A Framework of Creating Intelligent Power Profiles in Operating Systems to Minimize Power Consumption and Greenhouse Effect Caused by Computer Systems

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Abstract

This paper presents a framework for creating intelligent power profiles that can be incorporated in operating systems to minimize the power consumption of computer systems. This intelligent power profile implements three methods at the time of login into the system that continuously measure the power consumption of running software in a given period of time. Moreover, this paper also emphasizes various effects of heat dissipation by the CPU into the environment on indoor air and on human health.

Keywords: power consumption, intelligent power profile (IPP), greenhouse gas (GHG), volatile organic compounds (VOCs).

1 Introduction

With the explosive growth in personal computer sales, computers have become a great source of power consumption and environment pollution. The user interface for operating systems (e.g. Microsoft Windows Vista is com-

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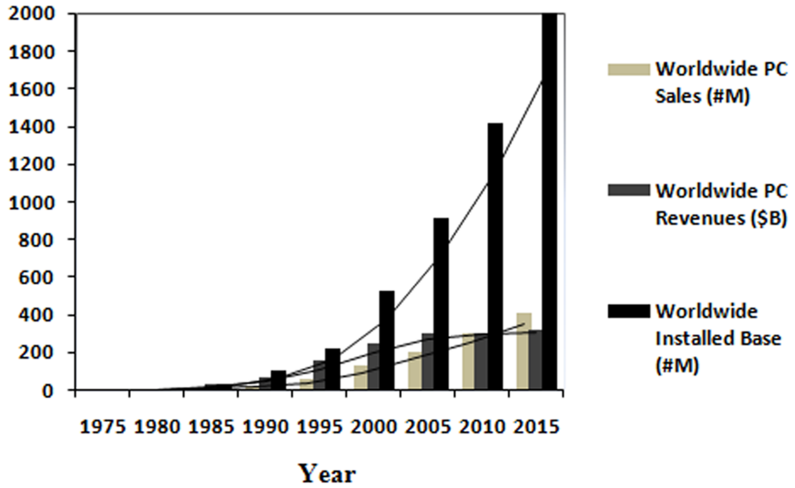
pletely different from Windows 3.1 or 95) is changing very rapidly except for their power scheme features. In the typical business, computers are averagely used only four hours each business day. Yet, even when they are idle, they continue to use energy. Nearly 40–50% of the power consumed by IT equipment is used by desktops and their ancillary equipment. Experts estimate that approximately 70% of energy used by computers and monitors is actually wasted because they are often simply not turned off when employees leave for the evening. According to one survey a standard computer (including monitor) contributes over half a ton of carbon dioxide (CO_2) to our atmosphere every year [1]. This means carbon emissions by a small office with about 15 PCs is equivalent to that of a small size car with a 800cc engine. Average concentrations of atmospheric CO_2 in the year 2005 were about 380 parts per million whereas prior to 1700, this level was about 280 parts per million [2]. This increase in carbon dioxide in the atmosphere is primarily due to various human activities. Minimizing power consumption and GHG is one of the most fundamental problems in computer science and has been studied extensively in the literature [3–9].

Software has been designed [7] and implemented that allows system designers to perform power management through a template. The proposed template is implemented as kernel-level filter drivers that attach to the device derivers from hardware vendors. Moreover, two management algorithms are implemented to compare the standard power manager of Windows. The first algorithm is a time-out scheme that performs its own idleness detection by communicating with other programs. The other algorithm is an adaptive scheme that adjusts the time-out value by considering the bursty nature of disk accesses.

