(Article begins on next page)

Energy Profiling of ISP Points of Presence

Edoardo Bonetto, Marco Mellia, Michela Meo
Dipartimento di Elettronica e Telecomunicazioni, Politecnico di Torino, Torino, Italy
Email: firstname.lastname@polito.it

***Abstract*—Points of Presence (PoP), large aggregation nodes of a telecommunication network in which users lines are interconnected to the ISP backbone network, are relevant elements of the ISP network infrastructure. Motivated by the today interest of both ISPs and researchers to more energy efficient Internet, we investigate the power consumption of PoPs of FASTWEB, a national-wide ISP in Italy. Energy profiling spans a year long period, and includes both ADSL and FTTH access technologies. This extensive and unique dataset allows us to shed light on energy consumption of ISP networks, which we profile against other measurements, such as external temperature and PoP handled traffic. Results show that energy consumption is independent on the traffic, while it is strongly correlated with both daily and annual variability of temperature, due to air conditioning energy cost.**

Starting from these results, we investigate some possible strategies to reduce ISP electricity bill. We consider the adoption of energy proportional architectures which are currently being investigated by both manufacturers and researchers. Moreover, we evaluate the possible energy savings using real traffic data and we obtain that simple PoPs energy saving models based on two-three energy operating configuration can achieve results comparable to fully energy proportional model.

I. Introduction

Recently, energy consumption has become a major concern of humanity, and the Green economy is attracting a lot of investments. Telecommunication systems and ICT in general are seen as major players to reduce energy consumption, due to the “move bit, not atoms” paradigm.

In this paper we perform a detailed energy profiling of FASTWEB [1], an Italian national-wide ISP which offers wired Internet connectivity to more than 2 millions customers. We present measurement data of the energy consumption of FASTWEB Points-of-Presence (PoP), large network nodes that act as both aggregation points for user lines and large traffic switching points. Each PoP hosts tens of networking devices and it consumes energy for both powering on these devices and the cooling systems.

We investigate the power consumption of the major ISP PoPs, considering a dataset which includes information about: i) energy consumption, ii) external temperature and iii) total handled traffic. This unique dataset allows us to search for possible correlations among the energy consumption and other characteristics of the PoP, including its size, prevalent technology, etc.

Results show that energy consumption is correlated with the daily and seasonally variation of the external temperature, while it is practically independent on actual traffic. The first phenomenon is clearly related to the air conditioning cost, while the second phenomenon calls for novel approaches that would enable energy proportionality with respect to periodic traffic variations. To this extent, we provide some “what-if” analysis in which we consider possible energy proportional functionalities in network devices and, thus PoPs, in order to reduce their total energy consumption.

Indeed, at a first glance, the PoP energy consumption weights for 26% of the total energy consumed by the ISP, corresponding to about 30 GWh of energy in a year and an electricity bill of around to 3 million Euros for PoP cost only, a not negligible amount which ISPs (in general) would like to reduce.

Several research studies have already analyzed the energy consumption of data centers and they have also proposed strategies to increase their energy efficiency [2]–[5]. In this paper, for the first time to the best of our knowledge, the focus of the research is the energy profiling of ISP PoPs. We quantify their energy consumption, by means of an extensive dataset, and we demonstrate that future energy efficient networking devices and architectures, that make consumption more traffic proportional, will guarantee large savings. Note that the evaluation of the energy savings have been performed using measured traffic data.

The paper is organized as follows: in Sec. II we introduce the available metrics and the dataset. Sec. III deals with the energy characterization of the PoPs and the correlation among energy consumption and the other metrics is evaluated. In Sec. IV, we estimate possible saving achievable with energy proportional technologies. In particular, we perform a characterization of the PoPs traffic behaviors, we then explain the considered energy saving strategies and, finally, we evaluate the possible savings. Eventually, conclusions are drawn in Sec. V.

II. Available metrics and dataset characteristics

Since September 2010, FASTWEB started instructing a system to collect energy consumption of all its systems to better understand which elements are mainly responsible for the high energy cost. In this work, we focus on FASTWEB PoPs, which are several tens and cover the largest cities in Italy. We select eight of them that well represent the heterogeneity of technologies, sizes, placement, handled traffic. Those are hereafter identified by letters from A to H.

