Deriving a Generic Energy Consumption Model for Network Enabled Devices

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Abstract—Energy saving has become a global issue when people use network enabled equipment in the office or at home. However few methods exist to measure and monitor energy use per user or per application, or to control equipment power states. We propose a generic energy consumption model that is based on the power state of network attached equipment, and that supports power management capabilities. This includes measures for each power state (on/off/sleep) and for per bit energy consumption, per interface, per application and at the network QoS (Quality of Services) level. Given the power state of a network device, a network manger could remotely inspect the energy consumption and make changes to the power management setting; for this to happen we introduce a new MIB (Management Information Base) schema to capture the attributes of relevance. Using an agent based modeling framework, we introduce the overall autonomic architecture that makes it possible to minimize energy consumption of network enabled equipment.

Keywords-power management; Energy Aware MIB; SNMP; energy efficiency; generic energy consumption.

I. INTRODUCTION

The commercial drivers for Green ICT have risen dramatically in the current economic and environmental climate. Rising energy costs and consumption level in electrical devices is a hot topic for service providers and consumers in every workplace. As utility prices continue to rise, energy efficiency has moved to the forefront.

According to the Smart 2020 report, the ICT sector accounted for more than 2% of the global CO_2 emissions [1]. Moreover, office equipment consumes approximately 7% of commercial electricity or $1.8 billion in costs to businesses [2]. For example, customer premises such as government offices, universities, companies or individual homes will typically have a wide range of digital equipment including set top box, wireless router, IP devices, and printers. They will spend considerable amounts of money on printing and copying, with bills at these large institutions being well in excess of £1 million annually [2]. Most of these devices consume more power in standby and sleep modes due to the number of hours they remain idle during the day or overnight rather than in active use. Consequently, every year electricity worth billions of dollars is used to keep network hosts fully powered on at all times only for the purpose of maintaining network connectivity or “presence” to respond to anticipated user traffic which may not arrive for some time.

Also, the European Commission is estimating that by 2012 the energy consumption in the home for BB (Broad Band) fruition will reach 50 TWh, from basically 0 TWh in the year 2000. Of the 10% (electricity consumption) globally spent for ICT, already today 70% is spent in homes / offices and 30% in the network/server farms [3]. As a matter of fact, new services appeared such as Broadcast TV, HDTV (High Definition Television), IPTV (Internet Protocol Television), online gaming and Voice over IP (VoIP). These new services have increased bandwidth requirements and must be incorporated with normal network traffic. However, they can tolerate only a minimum amount of packet loss, delay and jitter. As IP traffic increases, the capabilities of equipment required to process and route this traffic must grow at a corresponding rate. A consequence of this is a growth in power consumption of the network-enabled equipment [4].

At the system level a number of endeavors have been made by hardware manufacturers to find new processes to build better hardware for power management. One of the major advances was to define multiple power states for different devices and provide more efficient cooling systems in the case of data centers. For example dynamic power management methods address the problem of energy usage of electronic devices by putting devices into low-power sleep states when they are not in active use. Significant research has been undertaken in the area of power management focusing on predictive time-out schemes, frequency-voltage scaling, and other device-specific methods and stochastic control methods [5].

In order to reduce the energy use of network attached equipment, there must be a means of monitoring and controlling such usage. In addition, there is a need for associated energy aware QoS management on a per user and per service basis. Thus, the open problem to be addressed is how the power state of network attached equipment can be exposed in a standard manner compatible with existing network management protocols, whilst also providing an energy aware QoS on a per user and per service basis. Little previous research has focused on these challenges.

In this paper, we investigate how power state can be exposed and how it can be exploited to maintain a network’s energy aware QoS level.

As the basis for the above objective, we develop these issues within a framework of a generic energy consumption model which is lean, integrative and scalable, and can be used directly in any network attached devices and which provide energy saving in different scenarios based on the available information captured in our new MIB scheme.

The contributions of this paper are (i) the design of an Energy Aware MIB, (ii) a generic energy consumption model at the system level, and (iii) an autonomic architecture which has capabilities for monitoring and controlling power usage on a per user and per application basis.

The remainder of this paper is organized as follows. Section II provides motivation for the work in relation to power management, SNMP, and network level QoS. Section III describes the design of our SNMP Energy Aware MIB, the basic energy consumption model, and autonomic architecture. Section IV describes an example application and Section V provides a summary and describes future work.

