International Journal of Scientific Engineering and Technology (ISSN : 2277-1581)
Volume No.3 Issue No.6, pp : 715-717 1 June 2014

Green Computing Strategies for Improving Energy Efficiency in IT Systems

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Abstract— ***Increasing energy efficiency and reducing the use of hazardous materials are the main goals of Green computing. Energy efficiency has become an important issue in today's global IT scenario. From embedded systems to large scale systems, all sectors of IT are facing this challenge. The various facts and challenges faced in the Green IT environment are discussed in this paper. This paper also focuses on the various energy conservation methods in the software and hardware levels of computing systems. A survey is also done on the solutions proposed by researchers and practices to be followed in data centers for improving energy efficiency.***

Keywords— **Green computing, Green IT, energy efficiency, Data centers.**

I. Introduction

Utilizing resources effectively, improving environmental performance and defending global warming are in priority on the list of global challenges that must be addressed urgently. Governments and business associations have introduced a range of programmes and initiatives to address environmental challenges, particularly global warming and energy use. Business associations have mainly developed initiatives to reduce energy costs and to demonstrate corporate social responsibility. Green computing is a large and increasing area. The need for saving energy has become a top priority in almost all segments of the IT market. The need for power efficiency has become a critical factor in the design of high performance computing. The information and communications technology (ICT) industry needs to further improve its environmental performance, and ICT applications have very large potential to enhance performance across the economy and society.

Energy conservation can be made at hardware and software levels. Software level energy conservation can be achieved by implementing various Green scheduling techniques in the operating system. Energy can also be saved during various stages of software development life cycle such as software analysis and design, by applying different green approaches.

Data centers are found in all economic sectors, as they provide computational infrastructure for a wide range of applications. The most valuable possession of companies is information. It is expected that data centers should always be available with its secured data. A loss of information or lack of availability may result in large economical loss. The need for power efficiency has become a critical factor in the design of data centers also.

This paper focuses on the various energy conservation methods in the software and hardware levels of computing systems. The paper also lists out the best practices to be followed in data centers for improving energy efficiency.

In section II, the green techniques that can be applied at the compiler are explained. The green strategies, which can be followed by programmers during software development, are discussed in section III. Various methods for reducing energy consumption at the hardware level are given in the section IV. The best practices to be followed in energy efficient data center design are described in section V. In section VI, the paper is concluded.

II. Green Strategies for Compilers

Software programs are analysed at run time using energy aware compilers and software source code are reshaped by applying several green aspects during code transformation. The green techniques that can be applied at local, global or inter-procedural level to make program energy aware [1] are given below.

2.1 Cache skipping

Loops are very useful in programming and it increases performance, but causes high energy consumption due to repetition of the same thing. A good method is skipping of cache operations during unnecessary replication. The study in [2] presents an efficient method to solve cache-skipping problem by modification in compiler. In this technique, compiler needs to separate the blocks that has less chance for execution. It is found from study that in some cases there is no use of cache and hence this technique results in reduced power consumption.

2.2 Instruction clustering

The study in [3] shows that instruction clustering can conserve energy from 26% to 47%. A compiler with special type of architecture, can execute a cluster of instructions in one cycle. For example in signal processing applications, a cluster of related or similar signals can be compiled in one run. It will reduce the running time of program and leads to energy conservation.

2.3 Instruction reordering and memory addressing

Sometimes the order of instructions and memory addressing is not in the favourable order which supports energy saving mode. Energy consumption can be reduced by changing the order of instruction in such a way to suit the power-safe mode.

A method is proposed in [4] using Gray Code and Cold Scheduling. Gray code is used to reference consecutive memory location. Using Gray code reduces the energy consumption by 36% as compared to binary representation of memory. Cold scheduling algorithm for instruction scheduling uses gray code that reduces 20% to 30% instruction switching.

2.4 Optimized energy cost tree

Energy aware compilers can use energy cost database for each transaction/instruction. This database can be used in code parsing and parse tree generation algorithms. During the first run of code processing, all possible parse trees are generated and their respective energy cost is stored in energy cost database. In subsequent run, tree with minimum cost will be selected for further compilation [4].