A. Available measurements

The energy management system implemented by the ISP provides, per each PoP, measures of:

• **Total energy** consumed by all the devices (network equipments and air conditioning system) that are installed in the PoP. The energy is expressed in kWh and the measures have a granularity of the quarter of hour. Denote by Δ the time granularity, $\Delta = 15$ min for a total of 8640 measurements. $E_X(n)$ is the energy consumed by PoP X during the $n-$th time window since the beginning of the measurement campaign. To avoid outliers, we restrict the set of measurements to the subset of $E(n)$ values within the 1-st and 99-th percentile of $E_X(n)$ distribution. We denote this set with $\mathcal{E}_X$.

• **Normalized energy**, $\hat{E}_X(n)$, is used, in some cases, when we need to compare the correlation between metrics. It is defined as,

$$\hat{E}_X(n) = \frac{E_X(n) - \min(\mathcal{E}_X)}{\max(\mathcal{E}_X) - \min(\mathcal{E}_X)} \tag{1}$$

for the samples $E_X(n)$ that belong to $\mathcal{E}_X$.

• **Air temperature** at the external of the PoP. In this case, the temperature is measured with a granularity of an hour, but for ease of notation we denote the air temperature by $T_X(n)$ referring to time windows of length Δ, defined as above.

• **Normalized bitrate** of traffic processed by a PoP. The system exposes $B_X(n)$, the total amount of traffic processed by PoP X in Δ time, which corresponds to the sum of all the data that are going from the users associated to PoP X to the network and vice-versa. Thus, the average bitrate in time window n is given by $B_X(n)/\Delta$. Finally, we normalize the bitrate to an arbitrary value that we choose to be equal to 0.8 the maximum observed bitrate. That is,

$$R_X(n) = 0.8 \frac{B_X(n)/\Delta}{\max_i(B_X(i)/\Delta)} \tag{2}$$

This is equivalent to assuming that the PoP capacity has been dimensioned so that the traffic load does not exceed 0.8.

B. Dataset

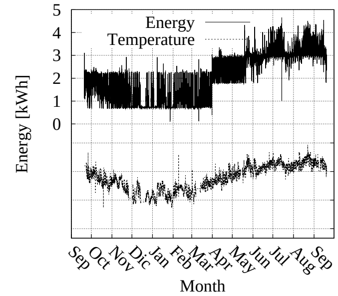
Energy and temperature measurements started to be collected from mid September 2010; thus, the period of time our dataset refers to is from September 2010 to September 2011, spanning a year long period which covers all possible seasons. We consider traffic measurements from beginning of January 2011 to end of March 2011 [1].

Table I summarizes the main characteristics of the PoPs. Two coarse classes of cooling systems are deployed by FASTWEB: normal heat pump systems, and free-cooling aided systems. The percentage of cooling capacity of a PoP, obtained using air conditioners with the free cooling option, are reported in the second column of the table. For what concerns access technology, FASTWEB offers both ADSL and Fiber-To-The-Home Ethernet-based technologies. Some PoPs host only ADSL or FTTH systems, while others have a different mix of the two. The third column of Table I reports, for each PoP, the percentage of users with FTTH access technology. The number of users ranges (fourth column) from a few thousands for PoP A to more than 60 thousands for F or G. Similarly, the approximate number of devices (the number of devices accounts for the backbone routers only) in the fifth column ranges from a few units of PoP A to more than 60 of PoP F. Finally, the last two columns report the minimum and maximum energy consumption of PoP X selected in the set $\mathcal{E}_X$.

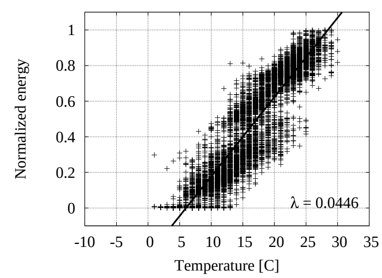
[1] We restrict our analysis on traffic to this period, since the number of users at each PoP can be considered stable, while it typically changes during other periods of the year when customers are attracted by special offers.

