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Review on Green Networking Solutions

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Abstract : *Empirical studies have revealed that a significant amount of energy is lost unnecessarily in the network architectures, protocols, routers and various other network devices. Thus there is a need for techniques to obtain green networking in the computer architecture which can lead to energy saving. Green networking is an emerging phenomenon in the computer industry because of its economic and environmental benefits. Saving energy leads to cost-cutting and lower emission of greenhouse gases which are apparently one of the major threats to the environment. 'Greening' as the name suggests is the process of constructing network architecture in such a way so as to avoid unnecessary loss of power and energy due its various components and can be implemented using various techniques out of which four are mentioned in this review paper, namely Adaptive link rate (ALR), Dynamic Voltage and Frequency scaling(DVFS), Interface proxying and energy aware applications and software.*
Keywords: *Green networking, Adaptive link rate (ALR), Greening, Interface Proxying, Dynamic voltage and frequency scaling (DVFS), Energy aware applications, Energy aware software, over-provisioning, selective connectedness, resource consolidation, proportional computing*

I. INTRODUCTION

There is an immense need to conserve energy in every possible way. Saving energy is not just restricted to the transport, industrial or domestic sectors. It has also reached to the Information and Communication Technology sector (ICT). It may seem a little blur and unthinkable but the network components and devices operating in an industrial firm, data centers, IT farms etc. are responsible for the emissions of Greenhouse Gases (GHG), mainly carbon dioxide. It is not indiscernible to expect and approximate the harm caused by these emissions to the environment and thus to mankind.

It's not just the environment that is getting damaged, it also impacts the economy as there is a loss of energy and power that could be saved using proper techniques in the architecture or the core framework. Thus in this work solutions are presented as well as their prospects to achieve greening of networks, i.e. designing the networks in an energy and power saving manner to overcome the ambiguities and the loopholes in the existing ones.

1.1 Existing Problem

The network components and devices are designed in such a manner so as to handle the peak load traffic. This results into two obvious problems which are also the characteristics of the existing architecture: over-provisioning and redundancy. Dan Chen et al state that "The two major drivers for energy efficient networking are: (a) high carbon footprints because of electrical energy use and (b) consumption of an enormous amount of energy by the networking equipment and the resulting high cost of energy" [1].

Energy consumption in the ICT sector leads to the emission of Green House Gases (GHG). The ICT sector is responsible for almost two percent of the man-made carbon dioxide emissions for every 1 TeraWatt hour (TWh) energy consumption, which is approximately equal to that made by the global aviation industry, with the potential risk of its increment(by almost six percent). If this be the condition, not only will the cost of maintenance and production rise, but it will also pose a major threat to the environment which cannot be ignored.

1.2 Proposed Solutions

Almost all the network devices remain active for most of the time independent of their utilization. For instance, the NIC remains idle for most of the time and its average load is 5 percent for normal computers and 30 percent for servers [1]. Also the idle links that are not used in packet transfer are responsible for causing unnecessary traffic in the network which can be avoided using proper techniques. Thus, summarizing the aforementioned facts, the solutions for green networking can be summed up as-

- Utilizing renewable energy in ICT sectors
- Designing components to operate on low power

- Geographical re-localization of network resources and devices
- Fault tolerant and secure service “migration”

There are a number of ways of greening the networks. In general, all these ways fall under one of the following key characteristics of green network architecture-

- Resource consolidation: This feature exploits the characteristic of over-provisioning of the networks. It demands shutting down underutilized devices and consolidating the network load on a selected cluster of active components.
- Selective connectedness: This characteristic calls for transitioning the idle devices to low power or sleep modes as transparently as possible, thus transferring the traffic on some other device that is active. Interface proxying uses this technique thereby freeing the main end device.
- Virtualization: This characteristic refers to operating multiple services at a single piece of hardware, thus reducing the under-utilization of resources which in turn reduces the energy consumption.
- Proportional Computing: This characteristic refers to the concept of consuming energy proportional to resource utilization. This means that idle devices or components should consume less energy as compared to the active or working devices. This is characteristic of the two techniques of Adaptive Link Rate (ALR) and Dynamic Voltage and Frequency Scaling (DVFS).

