GREENING THE NETWORKS: A COMPARATIVE ANALYSIS OF DIFFERENT ENERGY EFFICIENT TECHNIQUES

M.J. ARSHAD, *SAMEEN S. SAEED, N. JAVED and A.I. DURRANI[1]

Department of Computer Science and Engineering, University of Engineering & Technology, Lahore, Pakistan

[1]Department of Chemistry, University of Engineering & Technology, Lahore, Pakistan

From a room electric bulb to the gigantic backbone networks energy savings have now become a matter of considerable concern. Issues such as resource depletion, global warming, high energy consumptions and environmental threats gave birth to the idea of green networking. Serious efforts have been done in this regard on large scale in the ICT sector. In this work first we give an idea of how and why this modern technology emerged. We then formulate a precise definition of the term green technology. We then discuss some leading techniques which are promising to produce "green-results" when implemented on real time network systems. These technologies are viewed from different perspectives e.g. hardware implementations, software mechanisms and protocol changing's etc. We then compare these techniques based on some pivotal points. The main conclusion is that a detailed comparison is needed for selecting a technology to implement on a network system.

Keywords: Energy, Power, Green, Networking

1. Introduction

Man has been using natural resources and depleting earth's natural environment since the time of industrial revolution. We are already approaching resources to their limits. If this trend goes on our global environment will no longer sustain it. Depletion of earth's natural resources has become a serious issue now. As it is now approaching to the alarming levels. There is a tremendous growth in IT sector electricity consumption which is expected to be more than triple by the year 2020 [1]. Communication technology industry is not only consuming a notable fraction of world's energy consumption but also contributing to the global warming through green house gases (GHGs) and carbon emission levels. With internet penetration and prevailing trend of handheld devices ICT networks are growing rapidly. These fast growing networks demand for high energy consumptions. Estimates have shown that powering wired networks of the United States costs 0.5-2.4 billion dollars a year [2] and these figures are expected to grow exponentially in the upcoming years.

ICT is contributing 8-10% of EU's electricity consumption and is responsible for 2.5 to 4% of its carbon emissions. This contribution is growing and may double by the end of 2020 [3]. There are estimates that every minute of a day, 52 hours long video content is uploaded on YouTube, 800,000 users share Facebook content and more than 2 million queries are directed to Google while a single search query may be responsible for from a few tenths of grams to few grams of carbon emission. After encountering such alarming facts governments are now concerning the environmental impacts of using ICTs. There are many incentives for governments and enterprises and organizations to introduce green technologies. With global rise in environmental awareness, there are promising enterprise challenges for energy efficiency and cost reductions. Enterprises not entering in this green technology era will miss their chance to get energy efficient at reduced costs. There is a huge variety of modern and challenging technologies such as virtualization, server consolidation, green data centers, sleeping switches/links and energy efficient hardware to name a few , which aim at less power consumption and hence low carbon footprint.

Going green is no longer an engineering practice; it is soon turning into the inevitable solution of present century. In a nutshell green networking technology refers to the hardware devices, software solutions and management strategies which consume less power emit less carbon dioxide and are energy aware. Green networking optimizes the ICTs and internet for energy efficiency using new technologies e.g. switches, routers links etc. which will consume less energy and leave less adverse impacts on environment.

From an environmental point of view the main target of greening the network is to cut down the GHGs emission. From an engineering perspective the green technology is a strategy which runs the system with low power consumption while having no compromise on the overall system performance. At the same time there are economical fronts which aim at reducing cost while maintaining the same level of performance. Going green

* Corresponding author :   sameenseher@gmail.com

will allow developing nations to go on in ICTs with their low power resources and keep pace with developed nations. Green technology inflation has now spread into the field of networking and telecommunication all over the world. Old systems are running on the techniques that are based on the principles which are in opposition to the ones on which green technology relies. As in existing non-green networks all the links, switches, line cards and routers remain always on. They are never put to sleep in off-peak hours. Hardware redundancy is a very common practice. There are idle machines which are doing no useful work and are intended to take the control if any machine fails, these idle machines add much more to the overall network energy consumption. In the same way link capacity is designed to deal with the traffic of peak hours and an enough portion of this capacity sits idle during low traffic periods. There are many ways to achieve green networking goals. Resource redundancy can be reduced while at the same time having no compromise at performance. Similarly elements of core network can be designed to put to sleep during low traffic intervals. Same is the case with underutilized devices, say routers, which can be shut down and reroute the traffic on other network elements while at the same time achieving overall same performance. There will be a need to shift to new protocols in order to achieve goals from these new strategies. Energy agnostic devices are needed to replace with energy proportional ones. This will reduce energy consumptions up to great extent. Energy aware resources consume energy in proportion to their usage unlike agnostic ones which keep a certain level of consumption irrespective of their utilization.