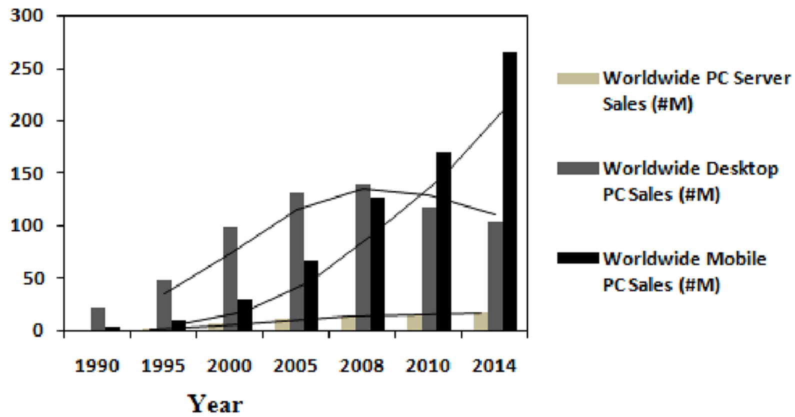
A model presented by Chia-Hung Lien [8] measures the power consumption of the streaming media server with respect to the CPU utilization without an additional hardware meter. A formal approach demonstrated by Gary Cameron [9] towards establishing a power consumption model for any processor running on an arbitrary target describes the general modeling approach that includes the effect of instruction, ALU, cache and data path accesses, which can be applied to any processor architecture.

2 Worldwide PC Market Growth

Since its beginning in the Spring of 1975, the PC industry has been developing rapidly. Figure 1 shows the tremendous growth of PC industry worldwide in the last 30+ years [10].



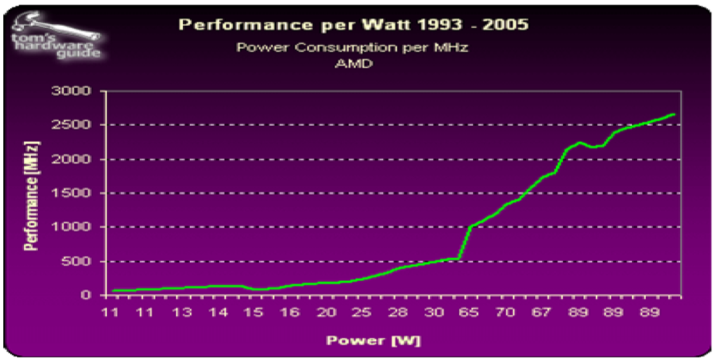
(a)



(b)

Figure 1 (a) Worldwide PC market growth; (b) worldwide market segments of server, desktop & mobile PC

From Figure 1a it is clear that in 1975 less than 50,000 PCs were sold with a value of about $60M. From this limited start the PC industry has grown to unit sales of around 300 M units in 2010 and this growth of the PC industry will continue in the future.



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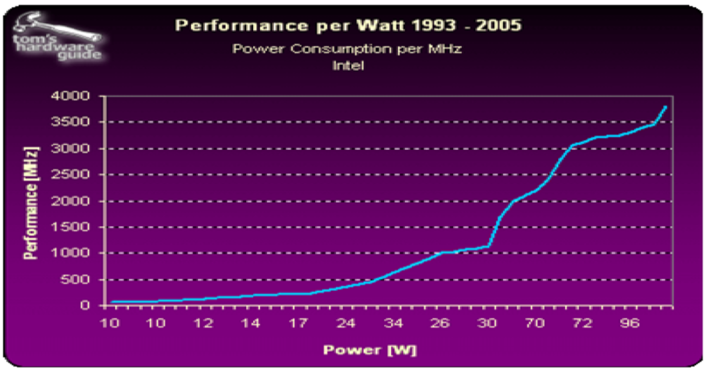

(b)

Figure 2 Performances per Watt of processors (a) AMD (b) Intel

2.1 Market Segment of Servers, Desktops and Mobile PCs

From Figure 1b it can be seen that a large market share has been occupied by servers and desktop PCs [10] that are a great source of power consumption and environment pollution. Mobile PC sales include laptops, notebooks, and emerging tablet PCs and wearable computers. Though mobile PCs consume less power in comparison to desktops and servers they also create environment pollution by dissipating heat. The graphs in Figure 2 show the development of performance per Watt of AMD and Intel processors from 1993 to 2005 [11].

