measurement approaches puts the CPU in the main frame

B. Software-based approaches

These kinds of approaches are also known as Dynamic Power Management (DPM) where a software program is used for measuring the power consumption of a computer system. In [24–32], the authors have presented a survey and various techniques for minimizing power consumption using DPM. DPM at the OS level refers to supply voltage and clock frequency adjustment schemes implemented while tasks are running. Basically, DPM deploys three types of techniques:

i. Predictive approach
ii. Stochastic approach
iii. Time-out approach

By using these three kinds of approaches, one can achieve energy-efficient computation by selectively turning off system components when they are idle.

In [33, 34], the authors have presented the predictive system shut-down approach for event-driven applications to save energy. The authors have predicted the system idle period for taking action to shut down the system, but before shutting down the system, the system must go into the sleep state and wait there for a command. Stochastic approach has many advantages over and above the predictive approach. Using the stochastic approach, one can design the system model while taking workload into account, but the system cannot be powered down if any program is running. In [27–30], the authors have presented various stochastic approaches which utilize probability distributions to describe the uncertain properties of the power management systems and the environment.

The time-out approach is a widely used approach in the industry, and is supported by a number of OSs, like Linux, Microsoft Windows, and so on. In this kind of DPM approach, whenever the time last at idle state reaches an assigned time-out value, this approach switches the system component to low power mode. Moreover, some researchers have implemented the DPM approaches in different ways, that is, either they have considered the architecture and algorithm to shut down the HDD [35] irrespective of the value declared by the "timeout after idleness" algorithm in most of the Windows-based computer systems, or by considering the parameter of Dynamic Voltage Scaling by proposing a smart *Sleep* [36–37] power-saving scheme with minimal performance impact. This scheme adopts the sleep mode and forces the system into sleep mode, though this may not be a good choice, as it is difficult to find such a state where server utilization is low.

As we know, DPM approaches are being used by most of the researchers to force the computer system and its connected devices into sleep mode by using various schemes and algorithms. They have also found that the CPU is the largest consumer of power. For this reason, various algorithms are designed around the CPU utilization. According to work done by some communities of researchers, they have developed a system that monitors and displays the power consumption of various ICT products [38] listed in Figure 1. They have also analyzed their operating state with no additional devices, and suggest that this technique will motivate the user towards power saving by displaying the power consumption information of each device, and by setting a total power consumption target. Some have used the real-time software-based approach [39] for estimating the power consumption of a media server by tracking the CPU utilization and various other operational parameters of the measured servers. They have designed virtual instrumental software for measuring the power consumption. Some have measured the energy consumption of a typical Web server [40] under a variety of workloads, and have created a power simulator that estimates the CPU energy consumption. Thus, the CPU plays the main role when we talk about minimizing power consumption. Various models have been designed by keeping the CPU in the main frame. As in [41], the researchers have demonstrated the formal approach for measuring the power consumption by any software, and this model is based on the power consumed per CPU operation is assumed to be the sum of the power used to move the data across. In [42], the authors have developed a software subsystem for building a power consumption monitoring and management system. This software-based system calculates the power consumption of various devices like chiller, HVAC (Heating, Ventilation and Air conditioning), cooling pump, and elevator.

C. Minimizing CPU Usage

In [24], the authors have presented a systematic method of CPU usage metering and stated that the OS manages all resources, including CPU time. It keeps track of each process's resource consumption. It also updates the CPU time utilization of a process at every timer interrupt, which is generated at a fixed time interval. There are some models of machines that learn prediction [43], and that finds the CPU's idle and activity patterns. This prediction model utilizes the concept of a variety of C-states defined by ACPI [44]. These C-states are C0, C1, C2 and C3. Where C0 refers to active state, and rest states are the idle state where power consumption of the CPU decreases as we move from C1 to C2 to C3. Some other models, like cluster model [45, 46] and scheduling model [47] are also presented by the authors for minimizing the CPU usage for reducing power consumption. Some research studies focus on CPU power management [45], or monitoring activities of devices [48], or CPU sharing [49] for minimizing energy consumption. In [39], the authors have stated that the CPU and all its devices, like memory, chipset and bus controller are not controlled by the device driver, and this could be done by observing the OS kernel itself. If the OS kernel is busy it shows that the CPU and various other devices are busy in processing, and by minimizing the CPU processing, energy used could be minimized.

D. Using Algorithmic Approaches

Some communities of researchers are working on various algorithms to minimize power consumption by a computer system and its peripheral devices like CPU, HDD. These algorithms are given below:

1) *Back-off algorithm* [50]:

By using this proposed algorithm for switching on or off the user equipment which supports the multiple radio access technology to save the power.

2) *PowerNap algorithm* [51]:

By using this proposed algorithm, it enables the entire system to transition rapidly into and out of a low power state, and all activities are suspended until new work arrives. This approach works on two modes, the active mode and the nap mode.