The reality is that green networking technology is now becoming popular and soon it will prevail as a major trend. But achieving green goals will require a fair deal of insight in measuring costs and benefits. There are multiple ways for achieving energy awareness in existing systems; the point of decision is which one to go with. One scenario may require one particular technology implementation to get the target while on the other hand some other scenario may require putting a blend of two or more techniques to get expected results.

In this work we give a precise overview of few green technologies that are responsible for achieving energy efficiency. Here our focus is only on wired network technology. Then we evaluate these technologies in a comparative way based on some key factors and give tabular comparison of them.

Section II offers the overview of green technologies. In Section III, we formulate a comparison of the techniques presented in the second section. Conclusion appears in the last section.

2. Green Techniques

Reduction in energy consumption requires two steps. First, at hardware level, network elements such as routers, switches, NICs etc. need power management primitives. Second, network protocols should make best use of these hardware primitives. Given, some strategies that indicate how different algorithms, architectures and protocols can be used to meet the goal of energy consumption reduction without any delay, latency or adversely affecting the network performance.

- Sleeping Network Components
- Rate Adaptation
- Shutting down Individual Cables in Bundled Links
- Eliminating Server Idle Time Power

2.1. Sleeping Network Elements

A network element is idle when it is powered on but not processing any data packet. One of the power management schemes is to put the element to sleep when it is idle. This will result in significant energy saving. Sleeping can be performed at individual hardware element, at the network level, by modifying internet topologies and at the network interface depending upon the sleeping approach.

There are two sleeping approaches. Coordinate sleeping (or network wide approach) which is performed on network layer using TDMA or 802.11b protocol. This routing protocol explicitly aggregates network traffic into fewer routes, enabling other interfaces or routes to sleep. This approach is applicable during less traffic load in the network and it may cause loss of packet. Other approach is uncoordinated sleeping (or link layer approach) which is performed at MAC layer using distributed algorithms. In this mechanism an interface or a network component decides to sleep alone. It just inform its neighbor routers about its decision when it is about to sleep. When the neighbor wants to send data to the sleeping element, it first sends a request packet to wake the sleeping interface. Then it waits for wake up and after that send actual data. This approach may cause traffic delay.

When we decide to put an element rather it is a switching component or an entire router, a link card or a route to sleep. We must answer following queries.

- How long the component will sleep?
- Sleeping device require some additional energy to wake up. Thus a network component must sleep enough that it may compensate this additional energy to make sleeping effective. It means sleeping time must be greater than wake up time i.e.

if a component takes Yµs to wake up and it sleeps for Zµs then

- Z > Y

- By this mechanism we can easily calculate the time period for which a device may sleep.

- How to take sleeping decision?

- If the sleeping decision is uncoordinate, a router or switch first monitor network traffic on all its interfaces, calculate inter-packet time, make estimations for expected inter-arrival time of packet and then based on these calculations put its some or all interfaces to sleep. It may happens that a packet arrive before its expected time. In this case arrived packet wakes up the sleeping interface to continue network traffic and the route next recalculate its sleeping time.

- In coordinate sleep decision, the network flow is estimated and after aggregating it, selected router or switch is put to sleep.

- Which router/switch is most suitable to sleep?

- Based on the internet and network topologies, some routers are most amenable to sleep than others. For example, within a network router who routes the traffic from end user to server may sleep for a long time interval during inactivity of end user (usually at night). Similarly the router that is connected to backbone network may sleep for a time period when traffic load is low and there are some other routers to control this traffic.