2.5 Loop optimization

Loop optimization methods are used to increase energy efficiency, which checks nested loops across dependency graph. Dependency graph are prepared for loop body in which nodes represent statements and edge corresponds to data dependency. If there is no cycle in the graph, compiler will create loop for each statement and run them in parallel using interleaved processing. Loop optimization and memory partitioning technique are explained in [5] which cut down energy consumption without degradation of performance.

2.6 Dynamic power management

Power consumption in Complementary Metal - Oxide Semi conductors (CMOS) is classified into static and dynamic. If circuit is in operating state and there is no power leakage happens then power consumption is dynamic. Whereas power consumption is static, if circuit will not be in running form but it is still powered. Dynamic power management system sets the power of its hardware as per demand to decrease probable wastage of power.

2.7 Resource hibernation

Hibernation is the process of using low power mode. Idle resource can be kept in hibernate state but changing to and from this state can be wastage of precious resources and time. A compiler algorithm reshapes a program behaviour using source level transformation in such a way that idleness threshold of a resource can be extended, and it can be changed to hibernation mode with less switching. A compiler needs to call OS directives for activeness and inactiveness of specific resource [1].

2.8 Cloud aware task mapping

Services provided by different clouds can be used for cloud aware task mapping. A compilation technique uses cloud services at host level for possible computation by parallel processing and keeping records. A machine independent compiler can also use all services from remote clouds and can be in hibernation mode during progression of these services.

There are limitations for this technique, one of them is the cost of virtual machine and migration cost of host machines. Second problem is failure of network machines causing delay in compilation or other service utilization.

2.9 Eliminate recursion

Recursive procedures using stack executed by compiler takes a lot of space and time causing reduced performance as well as additional energy consumption. Using compiler which can converts recursion into iteration may save time and energy in some cases [6].

III. Green strategies in software development

During various stages of software development life cycle such as software analysis, design and implementation, energy can be conserved. At design level, energy can be saved by making energy efficient software structure. Programmers can use following strategies during software development.

3.1 Use of green compiler

Several energy aware or green compilers are available, which can be used for energy conservation. For example Green Hill compiler can be used for C and C++, encc can be used for C++.

3.2 Use of readymade computer resources

There are number of readymade computer resources available as a service, for example currency converter, calculators etc. Making use of these readymade resources in program will be beneficial in terms of energy, cost and time.

3.3 Using iteration

More energy consumption happens in the case of recursion due to longer execution time. Therefore, a better approach is to use iteration and avoid recursion as much as possible in software development.

3.4 Data structures and algorithms

Using algorithms with less time complexity and energy efficient data structures in software development can be helpful for saving energy.

IV. Hardware Energy Saving Methods

Research is going on to find new materials that can be used to do computations and to operate transistors at lower voltage levels. It is assumed that near threshold computing can reduce energy requirements by 10 to 100 times in future systems [7]. Many digital design techniques are described in the book “Power reduction techniques for microprocessor systems” by V.Venkatachalam, M. Franz [8]. These are:- making smaller transistors, reordering transistors in a circuit, logic gate restructuring , technology mapping where the components are selected from a library to meet energy constraints and the use of low power flip flops.

4.1 Dynamic Voltage and Frequency Scaling.

DVFS requires special hardware components, but is controlled by software. It is used to reduce the supply voltage of a processor when the work load is too less that the processor can reduce its speed and still have a performance , that is sufficient enough to meet the system requirements. Frequency reduction makes it viable to reduce supply voltage since gates can take longer time for switching. This will reduce the dynamic power consumption.

4.2 Sleep mode

Energy can be saved, if the system is put into sleep mode, after finishing the execution.

4.3 Power management techniques at the OS level

Many power management techniques control the amount of parallelism dynamically. FDT(Feedback driven threading) [9] is a framework that dynamically controls the number of threads using run time information. FDT can be used to implement synchronization aware threading SAT. BAT, Bandwidth Aware Threading ,predicts how many threads can be executed before the off chip bus get saturated. Both these techniques can reduce execution time and power consumption upto 70%[10].