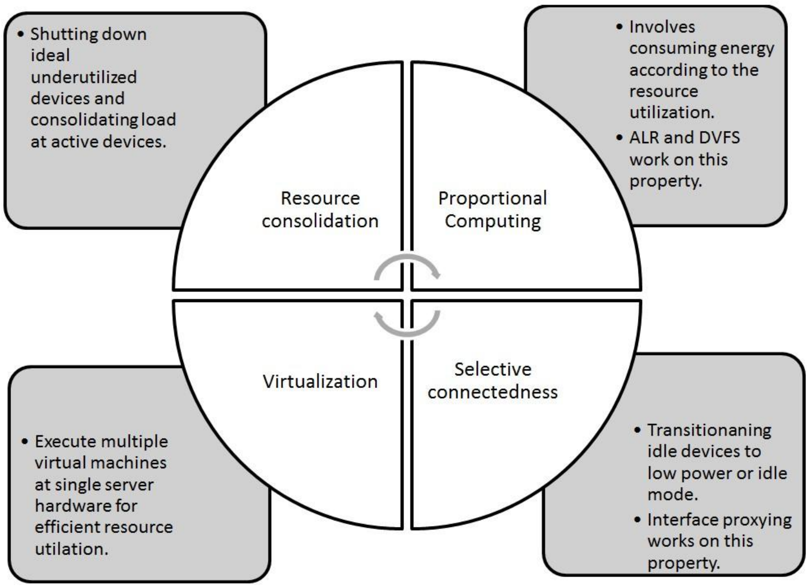

Fig. 1. Characteristics of green network architecture.

II. Techniques To Achieve Green Network Architecture

This section aims at understanding the four widely used techniques to achieve greening of computer networks. There are other related techniques too, but since they require a wider perspective and complex purview, the focus here will only be on the following methods for a more adjacent and converged aspect.

2.1 Adaptive Link Rate

Experimental results showed that energy consumption in an Ethernet cable is independent of the link utilization.Even when there are no data packets being sent, links are being continuously sent and received to maintain synchronization and to avoid time delay in case of transmission of a longer frame. This leads to unnecessary energy loss without work being done. This issue can however be avoided by properly adapting the link rates by the following two methods-

2.1.1 Changing the state of the links to sleep/idle mode

This state allows the links to function in either sleep mode or a fully awake mode. Depending on the reactivity of the links to the network traffic following situations may arise

- Drop packet in sleep mode: These policies discard any incoming packet during sleep state
- Fully awake on packet arrival: These policies transition to active state when a packet arrives during sleep state

- Wake-up on meeting the buffer threshold: Packets are buffered for later processing during sleep state. The link is transitioned to active state either on sleep interval timeout, or when number of incoming packets increases a threshold[1]
- Buffer the packets to process them in the active state: These policies buffer the incoming packets in sleep state to process later when link becomes active
- Use shadow ports to service the packets on behalf of cluster of sleeping ports: These policies use dedicated port (Shadow port) for a cluster of sleeping ports to process packets on behalf of the sleeping ports.

Even though this serves to be an effective technique to save energy, there are chances of energy consumption at various transitions, like the one from sleep mode to active. Another disadvantage includes the loss of data packets in case the links are in sleep mode and the time delay to process the packets after returning to active state.

2.1.2 Reducing the line rate during low utilization period, which is known as rate switching

This method refers to scaling down the link rate as it was observed that operating the links at lower rates leads to energy saving. Experiments were performed which concluded that there is a significant difference in power consumption among different link data rates. Gunaratne et al. [3] reported that the energy consumption was 3 W less in switching from 1 Gb/s link speed to 100 Mb/s at NIC, and about 1.5 W less at switch interface [2]. It was also found that 99 percent of the time links can be operated at 10 Mb/s, without any perceivable delay by users [2]. The link rate scaling can further be categorized on the following basis-

- Link Utilization and buffer occupancy: These policies consider buffer occupancy along with link utilization. They also prevent the switching of data rates based on buffer occupancy
- Buffer occupancy: These policies consider buffer occupancy to transition the link to lower data rates and the reverse.
- Heuristics: These policies use heuristics to determine the time that is needed to remain in a switched state and data rate switch.