II. MOTIVATION

Most IT equipment, including desktop PCs and printers maintain internal power state, support some form of power management and have network management capabilities. The Advanced Configuration and Power Interface (ACPI) is an industry standard that defines common interfaces for hardware recognition, device configuration, and power management [6]. ACPI defines seven states for computers: working G0 (S0), sleeping G1 (S1, S2, S3, S4), soft-off G2 (S5), and mechanical-off G3. Device states are: fully-on D0, intermediate D1 and D2, and off D3. Processor states are: operational C0, halt C1, stop-clock C2, and sleep C3.

Power Management (PM) capabilities include turning on, turning off or putting system subcomponents or the entire system in sleep mode after a fixed period of user inactivity [7]. However, dynamic power management is predominantly focused on developing policies to increase power saving including device performance at the system level. For example, a hard disk may be entirely power managed to extend its battery life (i.e. minimize power consumption) but its performance might be reduced as it might respond slower to user requests. The fundamental task of the power management policy is to predict (based on past information) whether the current idle period will be long enough to justify the transition cost [8]. In addition, if the policy can predict when the next user request will be made, it can minimize user annoyance levels by putting the device into active/wake up mode [9]. For the network enabled devices researchers have proposed several strategies to improve energy awareness such as link rate adaption during periods of low traffic and sleeping during no traffic [10-12].

One of the most common uses of SNMP is for remote management of network devices. An SNMP-managed network typically consists of three components: managed devices, agents, and one or more network management systems. A managed device can be any piece of equipment that sits on the data network and is SNMP compliant. Routers, switches, hubs, workstations, and printers are all examples of managed devices. An agent is typically software that resides on a managed device. The agent collects data from the managed device and translates that information into a format that can be passed over the network using SNMP.A network-management system monitors and controls managed devices in terms of power state, battery state, and total and current power consumption. The network management system issues requests and devices return responses. Network management systems and agents communicate using messages: GetRequest, SetRequest, GetNextRequest, GetResponse, and Trap. Figure 1 shows the basic operation of an SNMP manager. MIBs are defined for specialized devices and capabilities [13]. There are already several standards available but they do not cover next generation a network power management requirements. In [14] the authors have proposed a Power State MIB for Windows Vista. However, it did not consider how SNMP access can be maintained for sleeping devices and consequently hasn't defined a standardized Power State MIB.

In this paper, we investigate how power state can be exposed and how it can be exploited in the network's energy aware QoS level in order to allow any network enabled devices to lower their energy consumption and maintain services.

The total energy consumption needed to perform a job can be defined as the sum of (i) the power required in moving a packet from one piece of equipment to another within a network, (ii) the power required in getting to a desired transition state e.g. 'warm up' to 'ready' power state, and (iii) the power consumption required to maintain component operating states e.g. storage, forwarding, routing etc. It is clear that the above three areas have considerable potential to reduce energy in a network enabled environment. In order to meet these requirements we propose an Energy Aware MIB, thus allowing a network manager to remotely inspect the energy consumption at the system, component and network level.

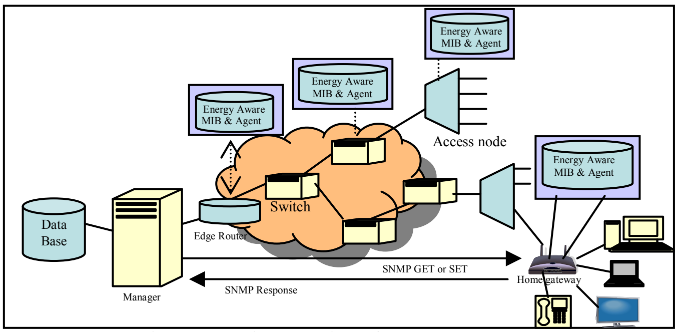

Figure 1. Basic Operation of SNMP

III. A GENERIC ENERGY CONSUMPTION MODEL

Motivated by the limitations of existing approaches and focusing on the usage-dependent variability our approach aims to provide a generic analytical framework, which is well suited in an environment consisting of network attached equipment, with multiple system and component level power states. The following sections explore this in more detail.

1) *Design of the Energy Aware MIB Group*

The first step in the design of an Energy Aware MIB was deciding which state objects need to be exposed for monitoring and which power management parameters needed to be controlled, including on an interface and network QoS basis .The following attributes in IT equipment illustrate where power can be monitored and controlled:

Off State - Power consumption, capabilities, and reactivity of the device are less than in the On or Sleep states.

Sleep State - Power consumption, capabilities, and reactivity of the device are greater than in the Off state, but less than in the On state.

On State - Power consumption, capabilities, and reactivity of the device are greater than in the Sleep or Off states.

