Abstract In this paper we detail the TREND meter, a tool for monitoring the power and the utilization of networked devices. Our solution is based on standard measurements and data export methods. The TREND meter provides graphed energy consumption and load information of each measured device. After detailing the TREND meter architecture, we report the main results that we have obtained by collecting measurements from a variety of devices. Our solution represents the starting point towards a more complex tool able to monitor a network infrastructure and to trigger energy saving techniques when traffic conditions change.

Keywords: energy-efficiency, measurements, energy and performance, power monitoring systems, networked devices.

I – INTRODUCTION

Information and Communication Technology (ICT) and telecommunication networks have been historically and fairly considered as the enabling factors for monitoring third-party energy wastes and in achieving high levels of efficiency (EU Commission, 2008). For instance, the ICT and network technologies are even more applied for building smarter and more energy-efficient environments (e.g., buildings, homes), in energy distribution (i.e., smart grids), and in many other industrial fields. But today, state-of-the-art ICT and network technologies themselves are not ready to effectively support all these third-party applications, since they are not enough energy efficient (Roth, 2006), and even the same evolution of the Internet might be eventually constrained by energy-related aspects (Baliga, 2007). The International Telecommunication Union (ITU) estimated the ICT carbon footprint (excluding the broadcasting sector) to be between 2% and 2.5% of total global greenhouse gas emissions (ITU, 2009). The main components within the ICT industry include the energy requirements of PCs and monitors that contribute with 40% and data centres with 23% of the total emissions. These figures become not so surprisingly, if we consider that, except for mobile and handled devices, energy-efficiency has almost never been a design constraint/objective.
Triggered by the increase in energy price, the continuous growth of customer population and networked device density (e.g., PCs at homes or offices, servers into datacenters), the spreading of broadband access, and the expanding number of services (in datacenters) being offered by telecom operators and Internet Service Providers (ISPs), the energy efficiency issue has become a high-priority objective also for wired networks and service infrastructures. For these reasons, the control of energy consumption on telecommunication networks and networked devices is nowadays a research topic of enormous interest in academic and industrial communities. Much likely as in other fields, there are two main motivations that drive the quest for energy-efficiency (Bolla, 2011):

1) the environmental one, which is related to the reduction of wastes, in order to impact on CO2 emission;
2) the economic one, which stems from the reduction of costs sustained by the operators to keep the network up and running at the desired service level and their need to counterbalance ever-increasing cost of energy.

Many efforts have been undertaken by the research community in order to deeply understand the source of such inefficiencies, to develop new technologies and eco-friendly solution, and to reduce ICT and network energy absorptions (see section II). Next-generation network nodes, ICT equipment, and protocols will certainly include new advanced energy-aware capabilities, allowing to drastically increase their energy-efficiency and making their energy absorptions proportional to the real workload.

However, in systems so complex, multi-layered and distributed like the ICT ones, these research efforts may benefit of the presence on the field of auxiliary tools able to monitor and to suitably and synthetically evaluate current deployed infrastructures in terms of operating behaviours, instantaneous performance and energy consumption. Notwithstanding these auxiliary tools may eventually increase the overall energy consumption, as suggested by the Jevsons’ paradox (Alcott, 2005), they can provide very useful data that may help researchers, engineers and system administrators in evolving, designing and developing new green technologies, as well as suitably dimensioning and consolidating future ICT infrastructures and services.

Starting from the previous considerations, we implemented a toolchain, the “TREND meter”, for monitoring the power consumption and the performance/workload of networked devices. The TREND meter is based on standard measurements and data export methods. The TREND meter provides you with easy to read, graphed energy consumption and load information of each measured device. The TREND meter represents the starting point towards a more complex tool able to monitor a network infrastructure and to trigger energy saving techniques when traffic conditions change. Our tool has been developed inside the context of the European project TREND (Towards Real Energy Efficient Network design), which actually supported this work.

The paper is organized as follows. A summary of related work is presented in Section II. Section III provides an overview of the TREND meter architecture. Section IV describes the measured networked devices. Section V presents the energy results of networked devices. The discussion of our solution is reported in Section VI. Finally, conclusions are drawn in Section VII.

