Energy-Aware Admission Control for Wired Networks

Christina Morfopoulou and Georgia Sakellari and Erol Gelenbe

Abstract Overprovisioning and redundancy has contributed towards better survivability and performance in networks, but has led to inefficient use of energy. Proposals for energy aware networks of the near future aim to reduce the energy consumption by switching off or putting to sleep individual network devices. Here we propose a mechanism that is taking this concept once step further through the use of admission control. Admission control has been traditionally used in wired networks to control traffic congestion and guarantee quality of service. We propose a two-fold approach. First, an admission control mechanism delays the users that are projected to be the most energy demanding, and whose acceptance would require the turning on of devices. At the same time, an auto-hibernation mechanism regulates the rate at which machines are turned off due to inactivity. Collectively, the two mechanisms contribute towards energy saving by monitoring both at the level of entry in the network and at the level of active operation.

1 Introduction

The carbon imprint of ICT technologies is estimated to be over 2% of the world total, similar to that of air travel [5]. Yet, research on the energy consumption of ICT systems and its backbone, the wired network infrastructure, is still at an early

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stage. Until recently, energy saving in networks focused more on longer battery life and smart wireless network design [6] and more attention has been devoted to energy consumption of Cloud Computing [1].

The mechanism proposed in this paper acknowledges the need for energy awareness in networks and the design of network components. By leveraging the admission control idea, traditionally used in networks to control traffic congestion, we propose an energy aware admission control mechanism that takes advantage of the future network devices that will have the capability to be temporarily switched off or transit to a sleep state. More specifically, in our experiments we examine the potential savings in energy by turning off nodes that have been inactive for a long enough period of time and using admission control to determine whether a user should be accepted into the network. The admission control mechanism is responsible to make sure that all nodes of the required path are ON before admission of the new user and also try to delay users before entering the network in order to increase efficiency. Performance investigations show savings up to 20% in the total network power consumption revealing that this idea of admission control can be of large importance on top of energy saving mechanisms of future network devices.

The remainder of this paper is organized as follows: the next section refers to the related existing work, both in respect to admission control and the behaviour of power consumption of wired networks; Section 3 presents our proposed energy-aware admission control algorithm; Section 4 reports the configuration of the experiments and experimental results of the algorithm achieved on a real testbed; finally we comment on the results in Section 5 and we conclude the paper in Section 6.

2 Previous Work

2.1 Admission Control

Admission control in wired networks has been traditionally used as a way to control traffic congestion and guarantee QoS [13]. The metrics considered in the decision of whether to accept a new flow into a network are mainly bitrate, delay, packet loss and jitter [9]. To the best of our knowledge, there is no work proposing the use of energy as a criterion to an admission control algorithm in wired networks. In our recent work [14], we examined the possibility of using energy criteria to admit users in the network using an ideal power profile of the nodes. This paper examines such an admission control algorithm in experiments using real online power measurements and by turning on/off nodes.

2.2 Power consumption in energy aware networks

As described in the survey of [2] several techniques have been recently proposed in order to enable energy efficiency in networks. Early work suggesting the idea of energy savings in the Internet [10] proposed routing modifications so as to aggregate traffic along a few routes, leading to a modification of the network topology based on route adaptation and putting nodes and devices to sleep. The problem of energy aware routing is examined via an analytical approach in [8] where an optimization algorithm is built that minimizes a composite energy and QoS cost function. In [7] an autonomic algorithm that utilizes adaptive reinforcement learning is proposed that attempts to minimize the power consumption while meeting the requested end-to-end delay bounds. In [3] two widely used routers are measured in terms of system power demand based on different configurations of line cards and operating conditions. Traffic was shown to have only around 2% impact on power consumption. A similar study is presented in [11], suggests that the impact of port utilization on power consumption is under 5%. So, these studies indicate that the power consumption of current networking equipment is largely independent of its utilization and thus there is significant energy waste when the nodes are inactive or lightly loaded. In [12] a rate-adaptation for individual links is examined based on the utilization and the link queuing delay. Moreover, a sleeping approach is proposed, where traffic is sent out in bursts at the edge routers enabling other line cards to sleep between successive bursts of traffic. In [4] the authors select the active links and routers to minimize the power consumption via simple heuristics that approximately solve a corresponding NP-hard problem.

