EEE Savings Estimates

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The amount of energy and money saveable through Energy Efficient Ethernet (EEE) technology is necessarily speculative, but decisions about the value of the technology rely only on the general magnitude of the savings, not the precise amount.

This document summarizes what is known to date about potential savings. Two past estimate are covered, as a more current estimate range. While some members of the EEE Study Group were consulted in preparing this, it reflects only my opinion.

This current estimate is considerably higher than the prior ones; I am assuming that discussion over the coming weeks will reduce this.

Summary

Direct EEE savings are driven by the following factors, each of which needs to be assessed separately for each PHY type (10G, 1G, backplane, fiber, …).

- Links — The number of EEE capable links that exist in any given year
- Power — The difference in power consumption between the high and usual low data rate
- Usage — The fraction of each year that EEE technology causes each link to move to a low data rate
- Price — The relevant electricity price

The savings will vary from year to year, as these factors change. It is valuable to have estimates for the U.S., as well as for the whole world.

The current new estimate is shown in Table 1; this assumes that **all** Ethernet edge links are EEE capable and used that way, and reflects potential links in a 2011 timeframe.

Table 1. May 25 EEE Estimate *($ million/year)*

	1 G	10 G	Total
U.S.	300	300	600
Global	900	760	1,660

These values include only the savings due to the network interface hardware, and do not include savings the rate reduction might facilitate elsewhere in the product ("enabled savings"), or in power or cooling infrastructure ("external savings").

The remainder of this paper reviews electricity prices, the prior two estimates, a new estimate data on links, power levels, usage patterns, and the larger context of EEE energy savings. Details are in appendices.

Electricity Prices

Average 2005 electric rates in the U.S. (EIA, 2007), were 9.45 cents/kWh for residences, 8.67 for commercial buildings, and 5.73 for industrial facilities (many data centers pay industrial electricity rates). The overall average was 8.14 cents/kWh. Prices rose an average of 7% over 2004 and every expectation is that 2010 prices will be notably above those in 2005. Elsewhere in the world, electricity is often more expensive. For example, in Europe in 2006, the average price was about 0.14 €/kWh (Eurostat, 2007)[3], or over 18 cents/kWh.

All of the estimates below use 8 cents/kWh.

Prior Estimates

Details on each estimate are presented in Appendix A. Note that the two estimates differ in geography (global vs. U.S) and coverage (sales vs. stock), and so are not directly comparable.

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[2] Modified March 20, 2008 only to correct Table 1 units to $million/year.

[3] The prices as of January 1, 2006 were 13.54, 13.85, and 14.76 Euro per 100 kWh for the EU-25, EU-15, and Euro area respectively. On May 16, 2007 each Euro was worth $1.35.

March EEE SG Estimate

This estimate[4] was constructed at the March 2007 EEE study group meeting by Bill Woodruff of Aquantia. 2010 **global** savings based upon **shipments in 2010** would be 2.4 TWh, or **$189 million** at 8 cents/kWh . It only accounts for device power reduction, not the additional savings in the AC/DC conversion process. The device power savings from EEE are estimated at 2.6 W for each 10 G PHY and 0.2 W for each 1G PHY. It is assumed that each PHY operates at the lower power speed for 90% of the time.

November CFI Estimate

This was constructed in advance of the November 2006 CFI by Bruce Nordman of LBNL. It began with projections for the stock of various Ethernet-using products in homes and commercial buildings, and an estimate of total EEE 10G ports. For each product type, an estimate was made of the average number of NICs/product, the average % of these occupied by a data cable, and the % of time each of these could be in their low rate mode (taking into account the percent of time the device was off with no link, or for notebooks, asleep and already at a low data rate).

Two energy estimates were made: a high estimate with 1.5 W and 10 W savings per 1 G and 10 G NICs respectively, and a low estimate with 1.0 W and 5 W savings. This **U.S.-only** savings for the **total stock of Ethernet links** was estimated to be about $300 to $450 million/year at 8 cents/kWh.