II – RELATED WORK

Monitoring the status of the network and of its devices has always been an issue of great interest. In recent years, the collective consciousness for the need of more sustainable future network technologies had led to the definition of novel key performance indexes (KPIs) related to the energy consumption (ECR, 2009). The KPIs’ definition is a very important aspect to make easier the understanding of system performance levels and of eventual wastes or inefficiencies, especially with respect to the offered performance and workload levels. By means of such energy-related KPIs, clear visualization and immediate identification of energy-wasting areas can be possible. Before becoming aware of the importance of energy efficiency in telecommunications networks,
most of network monitoring tools mainly provided only metrics on traffic control and detection of network failures. For instance, the INTERMOM project (INTERMOM) offers an inter-domain QoS monitoring, where the modelling is based on abstractions for traffic, topology and QoS parameter patterns. Since this solution is not suitable to a multi-domain environment, perfSONAR (Hanemann, 2005) extended the INTERMOM results to a multi-domain network environment based on service oriented architectures.

Several studies and research projects have concentrated their efforts for extending classical monitoring tools to energy-aware KPIs in all networking fields. Alahmad et al. (Alahmad, 2012) conducted a study for monitoring the energy consumption patterns in the residential sector, which accounts for 21% of the total electricity use in the United States. The results had shown a statistically insignificant reduction in electricity consumption in homes participating in the study. According to the authors, this could be due to the self-selection of participants and their possible action of saving energy before the study began. In order to reduce the energy consumption in homes Seong Ho Ju et al. (Seong Ho Ju, 2011) proposed a simple and effective Home Energy management Model System (HEMS) based on Automatic Meter Reading (AMR) network with a built-in PLC module. The system consists of a home agent, a device agent and an UI device in the house. Weiss (Weiss, 2010) and Guinard (Guinard, 2010) presented a device-level monitoring system to monitor power consumption on outlets. The system is based on off-the-shelf components and allows users to monitor the energy consumption of their appliances in real-time via web or mobile phone interfaces. In a wireless environment, Energino (Gomez, 2012) allows the user to identify which wireless devices are absorbing more energy. The Energino prototype is a plug-load power meter based on the Arduino platform. It has to be inserted between the power supply of the device in question and the electrical outlet. The OpenEnergyMonitor (EMON) is a project addressed to develop an end-to-end open-source energy monitoring system, also based on the Arduino platform, for monitoring and analysing the energy efficiency for a variety of applications from a home energy monitor to solar PV import/export monitoring.

Currently in an energy environment is difficult to obtain the energy data directly from network devices, without the use of some physical tools, due to the lack of standards within the area of energy management and agents present on network devices able to get this type of information. The most commonly used network protocol for collecting data from network/networked devices is the SNMP (Simple Network Management Protocol) (Case, 1990), which is already available in most network devices (e.g., switch, routers) and hosts (e.g., PCs). Over the time, SNMP has become the accepted standard for discovering network topology and monitoring its status. Considering the importance and the necessity for obtaining the energy data of some important network devices in the SNMP environment, the IETF Energy Management (EMAN) Task Force proposed a “Power and Energy Monitoring MIB” (Management Information Base; Chandramouli, 2012), which allow to access to the energy management capabilities of remote devices within or connected to communication networks. The proposed MIB modules are designed to provide a model and some KPIs for energy management, which includes monitoring for power state and energy consumption of networked elements such as routers, switches, hosts, servers, etc.

In the GREEN-NET project (Da-Costa, 2009), authors propose energy-aware software frameworks for large scale distributed systems aimed to collect information of energy usage and provide them to resources managers and schedulers. Faruqui et al. (Faruqui, 2010) analysed various utility pilot programs to investigate the effect of In-Home Displays (IHDs) on consumer behaviour. From information feedback it has been found that customers could reduce their energy consumption of a percentage equal to 7%.