All this work, identifies the potential savings by turning on/off nodes but ignores implementation obstacles like the need for a mechanism that manages the network, the extra power needed to turn on/off a node and the induced delay thereof. In this work, we propose an Energy Aware Admission Control (EAAC) mechanism, evaluate its performance with experiments in a PC-based network topology and explore the implementation challenges and problems that arise.

3 Energy aware admission control mechanism

3.1 Problem description

The existing work identifies the gains of turning devices off in order to increase energy efficiency in networks. This though, still entails huge challenges as the current networking equipment is not capable of entering and exiting a low-energy sleep mode. Moreover, turning a machine off and on comes with energy and delay costs. Most of the research conducted so far is based on simulations of the future behaviour of the networking equipment. In this work we use a real laboratory PC-based testbed with on/off capabilities. Thus, we are able to examine a real case scenario where the nodes are turned off when idle and they are informed to wake up where they are needed to route traffic. The power consumption is monitored in real time using a power meter and the delays induced to the new traffic flows are measured in order to examine the trade off associated with the Quality of Service (QoS) provided.

We first examined the behavior of our PC-based routers during their shutdown and wake up times. Figure 1 shows the power consumption of one of our testbed's nodes. It is initially turned off and then it receives a "wake on lan" packet (10th second). The process of "turning on" lasts from second 10 to around second 40 and then the node is asked to turn off again at the 67th second and its finally off around second 80. We can observe significant spikes in power consumption when turning on and off which result in a large energy waste, since the nodes are not processing any traffic during this time. So, when deciding to turn off a machine one has to take into consideration the additional energy spent for turning off and on and whether this is smaller than the savings during the time for which the node is off. Also, it is evident that the time needed to wake up a node in our PC-based routers and turn it off is quite long (we have measured an average of approximately 35 seconds for booting and 10 seconds for shutting down). Current networking research targets to introduce sleep modes in routers or individual router components and the relevant times should be significantly smaller in the future.

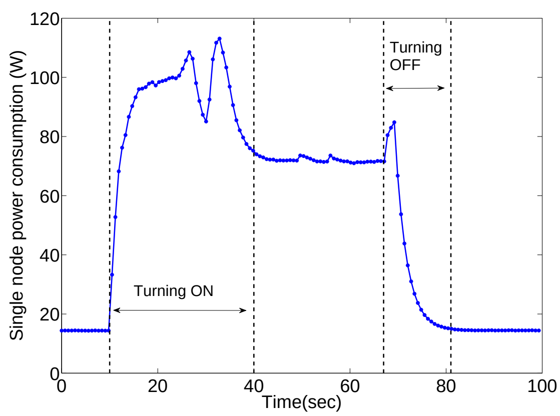

Fig. 1 Power consumption measurements when turning on (10-40sec) and off (67-80sec) a node

3.2 Algorithm description

The steps of the proposed Energy Aware Admission Control (EAAC) algorithm are

1. A new user i informs the EAAC about its source s_i and destination d_i. It also sets a maximum time limit W_i that the user is willing to wait until it is admitted into the network.
2. The EAAC calculates the minimum hop path π_i from s_i to d_i and collects the information about the current state of these nodes (whether they are currently ON or OFF).
3. If all of the nodes on the shortest path are ON, the flow is admitted into the network, else the flow is sent to a waiting queue.
4. If the waiting time of a flow in the waiting queue W_i expires, the EAAC turns on the nodes on the path that are OFF. Once they are ON, the flow is admitted.
5. The requests in the waiting queue are occasionally re-evaluated for admittance.

Note that in parallel, an auto-hibernation mechanism is running on all nodes which turns off the machines when they are inactive for a specific amount of time.

3.3 Implementation details

The auto-hibernation mechanism decides when to turn a node off based on whether the node has been inactive for a specific amount of time. The inactivity of a node is based on the amount of traffic that has been processed, which is being monitored by a built-in function of the node.