2.2 Interface Proxying

As the name suggests interface proxying involves the use of a proxy that acts as an interface to the incoming traffic and can also process it at times. As compared to the ALR technique where the functionalities could be turned off, in the case of an end device, this is not possible and the traffic needs to be processed. This means that even though the users are idle, the constant incoming background traffic needs to be processed. However, keeping the end device in an active mode to deal with this traffic will cost much more energy than what is required for the traffic computation. Thus to overcome this problem, a proxy acts as the end device and processes the traffic that require minimal computation. Interface proxying can further be divided into internal (Network Interface Card) and external interface proxying.

2.2.1 Network Interface Card (NIC)

An NIC is inbuilt in the CPU which contains a low energy processor and remains idle most of the time. Thus it can be utilized for filtering or light processing of data packets. The NIC may drop the chatter while the full system activates only on the incoming of non-trivial packets that require further processing.

This allows energy saving without disrupting the network connectivity. Usual exchanges, such as ARP [Address Resolution Protocol] processing, ICMP [Internet Control Message Protocol] echo answering or DHCP [Dynamic Host Configuration Protocol] rebinding, are simple tasks that could be easily performed directly by the network interface.

Extending this technique, some more complex tasks usually performed by the main CPU to the NIC are offloaded. The experiments show that it is possible, through the use of dedicated memory or direct memory access (DMA), to handle most of the network tasks that do not need interaction from the user, like Peer-to-Peer (P2P) applications, FTP downloads, status message update on Instant Messaging (IM) systems, etc.

2.2.2 External Proxying

External proxying is used in larger Local Area Networks (LANs) where a proxy acts as an interface for all the devices connected to it and thus offloads the main end host from a number of network maintenance tasks apart from the economy of scale.

External energy-aware proxies have also been evaluated in the context of P2P file-sharing applications. In P2P, edge device network presence represents a key issue to guarantee the robustness of the network: in this case, interface proxying represents a good way to save energy, without disturbing the system[2].

2.3 Dynamic Voltage and Frequency Scaling(DVFS)

DVFS, like ALR involves proportional computing. It aims at reducing the power and energy consumption of microprocessors since they are estimated to consume almost 50 percent of the total energy of a computer system. Under this method, analysis on the Complementary Metal Oxide Semi-Conductor(CMOS) is done since all digital circuits these days are constructed using CMOS, especially processors. Considering the equation (1):

$$P_{dynamic} \alpha\ C_L\ V_{dd}^2\ f_{clk}$$

Where C_L is the collective switching capacitance, V_{dd}^2 is the supply voltage and f_{clk} is the clock frequency.

It can be concluded that lowering the supply voltage can reduce considerable amount of energy because of the square relation. Reducing the operating frequency and supply voltage can further reduce the energy and power consumption.

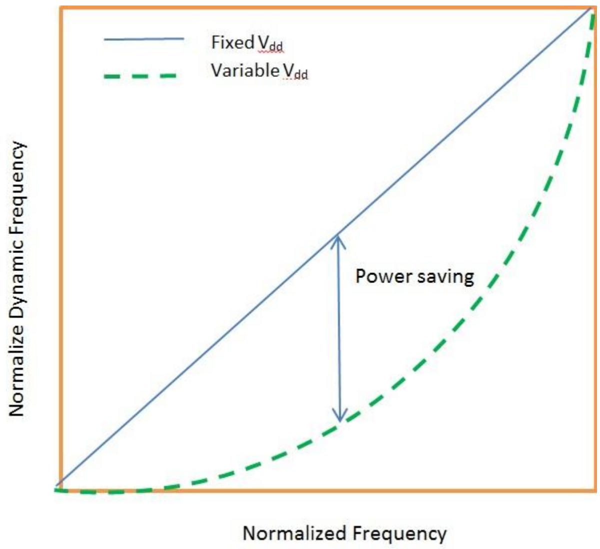

Fig. 2 Approximate amount of energy that can be saved

There are three key components for implementing DVFS

- An operating system that can vary processor speed.
- A control loop that generates voltage required for desired speed.
- A microprocessor that can operate over a range of voltages.