Agarwal (Agarwal, 2010) and Reich (Reich, 2010) proposed a network-based sleep proxy for allowing the end-host to enter in low power sleep modes without compromising network connectivity or availability. In a software router device, the authors in Ref. (Bolla, 2009) exploited power management features already available in PC hardware platforms to adapt the energy consumption to the network traffic load and performance requirements. They also obtained an
empirical model able to capture the relationship between network performance and the Software Router energy consumption. In (Nedevschi, 2008), the authors evaluated the energy savings from sleeping and the possible savings from rate-adaption. Finally, in our previous work (Chiaraviglio 2010, Chiaraviglio, 2012) we have proposed and evaluated a software, called PoliSave, to reduce power consumption in computer networks. PoliSave is a simple web-based architecture which allows users to schedule power state of their PCs, avoiding the frustration of wasting long power-down and bootstrap times of today PCs.

III - SYSTEM ARCHITECTURE

The main goal of the TREND meter is to collect measurements of power and utilization from a variety of devices located in the Internet. The idea is to build a centralized server which collects the measurements from the devices. As second goal, the TREND meter aims at consolidating these measurements together to study whether there are similarities or not in the patterns of power and utilization of the devices. Additionally, the TREND meter aims at making publicly available the collected data to the community, and to easily show this information with a graphical representation.

The design of TREND meter architecture had to face a complex and very heterogeneous scenario. In the following, we report the main issues that we have faced while designing our tool.

Device Heterogeneity
The scope of TREND meter is to present into a unified view the measurements from devices. In particular, the software has to deal with a variety of devices, ranging from single devices, group of devices, experimental machines, and server machines. Such heterogeneity imposes to build a system both robust and scalable.

Measurements Heterogeneity
Different techniques have to be adopted to measure power and utilization of devices. Such techniques depend on the device type, as well as the amount of information that the device owner is willing to disclose to users. Therefore, the TREND meter has to build interfaces with a variety of measurements.

Security
The measured devices are located in different centres and even different countries. Therefore, the measurements data have to be transferred over the Internet. To guarantee security and confidentiality, a secure connection has to be established between the TREND meter architecture and the devices.

User Friendly
The measurements presented to users have to be simple to understand, as simplicity is one of the main goal to extend to a big audience the consciousness of energy efficiency of telecommunication networks. Moreover, the access to measurements has to be made publicly available.

Easy Customization
As we expect to constantly increase the number of measured devices, the system has to require a low level of additional work when a new device is added.

1) Architecture Description

A detailed scheme of the implemented architecture is reported in Fig. 1. The architecture is composed of three main units: a device back-end for collecting the measurements, a server back-
Collecting and storing the information from all devices, and a server front-end to display the information on a web site.

**Device Back-end**
The device back-end collects information of power consumption and traffic for each device and sends the refined measurements to the energy-related database. Initially, traffic is measured from the device, adopting standard networking tools, like the `ifconfig` command or a SNMP query. Additionally, power consumption is directly measured on the device with a power meter or estimated from the amount of traffic flowing on the device. Thus, for each device, it is possible to choose a method of measuring power and traffic. After this step both power and traffic are then correlated, and a common time reference is added to them. The reference is used to match the power consumption value with the device utilization at a given time. Then, the measurements are collected by an interface gateway, which is a software module that has been developed on a separate machine to save the measurements in temporary files. The interface gateway acts as a middle layer. In particular, both traffic and power are measured with an high frequency (typically one measurement per second), then the measurements are averaged over a coarser time scale (in the order of one minute), and finally sent to the server with a granularity in the order of minutes. The idea is in fact to avoid sending to the server frequent updates which may create congestion, but at the same time to maintain a high level of accuracy. Note also that each device can choose the frequency for making measurements and also how often to send them to the server.

Each row of the temporary files sent to the server includes the name of the device (which is an unique identifier), the time reference, the power consumption expressed in Watts and the traffic exchanged in Mbps. Both power and traffic are averaged over the considered time period, i.e., the difference between the current timestamp and the previous one.

**Server Back-End**
The measurements included in the temporary file are then sent at regular intervals to the server back-end which collects them. A secure connection is established between the server and the interface machine in order to guarantee privacy of data. In particular, the secure connection is established using the SSH software. The public keys of the machines running the interface gateway module are preliminary exchanged offline with the server. Then, the public keys are stored in the server machine: in this way the connection between each interface machine and the server does not require any password and can be fully automated.