As for the 'waking up' mechanism; when the waiting time of a user request expires, the admission control mechanism sends 'wake on lan' packets to the nodes that are on the user's path and that are currently off. Note that a 'stay alive' flag is set on the nodes that are already ON, to prevent the auto-hibernation mechanism from turning them off, while trying to turn on the rest of nodes on the path.

4 Experiments

4.1 Configuration of the experiments

In order to evaluate our mechanism we conducted our experiments on the real testbed located at Imperial College London. Our testbed consists of 12 PC-based routers as shown in figure 2 and the intermediate nodes are connected to a Watts up?. Net power meter [1].

In the experiments we had 5 users corresponding to 5 Source-Destination (S-D) pairs independently making requests to send traffic into the network at random intervals. More specifically, we have the pairs (106,109), (103, 211), (109, 106) and (106, 103) which generate traffic every 150-200 seconds, with randomly distributed

[1] https://www.wattsupmeters.com.

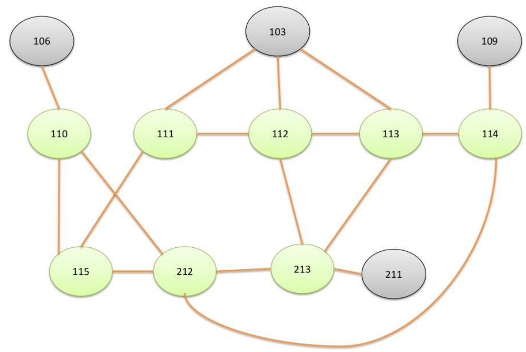

Fig. 2 Experimental topology. Green nodes can be turned off/on and their power consumption is being measured. Grey nodes are sources/destinations and are always on

bandwidth request of 200-500Kbps. Note that these source-destination pairs were selected to cover the whole network and not leave any nodes unused. We assume that all users are willing to wait at least for $W = T_{on}$. T_{on} is the time it takes to turn on a node, in case that one or more nodes of the required path are OFF at the time of the user's arrival. Moreover, we add a voluntary waiting time randomly distributed between 0-20 seconds, which is additional to the T_{on}, thus $W = T_{on} + [0-20]$. We run the experiment for 1000 seconds comparing the EAAC with the no admission control case, where the users are not willing to wait and thus all nodes are constantly ON, ready to carry traffic.

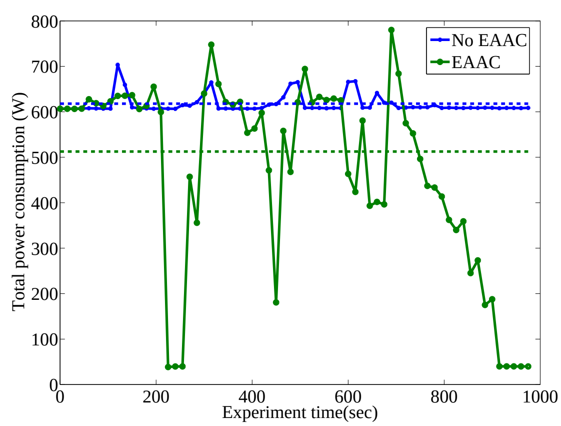

Fig. 3 Power consumption results. Dotted lines represent the average values. 17% average power savings are observed when using EAAC.

The total power consumption over time for both cases is shown in figure 3. As expected, the power consumption of the no admission control case where all nodes are ON, is almost constant. On the other hand, when using the EAAC we observe sharp falls from turning off the nodes. However, there are also significant spikes from the extra power needed to turn on nodes, as was investigated in figure 1.

The average value (measured until the 700 second for fairness) indicates a saving of 105 Wattts which corresponds to 17%. This energy saving comes at the cost of delaying the users before entering the network. The resulted average waiting time for the EAAC in this experiment is 22 seconds. This number is the average over the users who were put in the waiting queue as well as the users who found all nodes of their required path ON and were immediately admitted in the network. The users that are put in the waiting queue will have to wait for at least T_{on} until the required nodes are turned on. The voluntary waiting times of the flows were respected in all cases.

