# Using energy criteria to admit flows in a wired network

Georgia Sakellari and Christina Morfopoulou
and Toktam Mahmoodi and Erol Gelenbe

**Abstract** Admission control in wired networks has been traditionally used as a way to control traffic congestion and guarantee quality of service. Here, we propose an admission control mechanism which aims to keep the power consumption at the lowest possible level by restricting the more energy-demanding users. This work relies on the fact that power consumption of networking devices, and of the network as a whole, is not proportional to the carried traffic, as would be the ideal case [1]. As a result some operating regions may be more efficient than others and "jumps" may arise in power consumption when new traffic is added in the network. The proposed mechanism aims to keep power consumption in the lowest possible power consumption level, hopping to the next level only when necessary.

## 1 Introduction

The carbon imprint of ICT technologies is estimated to be over 2% of the world total, similar to that of air travel [7]. Yet, research on the energy consumption of ICT systems and its backbone, the wired network infrastructure, is still at an early stage.

Georgia Sakellari
University of East London, Computer Science Field, School of Architecture, Computing and Engineering, E16 2RD London, UK, e-mail: g.sakellari@uel.ac.uk

Christina Morfopoulou
Imperial College London, ISN Group, Electrical & Electronic Engineering Department, SW7 2BT London, UK e-mail: christina.morfopoulou08@imperial.ac.uk

Toktam Mahmoodi
Kings College London, Centre for Telecoms Research, Division of Engineering, WC2R 2LS London, UK e-mail: toktam.2.mahmoodi@kcl.ac.uk

Erol Gelenbe
Imperial College London, ISN Group, Electrical & Electronic Engineering Department, SW7 2BT London, UK e-mail: e.gelenbe@imperial.ac.uk

In this paper we acknowledge the fact that the behaviour of power consumption in today's networks is not proportional to the carried traffic, as has been identified to be the ideal case [1], though, several techniques are being examined as solutions to increase proportionality in future devices. But even if these techniques are applied, this would result in a distinct number of possible operation states, thus a multi step power profile, close to the ideal fully proportional case. Another way investigated in the literature in order to increase energy efficiency of future devices is by putting links or nodes into a sleep state [3].

The implementation of such solutions in network devices will lead to a more complicated behaviour of the power consumption of a network with relation to the carried traffic. Some operating regions may be more efficient than others while "jumps" may arise in power consumption when new traffic is added in the network. The mechanism proposed in this paper acknowledges these changes and aims to keep power consumption in the lowest possible level, by avoiding the more energy demanding operating regions. More specifically, in our experiments we examine the potential savings in energy by using the case of a multi-step power profile in each network node. The admission control mechanism then aims to keep the power consumption at the lowest possible level by restricting the more energy-demanding users and by hopping to the next power consumption level only when necessary. Performance investigations show savings up to 17% 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.

## 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 [6, 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 [2, 11]. To the best of our knowledge admission control has never been used as a tool to restrict user entrance in a wired network in order to minimise energy consumption. However, the concept of admitting users according to their power consumption has been used in wireless networks where flows are accepted based on the estimated residual energy or the transmit power of the nodes along a routing path [4, 5].

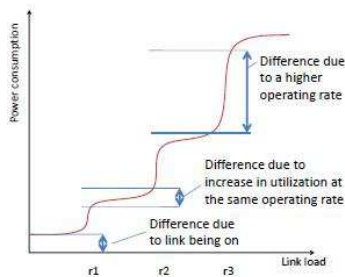### 2.2 Power consumption in energy-aware networks

Energy proportionality is examined in [14] where the authors explore the potential savings of hardware capable of supporting $N$ performance states, each corresponding to a different link rate. They state that in general, operating a device at a lower

frequency can enable dramatic reductions in energy consumption. Also, operating at a lower frequency allows the use of Dynamic Voltage Scaling (DVS) that reduces the operating voltage. DVS is already common in general purpose processors for these reasons and is particularly appealing given that reducing the voltage has a dramatic effect (quadratic decrease) on energy consumption. The technique of Adaptive Link Rate (ALR) assumes that individual links can switch performance states adapting to the carried traffic. Hence the savings that are obtained apply directly to the consumption at the links and interface cards of a network element. Adaptive Link Rate and Dynamic Voltage Scaling is also examined in an energy-aware online technique, proposed in [15], which aims to reduce energy consumption of the backbone internet by spreading the load among multiple paths. Their proposed technique is based on the assumption that the hardware is designed to automatically switch to one of four possible operating rates according to its load and that the power consumption of the hardware would follow the curve shown in Figure 1.