TABLE I
SUMMARY OF PoP CHARACTERISTICS

ID	Free cooling [%]	FTTH [%]	Users [k]	Devices	min($\mathcal{E}$) [kWh]	max($\mathcal{E}$) [kWh]
A	100	100	3.8	6	0.7	3.99
B	0	33	52.2	31	14.28	16.75
C	12	0.2	22.8	35	10.34	14.56
D	0	86	16.3	19	6.18	7.53
E	0	92	13.5	34	13.63	16.84
F	40	11	62.3	72	41.4	59.42
G	100	6	61.9	44	21.44	29.13
H	4	0.2	22.5	32	12.41	17



(a) Energy consumption and external temperature versus time



(b) Normalized energy consumption versus external temperature

Fig. 1. PoP A

III. ENERGY CHARACTERIZATION OF THE POINTS OF PRESENCE

In the following, we investigate which are the parameters that affect the energy consumption of PoPs. In particular, we focus on the correlation of energy consumption with temperature and traffic.

A. Energy consumption versus external temperature

Fig. 1(a) reports energy and temperature during the whole measurement campaign for PoP A. The plot is composed of

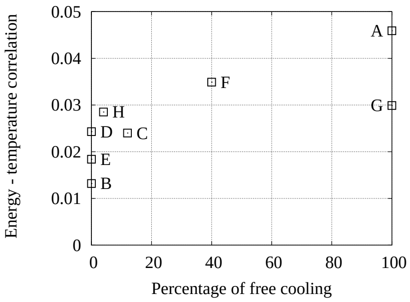


Fig. 2. Energy-temperature correlation versus percentage of air conditioners capacity due to free cooling

two parts: the top part shows energy consumption, $E_X(n)$, the bottom part the temperature, $T_X(n)$. The trend of consumed energy follows quite closely the temperature trend. In particular, during the coolest days of the year, the consumed energy reaches its minimum values; when spikes in the temperature are present, the consumed energy is large. The sudden jump at beginning of April in Fig. 1(a) is due to a change in the configuration of the cooling system.

Fig. 1(b) highlights the correlation among energy consumption and temperature. It reports normalized energy, $\hat{E}_X(n)$, versus temperature, $T_X(n)$, for PoP A. To numerically quantify the correlation, the linear interpolation of the data obtained with a least-squares fitting method is depicted. The coefficient of the resulting interpolated equation, reported on the figure with the symbol λ, can be used to determine if a PoP has a smaller or a larger energy-temperature correlation with respect to other PoPs.

By comparing the results for the other PoPs, we observed that all the PoPs with free cooling present high energy-temperature correlation. This trend can be seen in Fig. 2, which depicts the correlation parameter λ_X of each PoP X versus the percentage of free cooling air conditioners capacity.

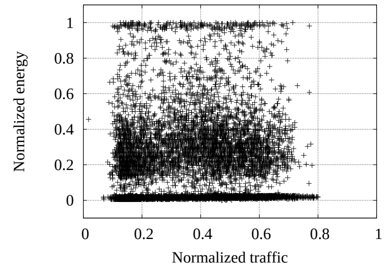
B. Energy consumption versus traffic

We focus now on the investigation of possible correlation of energy consumption with processed traffic. Focusing again on PoP A, Fig. 3(a) plots the normalized traffic, $R_X(n)$, vs normalized energy, $\hat{E}_X(n)$. Somehow surprisingly, there is little or no correlation at all between these two measures. Other PoPs, whose plots are not shown for the sake of brevity, have similar behavior.

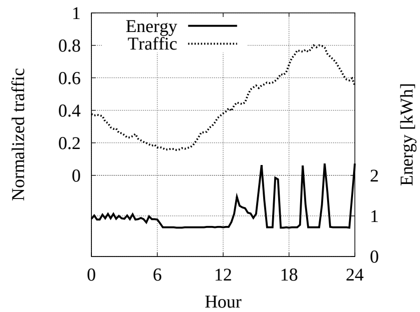
To give more insights, the daily variation of consumed energy and traffic is plotted in Fig. 3(b), considering a randomly selected day for PoP A. Left y-axis reports the normalized traffic, while right y-axis reports the energy consumption. In PoP A, whose energy consumption is strongly correlated with the external temperature, the energy consumption is almost constant during the coolest hours of the night and early morning, while compressors kick in only after 12 pm when the free cooling air conditioning is not sufficient. Note that, when compressors kick in, energy consumption doubles.