Toward a new estimate

The new estimate will be drawn in data and form from the previous estimates, modified by additional data and insight. The key endpoint for revising this is the July 2007 IEEE 802 plenary meeting. Key items include:

Power savings per NIC

The existing power level figures for 1 G NIC savings from reducing the link rate vary widely. Some of this is likely due to the varying vintage of components involved, the varying features of the products, and the different architectures involved (e.g. add-in cards vs. on-board hardware). It is likely that most future NICs will be on-board, and that manufacturers will make energy efficiency a higher priority in the coming years as well as take advantage of newer (more efficient) process technologies. Therefore, the pre-CFI “low estimate” of 1 W per NIC is used.

For 10 G NICs, the data available are not surprisingly more sparse. This figure needs more input from members of the EEE SG. as a placeholder, 8 W is used for 10G-BASET and 4 W for backplane Ethernet.

Usage of ports

For Ethernet connections, the amount of low-power (low-rate) time that could occur depends on the amount of time the data connection is active at all, and the percent of that time the low-power mode could be occurring. For 1 G NICs, the largest other uncertainty is in times the link is down (or already at the low rate) and so not able to save energy. For 10 G NICs the largest other uncertainty is the percent of time with low data rates. It is also the case that many ports that are shipped do not have a cable connected at all.

All that said, the uncertainty in the total introduced by differing assumptions of usage is considerably smaller than the uncertainty in power levels and number of ports/links that will exist.

Number of ports

It is useful to assess this based on forecast PHY shipments and separately from forecast stocks of products that are expected to have Ethernet interfaces. At this time, sufficient PHY shipment forecast data are not publicly available.

For 1 G savings, we use the “low estimate” values from the CFI estimate; that differed from the high estimate only in the per-NIC savings. The low estimate is used on the assumption that manufacturers will make energy efficiency a higher priority in the coming years as well as take advantage of newer process technologies. For global saving, we assume that the U.S. will have a third of global 1G Ethernet links in future. This percentage may be high, and reducing it would increase the global estimate.

[4] The spreadsheet is named “EEE energy savings.xls”.

For 10 G savings, the process to produce report for the EPA on servers and datacenters (Masanet, 2007) includes projecting “current trends” of server stocks in the U.S. Table 2 below shows a new estimate for 10 G savings. This covers only edge links to servers. At $0.08/kWh, this is $300 million/year.

A recent estimate of global server energy use (Koomey, 2007) found that about 40% of servers are in the U.S. So, the U.S. figure is multiplied by 2.5 to get a global figure of 9.5 TWh/year, which at $0.08 is $760 million/year.

This estimate does not include 10 G uplinks from switches that serve banks of office Ethernet links (principally desktop PCs). Assuming a ratio (including redundant links) of about one uplink per 25 downstream devices, and 100 million active links of this form (in the U.S.), this would add about 4 million links, or increase the total by about 10%. These are not included in the total at present.

Table 2. Estimated 10 G NIC power savings from EEE (U.S. only)

Server type	**Stock** *(000)*	**10 G ports per system**	**10 G server ports** *(000 000)*	**Power per port** *(AC W)*	**Low- power time** *(%)*	**Annual savings per port** *(kWh/year)*	**Annual savings** *(TWh/year)*
Volume	17,300	2					
- blade	5,767	2	11.5	4	90%	32	0.36
- non-blade	11,533	2	23.1	8	90%	63	1.45
Mid-range	304	4	1.2	8	80%	56	0.07
High-end	15	8	0.12	8	60%	42	0.01
Total servers			**35.9**				**1.89**
Switch end of links			35.9				1.89
Total 10 G			**72**				**3.8**

Outstanding Issues

To the degree that savings in the balance of the system (beyond the NIC) are enabled by throttling the data rate rather than by the link rate reduction itself, mechanisms to accomplish that throttling might enable savings in fiber NICs that don’t have energy-saving ways to reduce the link rate. It also might be possible to accomplish the throttling on non-EEE copper links, and do so sooner than EEE NICs (and EEE links with an EEE NIC on both ends) could be deployed. This should be explored.