4.4 Energy Efficient Algorithms

A survey of algorithmic techniques to solve energy management is given in the research paper by S albers[11].The aim of these algorithms to reduce energy consumption without compromising on performance.

V. Energy Efficient Data Center Design

The power consumption of data centers are 100 to 200 times that of standard office spaces. With such large power consumption, they are prime targets for energy-efficient design measures that can save money and reduce electricity use. The following practices are recommended for energy efficient data center design [12].

5.1 Efficient servers

Servers represent the largest portion of the IT energy load in a typical data center and drive entire operation. Most of the energy wastage also happens through these servers. Even the percentage of utilization of most of the servers is 20% or below, it draws full power during the process. Recently vast improvements in the internal cooling systems and processor devices of servers have been made to minimize this wasted energy. When purchasing new servers it is recommended to look for products that include variable speed fans as opposed to a standard constant speed fan for the internal cooling facility. Using variable speed fans make it possible to deliver sufficient cooling with less energy consumption while running slower. The Energy Star program helps consumers by recognizing high-efficiency servers. Servers that meet Energy Star efficiency requirements will, on average, be 30% more efficient than standard servers.

5.2 Storage devices

Power consumption depends on the number of storage modules used. Storage redundancy needs to be rationalized and right-sized to avoid rapid increase in size and power consumption. Consolidating storage drives into a Network Attached Storage or Storage Area Network are two options that take the data that does not need to be readily accessed and transports it offline. Taking superfluous data offline reduces the amount of data in the production environment, as well as all the copies. Consequently, less storage and CPU requirements on the servers are needed, which directly corresponds to lower cooling and power needs in the data center.

5.3 Network equipment

There are active energy management measures that can be applied to reduce energy usage as network demand varies. Such measures include idle state logic, gate count optimization, memory access algorithms and input/output buffer reduction.

5.4 Power supplies

Most data center equipment uses internal or rack mounted alternating current/direct current (AC-DC) power supplies. Historically, a typical rack server's power supply converted AC power to DC power at efficiencies of around 60% to 70%. Today, through the use of higher-quality components and advanced engineering, it is possible to find power supplies with efficiencies up to 95%. Using higher efficiency power supplies will directly lower a data center’s power bills and indirectly reduce cooling system cost and rack overheating issues.

5.5 Virtualization

Virtualization is a method of running multiple independent virtual operating systems on a single physical computer. It is a way of allowing the same amount of processing to occur on fewer servers by increasing server utilization. Instead of operating many servers at low CPU utilization, virtualization combines the processing power onto fewer servers that operate at higher utilization. Virtualization will drastically reduce the number of servers in a data center, reducing required server power and consequently the size of the necessary cooling equipment. Some overhead is required to implement virtualization, but this is minimal compared to the savings that can be achieved.

5.6 Air management

Air management for data centers entails all the design and configuration details that go into minimizing or eliminating mixing between the cooling air supplied to equipment and the hot air rejected from the equipment. Effective air management implementation minimizes the bypass of cooling air around rack intakes and the recirculation of heat exhaust back into rack intakes. When designed correctly, an air management system can reduce operating costs, reduce first cost equipment investment, increase the data center’s power density (Watts/ square foot), and reduce heat related processing interruptions or failures.

5.7 Electrical systems

Following are general guidelines for delivering electrical power in the most energy-efficient manner possible:

• Minimize the resistance by increasing the cross-sectional area of the distribution path and making it as short as possible.
• Maintain a higher voltage for as long as possible to minimize the current.
• Use switch-mode transistors for power conditioning .
• Locate all voltage regulators close to the load to minimize distribution losses at lower voltages.

VI. Conclusion

Identifying the problems in energy use is the first step toward finding ways to save energy. In this paper, several methods for green compilation are discussed. This paper also highlighted some methods a programmer can follow while developing software. Various hardware energy saving methods are listed out in this paper. The paper also addressed the various strategies in the design of an energy efficient data center.

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