When a network device is ON it can either be transmitting or receiving packets on each of its interfaces. When it is inactive, the equipment could be in a Sleep state to save energy. A key goal of controlling the power management setting is to minimize ON-time in favour of sleep time while maintaining energy aware QoS. Thus, we need to be able to monitor both total and current On (active and inactive), sleep, off times, and the QoS attribute on a per user, per application and per interface basis. We also need to be able to access power management settings (specifically, the inactivity time-out values for system Sleep and Off).

It is also desirable that monitoring should be available for individual components of devices, such as line cards, processors, hard drives, and ports etc. Furthermore, traffic characteristic in terms of packet size and inter packet delay, at each port of the network equipment also affects the power consumption [15]. Thus, it is important to monitor system, individual components, traffic load, and topology within a network which can be controlled by their PM settings. In addition, components within network enabled equipment, and other IT equipment, usually support ACPI states and we need to monitor these states (both current and previous state values).

The Energy Aware MIB has many groups and objects. Figure 2 illustrates some of the groups, and Table I describes the MIB objects. All objects encapsulated by the Energy Aware MIB can be divided as follows: system-only objects, subsystems objects network QoS objects and network interface related objects.

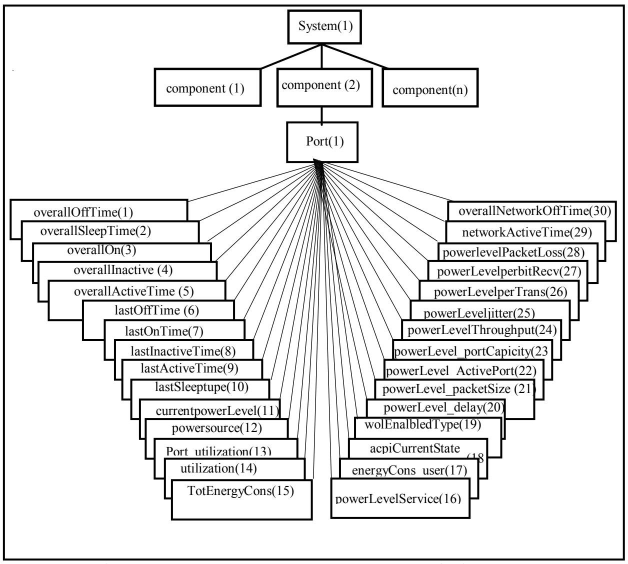

Figure 2. Energy Aware MIB Tree Description

2) *Basic Model Structure at the System Level*

Our objective is to provide a generic power state transition model for network equipment components supporting power saving mechanisms.

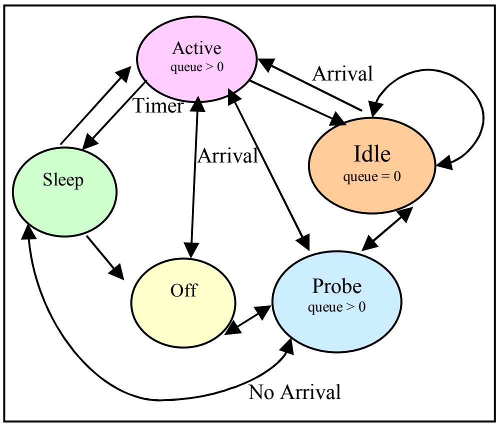

Figure 3. Power State Transition Model

In the following discussion, we derive a power state transition model for an individual component of the network device. Further, our proposed power state transition model can be employed for a complete network device and whole network by using our Energy Aware MIB. In starting from these considerations, we assume a power state Si of a network enabled device depends on what type of traffic arrives, how many subcomponents are affected to operate it, transition time to get the target state, and what are the optimal power control parameters in state Si while providing the necessary QoS. Thus a state Si can be given as a tuple:

$$S_i= (A_J,\delta t,D_{c,},Q_{i,c}) \qquad (1)$$

here system S can have different number of states i; has c subcomponents (e.g. devices, D); δt denotes the transition time from one state to another state , and AJ shows traffic characteristics where J shows number of packets . Qi,c is the optimal power control parameters of subcomponents c in state Si while providing the required QoS performance level.

Figure 3 illustrates the power state transition model. In the active state in which a networking component (interface) is either transmitting or receiving packets, and the respective queue contains at least one job pending. Once the queue is emptied, the system transitions to the idle state .In our model we attempt to introduce a new power state probe which continuously observe about the incoming traffic characteristic, link and topology information of the networks. In addition, it also indentifies availability and utilization of resources while other sub components might be in off mode to save energy. Therefore, the probe power state intends to take decisions based on traffic, link, network protocol and QoS characteristic, to transition into active/off state or remain in probe state to deliver charges to other interface (components) in order to obtain better performance.