We have also studied the correlation between the PoP energy consumption and other parameters, such as the size of the PoP in terms of number of users, the predominance of ADSL or FTTH technology, but we do not notice any trend that can be associated to these two metrics. Results are not reported here due to space constraints.

In summary, PoP (and ISP) energy consumption exhibits a natural dependence on the external temperature. However, the substantial independence of energy consumption on traffic variations motivates novel approaches that enable energy saving by exploiting periodic traffic variations. In the remaining of the paper we perform a "what-if" analysis to gauge the possible benefit of this feature.



(a) Normalized energy consumption versus traffic



(b) Energy consumption and normalized traffic profiles during one day

Fig. 3. PoP A

IV. Energy savings strategies

Energy proportionality consists in enabling networking devices to adapt the consumed energy to the actual traffic load. While most of current networking devices do not have this capability, as shown in [6] and testified by the measurements shown in previous section, the idea of energy proportionality is very appealing. Indeed, while traffic is typically highly variable, most of the devices consume an amount of energy that only marginally depends on traffic and this translates into a huge energy waste. Current devices consume energy not for the work they actually do, and the used bandwidth, but for the deployed capacity. Thus, several research projects are currently investigating how to achieve energy proportionality by implementing energy saving capabilities on the individual devices or the system architecture [7]–[10]. These techniques act on the consumption of network devices only and not air conditioning systems. However, since the emitted heat depends on devices consumption, it can be expected that some saving can be achieved also by the air conditioning system.

In particular, a possible strategy might rely on a modular organization of the devices in the PoP. Following the *resource consolidation* practice [5], [11], [12], during low traffic demand periods, a fraction of the networking equipments of the PoP can be kept active, while the remaining is temporarily put into low consuming sleeping modes. In this way, the deployed capacity (and the consumed energy) is not constant but adapts to the traffic needs. For example, consider a PoP with two possible configurations corresponding to High and Low capacity, with High/Low capacity states entered when traffic goes above/below a given threshold. Since the number of devices in sleep mode is larger in low capacity state configuration, the overall energy consumption decreases.

While nowadays these technologies are not available yet, in this paper we investigate if substantial energy saving can be achieved using them and if there is a good motivation to invest in this direction, as several manufacturers are already doing.

A. Traffic variation analysis

Important premise to the evaluation of energy proportionality advantages is the study of how the PoP traffic changes over time. The convenience of these strategies depends on the traffic dynamics characteristics. For instance, if a PoP has very limited traffic dynamics, i.e., it presents a small difference between the minimum and the maximum amount of processed traffic, more than one configuration would lead to negligible energy saving.

After having analyzed the traffic variations for the each PoP, we have determined that traffic follows a day/night periodicity with a typical sinusoidal behavior and with off-peak traffic that is about one forth of peak traffic; just small differences can be noticed in different days.

To better gauge the variability of traffic, we look at the ratio between the peak and off-peak traffic values. In particular, since the traffic is a noisy measure, and the actual value of the peak may depend on different local phenomenon, we compute for each day the ratio among the 80-th and 20-th percentile of the traffic measurements of the day. The computations show that the daily excursion of traffic is very large, with typically 80% of peak hour traffic three times larger than the 20% of off-peak value. Interestingly, this variation seems insensitive to the location, size, and kind of PoP, meaning that the overall behavior of an aggregate of users is variable in a day in a quite stable and easily predictable way.

B. PoP energy saving models

In the following we speculate on possible energy savings that can be achieved given an energy proportional or resource consolidation technologies. We assume that the normalized energy consumption of the current technology (no proportionality) is equal to 1, and that this is also the consumption that any scheme would have at maximum traffic load. Denote by S_X the total energy saving that can be achieved in PoP X by a given scheme, S_X is defined as $S_X = 1 - \frac{1}{N}\sum_n f(R_X(n))$ where $f(x)$ is the energy consumed by the PoP when it is processing traffic load equal to x, with $0 \leq x \leq 1$ and N is the total number of samples n.