Once the temporary file is received by the server, it is stored in a folder, different for each interface machine. A software module, called Measurement Collector, periodically updates the energy-related database from the temporary files received by the interface modules. In particular, each file is processed row by row (to increase the robustness in case of misaligned or corrupted lines). Each row which is compliant with the specifications is then inserted into the energy-related database with a SQL update instruction. When all the rows of a file have been processed, the file is deleted from the server.

The energy-related database stores all the measurements, adopting the MySql database software tool. A single table is used to save the measurements. The information fields are: the equipment name, the timestamp, the power and traffic values, and three fields left optional for future extensions. Each measurement is uniquely identified by the equipment name and the time stamp, which define the primary key.

**Server Front-end**
The front-end of the TREND meter tool reports real-time graphs on a public web site. Moreover, an interface for making query to the database and perform a more detailed analysis has been implemented. Specifically, the web site integrates both static and dynamic pages, coded in HTML.
PHP and bash script languages. In the static section of the site, general information is provided, as well as the descriptions of the measured devices. The dynamic part of the site instead shows the graphs in real time and let the users to interact with the database and plot different graphs.

The real time graphs are updated by a module which periodically queries the database with SQL scripts and create the plots with the RRD graph tool. The produced images are then automatically moved to the web page area of the server. The module produces several plots for each device, with a different time granularity to easily capture both power and traffic trends over different time scales. Additionally, the functionality to query the database has been added by means of a web interface. In particular, the user can select which devices to insert in the database query, as well as the time period. The possible data that can be displayed are: the power consumption over time, the traffic over time, and the power consumption vs. traffic for the considered time period. Once the submit button of the page is pressed, the database is queried and the output is displayed in a graph format. The query to the database is done via PHP and SQL scripts, while the graphs are displayed by invoking a script in Gnuplot, which is dynamically modified for each query.

IV - MEASURED DEVICES

A – Personal Computer

The personal computer is a server machine equipped with an Intel Core 2 Quad Processor and 4GB of RAM, used for simulation and server purposes. Power consumption of the personal computer (including a LCD monitor) is measured with the power meter Raritan DPXS12A-16. The power meter is connected to a private network at the Politecnico di Torino and it is periodically queried by a shell script run at fixed intervals on the server machine. The power meter is compliant with the SNMP protocol, therefore the query is done by invoking the `snmpget` command. An example of query is the following one:

```
snmpget -v 2c -c raritan_public -O e $ip_raritan 1.3.6.1.4.1.13742.4.1.2.2.1.7.$port_number
```

where “$ip_raritan” contains the IP of the power meter, and $port_number is the power port at which the monitor and the computer are plugged. Additionally, the script also computes the amount of traffic, which is obtained from the output of the `ifconfig` command.

B – Campus Subnet

The subnet is a private network located at the Department of Electronics and Telecommunications (DET) of the Politecnico di Torino. A set of personal computers is connected to the network. The traffic level of this network element is monitored through the `tcpdump` tool, by sniffing all the traffic that is broadcasted inside this network. Additionally, the power consumption is estimated from the number of powered-on machines in the sub-network, which is measured through the `nmap` tool. Measurements are executed every minute, and traffic measurements represent the average over the one-minute interval.

C – Campus Router

The Campus Router monitored in the Engineering Faculty campus of the University of Rome “Sapienza” is a Cisco Catalyst 4506. The Campus Router is the gateway towards the main university campus, dislocated in a different location than the Engineering faculty. The two locations are interconnected through a 1 Gbit/s optical link. The Campus Router has also 16 optical links for the interconnection of the different departments’ buildings in the internal network. The Internet access point is hosted in the main campus so the Campus Router is traversed by the overall traffic among the faculty campus and the Internet.

The power consumption of the Campus Router is measured with a Raritan Dominion PX-5000 power meter, directly connected to the power supply of the router. The traffic traversing the Campus Router is obtained exploiting the SNMP protocol enabled on the router: a script running on a Linux machine hosted in the DIET department of the Engineering Faculty periodically sends an
SNMP request to the router and so collects details about the amount of incoming/outgoing traffic.