Table 1 Measuring CPU performance under condition of quick heating

Parameter	P4 – 1.8 GHz	P4 – 2.0 GHz	P4 – 3.06 GHz
Core architecture	Northwood	Northwood	Northwood
Voltage (V)	1.50	1.50	1.60
L2 cache memory (KB)	512	512	512
Clock frequency (MHz)	100	100	100
Heat emission (W)	49.6	54.3	81.8

As we can see, the performance per Watt has greatly increased over the years. However, the results for current CPUs are not necessarily indicative of higher performance, since their higher clock speed does not always equate to proportionally higher performance. What good are higher clock speeds to the end user if the heat dissipation reaches unacceptable levels? In times of rising energy costs, a new standard is becoming more of a deciding factor, namely performance per Watt, where Watt is the unit that measures a processor's power consumption.

2.2 Effect of CPU Temperature on Environment

With the rise in capacity and frequency of processors over the last few decades the amount of heat dissipation and power consumption by processors has increased proportionally [12]. This situation is shown in Table 1 where three Pentium 4 (P4) processors with Northwood core and 512 KB L2 cache memory operating at a 100 MHz clock frequency are compared. Here CPU performance was measured under condition of quick heating [13].

From the results in Table 1 it is clear that heat emission is proportional to the CPU frequency. This heat emission results in more greenhouse gases.

3 Greenhouse Effect

Computers and computer monitors are responsible for the unnecessary production of millions of tons of greenhouse gases every year, according to the Environmental Protection Agency [14]. In US companies alone, more than $1 billion a year is wasted on electricity for computer monitors that are turned on when they should not be [15]. The amount of heat energy added to the atmosphere by the greenhouse effect is controlled by the concentration of greenhouse gases in the earth's atmosphere [2]. All of the major greenhouse gases have increased in concentration since the beginning of the Industrial Revolution (about 1700 AD) [2]. As a result of these higher concentrations,

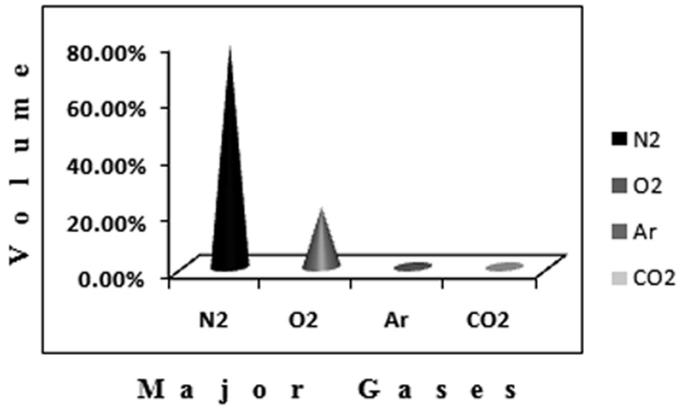

Figure 3 Composition of main gases in air

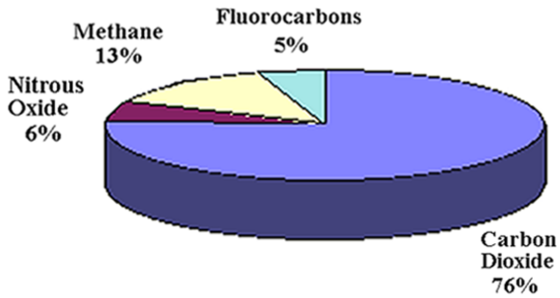

Figure 4 Distribution of GHG in the earth's atmosphere

scientists predict that the greenhouse effect will be enhanced and the earth's climate will become warmer. Air is mainly composed of nitrogen, oxygen, argon, and carbon dioxide, as shown in Figure 3, which together constitute the major gases of the atmosphere [16].