Reported Power Data

The existing data on power savings from dropping link rates come from a variety of sources: AC and DC values; measurements and specifications; and from manufacturers or from others. When DC values were reported, they were increased to account for power supply losses. Table 1 shows reported values for 1 G NICs.

Table 3. Reports for savings from dropping rate from 1 G (to 100 M or 10 M)

AC W ∆ - 100	**AC W ∆ - 10**	**Type**	**Comments and Source** (and lower speed)
3		add-in card	Christensen, 2006 (personal comm..).
3.3	4.5	add-in card	Bennett and Nordman, 2006 (personal comm..)
0.32		small switch	5 port switch. Blanquicet, 2007 (personal comm..)
1.48		switch	24 port switch
3.7	4.3	add-in card	Intel (2.8 and 3.2W DC)
0.9	1.2	specification	Intel (0.71 and 0.90 W DC)
2.4	2.7	on-board	Intel
3.3	3.3	add-in card	Netgear
2.4	2.9	add-in card	Linksys

For 10 G NICs, no solid figures have been reported for the power savings. Table 4 is included as a placeholder for when such values are available, at least as professional judgments

Table 4. Reports for savings from dropping rate from 10 G to 1 G

AC W ∆	Comments and Source

Table 5. Reported 10 G NIC power

AC W	Comments and Source
20	2007 product (Tehuti); 30 W for dual adapter
10	2008 product (Tehuti); 15 W for dual adapter
14	Fiber adapter; may be DC power

Reported Utilization Data

The presentation "Server Bandwidth Utilization plots" by Mike Bennett to the EEE Study Group contains several traces of Ethernet utilization data (Bennett, 2007a). It shows four traces, three for links at 100 Mb/s and one 1 Gb/s. Note that if the 100 Mb/s links were converted to 1 Gb/s, the 10% utilization times would become the 1% times, and the 10% times would become zero. Table 6 summarizes these traces quantitatively, along with similar data for three desktop users at LBNL (Bennett, 2007b)

Table 6. Edge link utilization data — %s are % of time at or above this utilization rate.

Edge Device	Link Rate	Trace length *(hours)*	10%	5%	1%	Sample Rate *(seconds)*
Domain Name Service	100 Mb/s	8.0	0.13	0.14	16.1	1
DHCP service	100 Mb/s	1.0	0.3	0.3	2.7	11
E-mail	100 Mb/s	18.2	0.008	0.01	0.66	1
File Server	1 Gb/s	0.4	9.1	13.1	24.8	1
Desktop "A"	1 Gb/s	24	0	small	0.53	1
Desktop "B"	1 Gb/s	24	tiny	tiny	0.05	1
Desktop "C"	1 Gb/s	24	0	0	0	1

Some of the server links show regular bursts of activity, presumably for table updates — the DNS server has bursts are every 30 minutes, and the DHCP and e-mail servers burst every 10 minutes (though the e-mail bursts are small). Example graphs are shown in Appendix C. The desktop data show virtually no need for the high data rate in the course of 24 hours for these three users.

Energy Savings Context

None of estimates go beyond the direct AC savings of the products that include EEE NICs. To describe this, we introduce two new terms as follows.

Enabled Savings

EEE may facilitate savings beyond the NIC in network equipment, servers, and PCs. The details of these savings are not standards based and so will be vendor-specific. An obvious example is to apply frequency and voltage scaling — already commonly used in servers and PCs — to reduce power use by switches by reducing switching capacity when not needed. It also may be accomplished by slowing down energy-intensive data paths, or even switching subsystems to separate lower power (and

External Savings

A recent report (EPA, 2007) estimates that the power and cooling infrastructure (principally UPS) in data centers typically uses as much energy as the IT equipment, and other estimates place this burden even higher. For homes and offices the %s are much lower and likely not worth putting any quantitative estimate .