**D – Software Router**
The software router is a Linux workstation equipped with an Intel i5 processor running at 2.68GHz, with 4 physical cores. The workstation is equipped with 2 GB of DDR3 RAM, and an Intel PRO Gigabit Ethernet adapter. The Operating System (OS) is the Linux Debian 5.0.6, and the kernel version is the Vanilla 3.4, which supports Symmetric Multi-Processing (SMP). The software router is used as gateway inside of the Laboratory of Telecommunications at University of Genoa. Power consumption is measured with a power meter Raritan DPXR20A-16. The power meter offers real-time remote unit-level and individual outlet-level power monitoring of current, voltage, power and energy consumption, accessible via SNMP protocol. SNMP services are active in the software router and provide the system’s current configuration; via SNMP protocol we obtain the current traffic measurements. A periodical bash script running in a Linux machine queries the software router in order to obtain the power consumption and the current traffic in real time, sending data to the TREND meter database.

**E - Data Center**

1) **Measured Datacenter Architecture**

Datacenters incorporate IT (critical) and network critical (supporting IT) equipment. Critical equipment are related to devices that are responsible for data delivery such as routers, switches, server, etc. Network critical equipment are devices responsible for cooling and power delivery and hold a supporting role to the operation of IT. They are usually referred as Non Critical Physical Infrastructure (NCPI). In Fig. 2 the block diagram of the monitored local datacenter is presented. The NCPI equipment are the air-conditioning unit (cooling) that protects the equipment from overheat and the UPS which is coupled with a battery bank unit for emergency break downs. The NCPI equipment supports the functionality of the IT equipment. The IT devices are divided in two units. IT1 (of Fig. 2) corresponds to the telecommunication equipment, i.e. the router and the switches, responsible for data transport. IT2 unit is a 9 server rack, responsible for data processing. The overall power consumption of the datacenter is related to the associated power consumed by each unit. The available power from the electricity grid ($P_{IN}$ of Fig. 2) is a three-phase electricity installation of 230Volt. This power is divided in an in-series path towards the power unit ($P_{UPS}$) and in a parallel path towards the cooling infrastructure ($P_c$). The UPS protect from utility failures and provide smooth transition to the emergency generator system. The parallel path feeds the cooling system (air condition fans) that is important for the heat protection of a datacenter. The in-series path, after the UPS, feeds the IT devices ($P_{UPS} = P_{IT}$) and provides the necessary power for data process, manipulation and transportation. The power consumption of the telecommunication equipment is represented as $P_T$ and the power consumption of the servers as $P_S$ in Fig. 2.

2) **Measured Metrics**

In order to investigate and propose directions to optimize energy consumption in a datacenter it is important to quantify its performance. This can be achieved by using a standard metric to measure the inefficiencies. Datacenter’s energy efficiency can be broadly defined as the amount of useful computation divided by the total energy used during the process (GreenGrid 2012). There are two types of energy efficiency metrics. The first describes the efficiency of the NCPI equipment and the second models the useful work related to the power consumption. A detailed description is presented in (GIPC 2010, GreenGrid 2008).

Power Usage Effectiveness (PUE) is defined as the ratio of the total facility input power over the power delivered to IT. Datacenter infrastructure Efficiency (DCiE) is the inverse of PUE and can be described in a mathematical form as (GreenGrid 2008)
\[ PUE = \frac{1}{DCiE} = \frac{P_{IN}}{P_{IT}}, \quad 1 < PUE < \infty \]  

The metrics of (1) characterize the performance or the power wasted in the non-critical components of the datacenter. The closer the PUE is to 1, the more efficiently the NCPI equipment operates. A study over 24 datacenters showed that the mean value of the measured PUE is approximately 1.83 or 0.53 (53%) DCiE (Barroso 2009).