As described in the survey [3] these techniques of DVS and ALR are widely proposed in order to enable energy efficiency in networks. The result of the application of these techniques would be a multi step profile much closer to the ideal case of energy proportional as shown in Figure 2, where energy coarsely adapts to the load. Our work builds upon these proposals for future design of networking devices. In this paper we examine the case of multistep power profiles of the network devices, though the same mechanism could be implemented in the single step case (sleep state) or any set of given non-linear power profiles.

## 3 Energy aware admission control mechanism

As discussed in the previous section, the proposed algorithm assumes a non linear power consumption behaviour of the network with relation to the carried traffic, where "plateaus" and "jumps" may arise. Since some of the operation areas are more power efficient than others, by using admission control we could reduce the total



**Fig. 1** Predicted power consumption of a device vs load [15]
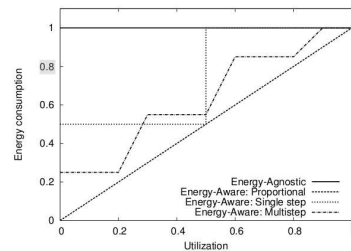
**Fig. 2** Power consumption for proportional and non proportional cases [3]

network energy consumption. Our proposed centralised Energy Aware Admission Control (EAAC) mechanism follows the steps described next:

1. A new user $i$ informs the EAAC about its source $s_i$, destination $d_i$ and demanded bandwidth $bw_i$. 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 $\pi_i$ from $s_i$ to $d_i$ and collects the information about the current power consumption of the nodes $n$ on this path.
3. Using the known power profile and the bandwidth of the flow, it estimates the increase in power consumption after the acceptance of the new flow.

$$\delta P = \sum_{n \in \pi_i} p_n(\lambda_n + bw_i) - \sum_{n \in \pi_i} p_n(\lambda_n) \qquad (1)$$

where $p_n$ is the instantaneous power consumption of node $n$ and $\lambda_n$ is the current packet rate of the node $n$ on path $\pi_i$.

4. If the estimated wattage increase $\delta P$ is smaller than a fixed value $\Delta$ the flow is accepted and admitted into the network ($\Delta$ is the threshold in increasing the power consumption that is acceptable by the EAAC). If not, the new flow is sent to a waiting queue. Note that the flows are stored in the waiting queue in a ascending order of their remaining wait time.
5. If a new flow arrives while the mechanism is busy estimating the $\delta P$ of the previous flow, it joins a request queue. The mechanism checks in first-come-first-served order the flows in the request queue, going back to step 2. If no flow waits in the request queue, the mechanism picks a waiting user from the waiting queue and follows the same process from step 2.
6. If the waiting time of a flow $w_i$ expires, the flow is immediately admitted into the network, irrelevantly of its estimated power increase.

## 4 Experiments

### *4.1 Configuration of the experiments*

In order to evaluate our mechanisms we conducted our experiments on the real testbed located at Imperial College London. Our testbed consists of 18 PC-based routers and we assume that the power consumption profile of these machines has a step-like behaviour as shown in Figure 4. For less than 100 packets/sec a minimal power consumption of $10W$ is assumed.

The topology of our experimental testbed is shown in Figure 3. In the experiments we had 4 users corresponding to 4 Source-Destination (S-D) pairs independently making requests to send traffic into the network. In order to avoid having more than one users requesting to enter the network at the same time, each flow enters a queue ("request queue") at the data gathering point. Thus all users from all

source nodes will queue there in order to enter the network. After making a request, each user waits for a random time *intertime* and then makes a request again. We set this random *intertime* among requests, so as to have different rates for the arrivals.