Caveats

These estimates are for **all** Ethernet edge links using EEE. Even if this is ultimately achievable, it will occur over an extended period of time, during which many links will lack EEE NICs on one or both ends of the link. This means that EEE savings will phase in over time, though there may be methods to get some savings on non-EEE links in the interim that should be explored.

Data Needs

- More data or opinions on the future number of Ethernet links of each PHY type.
- More data or opinions on utilization — the potential time at low data rates.
- More data or opinions on the power level reductions likely to occur from going to the low data rate for the 10 G and 1 G NIC cases.
- Whether the "0 BASE-T" proposal has a different power level difference from the standard 10 G and 1 G cases, and if so, what that delta is, and how widespread this might be used.
- Standard value(s) for power conversion losses from high voltage AC to low voltage DC. Could differ between 1 G and 10 G NICs.
- Potential magnitude of enabled savings in servers and network equipment (relative to NIC savings), and whether this estimate should put any quantification on this at all.

References

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Appendix A — Prior Estimate Details

March 2007 EEE SG Estimate (Woodruff)

The stock of EEE links is derived by taking “Switching only” PHY sales projections from Dell’oro, establishing values for PHY power use at various speeds, and % of time at the lower speed. Estimates start with shipments in 2010. This figure is then augmented to account for units shipped on servers/PCs by increasing the PHY count by 60%. Power savings beyond the PHY (in the MAC and Switch) are estimated to be equivalent to the power savings. Savings for years post-2010 are estimated to grow 20% per year, with annual savings in out years representing the cumulative benefit of EEE.

Savings for post-2010 are estimated through annual 20% increases in energy savings. Table A-1 presents the actual spreadsheet data from this estimate.

Table A-1. Spreadsheet from March 2007 Estimate

Switching Only, Dell'oro 1/07						
# of 10G phys in 2010	8,757,000	copper %	42%		Total Copper	3,677,940
# of 1G phys in 2010	281,167,000		94%			264,296,980
Power at 10G	3					
Power at 1G	0.4					
Power at 100M	0.2		Avg. power for 10G		0.66	
			Avg. power for 1G		0.22	
Assumption: Time at lower speed = 90%						
			Power savings for 10G		2.34	
Avg. power for 10G	0.66		Power savings for 1G		0.18	
Avg. power for 1G	0.22					
Power savings for 10G	2.34					
Power savings for 1G	0.18					
Power savings in 2010, 10G	8,606,380		Energy Savings,		kWh	
Power savings in 2010, 10G	47,573,456					
	56,179,836		56MW			
Hours per year	8,760					
Cost per kwh	$0.08					
Total cost, one year's production, switching PHYs				$39,370,829	492,135,363	
Added for server/PC	60.00%			$62,993,327	787,416,581	
Added for rest of system	100.00%			$125,986,653	1,574,833,163	
First year savings				$188,979,980	2,362,249,744	
Second year	20.00%			$226,775,975	2,834,699,693	
Third	20.00%			$272,131,171	3,401,639,632	
Fourth	20.00%			$326,557,405	4,081,967,558	
Fifth	20.00%			$391,868,886	4,898,361,069	
Total Savings				$1,406,313,416	17,578,917,696	

Pre-CFI Estimate

Tables A-2 summarizes the results from the pre-CFI estimate. Table A-3 presents the detailed assumptions that underlie the estimate for 1G savings. Note that the low estimate only differs in the power level assumptions, not in any of the other assumptions shown in the first four data columns of Table A-3.