1) Linear proportional energy consumption: In this strategy, the energy consumption is directly proportional to the traffic load: $f(x) = \alpha \cdot x + E_0$, where $\alpha \cdot x$ represents the variable component of consumed energy, α being the proportionality factor, and E_0 represents the amount of fixed energy consumption of the PoP, i.e., the static consumption. Since we consider the normalized energy, $f(1) = 1$. Thus, the fixed energy cost $E_0 = 1 - \alpha$. The case $\alpha = 0$ corresponds to current technology, whose consumption is constant, regardless the load; for $\alpha = 0$, the normalized consumption is 1.

2) Resource consolidation with two operating configurations: In this scenario, we assume that the PoP can operate in two configurations. In the first one, the PoP can support the maximum traffic load and consumes the maximum amount, while in the second configuration, the PoP can process a limited amount of traffic and it has a lower energy consumption. When the traffic is above a fraction m of the peak traffic, the PoP is fully operative and consumes the maximum energy, that is normalized to 1. When traffic is below a fraction m of the peak, the PoP can work at a fraction m of its full capacity, and, for simplicity, we assume that it is also consuming a fraction m of the consumption at full capacity. Thus,

$$f(x) = \begin{cases} m & x < m \\ 1 & x \geq m \end{cases} \tag{3}$$

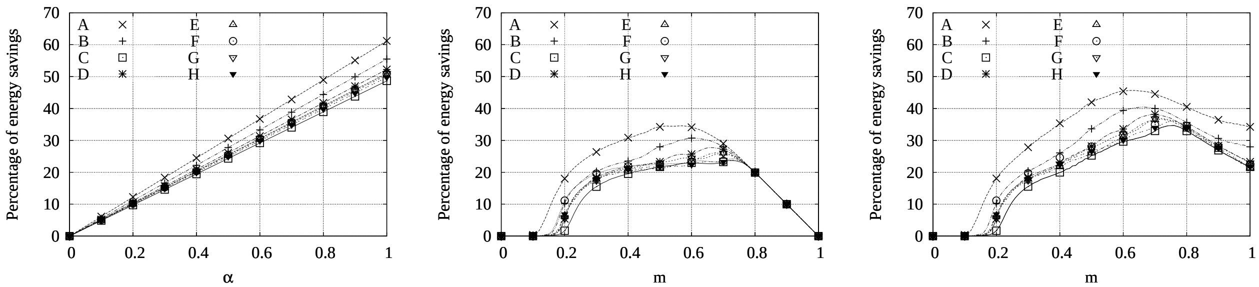
3) Resource consolidation with three operating configurations: In this scenario, we extend the previous case and assume that a PoP can work in three configurations: one for low traffic, one for medium and one for maximum traffic. As before, we consider that traffic and energy are normalized and

$$f(x) = \begin{cases} l & x < l \\ m & l \leq x < m \\ 1 & x \geq m \end{cases} \tag{4}$$

where l and m are the traffic thresholds and corresponding energy consumption values for low and medium traffic, respectively.

C. Results

The energy saving that can be achieved by linear proportional consumption is reported in Fig. 4(a) for various values of the parameter α in (IV-B1). We compute the savings considering the measured values of traffic. When $\alpha = 0$, the consumption is not proportional at all; no saving is possible and the consumption is the same as it is now. As the quantity of energy that is proportional to load increases, savings are possible; when consumption is fully load proportional (α =1), up to 50-60% of energy can be saved. The saving depends on the traffic pattern, and, since traffic patterns are very similar in the PoPs, savings are almost the same for the different PoPs.



(a) Linear proportional energy consumption (b) Resource consolidation and two operating configurations (c) Resource consolidation and two operating configurations

Fig. 4. Energy savings for PoPs

Fig. 4(b) shows the energy saving achieved by each PoP when resource consolidation is used and two configurations are possible. In the plot, the threshold value m varies from 0 to 1. When m is small (below 0.2 of the peak traffic) no saving is possible, since traffic rarely drops below m and low capacity configuration is rarely entered. When m >0.8, only the low capacity configuration is used, and saving depends on the actual value of m only. Depending on the traffic characteristics of the PoP, the optimal value of m slightly changes, but it is typically around 0.65. As shown in [13], the optimal value depends on the amount of energy that is saved in low capacity scheme and on the duration of the periods in which traffic is low and low capacity configuration can be entered.