The energy efficiency of the overall datacenter’s performance is computed according to metrics that take into account the IT operation. The term ‘useful work’ is highlighted in (GreenGrid 2008) and is described as a list of 8 proxies that describe different IT operations of the datacenter. The metric that models the efficiency of the telecommunication equipments \((M_T\) and \(M_{T,IT}\)) is presented in (2).

\[
M_T = \frac{\sum b_i}{E_{IN}}, \quad \text{[Mbits/kWh]} \]  

In the above equation \(k\) is the number of routers in the datacenter and \(b_i\) is the total number of bits coming out from the \(i\)-th router during the assessment window. \(E_{IN}\) is the total consumed energy by the datacenter during the assessment window. The assessment window must be defined in such a way to allow the capture of datacenter’s variation over time. The metric \(M_T\) can measure the underutilization of routers or redundant components in the system. An example on the use of these metrics is to consider a stream of bits forwarded by a small router which would require less energy than the same stream of bits forwarded by a pair of large redundant routers. The small router would have a higher “bits per kilowatt-hour” metric, implying a more energy efficient system for forwarding the bit stream. The metric in (2) can provide important conclusions regarding energy efficiency actions. For example, identify and remove idle servers without affecting outbound bit stream, provide server consolidation and identify methods to increase bit rates without increasing the power consumption (GreenGrid 2008).

The efficiency of the servers is modeled as a function of the average CPU utilization and is correlated to the SPECrate \((B)\) and SPECpower \((S)\) values presented in (GreenGrid 2008). The CPU utilization for each server in the datacenter is averaged over the assessment window of time \(T\). The used metric models the Mean Server Productivity (MSP) related to the total datacenter power consumption (3).

\[
MSP = \frac{T \sum_{i=1}^{n} U_i S_i \left( \frac{CC_i}{CB_i} \right)}{E_{IN}}, \quad \text{[ssj_ops/KWh]} \]  

In the above formulation \(n\) is the number of servers, \(U_i\) is the average CPU utilization over the assessment window \(T\) of server \(i\), \(S_i\) is the SPECpower ssj_ops/sec at 100% server utilization of server \(i\), \(CC_i\) is the nominal clock speed of the CPU of server \(i\), \(CB_i\) is the clock speed of the CPU, used to establish \(B\), which is the rate benchmark result of server \(i\) (GreenGrid 2008). Parameter \(S_i\) (ssj_ops/sec) describes the server side java operations per second and it is included in the specification list of the servers. This metric models datacenter productivity and the correlation of the actual useful work to the maximum possible work if all servers were running at 100% utilization. A more general formulation to measure the datacenter productivity, named as DCeP (Datacenter effective Productivity) is presented in (Barroso 2009).

3) Measurement Architecture

The energy efficiency of the datacenter is measured by two heterogeneous sensor networks and an IP connection from the UPS, the router and the servers to the data aggregator that enables data delivery through SNMP requests (Fig. 2). The power of the datacenter is captured using a star network configuration that incorporates a smart meter operating at 433MHz (RF unlicensed) which is connected to three clamp sensors that measures the current from the three phase installation. The voltage is 230V and it is converted to input power of the datacenter \(P_{IN}\). This information is
transmitted to a laptop computer (data aggregator) that can be assumed as the agent of the measurement system. Since the minimum window of observation is 5 minutes, the high frequency samplings of $P_{IN}$ were averaged over the 5 minutes window. The power of the datacenter is divided to an in-parallel path towards the cooling systems and to an in-series path towards the power unit (UPS). UPS is SNMP enabled through an Ethernet port and is capable to provide information regarding load and power through an IP connection to the data aggregator. UPS sends 5 minutes averaged readings of output power ($P_{UPS}$) which is the power that is delivered to the IT equipment ($P_{IT}$). The UPS also sends input power readings which is the power at the entrance of the UPS. The ratio of the output and input power of the UPS models the efficiency of the unit. Note that in Fig. 2 $P_{UPS}=P_{IT}$. The consumed power at the server rack is monitored with a mesh network architecture that employs sensors plugged to each server of the datacenter (this power reading was not used for the purpose of our investigation). The data transmission is performed over the IEEE 802.15.4 ZigBee protocol. The network comprises 9 sensors deployed on each server. One of the sensors acts as the sink between the mesh network and the agent. A mesh network configuration based on ZigBee protocol is also used to monitor temperature variations during the measurements. The network is based on an open Zigbee platform with embedded programming capabilities. For the purpose of our investigation two sensors are deployed, one placed at the datacenter room and one outside the room to observe energy efficiency variations as a function of the environmental conditions (ETSI, 2010). Regarding the useful work of the datacenter (parameters $b_i$ and $U_i$ of Eq. 2 and Eq. 3 respectively) an SNMP request was used similar to the UPS system. Average values over the 5 minutes window were transmitted and stored in the database of the data aggregator.