Table A-2. Pre-CFI Estimate Summary

	Electricity *(TWh/year)* Low	High	**Dollars** *(million/year)* Low	High
Residential	1.73	2.60	139	208
Commercial (1G)	1.47	2.21	118	177
10G	0.53	1.05	42	84
Total	**3.73**	**5.86**	**298**	**469**
1 G total subtotal	3.21	4.81	256	385

< Should substitute the low estimate numbers >

Table A-3. Estimated Savings from Adaptive Link Rate — High estimate

Product	**Future Stock (2012), Millions**	**# NIC/ Product**	**% NICs Occupied**	**% Time NIC could be in low speed**	**Savings per unit** kWh/year	**Potential 2010 savings** (GWh/ year)	**Potential 2010 savings** (million $/year)	**% of total 1 G savings**
Residential								
Computer, desktop	100.0	1	90%	40%	3.15	473	37.8	**9.8%**
Computer, integrated	1.2	1	90%	40%	3.15	6	0.4	0.1%
Computer, notebook	70.0	1	50%	50%	2.19	230	18.4	4.8%
MFD, inkjet	29.5	0.1	75%	70%	0.46	20	1.6	0.4%
MFD, laser	7.1	0.5	75%	70%	2.30	24	2.0	0.5%
Printer, inkjet	55.0	0.1	75%	70%	0.46	38	3.0	0.8%
Printer, laser	3.5	0.5	75%	70%	2.30	12	1.0	0.3%
Modem, cable	40.0	2	60%	75%	7.88	473	37.8	**9.8%**
Modem, DSL	40.0	2	60%	75%	7.88	473	37.8	**9.8%**
Router, ethernet	15.0	5	60%	75%	19.71	443	35.5	**9.2%**
Wireless access point	18.0	5	40%	75%	13.14	355	28.4	**7.4%**
External drive	10.0	0.5	90%	90%	3.55	53	4.3	1.1%
						2,601	**208.1**	**54.1%**
Commercial								
Computer, desktop	80	1	90%	70%	5.52	662	53.0	**13.8%**
Computer, notebook	40	1	80%	20%	1.40	84	6.7	1.7%
Printer, All	90	0.3	75%	90%	1.77	239	19.2	**5.0%**
MFD, all	20	0.5	75%	90%	2.96	89	7.1	1.8%
Scanner	10	0.1	75%	90%	0.59	9	0.7	0.2%
VOIP phones	10	2	100%	90%	15.77	237	18.9	4.9%
Switch (Lan) ports	120	1	75%	75%	4.93	887	71.0	**18.4%**
						2,207	**176.5**	**45.9%**
Total 1G Savings								
						4,808	**384.6**	**100.0%**
10 G Savings	**15**			80%	7.0	**1,050**	**84**	
Total EEE Savings						**5,858**	**468**	

The savings per NIC (AC W) 1.5 W for 1 G, and 10 W for 10 G. The low estimate used 1 W for 1 G, and 5 W for 10 G. The electricity price used for the entire estimate is $0.08/kWh.

Some of the product stock data were extrapolated from recent product saturation data based on a future number of households of 118 million; the starting point was estimated saturations for 2005; in most cases there are assumed to be higher household saturations in 2010.

Products that were explicitly not included in the 1 G estimate include residential (scanners, satellite modems, POTS modems), and commercial (WAN shelves and routers).

The total of both 1G and 10G is $469 million. Note that desktop PC links account for nearly 50% of all projected 1G savings

Appendix B — Power level details

DC measurements below are increased by **one third** to account for power conversion losses.

1 G NICs

Data from May, 2006 IEEE 802 Tutorial (Nordman and Christensen, 2005)

Cisco Catalyst 2970 LAN switch. 24 port capacity, tested witht 0, 2, 4, 6, and 8 ports active, with all at 10 Mb/s, all at 100 Mb/s, and all at 1 Gb/s. Power trend is close to linear from 0 to 8 ports. Power draw is about the same between 10 Mb/s and 100Mb/s. Each 1 Gb/s port adds 1.83 W, each 10 or 100 Mb/s port adds 0.35 W, for a delta between 1Gbs and the lower speeds of 1.48 W. All power measurements AC. (Also cited in Gunarate et al.)