4.2 Impact of the voluntary waiting time

In the experiments of section 4 the time that each user is willing to wait until admitted to the network was chosen to be $W = T_{on} + [0-20]$. Here we investigate the impact that this time has to the energy saving. We therefore compare the case where the users are only willing to wait for $W = T_{on}$, to larger waiting times. In the first case the additional voluntary waiting times are distributed between 0-20 ($W = T_1$) seconds and in the second case distributed between 20-40 ($W = T_2$). In figure 4 it can be observed that the willingness of users to wait more can further increase the energy savings in the network, since for $W = T_2$ we observe higher savings (20%) compared to $W = T_1$ (17%) and $W = T + on$ (13%).

In figure 5 we show the total number of times that nodes were turned off during the experiments. It can be observed that the total measured power consumption (figure 4) is not directly related with the total number of turned off nodes and it should not be considered as a measure of efficiency. Thus, a static solution that would try to turn off as many nodes as possible would not necessary be the most energy efficient.

5 Discussion of the results

In this paper we present and evaluate a novel Energy Aware Admission Control mechanism which can manage an 'energy aware' network in which nodes can turn off if idle. The EAAC monitors the network nodes and requests in order to reduce energy consumption and ensure path availability for any new request.

We evaluate the performance of the EAAC mechanism in a realistic scenario where the PC-based routers are controlled by a mechanism that detects inactivity and turns them off and then turns them on again when needed. The contribution

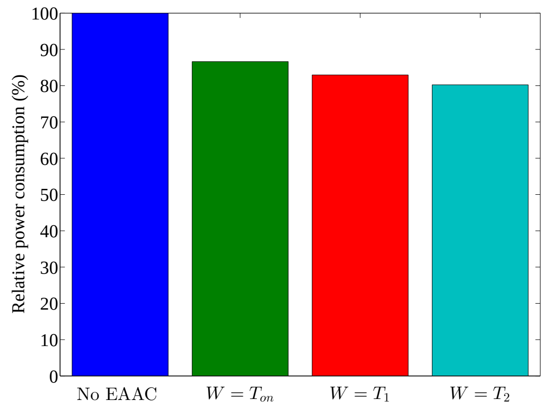

Fig. 4 Power consumption results for different values of the voluntary waiting time W. Larger values of W result in greater energy savings.

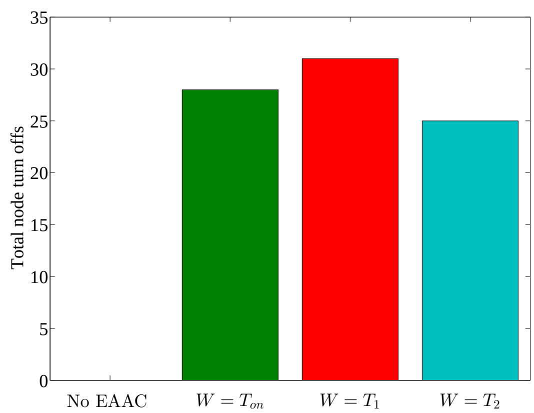

Fig. 5 Total number of times that nodes have been turned off during the experiment

of this paper is twofold. Firstly, we point out the implementation obstacles of turning off and on devices in a network and examine the resulting energy expenditure and delay cost. Secondly, we propose and evaluate the Energy Efficient Admission Control mechanism as a solution to energy efficiency and network management.

We show that significant savings can be achieved and identify the importance of sleep states that can be entered and exited quickly. In addition, we use the notion of 'voluntary waiting time' considering that some users may be willing to wait before using the network. We show that larger voluntary waiting times can further improve the energy efficiency.

6 Future work

The experiments and results described here show the effectiveness of the Energy Aware Admission Control mechanism and reveal room for potential energy savings. These energy savings largely depend on the capability of the nodes to enter and exit a low-power sleep state quickly as turning on the nodes on demand will induce a waiting delay for users before being admitted into the network. Though, it is expected that future hardware and operational systems will feature these capabilities.

Our future work will concentrate on examining the trade off between turning off machines and network QoS metrics, such as latency, and seek to identify optimal operating points in terms of energy efficiency and QoS.

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