Constraint: A processor goes to sleep because of some special instruction, and then it is woken up by certain interrupts, which cause idle intervals between the tasks. Thus, work load of the processor normally consists of a sequence of tasks and idles between tasks.

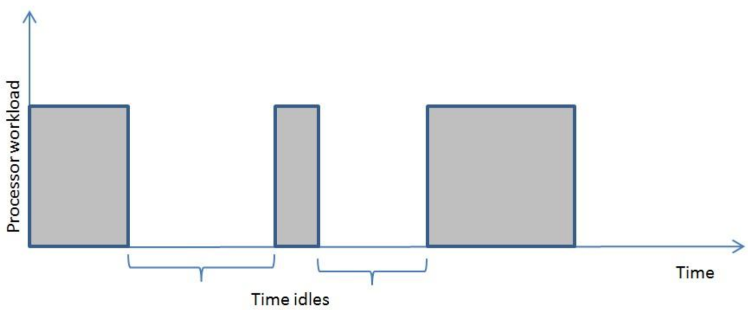

Fig. 3: A typical workload pattern with tasks and idle time between tasks

By scaling down the voltage and frequency each task is extended into the idle time after it. As long as the tasks do not overlap, DVFS is guaranteed to be correct.

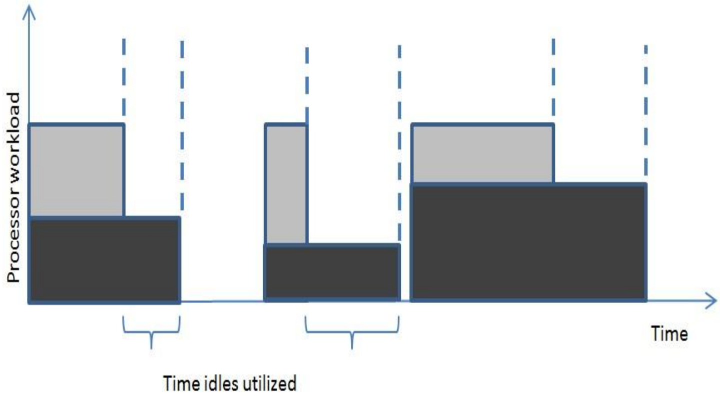

Fig. 4: A typical workload pattern with DVFS technique

But before designing the DVFS technique it is essential to prototype the workload. The concept of an event makes partitioning the workload to be possible. Two parameters α and β, as shown in the fig. 5, are used to describe an event; both in the unit of time, where, α measures the length of an event and β measures the length of an event plus idle time before the next event starts.

It can be concluded that utilization can be determined by dividing α by β. For example if utilization is 50 percent, it means that this particular event has the potential to be scaled down by a factor of two.

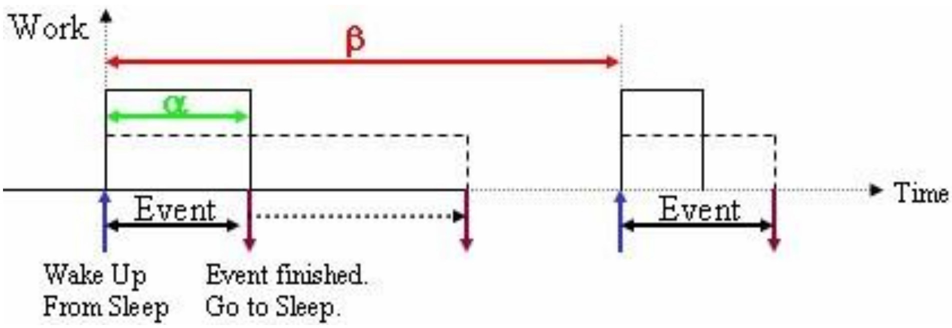

Fig. 5[3] Prototyping the workload with DVFS (ideal case)

2.4 Energy Aware applications and software

Energy aware applications and software meddle with the existing features of computer networks. The aim is incorporating energy-efficient techniques in the current architecture without making any changes to their existing functionalities. However due to robustness of the existing architectures, this technique is not widely used. It can be further divided to user-level applications and kernel-level applications.