V- RESULTS

In this section, we present the measurements that have been collected by the TREND meter tool. Fig. 3 reports the variation of power consumption and traffic versus time for the personal computer. The considered time period is almost five weeks. Interestingly, power consumption in normal conditions is below 30 W, meaning that the computer can efficiently exploit power management techniques to reduce energy. However, there are periods of time in which the power consumption is above 80 W: this is due to the fact that the PC is used for computation purposes, and hence its power consumption increases. Finally, the traffic exchanged by the PC (Fig. 3.b) is seldom above 0.5 Mb/s. Thus, we can conclude that for the PC there is not a strong correlation between power consumption and amount of traffic exchanged.

Fig. 4 reports the power and traffic for the Campus subnet. Interestingly, power consumption (Fig. 4.a) varies over time with a typical day night trend: this is due to the fact that during the night, some users tend to power off their own machine. However, the power consumption is always higher than 2.5 KW (apart from some spurious measurements), suggesting that most of the machines connected to the network are always powered on. To give more insight, Fig.4.b reports the traffic variation over time. Differently from the single PC case, in this case there is a more clear traffic variation between night and day.

Fig. 5 reports the measurements from the Campus router. Astonishingly, power consumption (Fig.5.a) is almost constant, while traffic (Fig.5.b) strongly varies over time. Moreover, we can observe that the amount of traffic exchanged during the week-ends is really low compared to that of working days. Despite this variation of traffic, the power is almost equal to 300 W, suggesting that the device is not energy efficient.

We then consider the datacenter, which is placed in a newly established University and it is expected to be underutilized due to limited number of traffic and requests. Fig. 6 presents the percentage of power delivered to the IT equipment ($1/PUE\cdot100$) accompanied with measurements of the datacenter room temperature and UPS efficiency. Measurements were performed with a time window $T$ equal to 5 minutes. A mean value of 2.1 PUE was obtained which proves that 47% of the consumed energy is delivered to the IT and the rest is used for cooling and NCPI operations. This
value is not constant with time and depends on the operation of the air condition units and the load of the UPS. At time steps between 1200-1400 the air-condition unit stopped working, yielding an increase of temperature but a dramatic decrease of the PUE (more energy delivered to IT devices). During the time that the air-condition stopped working, the portion of energy delivered to IT reached 78%. On the other hand, when the air condition unit started working it dropped to 30% since there was a higher effort from the air condition unit to establish a constant room temperature of 20°C. The UPS efficiency was measured to be approximately 92% and the UPS load was about 32%. NCPI equipment holds an important role in energy efficiency. Free cooling methodologies can dramatically reduce energy consumption and thus increase the energy efficiency. In addition, for large systems it is important to avoid multiple AC/DC conversions due to heat energy loss from the transformers.

In Fig. 7 the efficiency of the telecommunication equipment (router, switches) in terms of Mbits per kWh is presented. From Fig. 7 it can be observed that during the weekend efficiency is reduced. This is because traffic requirements and requests to the datacenter are low during the weekends.

Fig. 8 presents the metric MSP that models the server productivity. This metric is presented as a function of the overall datacenter energy requirements, named as \( (MSP_D) \). From Fig. 8 it is observed that there is a periodicity on the measured values. This can be justified by every day set up and organization procedures of the datacenter (i.e. back up operations). During this process, the servers present the highest efficiency since they work for back up operations and reorganization. The fact that the higher efficiency of the server is met during the periodic back up operation proves their underutilization from other traffic requests and jobs. In general it can be observed that the IT infrastructure is underutilized and thus efficiency is small in both router and server side. This can be justified due to the fact that the datacenter is placed in a newly established University and traffic is low. A strategy to avoid this issue is to use adaptable infrastructure and increase the capacity of the datacenter according to traffic. For the specific datacenter this was avoided since an increase of the traffic is expected in the near future making adaptable infrastructure a cost inefficient strategy to follow.