3) *Power-scheduling algorithms* [52–56]:

By using these power-scheduling algorithms, one can reduce the power consumption of portable embedded devices. In their approaches, either one has tried to minimize the data transfer in between CPU and memory, so that power consumption could be minimized, or proposed an algorithm that basically uses the system scheduling and sets the deadline of the task to the value indicated by the user to dynamically scale voltage and frequency, or presented an algorithm under different workload configurations with/without time constraint, respectively.

4) Soft Watt **[12]:**

By using this simulator-based algorithmic approach that basically checks the different states of the computer's hardware, like CPU, memory, HDD, one can identify the power-hungry OS services and characterize the variance in the kernel power scheme with respect to workload. This kind of approach is used by various researchers in their work over the period of time for measuring the power consumption of a PC using different methods.

5) Power–aware algorithms **[25] [57–60]:**

By using these algorithms, one can change the supply voltage and frequency at appropriate times to optimize a combined consideration of performance and energy consumption.

V. Challenges and Directions

Before concluding this paper, in this section we discuss the potential challenges and future directions in the area of minimizing power consumption of a computer system. We classify the power-minimizing challenges into four broad categories: 1) The challenges come with the use of hardware. If we look at the scenario from the end user's point of view, then the user has to pay an additional amount for buying the power-saving device. Will it be worthwhile? An answer to this question in most of the cases would be in the negative, because the user will consider such kinds of devices as optional, and will always try to avoid the additional amount of expenditure for this. This scenario is also best suited for users in developing countries like China, India, and Indonesia, where users always try to think about the many ways of how to minimize the cost of a computer system while purchasing a new computer system. Whereas, if we introduce some kind of chip, sensor or device at the motherboard level, capable enough to detect human inactivity, then this could be a good option, and the user will have to go in for it because, in that case, no other choice will be available. But, unfortunately, such a kind of motherboard that could detect human inactivity and take its own decision to switch off the computer system is yet to hit the market. 2) The challenges come from designing of the system software, application software or tools [61–64] for measuring and minimizing the power consumption of a computer system. If it is application software, then this is to be installed over the current OS, however, again the question will remain the same as it was in the previous section: how many users will be ready to pay for such a kind of software? Again the response will be in the negative. However, if we incorporate some changes at the OS level in the existing power schemes by providing some intelligent methods to detect human inactivity and unnecessary power consumption, this could be a better option at no extra cost from the end user's side. 3) The challenge comes from the CPU side, as currently, personal computers are equipped with 2 GB of memory, as whenever the execution of an application takes place for the first time, it is executed from the HDD, after that, it resides completely in the system's primary memory, and in that case, there is no role for the HDD. This may be another reason why in Figure 4 of Windows Vista & 7, the HDD turn off option has been dropped. In such a situation, processing continues in between the CPU and the primary memory, and this could be a better option if some power-saving techniques could be designed by measuring CPU utilization. Though measuring CPU utilization is possible in the OS, associating it with the Windows power-saving schemes could be the best way to save power, and finally 4) the challenges come from the end user's side. A proper knowledge and training of the end user is required in this situation, especially in the developing countries. Users must be informed about the benefit that by switching off a computer system not in use will not only save power but can also save up to half a ton of CO_2 per year.

Furthermore, in most of the cases, it is found that there is no awareness about the power-saving schemes among the users of PCs, and most of the time they continue working on the default power settings. This is not a good thing, because if your system is either in standby mode or in sleep mode, it consumes power. So this should be stopped by proper training of the end user.

Finally, in directions for the future, we can say that the future of the software and hardware industries is still very bright, and in the coming days, many new developments will take place. For solving of the problem we have focused on the software part, and suggested that in place of using the existing time-out options of the power schemes, we can design some intelligent methods, as discussed in [65], for sensing human inactivity and minimizing power consumption. Similarly, some more methods could be designed for the existing power schemes of OSs, which will be suitable for both end users as well as the environment.

VI. Conclusion

In this paper, we have presented a technical review of techniques for minimizing power consumption by computer systems. We have discussed and evaluated the various techniques used for reckoning power consumption by using hardware, software, CPU usage and various algorithmic approaches. On the basis of the aforementioned studies, we conclude that there is a great requirement for changing the OS's power schemes by proposing some intelligent schemes to sense human inactivity. The available options in the power scheme are based on the time-out approach, and are not sufficient enough to minimize power consumption. We also discussed the challenges, as well as future research directions, in developing effective solutions for minimizing power consumption by a computer system.

The main objective of this paper is to provide a comprehensive understanding of the various power consumption minimization techniques and the existing options used by various power schemes in an OS as well explored the impact of heat dissipation on the environment because of endlessly running, idle computer systems. We strongly believe that this is the major area for urgent future research, and hope that tomorrow's versions of OSs and hardware will be designed accordingly to effectively handle the power-wastage problem.

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