Results of resource consolidation with three configurations are presented in Fig. 4(c) for the case in which $l = m/2$, see (4). As expected, savings increase with respect to the two-configuration case, but only marginally.

Finally, from the previous results, we can state that linear proportionality achieves very high saving, typically about or higher 50%. Yet it is far from being available for current technology. However, resource consolidation schemes are likely to be deployable in the near future and, even if smaller, the possible saving can be quite large (20-30%). These solutions are probably very promising as short-term relief to high ISPs electricity bills.

V. Conclusion

In this paper, based on a wide dataset of real measurements performed in the operative network of a national-wide Italian operator, we have performed an extensive analysis on how the energy consumption of a PoP is related to parameters such as external air temperature and processed traffic. We observed a strong correlation between consumed energy and external temperature, mainly due to the air conditioning system, especially in the PoPs that employ air conditioners with the free cooling option. On the contrary, almost no relationship can be found between energy and traffic.

This result motivates us to estimate the energy saving that can be possibly achieved with strategies that make the PoP energy consumption proportional to the traffic. It is important to notice that the evaluation of the energy savings has been performed using real traffic data. Moreover, resource consolidation schemes, which are expected to be easily implemented, can achieve energy savings that are satisfactory in comparison to the linear proportional model results.

Since the possible energy savings are significant, our conclusion is that the design of energy proportional technologies is of strategical importance for the ISPs.

Acknowledgment

The research leading to these results has received funding from the EU 7th Framework Programme (FP7/2007-2013) under grant agreement n. 257740 (NoE TREND).

References

[1] FASTWEB Web Page, “www.fastweb.it/,” 2011.

[2] L. Liu, H. Wang, X. Liu, X. Jin, W. B. He, Q. B. Wang, and Y. Chen, “Greencloud: a new architecture for green data center,” in *Proceedings of the 6th international conference industry session on Autonomic computing and communications industry session*, ser. ICAC-INDST ’09. New York, NY, USA: ACM, 2009, pp. 29–38.

[3] B. Heller, S. Seetharaman, P. Mahadevan, Y. Yiakoumis, P. Sharma, S. Banerjee, and N. McKeown, “Elastictree: saving energy in data center networks,” in *Proceedings of the 7th USENIX conference on Networked systems design and implementation*, ser. NSDI’10. Berkeley, CA, USA: USENIX Association, 2010, pp. 17–17.

[4] J. Li, Z. Li, K. Ren, and X. Liu, “Towards optimal electric demand management for internet data centers,” *Smart Grid, IEEE Transactions on*, march 2012.

[5] D. Abts, M. R. Marty, P. M. Wells, P. Klausler, and H. Liu, “Energy proportional datacenter networks,” *SIGARCH Comput. Archit. News*, vol. 38, pp. 338–347, June 2010. [Online]. Available: http://doi.acm.org/10.1145/1816038.1816004

[6] J. Chabarek, J. Sommers, P. Barford, C. Estan, D. Tsiang, and S. Wright, “Power awareness in network design and routing,” in *IEEE INFOCOM 2008*, Phoenix, USA, April 2008.

[7] TREND Project, funded by the European 7th Framework Programme, “http://www.fp7-trend.eu/.”

[8] ECONET Project, funded by the European 7th Framework Programme, “http://www.econet-project.eu.”

[9] GreenTouch Consortium, “http://www.greentouch.org/.”

[10] D-Link Green Products, “http://www.dlinkgreen.com/greenproducts.asp.”

[11] R. Bolla, R. Bruschi, and M. Listanti, “Enabling backbone networks to sleep,” *Network, IEEE*, vol. 25, no. 2, pp. 26–31, 2011.

[12] L. Chiaraviglio, M. Mellia, and F. Neri, “Minimizing ISP Network Energy Cost: Formulation and Solutions,” *IEEE/ACM Transactions on Networking*, 2011.

[13] M. A. Marsan, L. Chiaraviglio, D. Ciullo, and M. Meo, “Optimal Energy Savings in Cellular Access Networks,” in *Proceedings of the 1st International Workshop on Green Communications (GreenComm ’09)*, Dresden, Germany, June 2009.