In order to determine the energy savings possible by the probe state, we used the following metric:

$$\gamma = E / E_p \qquad (2)$$

If $\gamma > 1$ then we get energy savings using the probe state otherwise, the probe state results in energy loss. Here Ep denotes the energy consumed if we use probe state when system queue is empty (No job arrival) but watching all relevant information about networks and E denotes the energy consumed without sleeping and probing state.

To get expressions for E and Ep, assume that over some length of time T, N packets are processed per second [12]. Then,

$$E = e_I\,(T\text{-}Nt_K) + Ne_K t_K \qquad (3)$$

(tK – time to process a packet and eK - energy to process packets) where the first term indicates the energy eI during idle periods when the interface is awake but not doing anything and the second term denotes the processing cost for the 0 packets. To compute Ep, assume that the total time spent probing is Tp. Then,

$$E_p = e_p T_p + E_I(T\text{- } Nt_p \text{– } N\delta \text{ - } T_s) + Ne_w \delta + Ne_K t_K \qquad (4)$$

where the terms are, energy spent in the probing state ep, energy spent in wake state (but idle) EI, δ is the transition time, energy spent to the wake up eW, and energy spent to process packets eK.

TABLE I. ENERGY AWARE MIB OBJECTS FOR THE NETWORKED COMPONENT LEVEL

Entity : Object ID	Description
overallEnergyConsumption : 1	Total Energy Consumption
overallActiveTime : 2	Total time in Active state
overallSleepTime : 3	Total time in sleep state
overallPowerlevelQoS : 4	Total power level when all QoS attribute deployed
overallNetworkOffTime : 5	Total time when network Off
overallNetworkActiveTime : 6	Total time when network in active state
overallMechnicalOffTime : 7	Total time when network in On state
powerlevelPacketLoss : 8	Total Power level when packet loss occurred
energyconsumptionPerBitRecv : 9	Energy Consumption per bit received
energyconsumptionPerBitTrans : 10	Energy Consumption per bit transmitted
powerlevelPerInterface : 11	Power level per interface in network enabled devices
totalEnergyConsumptionPerPort:12	Total energy consumption per port basis
totalEnergyConsumptionSubCom:13	Total energy consumption in subcomponent level
Powerlevel_jitter : 14	Total Power level when jitter identified
Energyconsumption_Throughput: 15	Total Energy consumption for throughput
powerLevel_PortUtilization : 16	Total Power level when actual throughput flowing through a port relative to it's specified capacity
powerLevel_PortCapacity : 17	Power level when forwarding capacity of it's individual ports
powerLevel_ActivePort : 18	Power level when total no of ports on the network device are active
powerLevel_packetsize : 19	Traffic characteristic at each port might also affect the power consumption. Power level according to their packet size
powerLevel_InterpacketDelay : 20	Power level when time between successive packets at a port
Powerlevel_perService : 21	Power level per Service (VOIP\IPTV\Online Gaming etc) basis
EnergyConsumption_perUser : 22	Total energy consumption per user basis

3) A Generic and Autonomic Energy Efficient Aarchitecture

Figure 4 illustrates a functional view of the architecture .It spans the complete network from service originator to the end user. Due to the heterogeneity in service and network configuration, every drop in services energy awareness and QoS must be tackled in a different way.

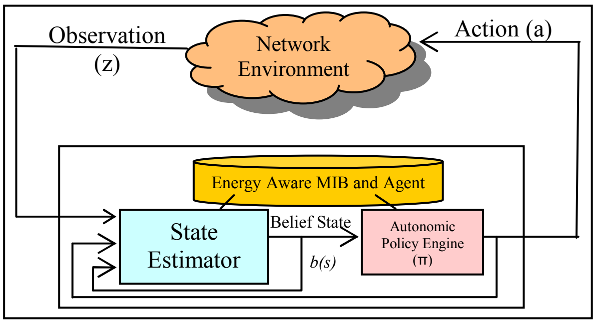

Figure 4. A generic and autonomic architecture to enable Energy and QoS management

