Energy Efficiency in 10Gbps Ethernet Transceivers: Copper versus Fiber

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Abstract: The new Energy Efficient Ethernet standard will significantly improve the energy efficiency of 10Gbps copper transceivers. This paper compares the energy efficiency of 10Gbps Ethernet copper transceivers that implement the new standard with fiber transceivers.

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1. Introduction

The efficient use of energy in communications is a growing concern for both industry and governments worldwide. The massive amount of communications devices that are used today, together with their expected growth, have led to the conclusion that significant energy can be saved by applying energy efficiency concepts in the design of communication systems [1]. Indeed, the Internet core is estimated to consume about 6 TWh per year, an amount which can be significantly reduced if energy-aware protocols are deployed. Ethernet is a good example of technology than can be made energy-efficient with important savings, estimated over 3 TWh [2].

Currently two different media are commonly used in high speed Ethernet links that connect switches and aggregate traffic from many sources. These media are copper, using several categories of unshielded twisted pairs (UTP), and optical fiber. For copper the 10Gbps standard is 10GBase-T that supports links of up to 100m whereas for fiber there are different standards that cover different fiber types and lengths. The 10GBase-SR standard targets short range fiber lengths and can be used in the same configurations as 10GBase-T. Each media has its benefits and drawbacks and in this paper the focus is to compare the energy consumption of 10Gbps fiber and copper Ethernet transceivers also known as PHYs.

10Gbps Fiber PHYs currently require much less energy than copper PHYs. For example 10GBase-SR PHYs are estimated to consume less than 1Watt while early 10GBase-T devices can consume more than 8Watts [3]. This difference will tend to narrow in the future with newer generations of 10GBase-T PHYs that are expected to consume less than 4Watts [4]. However 10Gbps copper PHYs will still consume more energy than their optical counterparts as they need to perform very complex signal processing operations in both the transmitter and the receiver.

The previous discussion seems to suggest that 10Gbps optical PHYs will always be more energy efficient than the copper PHYs. However the IEEE 802.3az Energy Efficient Ethernet (EEE) task force [5] is completing a standard that will greatly improve the energy efficiency of Ethernet PHYs. This new standard applies only to copper and backplane Ethernet PHYs and therefore fiber PHYs will not benefit from the adoption of EEE. This leads us to the following question that we try to answer in the rest of the paper: what is more efficient a 10GBase-T PHY that implements EEE or an optical 10Gbps PHY?

2. Comparison of EEE enabled 10Gbps Copper PHYs versus Fiber PHYs

The IEEE 802.3az Energy Efficient Ethernet (EEE) standard [6] tries to reduce energy consumption in Ethernet devices by defining low power modes. The idea is that a PHY that has no frames to transmit can be put into a low power mode and when new frames arrive, back into the active mode very quickly (in a few microseconds). This enables energy savings that are almost transparent to upper protocol layers.

The estimated savings while in low power mode can be close to 90% (see for example [7] for details on 10GBase-T) and therefore for links that spend most of the time in low power mode the energy consumption is reduced drastically. This can mean that for lightly loaded links a copper PHY that implements EEE may be more energy efficient than an optical one. For example for a 4Watts 10GBase-T PHY if the link is in the low power mode 90% of the time the energy consumption would be $0.1*4+0.9*0.4 = 0.76$ Watts that is in the range of what an optical PHY would consume.

However a recent performance evaluation of EEE [8] shows that the transition times in and out of the low power mode are significant and that even for low loads the link may spend little time in the low power mode as frames cause it to transition between modes continuously. For 10GBase-T the times to enter and exit the low power mode are larger than 4us and close to 3us respectively [6]. This compares with a frame transmission time of 1.2us for a 1500 byte frame. In addition, during those transitions the PHY consumes a significant amount of energy.

To evaluate under which conditions an EEE enabled 10GBase-T copper PHY would be more efficient than a fiber PHY performance simulations similar to those reported in [8] have been performed. As 10Gbps PHYs are commonly used in links that aggregate traffic from many sources it may be reasonable to use a Poisson model for the frame arrivals as proposed in [9]. The results from this model would provide an approximation that can be used for an initial comparison with the optical PHY. In the simulations, the link is set into low power mode when there are no frames to transmit and back to the active mode as soon as a frame arrives for transmission. The transition times between modes are those of the latest standard draft [6]. Finally, to estimate the energy consumption it is assumed that there is significant energy consumption during the transitions and in active mode while the energy consumption in low power mode is only 10% that of the active mode. The results obtained are presented in Fig 1 for both small and large frames. It can be observed that even for small loads the energy consumption approaches that of the active mode (a value of one). This is caused by the transition overheads and has a larger impact when small frames are transmitted.