The role played by each of these components is different. For example, nitrogen is the most important plant nutrient, while oxygen is responsible for respiration and combustion. Nitrogen is also important for diluting the oxygen concentration and stabilizing the atmosphere. The remaining gases are often referred to as trace gases, shown in Figure 4, among which are the greenhouse gases such as water vapor, carbon dioxide, methane, nitrous oxide, and ozone [17]. The concentration of greenhouse gases in the air is important for studying global climatic change [18]. The rising level of greenhouse gases like carbon dioxide (76%) and methane (13%) in the atmosphere is the major cause for global warming [19]. The greenhouse effect is directly related to this absorption and emission (or "blanket") effect. In emission, objects tend to emit amounts and wavelengths of radiation depending on their "black body" emission curves, therefore hotter objects tend to emit more radiation, with shorter wavelengths [20]. Colder objects emit less radiation, with longer wavelengths.

3.1 Major Sources of CO_2

Carbon dioxide (CO_2) is one of the major pollutants in the atmosphere. Major sources of CO_2 are fossil fuels burning and deforestation. In urban areas major sources are transportation (automobiles, scooter, motorcycles, etc.) and fuel combustion in stationary sources, including residential, commercial, and industrial heating and cooling and coal-burning power plants. Motor vehicles produce high levels of carbon monoxides (CO) and are a major source of hydrocarbons (HC) and nitrogen oxides (NOx) [18, 21]. The current increase in the sale of computers and mobile phones has increased CO_2 emission in both developed and less developed countries.

3.2 Indoor Air Pollutants, Sources and Their Health Effects

Indoor environmental quality is affected by numerous factors, including biological, chemical, and particulate pollutants; temperature and humidity; the quality of heating, ventilation, and air conditioning systems; noise; light; and odor [3]. The personal computer (PC) as a source of pollution indoors continues to be studied. Research found that PCs were significant sources of indoor pollution, contributing more than three times the pollution of a standard person [4]. The rapid increase in computer sales and people's dependence on computers has increased the indoor air pollution that poses many challenges to environmental and health professionals.

Gone are the days, when human bio-effluents were considered to be the most important pollutants of indoor air, and carbon dioxide (CO_2) was generally accepted as an indicator for quality of indoor air. CO_2 has lost this function partly because today many more sources than human beings emit pollutants into indoor air [5]. The hot, volatile air emissions from PCs may in fact contribute to the large concentrations of dangerous PBDEs (Poly-Brominated Diphenyl Ethers – a group of chemicals used as flame retardants in a variety of polymer resins and plastics found in computers) often found in indoor dust [6]. In fact the widespread use of new products and materials in our days has resulted in increased concentrations of indoor pollutants; especially the mixture of volatile organic compounds (VOCs) and ozone (O_3) are prominent pollutants in indoor environments and may affect human health [22].

Volatile organic compounds (VOCs) are emitted as gases from certain solids or liquids [23]. The majority of VOCs arise from plants. One indication of this flux is the strong odor emitted by many plants. The emissions are affected by a variety of factors, such as temperature, which determines rates of volatilization and growth, and sunlight, which determines rates of biosynthesis [24]. Since people today spend most of their time at home or in an office, this long-term exposure to VOCs in the indoor environment can lead to the condition of sick building syndrome. In offices there are many sources of VOCs, starting from new furnishings, wall coverings, and office equipment such as computers, laser printers, photocopy machines, which can "off-gas" VOCs into the air [24]. It stands to reason that the more personal computers you have the more ventilation you need to negate the ill effects on indoor air and workers' productivity these VOCs produce, resulting in increased energy costs to employers [6].

3.3 Sources

Organic chemicals are widely used as ingredients in household products. Paints, varnishes, and wax all contain organic solvents, as do many cleaning, disinfecting, cosmetic, degreasing, and hobby products. Fuels are made up of organic chemicals [23]. All of these products can release organic compounds while they are being used, and, to some degree, when they are stored. Major sources of man-made VOCs are solvents, especially paints and protective coatings, chlorofluorocarbons, tetrachloroethene used widely in dry-cleaning, fossil fuels, formaldehyde used widely in building material like paints, adhesive, wall boards and ceiling tiles [24].