Our experiments covered two cases, one with EAAC fully enabled and one with the admission control enabled (flows are queued up) but where the flows are always accepted. The second approach was chosen over not having admission control at all, in order to study the efficiency of our algorithm under the same conditions, since it is a centralised algorithm, and not allowing all users to enter the system at the same time, by itself, contributes to reducing the number of flows entering the network.

We point out that the experiments reported here are not carried out on a standard test-bed that runs the Internet Protocol. Instead, the router software is written for a QoS aware protocol called the "'Cognitive Packet Network" (CPN) [9]. However, while CPN can collect energy and QoS information and modify paths so as to minimise such metrics, our experiments were run on a test-bed that uses CPN but which selected all paths to be fixed minimum-hop paths. Furthermore, delays are measured via pinging and energy consumption of the nodes is estimated from the power profile. Therefore we think that the results we obtain will mimic the energy and delay characteristics that one would obtain in a standard IP network.

## 4.2 Power Consumption

In this experiment we have 4 source-destination pairs $(103, 209), (108, 212), (111, 214)$ and $(209, 215)$. We assume that new flows are generated every *intertime* seconds, where *intertime* is randomly distributed between 10 and 40 secs. We also assume a random flow duration of $10 - 30$ seconds and a randomly distributed bandwidth request of $1 - 10Mbps$. The packet size is set to $100bytes$. Finally, we assume that all the users are willing to wait up to 30 seconds before they are admitted into the network.

We ran the experiment with our EAAC and without (accepting in the network every new flow). New flows are generated for 300secs. Note that for the EAAC after
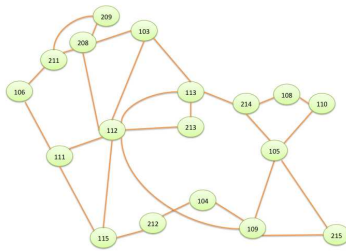
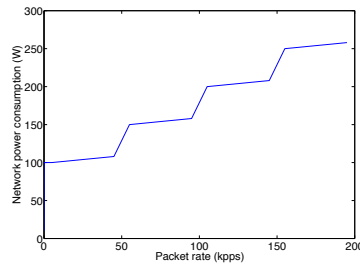

**Fig. 3** Network topology



**Fig. 4** Step-like router power profile used in the experiments

the 300secs we accept all the flows in order to compare the total energy spent for serving the same amount of users in the network.

The total network power consumption over time, for both cases, is shown in Figure 5, where the dashed lines correspond to the average values. As we can observe from this figure, there is an average power saving of around 17%. Note that all the presented results are averaged over three runs of the experiment. Also, the energy consumption is higher for the EAAC in the last part of the experiment since after the 300*th* second the EAAC accepts all remaining flows, regardless their energy consumption or waiting times. In Figure 6 the average waiting time of the users is plotted with and without the EAAC. As expected, the energy saving comes at a cost of delaying the users before they are admitted into the network.

## 4.3 The impact of the $\Delta$ value and the effect of delaying traffic

In order to study the effect of the threshold value $\Delta$, we load the network with higher rate of flows' arrivals, i.e. the *intertime* is set randomly between 10 and 20 seconds. Several values for $\Delta$ are examined and their impact on the energy saving is plotted in Figure 7. These results suggest that the best energy saving is for $\Delta$ equal to 60 and 100. Further observation from figure 8 reveals that the more strict the $\Delta$ value is, the greater the average waiting time is. The results plotted in Figure 9 clearly show this effect on the total number of admitted flows in the network. Thus, as we can see in figure 9, the more strict the $\Delta$ value is, the less flows are admitted into the network, and in all cases, the EAAC always accepts less flows compared to the no admission control case.