Intel Pro 1000/MT NIC (add-in PCI card) — DC Power
3.2 W difference between 1000 and 10. 2.8 W difference between 1000 and 100. No significant difference between idle and active link. AC power difference imputed to be 4.3 and 3.7 W (measurements by Brian Letzen from University of Florida (February 2005)

Intel 82547GI/82547EI Gigabit Ethernet Controller (NIC) — Specifications — DC Power
1000/10 delta: 910 mW; 1000/100 delta: 700 mW. Imputed AC power differences 1.2W and 0.9 W.

Data from Gunarate et al.

	10Mb/s		**100Mb/s**		**1000Mb/s (1Gb/s)**	
	On	Sleep	On	Sleep	On	Sleep
Intel PRO 1000/MT (on motherboard)	57.9W	3.2W	58.2W	3.6W	60.6W	7.0W
NetGear GA311 (PCI)	59.6	5.3	59.6	5.7	62.9	5.8
LinkSys EG1032 (PCI)	59.1	5.6	59.6	5.5	62.0	5.6
Change from 10Mb/s	**—**	**—**	**0.3**	**0.2**	**2.9**	**1.4**
Deltas	1000 / 10		1000 / 100			
Intel	2.7	3.8	2.4	3.4		
NetGear	3.3	0.5	3.3	0.1		
LinkSys	2.9	0.0	2.4	0.1		

Dell GX270 Pentium 4 PC with different NICs
(from Gunarate et al.)

Add-in Card

Netgear GA311 NIC (which uses a Realtek RTL6189S-32 Ethernet controller chip) on a WindowsXP Dell Optiplex GX270. At 100 Mb/s the power consumption of the GX270 was between 59 and 60 W. At 1 Gb/s the power consumption was between 56 and 57 W. This measured with a Kill A Watt power monitor at the wall socket.
(Christensen, 2006 — personal communication)

Same card measured at LBNL (Mike Bennett and Bruce Nordman, 2006) with a more accurate meter. Power drop from 1 G: 100 M – 3.3 W and to 10 M – 4.5 W. Removing card entirely dropped 5 W from 1 G power level — this on a desktop and on a server.

Small switch
5-Port Gigabit Switch (Linksys EG005W)
Power Rating: 12VDC 500mA

Connected Computers	Speed (Mbps)	Power (Watts)
0	0	4.41
1	100	4.41
1	**1000**	**4.71**
2	100 / 100	4.43
2	100 / 1000	4.73
2	**1000 / 1000**	**5.07**
3	100 / 100 / 100	4.44
3	100 / 100 / 1000	4.75
3	100 / 1000 / 1000	5.07
3	**1000 / 1000 / 1000**	**5.40**
4	100 / 100 / 100 / 100	4.45
4	100 / 100 / 100 / 1000	4.77
4	100 / 100 / 1000 / 1000	5.09
4	100 / 1000 / 1000 / 1000	5.40
4	**1000 / 1000 / 1000 / 1000**	**5.74**

Key result: Difference between 1000 M and 100 M for four ports: 5.74-4.45 = 1.29 — 1.29 / 4 = 0.32 W.
Measurements made by Francisco Blanquicet (USF) on May 13, 2007

10 G NICs

Most of the following reports are only of total 10 G NIC power, not the reduction to 1 G. The total does provide a maximum that the savings could be, so has some use.

From March, 2007 presentation: Blaine Kohl, Tehuti Networks
10GBASE-T Adapters. Total power: 20 W and 30 W for single and dual port adapters respectively.
2008 figures: 10 W and 15 W.

From March, 2007 EEE SG presentation "EEE for Backplane PHYs in Blade Server Environment", David Koenen, HP
10Gb KR PHY about 1.1 - 1.5W
1Gb KX mode: 0.6 - 0.8W
MAC XAUI + PHY ~ 2W per link
x 2 Links per Server Blade ~4W

Mike Bennett and Bruce Nordman (2006) measured a 10 G optical NIC as adding 14.4 W to a desktop without any outgoing link established, and 21.2 W to a server with both links established.