We also mention household products including: paints, paint strippers, and other solvents; wood preservatives; aerosol sprays; cleansers and disinfectants; moth repellents and air fresheners; stored fuels and automotive products; hobby supplies; dry-cleaned clothing [23].

3.4 Effects of CO_2 & VOCs on Health

Various health-related complaints may arise due to inside air pollutants like VOCs, CO_2 and O_3. In some cases, VOCs measured in office buildings are

Table 2 Energy labels used by desktop and mobile PC

Computers	
Desktop computer	60–250 watts
Sleep/standby	1–6 watts
Mobile PC	15–45 watts

associated with suffering from mucosal irritation and nonspecific symptoms such as headaches [25, 26]. There are some relatively minor issues related with eye, nose, and throat irritation; headaches, loss of coordination, and nausea; whereas damage to the liver, kidneys, the central nervous system, for example is more serious, and some VOCs are even suspected or known to cause cancer in humans. Key signs or symptoms associated with exposure to VOCs include conjunctive irritation, nose and throat discomfort, headache, allergic skin reaction, dyspnea, declines in serum cholinesterase levels, nausea, fatigue, and dizziness [23].

4 Energy Use by Computer Systems

There are times when we do not use computer systems for many minutes/hours, for example during meetings, presentations or demos at work, or when we sleep at home, or when other tasks make us leave the computer switched on for minutes/hours. At such times a power-management system to reduce the overall power consumption would be useful [14]. In general, a typical desktop computer uses about 65 to 250 Watts. As long as a computer goes into sleep/standby mode when not in use, it does not use very much electricity, compared to the rest of the household [27]. Over a year, a typical desktop PC can consume up to $500 in energy costs and 870 kilowatt hours of electricity. The cost of power consumption by a typical desktop PC may be calculated as follows [27]:

$$T_c = ((W \times H_u)/1000) * C_{\text{pkh}} \tag{1}$$

where T_c represents the total cost, W stands for Watt, H_u represents the number of hours of system use, and C_{pkh} represents the cost per kilowatt-hour. Table 2 represents the various energy labels used by Desktops and Mobile PCs [27].

Table 2 gives the theoretical maximum, not the typical amount used. An average PC consumes 600 units of electricity annually. Out of these, over 400 units are wasted by running the PC at full power even when it is not in use or by various software applications running on it [1]. A decade back PCs used

Table 3 Factors that affect the use of energy by computer system

More Energy	Less Energy
Ready to be used	Sleep/standby
Desktop	Laptop
Faster processor	Slower processor
Older processor (Pentium, G3/G4/G5)	Newer processor (Core Duo)
PC	Mac
Heavy use	Light use
(all drives spinning, processor-intensive task)	(e.g., email, word processing)
On the Internet	Offline

to work on a 100 W SMPS but now they are equipped with 400 to 450 W SMPS implying that they now consume over four times power to support ever increasing transistor chips on CPUs. In large organizations, almost 60% of PCs are never shut down irrespective of working hours, holidays or the regulations, merely because employees do not care for whatnthey perceive as trivial issues [1]. This also leads to the greenhouse effect.

For most people, their computers' energy use is not a significant portion of their total use, even if they use their computers much. Of course, it makes sense to make sure a computer is set to sleep automatically when not in use, because it is not good to waste energy, but the computer is not likely to be the biggest energy-user in homes [14].

4.1 Factors That Affect Energy Use

Table 3 represents the various factors that affect the use of energy by computer systems [27].

5 Proposed Framework to Minimize Power Consumption

The proposed framework to create an intelligent power profile is shown in Figure 5. This intelligent power profile starts working when the user logs into the system. In this framework OS repository plays the main role of keeping the record of all installed software and assigns the action of i-Shut and i-Hibnet for all installed software. This repository also maintains the record of power consumed by running software.

This profile implements the various techniques like i-Wait, i-Shut and i-Hibnet that could be used to minimize the average work load of CPU which in turn results in less heat dissipation and minimized power consumption.