The value of $\Delta$ could affect the efficiency of our proposed method and should therefore be selected carefully. As we can see from figures 7 and 8, if the $\Delta$ value is too large, the admission control admits almost all new flows and the savings are negligible. On the other hand, if the $\Delta$ value is selected to be too small, the admission control will be very strict and users will be obliged to wait until their waiting times
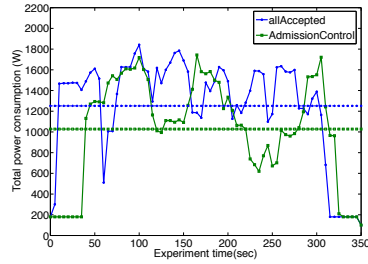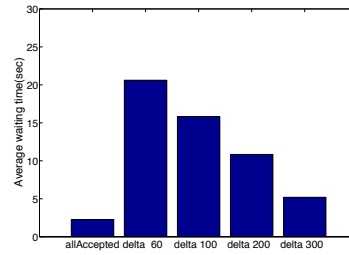


**Fig. 5** Network power consumption results for the admission control and no admission control case
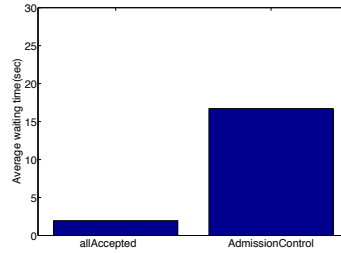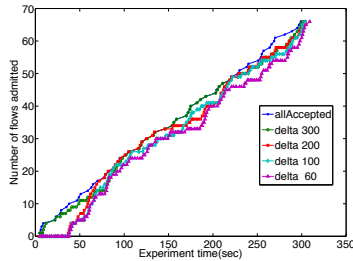


**Fig. 6** User average admission waiting time for the admission control and no admission control case
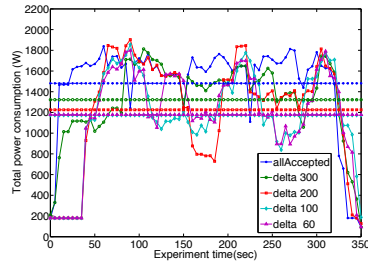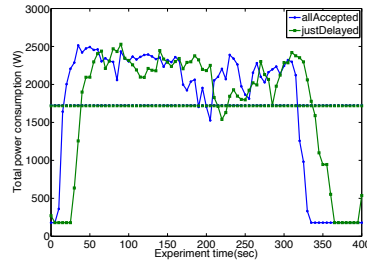
**Fig. 7** Network power consumption results for several values of the admission threshold value $\Delta$

**Fig. 8** User average admission waiting time for several values of the admission threshold value $\Delta$



**Fig. 9** Number of admitted flows in the network for the for several values of the admission threshold value $\Delta$

**Fig. 10** Network power consumption of no admission control compared to delaying of flows

expire. The selection of the most appropriate value is not straightforward and should be carefully examined. Our future work will involve finding the optimal value of $\Delta$ under several conditions. For example, a careful selection could be made based on the power profile of the nodes. Additionally, this value could also be readjusted online, based on the observed power savings and waiting times.

In order to see whether energy savings result from just delaying the flows, we run an experiment where all new flows are delayed up to their maximum waiting time with maximum waiting times $w_j$ selected uniformly in $[10,40]sec$. The result is compared to the case where all flows are accepted as soon as they arrive, see Figure 10, and we observe that initially the power consumption is lower but the overall average is the same. Thus there is no energy saving in just delaying the traffic.

## 5 Future work

We have proposed a novel Energy Aware Admission Control mechanism. To the best of our knowledge there is no previous work on Admission Control to improve energy efficiency in wired networks. The experiments and results described here

show the effectiveness of the method and reveal room for potential energy savings, but these energy savings come at the expense of increased waiting delay for users before being admitted into the network. Additional memory transfers and packet processing at the sources can have energy consequences that will be considered and evaluated in future work so that the overall impact of admission control can be considered both on total delay and total energy consumed for the flows and the network. Another aspect that we plan to pursue is the use of analytical models to predict and optimise the energy and delay related to the admission process; mathematical performance modeling tools are well established [8, 12] and will be applied to this particular problem in future work as we have done for energy-aware routing [10].

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