One solution to reduce electricity costs and increase the efficiency of the datacenter is to use renewable energy sources (RES) combined with storage capabilities to support operation during zero energy time periods. The energy source should be dimensioned in such way so as to be able to provide the required capacity to the system at any time. For the specific datacenter and the characteristics of the location, a combination of solar panels and a battery bank is an acceptable solution that will reduce the electricity costs of the system and will increase the efficiency. The efficiency will increase since parameter \( E_{IN} \) of Eq. 2 and Eq. 3 usually refers to grid and not ‘clean’ energy (GreenGrid 2008).

In the last part of our work, we have correlated power with traffic, as reported in Fig.9.a- Fig.9.e. While power consumption of the personal computer hardly varies linearly with power (Fig.9.a), some correlation between power and traffic emerges from the Campus subnet (Fig.9.b). Fig.9.c confirms that the power consumption of the Campus router does not depend with traffic. Moreover, for the software router (Fig.9.d), we can see some dependency of power with traffic. Finally, for the datacenter (Fig.9.e), power consumption varies almost independently from traffic. These results prove that in general the energy efficiency of networked devices should be improved. In particular, according to the related work in the literature (Bolla 2011), two possible complementary approaches should be pursued: sleep mode and energy proportionality. With sleep mode a device enters in a low power state for a long duration of time (typically in the order of minutes and hours). This approach requires a fine coordination among the devices to shift the traffic from the devices that are put in sleep mode to other devices that need to be powered on. On the other hand, the energy proportional approach tends to scale the power with the actual utilization. This approach requires strong technical efforts to design power proportional components (CPU, memory, etc.). At last, the two approaches could be potentially merged to further improve the energy efficiency.
VI- DISCUSSION

In the following, we discuss the operation of the different components of the TREND meter and some of the challenges that can potentially arise. In particular, our solution adopts standard software tools, and can be potentially replicated in other organizations and companies. Additionally, our solution is robust to possible failures in the devices or in the interface programs. Another aspect of the TREND meter which is relevant is the possibility to easily add new devices to the already monitored ones. In this context, the size of the database will consistently increase since the primary key is composed by the equipment name and the timestamp. However, it is possible to create specific views and indexes in the database to improve the execution of standard queries, i.e., like the ones used to draw the figures. Finally, our solution integrates the possibility to add more fields in the saved data (apart from power and utilization) which can be useful for future upgrades.

VII- CONCLUSIONS

We have detailed TREND meter, a tool for collecting measurements from networked devices. Our solution is composed by a centralized server which collects measurements sent from the devices. The server is composed by a database and a front-end which displays information to users. We have collected power and utilization data from different devices, including routers, data centers and single PCs. Our results confirm that current devices waste a considerable amount of power when the exchanged traffic is low (e.g. during night and during week-ends). We think that our solution can raise awareness about the wastage of power consumption in current networked devices. As next step, we plan to integrate the TREND meter with power management primitives in order the control the power state of the devices. Additionally, we plan to integrate our solution in network monitoring systems, and to extend the set of monitored devices.

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Fig. 1: The TREND meter architecture.

Fig. 2: The measured data-center.
Fig. 3: Measured power (a) and measured traffic (b) over time for the personal computer.

Fig. 4: Measured power (a) and measured traffic (b) over time for the Campus subnet.

Fig. 5: Measured power (a) and measured traffic (b) over time for the Campus router.
Fig. 6: Measured percentage of power delivered to IT (1/PUE), Temperature in datacenter room and UPS efficiency with a time step of 5 minutes.

Fig. 7: Energy efficiency of telecommunication equipments. Metric $MT$. 
Fig. 8: Energy efficiency of servers. Metric $MSP_D$. 
Fig. 9: Measured power vs. measured traffic for the different devices.