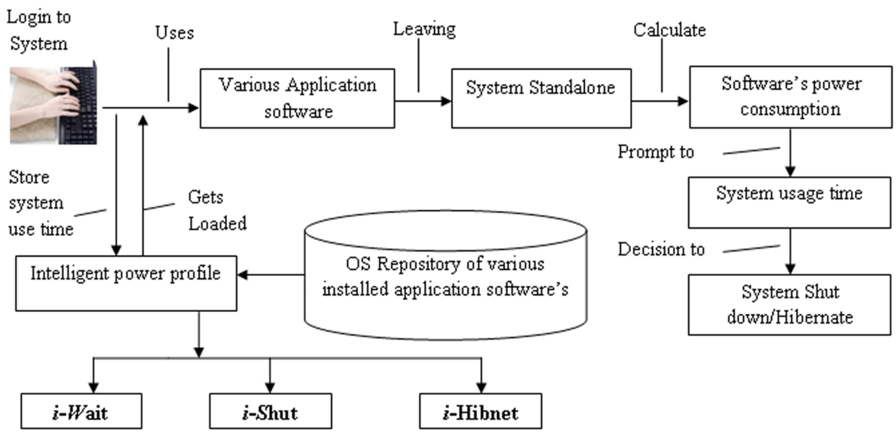

Figure 5 Proposed framework of intelligent power profile

Intelli-wait (*i*-Wait)

In this technique, users are supposed to enter the system usage time at login. If for any reason the user has to leave the system in the middle and system usage time is reached a prompt to enter new system usage time is invoked by IPP. In case the user does not reply to the prompt then IPP takes the decision for *i*-Hibnet and *i*-Shut of system. So use of this mode enables software to intelligently wait for events in the system.

Intelli-shut (*i*-Shut)

This is another useful technique supported by intelligent power profile (IPP). In this technique the OS repository keeps the record of software like Media player, CD player, Acrobat reader, etc. Thus, if the system gets *i*-Shut then there should be no data loss. Before getting *i*-Shut IPP checks the record of running software with the OS repository and then executes the necessary action.

Intelli-Hibernate (*i*-Hibnet)

In this technique the OS does not actually shut programs down, but leaves their contents in the memory and puts the processor into sleep mode, which turns off the processor core and peripherals but continues to power important internal peripherals, such as the real-time clock. At the time switch on the system the operating system can return directly to the thread that was running when the device was powered off.

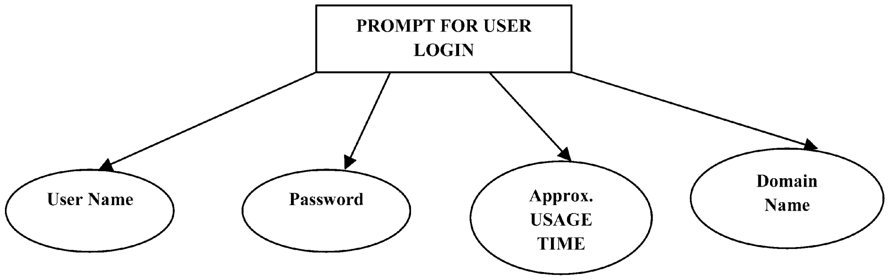

Figure 6 Proposed framework of login prompt

In this technique the OS repository keeps the record of software like MS office, any development software, etc. Again, if a system gets i-Hibnet no data loss should occur. An i-Hibnet procedure makes much sense, both for reducing power consumption and improving usability. Even in the case where IPP has to select a option in between i-Hibnet and i-Shut then it goes for i-Hibnet so that there should be no data loss.

5.1 Proposed Framework of Login Prompt

Figure 6 shows the proposed framework of login prompt.

User Name: In this field users are required to enter the authorized username assigned to them by the administrator.

Password: In this field users are required to enter the valid password for the given username. If an invalid password is given the user will not be able to logon.

Approx. Usage Time: This is the additional field which is proposed to be added to the existing framework of the login prompt. In this box users are required to enter the approximate system usage time for how long they are going to use the particular system. Given time is stored by the intelligent power profile.

