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An experimental power profile of Energy Efficient Ethernet switches

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ABSTRACT

The access network is believed to account for 70–80% of the overall energy consumption of wired networks, attributable in part to the large number of small and inefficient switches deployed in typical homes and enterprises. In order to reduce the per-bit energy consumption of such devices, the Energy Efficient Ethernet (EEE) standard was approved as IEEE 802.3az in 2010 with the aim of making Ethernet devices more energy efficient. However, the potential for energy savings, and their dependence on traffic characteristics, is poorly understood. This paper undertakes a comprehensive study of the energy efficiency of EEE, and makes three new contributions: first, we perform extensive measurements on three commercial EEE switches, and show how their power consumption profile depends on factors such as port counts, traffic loads, packet sizes, and traffic burstiness. Second, we develop a simple yet powerful model that gives analytical estimates of the power consumption of EEE switches under various traffic conditions. Third, we validate the energy savings via experiments in typical deployment scenarios, and estimate the overall reduction in annual energy costs that can be realized with widespread adoption of EEE in the Internet.

1. Introduction

The ICT sector is responsible for over 3% of the world's electricity consumption, and has global CO_2 emissions on par with the aviation industry (Gartner Estimate, 2008). Further, the energy requirements of computing and networking equipment are predicted to grow substantially in the coming decade [1]. Energy expenses are already a major operational cost in today's data centers [2], while the aggregated energy consumption of consumer electronic devices is growing at an alarming rate [3]. As far back as the year 2000, the energy consumption of Internet equipment was estimated to be over 6 Twh [4], and more recent studies suggest a larger consumption when end user equipments and access networks are considered [5]. There is a specific need to address energy efficiency issues in the access network, since they are believed to account for 70–80% of the wireline energy costs [6]. This is attributable in part to the large number of end-premises devices that are in deployment, and to their high energy consumption per-bit, since they tend to be always on and have a very low average load.

Most network equipment today has a nearly constant power consumption independent of the system load [7]. Recognition of the resulting poor energy efficiency in lightly loaded systems has lead to interest in making the energy consumption more proportional to system load. Among the first networking technologies to do so is Energy Efficient Ethernet (EEE). The IEEE 802.3az standard [8], approved in September 2010, defines a low power idle (LPI) mode that improves the energy efficiency of Ethernet physical layer devices under low loads. With an installed base of over one billion devices, the expected energy savings can be as high as 4 Twh [9]. Products that implement the EEE standard are becoming more common in the market and wide adoption is expected to occur in a few years. However, current products that implement EEE, e.g. [10–13], do not provide much information on the energy consumption profile, typically reporting only minimum and maximum power values. There is clearly a need to gain a better understanding of EEE power consumption and its dependence on various system and traffic parameters.

This paper is the first to conduct an in-depth experimental study of the power consumption profile of EEE-based small Ethernet switches, and to evaluate its dependence on various traffic characteristics. Our specific contributions are threefold:

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1. We use a high-precision traffic generator and high-fidelity power meter to measure the power consumption of commercial EEE switches from three vendors, and accurately characterize their power profile for varying traffic characteristics such as load, packet size and burst length.
2. We develop a simple yet useful model that yields analytical estimates of EEE switch power consumption as a function of traffic characteristics. The model is derived from first principles using the operating principles and parameters specified in the standards, and is shown to match well with our experimental measurements.
3. We evaluate the energy savings of EEE switches in typical deployment scenarios involving file transfers, and use our results to estimate the overall achievable reduction in annual energy costs as EEE adoption becomes more widespread in residential and small-enterprise networks.

To the best of our knowledge our work is the first to profile the power consumption of EEE switches under a wide range of operating conditions, and to develop a simple model that yields analytical estimates that corroborate well with real measurements. Our work can be used by other researchers wanting to explore higher layer energy saving mechanisms such as energy efficient routing [14] or selective link deactivation [15], and can inform current and future efforts within the IEEE 802.3 standards to extend the energy efficiency mechanisms to other Ethernet speeds and technologies.

The rest of the paper is organized as follows: Section 2 gives requisite background on Energy Efficient Ethernet (EEE) and prior efforts to profile switch power consumption. In Section 3 we experimentally profile the power consumption of three small Energy Efficient Ethernet switches, and evaluate the dependence on factors such as number of active ports, traffic load, packet sizes, and traffic burstiness. Using the insights from these experiments, in Section 4 we develop a simple EEE power consumption model, validate it against the experimental results, and discuss its applicability to practical deployments including TCP traffic. Section 5 discusses the savings that can be achieved with the introduction of Energy Efficient Ethernet, comparing it with previous estimates, and provides an overview of current energy efficiency efforts within IEEE 802.3. The paper concludes with a summary and directions to future work in Section 6.