We believe autonomic computing promises to reduce energy expenditure associated with operations, maintenance, and support, and to significantly improve the end user's experiences. To derive autonomic phenomenon, the system/network learns when to turn off/on components based on different user/traffic pattern. We are exploiting such concept by using stochastic Partially Observable Markov Decision Process (POMDP) models. The POMDP model is the combination of HMMs (Hidden Markov Model)/DBNs (Dynamic Bayesian Network) and MDPs (Markov Decision Process) [16]. The idea behind the POMDP model is to combine the strengths of HMMs (capturing dynamics that depend on unobserved states) and MDPs (taking the decision aspect into account) without significantly sacrificing computational efficiency [17]. A POMDP model describes sequential decision tasks under uncertainty. A power control policy in a POMDP computes an action after every observation such that in the long-run (discounted or average) the expected utility is maximised. A POMDP power policy computes actions at every time step after extracting information to an Energy Aware MIB in terms of, network configuration information, the available restorative actions and specific power level information. It is clear that an Energy Aware MIB plays an important role.

Due to the fact that the system state is not observed such as future traffic load in the network and uncertainty about the relevant power state (Probe/Sleep power state), the POMDP policy maps actions to all possible probability distributions over the states, otherwise called belief states B. The belief state b(s) represents the agent's current belief that the true state is s. The goal of the policy is to maximize the long-term reward.

IV. APPLICATION OF THE ENERGY CONSUMPTION MODEL

In this section, we will describe applications of an Energy Aware MIB and how the generic energy consumption model can be exploited in a system and subsequently applied to decision making on a real-time, tactical and strategic level.

A. Applications of an Energy Aware MIB

An Energy Aware MIB could be used for energy audits of network attached equipment installed in large companies/ universities. Such audits would discover what equipment exists in the company, its general activity patterns, the level of enablement of power management, and even the precise energy used. Consequently, the proposed generic power management architecture is an example of autonomic computing. Thus it facilitates self managing, self healing and self protecting autonomic characteristic. Every time step it computes a power managed policy that promises to reduce power expenditure associated with operations, maintenance, and support, and to significantly improve to the end user's experience.

B. *Generic Energy Consumption Model*

As an example of the generic energy consumption model in practice, we present the basic model structure for a Laser Printer. The Power State transition Equation (1), is graphically represented in Figure 5. Further, Figure 6 illustrates the energy consumption profile in the printers.

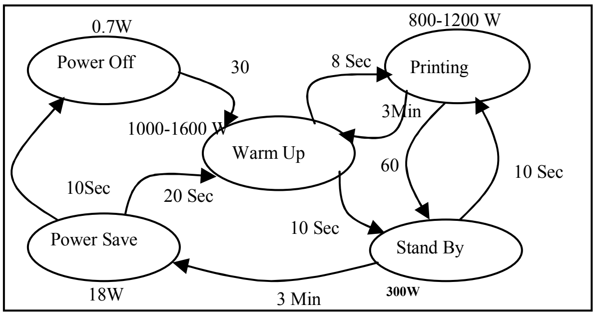

Figure 5. Average Power Consumption in each state and respective Transition Time

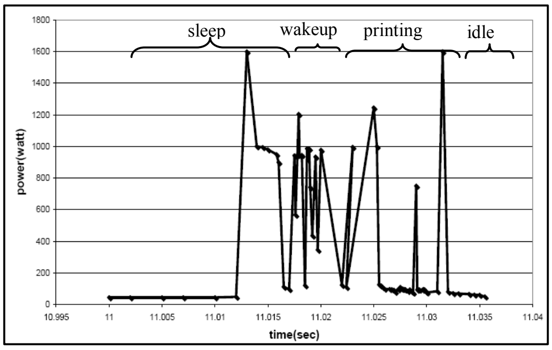

Figure 6 Energy Consumption behavior in a printer

If we consult a typical university campus environment that may have 800-1000 printers. The overall energy saving that can be obtained is more than 60 % by incorporating our Energy Aware Power State Model and Energy Aware SNMP MIB. In the case of the printer, idle power state consumes considerable amount of power due to warming up its element periodically so that the printer can take less time to come up into a printing state. However, by using our probe power state the printer can spend more time in sleep state rather idle state without any user annoyance.

V. SUMMARY

An Energy Aware SNMP MIB for exposing the power state of network-enabled devices has been proposed. Exposing power states along with QoS is the first step towards being able to monitor and control that is, fully manage energy consumption of IT equipment. Managing energy consumption is becoming increasingly critical to reducing TCO (Total Cost of Ownership) of IT equipment in data centers and enterprises. We have also illustrated how energy efficiency of network enabled devices can be generalized. We are currently working on more complex models and on methods for automatic discovery of context and learning of temporal dynamics with respect to energy awareness.

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