Domain Name: In this field users select the particular domain name available on network in which they want to login on the network.

6 Proposed Algorithm

```
Begin: Loads the Intelligent power profile
       Input the usage time (Tu)
       iWait = Tu
       While (Tu)
         For (OS checks for all processes P1, P2...Pn)
         If (no power consumption)
           OS repository is checked for running software;
           If (Any application software process is
           running)
              i-Hibnet;
              Else  i-Shut;           EndIf
         EndIf
       If (usage time has reached)
         Update usage time (Tu)
       EndIf
       If (any action has not taken to update Tu)
         Wait for a minute;
           OS repository is checked for running software;
           If (Any application software process is
running)
              i-Hibnet;
              Else  i-Shut;
           EndIf
       Endif
       End while
End:
```

7 Measuring Power Consumption of Running Software

This section describes the measurement of power consumption by running software. This is one of the steps mentioned in the IPP framework. For performing this measurement we have considered variables like CPU Usage, KernelTime, UserTime, UpdateDelay, RawUsage, and RawPower. These variables are described as follows:

CpuUsage: is a string variable used to display current CPU usage by each process in the process list.

For calculating the CPU usage of processes one needs to obtain a value that indicates for how much time they have used the process in a certain period of time. This value is equal to the sum of the time that kernel and user have spent on these processes.

For getting the CPU usage, we have used a function called *GetProcessesTimes*(). This function uses four parameters: CreationTime, ExitTime, KernelTime and UserTime. We have used KernelTime and UserTime for our calculation.

$$\text{CpuUsage} = \text{RawUsage} + \% \tag{2}$$

This displays current CPU usage of each process in the process list with a "%" sign.

KernelTime: the execution time of a process spent in kernel mode e.g. for networking, disk I/O tasks, etc.

UserTime: the execution time of a process spent in user mode. Various user programs and applications run in user mode.

CPU usage and power consumed by each process is calculated using UpdateCpuUsage() function that takes two parameters: NewUserTime and NewKernelTime.

$$\text{UserTime} = \text{NewUserTime} + \text{OldUserTime} \tag{3}$$

$$\text{KernelTime} = \text{NewKernelTime} + \text{OldKernelTime} \tag{4}$$

where NewUserTime and NewKernelTime are the recent user and kernel times of the current process; OldUserTime and OldKernelTime are the user and kernel times of that process before updating; and UserTime and KernelTime are the actual updated user and kernel time of that process.

UpdateDelay: represents the total interval of time elapsed. This could be calculated as follows:

$$\text{UpdateDelay} = \text{DateTime.Now.Ticks} - \text{OldUpdate.Ticks} \tag{5}$$

where

- *DateTime.Now.Ticks*: Gets the number of ticks that represent the date and time at an instance. A single tick represents 100 ns. The value of this property represents the number of 100ns intervals that have elapsed since 12:00:00; midnight; January, 1, 0001.
- *OldUpdate.Ticks*: Initial intervals of time elapsed.

RawUsage: is the part of total CPU Usage used by a process in percentage. It uses UpdateDelay variable. The result is converted to integer value using 'int' keyword.

$$\text{RawUsage} = (\text{int})(((\text{UserTime} + \text{KernelTime}) * 100)/\text{UpdateDelay} \quad (6)$$

RawPower: is the current power consumed by each process, which is calculated as follows:

$$\text{Rawpower} = (\text{float})(\text{UserTime} + \text{KernelTime}) \quad (7)$$