Today a variety of network elements are available and there is a huge diversity in their architecture. For instance, some routers based on shared memory architecture, some use memory with two PCI buses, some use TDMA (time division multiple access) switch, some use PXF (parallel express forwarding) switching technique and so on.

Regardless of the architecture, we can achieve sleeping through buffering. In buffering data packets are collected into small bursts and create enough gaps to sleep the element in a manner that minimize buffering delay.

Sleep state require three parameters. First, power drawn in sleep mode which require calculating the amount of energy drawn in idle state. Second parameter is Time that is required to define the time period for which a network element goes to sleep, how long it will stay sleep and when it will come out of sleep state. Third parameter is the mechanism for invoking and exiting sleep state. Two options may be used for this purpose. A "Time driven sleeping" mechanism: in

which an element sleep for predefine period of time and after expiring that period it exit from sleeping state. The packets that arrive during this time period are lost. Other option is the use of "wake-on-arrival (WOA)" mechanism: in which a circuit is used that remain powered on and sense the packet on sleeping interface. It awakes the sleeping element when a packet arrives. IEEE 802.3az network protocol is working on this mechanism [4].

2.2. Rate Adaptation

Even when there is no data transmission and the network is idle, the links remain active to obtain synchronization by sending meaningless data packets or frames. Rate adaptation deals with the reduction of energy consumption when a network is actively processing data traffic. Energy consumption depends on link capacity not on link workload. Higher the data rate, great the energy consumption. Based on the delay and utilization of links, this technique efficiently low the data rate on individual link. Figure 1 explains this technique. According to the workload of data packets we adapt the rate of operation or assign low frequency to network device.

Assigning low frequency to a link reduce energy consumption dramatically. It is because of two reasons. First, assigning low frequency to a network channel will offer slow transfer or processing of data and this will save energy because energy consumption depends on the data rate. In a local area network (LAN), if a link is operating between 100Mbps-1Gbps it consumes 2-4W energy, but when the same link operates at 10Gbps it consumes 10-20W energy [5]. A network interface card (NIC) of 10Mbps utilizes less energy than an NIC of 1Gbps. Estimation shows that this increase is about 3W which contributes approximately 5% energy consumption [6]. Similarly a network router with many interface consume energy at its each individual interface. So as many interfaces a router contain as much energy it consumes. Hence, adapting low data rate reduce energy consumption significantly.

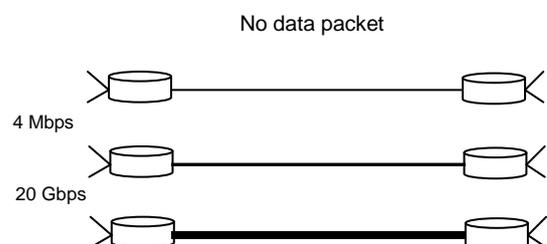No data packet

4 Mbps

20 Gbps

Figure 1. High energy consumption with increasing data rates (rate of 2GBps link can be reduced to 100 Mbps or even it can be made idle depending upon the traffic of neighboring routers) [6].

Secondly, energy can be reduced by using dynamic voltage scaling (DVS) and low frequency allows this scaling [5]. This frequency scaling is commonly used in many microprocessors today.

Rate adaptation can be implemented because all traditional system supports multi data rates. In existing networks before starting communication both sides first agree on a data rate (which is the highest common data rate) and then start communication at this rate. In a rate adaptive system this selection can be switched more dynamically among a wider range of available data rates. Instead of sticking to the one specific data rate for the full connectivity session the system can switch on different many data rates in order to consume less energy. Different data rate is achieved by implementing different internal clock in physical layer. Such algorithms are embedded which access the traffic conditions at run time. Frames which are ready to transmit are queued and the mechanism which selects the data rate keeps a certain threshold. If length of the queue falls below this threshold then low data rate is chosen and if this exceed this value than high data rate is selected.

Actually, sleeping and rate adaptation are very different because sleeping increases the idle time by processing as fast as possible while on the other hand rate adaptation minimize the idle time by processing at slow rates. As one technology goes in exactly the opposite direction of other, these two technologies cannot co-exist. Hence, network will run either sleep technology or in rate adaptation.