2. Background

In this section we give a brief background on the Energy Efficient Ethernet (EEE) technology, and on prior efforts by researchers to develop energy consumption profiles of network switches.

2.1. Overview of EEE

For over two decades, Ethernet has been the dominant technology for wireline LANs. It is widely used in residences and commercial buildings and almost all computers include one (or more) Ethernet connections. Although Ethernet supports a variety of transmission media, most of the Ethernet ports are connected by Unshielded Twisted Pairs (UTP), especially in homes and offices. For UTP, Ethernet currently supports four data rates: 10 Mb/s (10BASE-T), 100 Mb/s (100BASE-TX), 1 Gb/s (1000BASE-T) and 10 Gb/s (10GBASE-T). For data rates of 100 Mb/s and higher, Ethernet physical layer transmitters transmit continuously to keep transmitters and receivers aligned. When there is no data to send an auxiliary signal called IDLE is sent. This means that most of the elements in the interfaces are active at all times leading to an energy consumption that is high and largely independent of the traffic load.

To reduce energy consumption, the IEEE 802.3az standard [8] introduces the concept of Low Power Idle (LPI) which is used instead of the continuous IDLE signal when there is no data to transmit. LPI defines large periods (T_q) over which no signal is transmitted and small periods (T_r) during which a signal is transmitted to refresh the receiver state to align it with current conditions. The operation of the LPI mode is illustrated in Fig. 1. The energy consumption of a physical layer device (PHY) when it is in LPI mode is expected to be significantly lower than when it is in the active mode. Our previous work reported in [16] has confirmed that computer Network Interface Cards (NICs) operating at 1 Gbps can achieve 70% reduction in power consumption when using EEE.

The actual energy savings on a given link depend on the amount of time that the link spends in LPI mode. This time can be reduced by the transition overheads associated with activating (T_w) and putting it into LPI mode (T_s). During those transitions, there is significant energy consumption and the transition times are large compared with the frame transmission time [16,17]. The transition times for the different speeds are summarized in Table 1 and compared with the frame transmission times for a 1518 byte and a 64 byte packet. To measure the efficiency of EEE, the concept of single frame efficiency which measures the efficiency of EEE for single frame transmission is introduced. When a single frame is transmitted the link has to be activated to send a frame and then deactivated after the transmission. Therefore for a frame transmission time of T_f, the link is active or in transitions for $T_w + T_s + T_f$. The ratio of these times is defined as the Single Frame Efficiency: SFE$= \frac{T_f}{T_w+T_s+T_f}$. A high value of SFE is desirable as it indicates that the overheads of entering and exiting LPI are low. However, Table 1 shows that SFE values are relatively low, implying that the overheads of entering LPI mode become more significant as the time spent in LPI mode reduces. Stated another way, this suggests that the benefits of EEE saturate at medium or low loads, unless packets are coalesced as showed in [17]. Our example in [16] for a EEE NIC demonstrated that for a 1 Gb/s link, a 6% traffic load composed of evenly spaced packets prevented the link from entering into LPI mode altogether. Our study in this paper will therefore consider the effect of traffic burstiness on EEE switch power consumption.

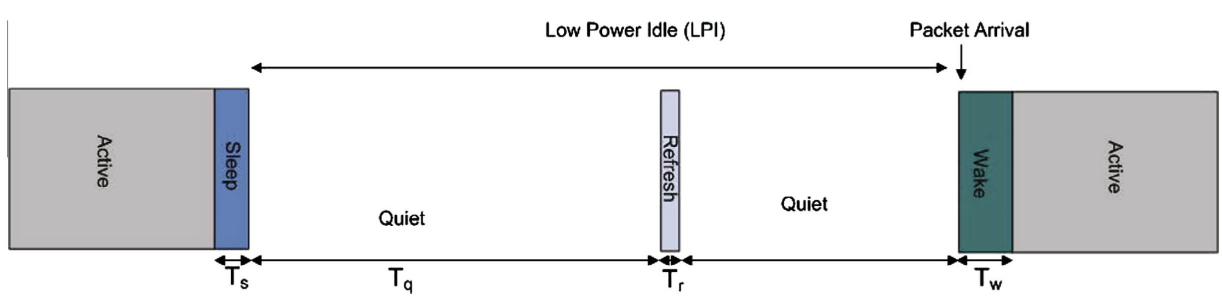

Fig. 1. Mode transitions in Energy Efficient Ethernet.