From above formula we get the rawpower in nW that can be converted it into kW as follows:

$$\text{Rawpower} = ((\text{Rawpower}/10^9) * \text{CpuUsage}) \quad (8)$$

8 Results

This section gives a detailed overview of the results of power consumption of software during user login. The following results are obtained in real time environment after implementing the above mentioned power consumption measurement technique in windows environment for time period of 120 sec. Figure 7a shows the graph of power consumption by gaming software, namely bubble shooter deluxe, while playing and not playing. From this figure it is clear that during the use of game there are a number of peaks that represent the power consumed by this software in a given time period. An interesting section of this graph shows that while this game is in standalone mode, it is showing peaks for power consumption though it should not do this. However, this is not the point of the discussion here; because it is the role of IPP what technique you have assigned between *i*-Shut and *i*-Hibnet in the repository for saving power consumption and GHG effects. Figure 7b shows the graph of power consumption by WinWord application software during use and non-use and from the graph it is clear that during its use there are a number of peaks of power consumption whereas, during its non-use there is a single peak that represents the execution of WinWord software.

The role of the proposed IPP is to check such processes where there is no power consumption during the entire period of system usage time. Whenever it is found that power consumed by all running software is zero or the system usage time limit has arrived then it takes the decision of *i*-Shut/*i*-Hibnet or prompt to enter system usage time again, respectively.

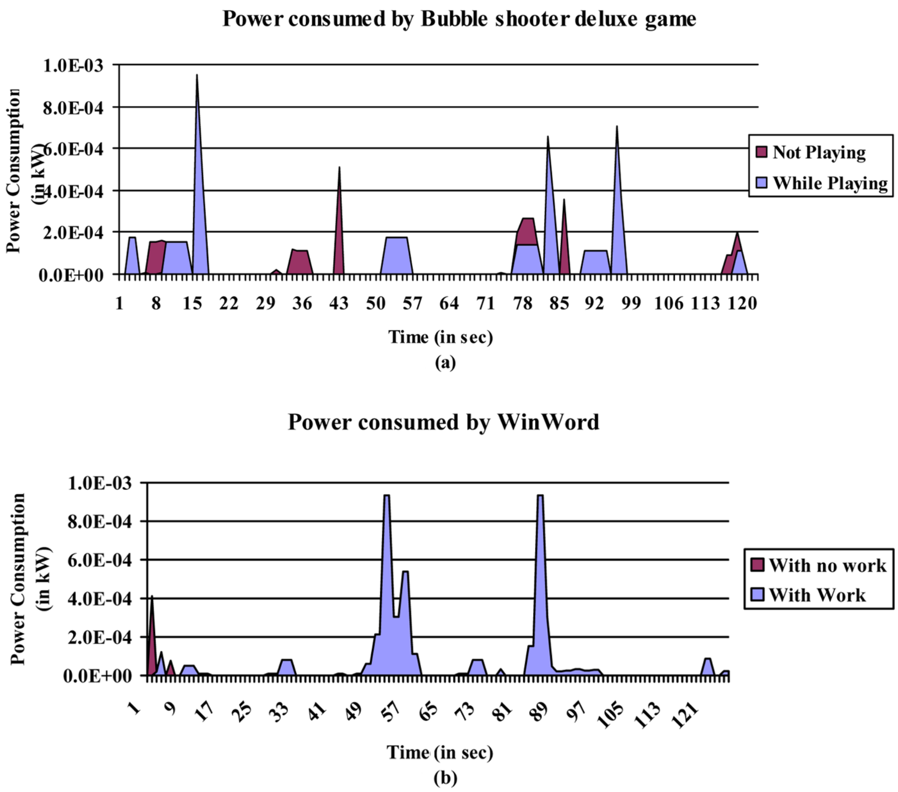

Figure 7 Graph of power consumption by (a) Bubble shooter deluxe game and (b) WinWord Application software

9 Conclusion

In this paper, we proposed a novel framework for minimizing the power consumption and GHG by computer systems. The framework is able to provide a clear picture of implemented IPP. By implementing the IPP discussed above, we show that a large amount of power could be saved by organizations and households, while also helping to reduce companies' carbon footprints as well as GHG emissions. Roughly estimated, this intelligent framework can save an organization between US$10 and US$50 per PC annually and also help to address environmental responsibility objectives. That is why companies today are finding that 'going green' is not only environmentally responsible, it is also financially smart.

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Biographies

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