From Tutorial
Chelsio N210 10GbE Server Adapter (NIC)
Typical power: 14 W
* From Chelsio N210 product brief (Rev 2.1, November 2004)
(Need to confirm that this is AC and not DC)

Appendix C — Utilization details

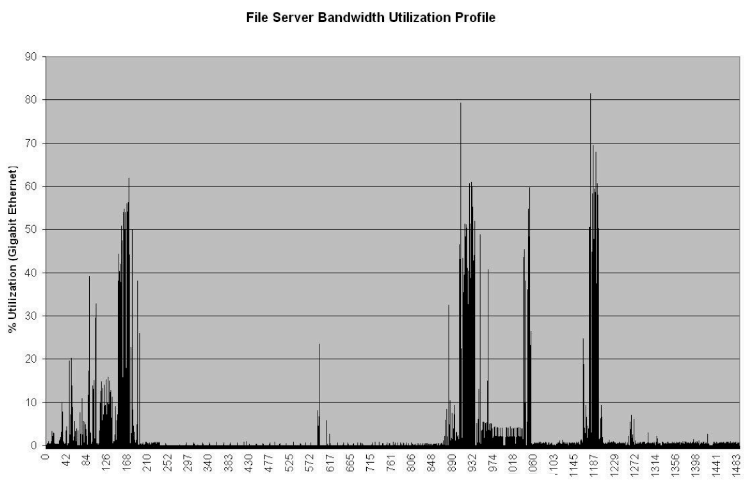
Data from May, 2006 IEEE 802 Tutorial

Traffic collection at University of South Florida (USF). Three traces from dormitory LAN (3000+ users) in mid-2004. All are 100 Mb/sec Ethernet links. USF traces are 30 minutes captured with Ethereal. The PSU data are from Portland State University, and represent two-hour traces.

Trace	Total busy time *(s)*	Total idle time *(s)*	Total low util time *(s)*	Average Utilization *(%)*	Link
USF #1	75	1759	1415	4.11	To the busiest user
USF #2	47	1771	1571	2.63	To the 10th busiest user
USF #3	0.55	1801	1799	0.03	To a typical user
PSU #1				0.13	To a desktop PC
PSU #2				1.01	Connecting two switches
PSU #3				1.03	Connecting a switch and router

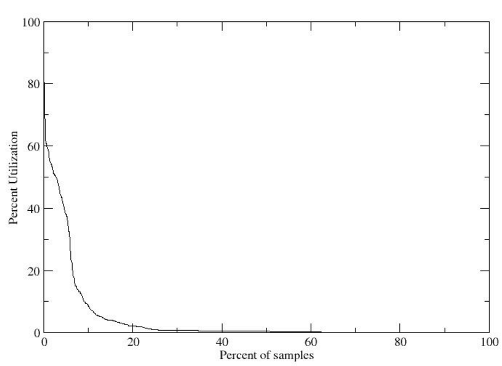
The tutorial also contains detailed discussions of the effect of different transition times on the packet

Data from Mike Bennett's March, 2003 EEE SG Presentation



The figure to the left is from the presentation slides. The total trace time is about 25 minutes. This trace is the most intensive in utilization of the four shown.

The figure below takes the same samples but sorts them from highest to lowest. This is called a 'load duration curve' (LDC) in energy analysis. One can pick any utilization level and see how much of the time is above and below this.



One possibility for additional analysis is to apply a policy such as keeping a link high for a longer period of time than the sample which caused the high rate to be instigated. For example, from the 1 second data, any time above 5% utilization could cause the link to remain high for the next 10 second. A new LDC could then be calculated.

Three 24-hour traces of office desktop data show very little use of link capacity. Graphs to be added.