2.4.1 User-Level Applications

Green telnet is the best example of energy conservation at the client/server lever. Green telnet is a modified telnet client/server that allows the client to go to sleep without breaking the session by queuing data for the client while it is asleep. Green telnet intents to increase the usage of power management in client machines by allowing them to go to sleep, thereby losing their connection to the server, but can still have their sessions remain active. Once the client wakes back up, the connection is restored and the session continues as normal. Green Telnet accomplishes this by buffering any data destined for an idle client on the server, and then transmitting the buffered data to the client when it wakes back up [1].

2.4.2 Kernel-Level Applications

Other than greening the application-layer in the user-space, it is also possible to improve the transport-layer at kernel- level for more energy efficiency. Specifically, modification of TCP in the operating systems kernels, would allow applications to open greener sockets, providing a framework for software developers. The authors suggest one such modification, introducing explicit signaling at the transport layer via a specific option (TCP SLEEP) in the TCP header, in which case the other party will buffer data received from the application instead of sending it right away [1].

III. Comparison Of The Techniques

Every technique has its own approach and solves the problem in a different and unique manner. Thus they have their advantages as well as disadvantages and mentioned below in the table.

Table 1. Advantages and Disadvantages.

Techniques	Advantages	Disadvantages
1. ALR	• Exploits over provisioning and causes energy saving to a considerable amount • Buffers can store packets reducing packet loss • Fewer ports remain active when using shadow ports	• Causes packet delay and loss • Packets may be lost if their number exceeds the buffer threshold • Using shadow ports may need changes at the hardware and protocol level
2. Interface Proxying	• Offloads main end device from trivial computation • It can be used for a number of end devices as in case of external proxying	• Sometimes important data may not reach the end device • Algorithms to process data by proxies are difficult and restricted
3. DVFS	• Improves processor speed and decreases processor's energy consumption • Easily implementable as voltage and frequency can be changed using electronic circuits.	• It only targets the working of processors and not the other components of a computer system • It demands the following three conditions: o An operating system that can vary processor speed o A control loop that generates voltage required for desired speed o A microprocessor that operates over a given range of voltages
4. Energy-aware applications and softwares	• Reduces the trouble of designing new architectures all over • Only a few changes need to be made to achieve greening of networks	• Difficult to implement due to the traditionality of existing architectures • Meddling with the existing architecture may lead to network disruption

IV. Inferences

In this review paper the focus is on the four main techniques of attaining green network architecture. Every technique is different from one another and have their own characteristic. ALR and DVFS fall under proportional computing whereas Interface Proxying falls under selective connectedness. Unlike ALR, interface proxying is applied at end devices. Out of all the techniques ALR is proved to be the most efficient as it directly exploits the over-provisioning and idleness of a network saving many terawatts of energy and thus billions of dollars. DVFS is an emerging technique and various algorithms have been proposed on it by different authors.

Energy aware applications and softwares is not that reliable due to the robustness and traditionality of the existing networks which are difficult to change.

V. Conclusion

Keeping in mind the aforementioned facts, conclusion can be drawn that there is a strong need for energy and power saving, not just from the cost/investment point of view but also from the environment perspective. The ICT sector has an adverse effect on the environment because of its current trends and functionalities. If monitory steps are not taken, there might soon be an economical and environmental problem. Thus this paper review on various techniques to overcome this problem. The techniques have their own properties and target different components of an architecture. Thus a combination of all these techniques is something that can be looked forward to for an utmost energy saving system.

VI. Suggestions And Future Scope

The possible prospects of this problem lie in the manner of using every technique at its target most efficiently and also extending it to other components of a network.

As mentioned earlier, a combination of all these methods would prove to be the ultimate solution since the entire network architecture can be aimed. DVFS can also be implemented at a basic level since it involves changing the frequencies and voltages and thus electronic circuits.

However, this might take a few years as this is a new aspect and thus requires core research. Though green networking is in its infancy at present, it can be meddled in many ways to obtain the most efficient network architecture that will prove to be economical, environment-friendly and handy.

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