2.3 Shutting down Individual Cables in Bundled Links

The overall energy consumption of network is aggregate of the individual consumption of nuts and bolts of network i.e. links, switches, routers etc. In the backbone network topologies, each pair of routers is connected by links. These logical links are physical cables which physically connect routers. These links are usually not driven by a single cable; but in fact bundle of many individual physical cables that make up one logical link. For example, if there is a link of the capacity of 50Gbps it may contain five physical cables of capacity 10Gbps each. There are line cards that drive these links.

So, the idea is to power off individual cables (some from whole bundle) of links and their line cards to cut down the overall energy consumption by the backbone network. Line cards are the devices that drive the links. A notable target of saving energy can be achieved as line cards make a large fraction of router energy consumption [7].

To implement this idea we need to know the maximum number of cables that can be powered off at any given time. To find out this number we require network topology and network traffic matrix at that given time. Unfortunately, these calculations involve NP-complete computations so several heuristics on greedy approaches are usually applied to address such computing problems.

In computational problems, network are represented as directed Graph $G(V,E)$, where V is the set of routers(vertices) and E is the set of links(edges). Let there are two routers j and k then link between these two routers $j,k \in V$ has capacity $C(j,k)$. As mentioned before each logical link is actually a bundle of physical cables so each link consists of N cables. Where N is the number of physical cables i.e. if a link consist of 5 physical cables then N=5. Traffic demand is represented by three values (d_i, d_e, d_t), where d_i is the ingress router, d_e is the egress router and d_t represent the amount of traffic exchanged between d_i and d_e and D is the collection of all these traffic demands i.e. $D = d_i + d_e + d_t$. All above mentioned variables are given as input to solve the problem of finding out the maximum cables to shut down. Moreover, solution should not lead to link overflow situation which will ultimately lead to congestion. Such algorithms usually scale down the given rate capacity.

There are three kind of heuristic approaches, which are implemented to solve this complex computational problem. These are Fast Greedy Heuristic (FGH), Exhaustive Greedy Heuristics (EGH) and Bi-Level Greedy Heuristics (BGH). In Fast Greedy approach, first of all flow assigned to each edge is obtained. Then edges are removed in an order that the overall flow still remain unaffected. We then find the edge with greatest spare capacity. If removing this edge still satisfied the overall traffic flow (with new edge weights) then we remove it otherwise will keep it. We keep it moving in this fashion that no more this cable needs to remove. Exhaustive Greedy Heuristic improves FGH in the sense that it also assigns a penalty for removing every edge (cable). So it removes the cable which leads to smallest penalty. This approach applies a look-ahead operation at every step, as penalty calculations involve watching out the traffic flow path. Penalty value increases when traffic flows along a longer path and vice versa. Bi-level Greedy Heuristic improves EGH in a way that it considers removal of cables in pairs. Now penalty is associated with pair of cables. Pair with smallest penalty will remove first. BGH is more time consuming than FGH and EGH but it gives more efficient results. Running time of these algorithms depends on the number of cables N in a bundle. These algorithms can be implemented successfully to get

astonishing energy savings while still keeping the same performance and fault tolerant targets.

2.4. *Eliminating Server Idle Time Power*

With the rise of gigantic web services such as Google, Amazon, Facebook, twitter, Wikipedia etc., the energy consumption in servers and data centers is growing to unpredictable levels [8]. Unfortunately a large fraction of this energy goes to powering idle servers. The cost of powering a server is getting closer to the cost of server hardware itself . Average server utilization is very low which gives an idea to save energy during idle server periods. The technique we are discussing saves energy by rapidly switching between an active state and an idle state. Where active state is high power consumption state and idle state is near-to-zero power state. In Figure 2 server power utilization patterns has been shown, grey boxes show idle time power consumption while white boxes represent active time power consumption. Server keeps on switching between these two states.
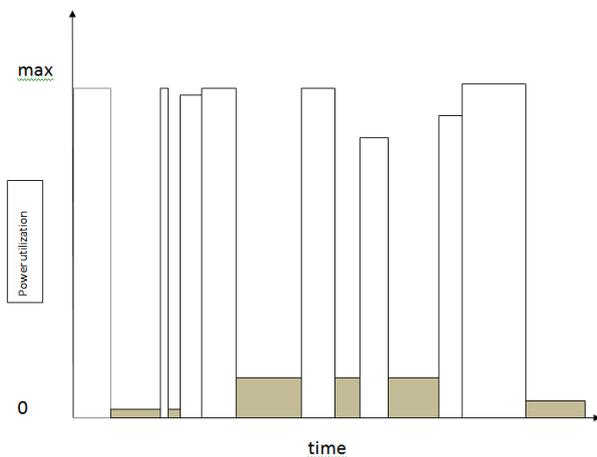

Figure 2.   Server power utilization.