Obviously the power consumption versus load in a practical configuration would depend on the sizes of the frames and the inter-arrival times, however the two results presented try to cover the two extremes (short and large frames) and others should have a power consumption in between these two. This is further corroborated by the analysis of real data traces from different scenarios performed in [8] that showed that the power consumption gets quickly close to that of the active mode for relatively small link loads.

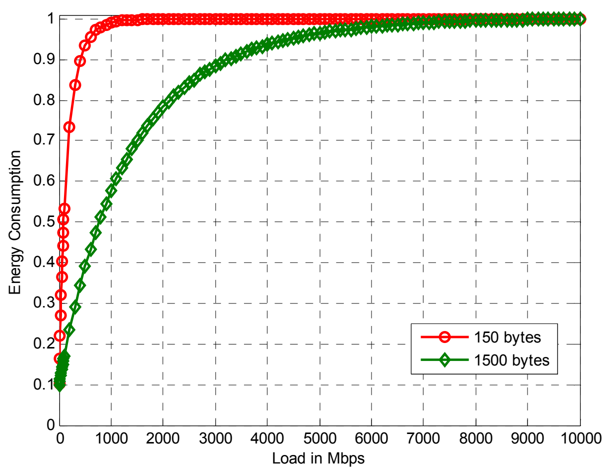

Figure 1. Energy consumption (relative to the active mode) versus load of a 10GBase-T EEE PHY for small (150bytes) and large (1500bytes) frames.

Making a preliminary comparison of power consumption of EEE 10GBase-T vs optical 10G is not straightforward, because it is not possible to know in advance to what extent the vendors will be actually able to reduce the consumption on the active mode in the next generation of copper transceivers, and get closer to their optical counterparts. However it is possible to estimate by how far copper transceivers can stand above the optical ones.

For this purpose, a relative measure will be used. This measure is the times that the copper PHY power consumption in active mode can be larger than that of the optical PHY and still be more energy efficient because of the use of the low power mode. For example, when the load is close to zero the power consumption of an EEE PHY would be approximately 10% that of the active mode and therefore the PHY power consumption in the active mode can be up to 10 times greater than that of a fiber PHY and still be more energy efficient.

The results obtained for this ratio are shown in Fig. 2 for small and large frames. It can be observed that the values tend to one for small load values and therefore the EEE copper PHY would only be more energy efficient if its power consumption in active mode is smaller than that of the fiber PHY. This is unlikely to occur in the near future as copper PHYs require much more complex processing than optical ones. In fact the use of EEE only helps significantly (ratios much larger than one) if the load is well below 1Gbps, that is if the link is underutilized.

Using current power consumption estimates and being aggressive on the copper side (4 Watts) and conservative on the fiber side (1Watt) we still get a ratio of four that can only be achieved with an extremely low load. From the simulations that load level would be around 20Mbps for short frames and around 200Mbps for large frames. That means that even with these conservative assumptions the optical PHY would be more energy efficient unless the link is almost carrying no traffic.
This leads us to the answer to our initial question: 10Gbps Ethernet fiber PHYs will remain to be more energy efficient than copper ones even when EEE is implemented on the copper PHYs except for links whose load is extremely low.

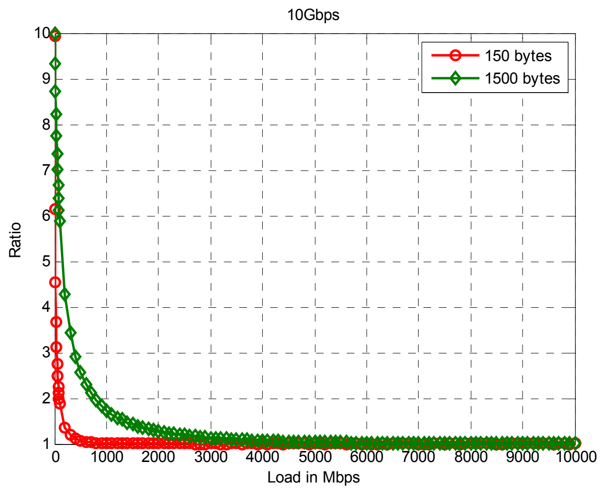

Figure 2. Number of times that the copper PHY power consumption in active can be larger than that of the optical PHY and still be more energy efficient.

3. Conclusions

In this paper the energy efficiency of 10Gbps Ethernet copper and fiber PHYs has been compared. The results show that optical PHYs will be more energy efficient even when the new Energy Efficient Ethernet standard is implemented on copper PHYs. This is an interesting result that ensures the advantage of optical Ethernet in terms of energy efficiency for the coming future.
Another relevant conclusion that can be made from this paper is that if at some point Energy Efficient Ethernet is extended to optical PHYs, the transition times should be minimized. In fact transitions times smaller than one microsecond are needed to achieve good energy efficiency on links unless they have a negligible traffic load. Unfortunately this seems to be in conflict with technological limitations as discussed in [10] where the implementation of low power modes on optical PHYs was proposed.

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