Successful efforts have been carried out in minimizing idle power in other devices like cell phones, laptops, routers, links, switches etc. however, reducing power in servers requires a different challenge. For the reason, that the servers even in their periods of low utilization show small and abrupt activity bursts.

This technique of eliminating server idle power switches the server to a nap state during which server exhausts all the pending work. In this state all the system components enter sleep mode. In this state server is not in the position to do processing any more. Some system components remain alive which are responsible for waking up the sleeping components before entering the active burst. So the total energy consumption during Nap state is the power consumed by those few components that were alive and this power is so low as compared to the power consumed by the active burst.

There are two main requirements for implementing this mechanism. One is rapid transition i.e. transition should be as low as possible. It should be of the order of milliseconds to microseconds and to achieve this we need special system hardware components e.g. volatile memory. The other requirement is to reduce power draw during inactive burst. For this we will have to redesign the blade-chassis power. To implement this technology, there are hardware and software mechanisms. At hardware level it includes redesigning of the components and subsystems that have considerable idle power draws. One approach is to put the processor in sleep state with low latency transitions. Moreover, clock gating gives substantial power savings. Solid state disks should be used for mass storage as they consume a very low power when they are in idle state. Making Network Interface Cards (NICs) to wake up only when some activity starts saves energy. Server has a supplementary circuit which monitors environment and regulate power consumption. DRAM (Dynamic Random Access Memory) consumes a greater fraction of system's total energy consumption. DRAM can be made to operate in a mode in which it will refresh itself in isolation from memory controller and will lead to low power consumption. Fans are also a dominant power consuming component in a computer system. Conventional computers have fans with constant speed. There is a need to make their speed variable based on observed temperature.

Such implementation at hardware level also need software and firmware support. Implementation of idle state or active state and transition between these two states require challenging software implementations at operating system kernel level. There is a need to redesign device drivers, clock timers and their background scheduling algorithms.

3.   Comparison

In this section we present a comparison among the technologies discussed in the last section based on some pivotal attributes. Table 1 shows this comparison, letters A, B, C & D represent Sleeping Network Elements, Rate Adaptation, Shutting down Cables in Bundled Links & Eliminating Server Idle Time Power respectively.

4.   Conclusion and Future Challenges

Each green technique discussed in the last section has its own pros and cons specific to a given scenario. Challenging technical problems may arise when deploying them on large scale real world core networks.

Table 1. Comparison of green techniques.

Attributes	A	B	C	D
Mechanism of implementation	Wake on arrival (WOA) Time Driven Sleeping [9]	Dynamic Voltage Scaling (DVS)	Heuristics	Hardware level, software and firmware [11]
Energy savings (%)	70	40	73	67
Medium Utilization	No	Continuous	No	No
Hardware replacement or up gradation	Up gradation	Replacement	No	Yes
Protocol amendments	Yes [10]	No	Yes	Yes
System performance	Average	Good	Aver-age	Good
Implementation cost	Low	High	High	Low

- How much time and money investment is done and how much gain is achieved by energy savings?

- In comparison to the existing system how much environment friendliness is achieved by the green system?

- Is the cost of hardware replacement is much more than economic gain of energy savings it result?

Actually the accumulative gain (over the span of year) will be comparable with deploying cost. We conclude that a comparison based on some key factors is very necessary for deciding the right technique for any system. The wide evaluation and comparison leads to more appropriate discussion. We examine the impact of each strategy at energy consumption environment. Although all the strategies are feasible but each individual technique requires some changes on hardware level or on protocol specifications. This modification to their internal architecture leads to energy savings.

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