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NetBem: Business Equipment Energy Monitoring through Network Auditing

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Abstract

Modern office buildings are fully equipped and furnished spaces with arrangements including networked business equipment, such as PC-class machines, copiers, wireless routers and fax machines, and other electrical equipment such as home appliances e.g. coffee machines, and appliances for environmental comfort e.g. electric heaters. The unique characteristics of networked business equipment are well-defined usage pattern, low-power current draw, and connectivity to the local area network (LAN). Business equipment is generally used over working hours adding up to important costs, motivating the need for a system capable of tracking equipment usage and associated energy expenditure, as well as identifying cost saving opportunities. Techniques for monitoring power loads are generally based on power step edge detection, and cannot be applied to business equipment due to the low power consumption of individual devices. This paper presents NetBem, a novel energy monitoring technique ad hoc to office buildings, capturing the contribution of networked business equipment to a power load via side-band detection of the equipment's operating state through the LAN. The technique is presented, and results from experiments within the School of Computer Science and Informatics at University College Dublin in Ireland are given.

Categories and Subject Descriptors

C.3 [Special-Purpose and Application-Based Systems]: Real-time and embedded systems; C.2.3 [Computer communication networks]: Network operations—*Network monitoring*

General Terms

Measurement, Experimentation

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Keywords

electricity, monitoring, local area network, office

1 Introduction

Electricity management is at a turning point with new technologies enabling access to remote and fine-grained electricity readings from the meters, for real-time feedback on buildings' electricity consumption. Appliance Load Monitoring (ALM) systems use electricity readings to decompose a given power load and identify the nature of the appliances and equipment contributing to the energy spending [1, 2]. Traditional ALM systems target power-hungry appliances, which represent the highest cost and potential largest savings in domestic and commercial buildings.

Office buildings have a different setup from domestic and commercial buildings. They are typically fully equipped and furnished offices with arrangements including networked business equipment, such as PC-class machines, copiers, wireless routers and fax machines, and other electrical equipment such as home appliances e.g. coffee machines, television sets and fridges, and equipment for environmental comfort e.g. lighting and cooling systems.

Figure 1. Power consumption over one phase of a university department, measured with a ZigBee-compliant 3-Phase electricity monitor [7]. The baseline power load varies between 2.5 kW during the night, to about 5 kW in the morning, and to less than 4 kW during lunch time.

Figure 1 illustrates the power load of a university computer science department, which is representative of typical

office buildings. Power peaks reflect the activation of appliances drawing a lot of current over short periods and targeted by traditional ALM systems, whereas the baseline power load represents the overall power consumed by equipment seldom changing operating states and possibly drawing little current generating undetectable power steps changes. Traditional ALM systems are not capable of disaggregating the baseline power load. In addition, current ALM systems require a tedious setup process to initially label unique power footprints [6]. Within this work, we propose NetBem, an unsupervised energy monitoring technique ad hoc to office buildings and complementary to traditional ALM systems.

Section 2 gives background information on existing appliance load monitoring techniques and motivates this work. Section 3 gives an overview of the system proposed for achieving disaggregation of the power load via information retrieved from the LAN. Section 4 presents a case study where we experimented the presented system within the School of Computer Science and Informatics at University College Dublin, in Ireland. Finally, Section 5 concludes.

2 Related work

The basics of appliance load monitoring were laid more than two decades ago with the Non-intrusive Appliance Load Monitoring (NALM) approach to disaggregating power loads [1]. Power loads retrieved from an electricity meter are normalized, and partitioned into segments—steady and changing periods, to characterize the power signal in successive steps or events, and the segments are eventually matched to known appliances’ unique power steps, enabling the recognition of appliances contributing to a given load. Since then, sharper recognition via better-tuned algorithms, machine learning techniques and heuristics has been experimented on, however using similar basic principles e.g. [2, 3]. Other approaches to disaggregating power loads have been shown feasible via powerline noise recognition and ambient sensing, observing electrical noise generated by appliances on the residential powerline [4] and capturing ambient sensory parameters and magnetic field variations generated by appliances [5, 6], respectively.

Such monitoring techniques are functional when each appliance has unique power footprints, whether they be unique current draw pattern, unique power noise harmonics, or unique generation of sensory information. Such unique footprints do not exist with business equipment. Indeed, low-power consumption means power footprints and power noise harmonics similar to background noise and not recognisable. Furthermore, equipment such as PC-class machines, laptops and wireless routers do not create distinct phenomena such as vibration, sound or heat that could be easily captured by ambient sensors. The ubiquity of business equipment prevents as well the deployment of expensive sensors for monitoring each device individually. Finally, office equipment is generally composed of multiple machines of the same brand and model, which makes traditional monitoring unsuitable; for example, determining a laptop contribution to a power load would not be sufficient as the laptop identification from the pool of identical laptops with similar footprints would be impossible.

Electricity readings returned by a 3-phase electricity monitor represent the electricity consumption of a whole building electrical equipment, including business equipment, lighting, heating, cooling and other. Monitoring business equipment should therefore be conducted in parallel to other appliance load monitoring systems, such as systems targeting power-hungry electrical appliances [2], and systems capable of capturing lighting activity with sensors [6].

3 VLANs monitoring tools for business equipment’s activity auditing

NetBem power load disaggregation of business equipment consists of identifying at a given time the nature and number of machines that are powered, in order to identify individual power contributions to the building’s overall power consumption. We propose to use network auditing tools on office buildings’ virtual local area networks (VLANs) to track equipment’s activity, and make the information gathered available to various applications. For instance, the list of machines active on the VLAN can be used to annotate the building’s power readings captured in parallel for real-time power load breakdown. Primary advantages of this novel approach are twofold: (1) recognition of low-power equipment contributing to a power load not possible with traditional ALM systems, and (2) scalability with no extra hardware/software required, and via unsupervised operation on the VLAN.

3.1 Virtual local area networks (VLANs)

Local area networks (LANs) are computer networks covering small physical areas, generally using Ethernet over twisted pair cabling and Wi-Fi as high data-transfer rate technologies. VLANs add logical grouping of network nodes, in order to reduce broadcast traffic and facilitate scalability, security, and network management. Logical subnets in the form of VLANs overlay the physical LAN, meaning that a computer at any location on the physical network can participate in a VLAN. Therefore, users in different buildings on the same office building or university department can be part of the same VLAN group, broadcasting messages to one another and sharing the same group servers, printers, and other resources.

3.2 Network monitoring tools

Utilities for VLAN exploration are typically used in office buildings by network administrators for network inventory and management. We identified this as a powerful opportunity to decompose power loads. VLAN scanning is realised with combinations of Internet Protocol (IP) and transport layer packets, in order to discover connected hosts, security holes and other network characteristics. A classical way to discover hosts on the network is to send Internet Control Message Protocol (ICMP) Echo requests, which should prompt target hosts to respond with ICMP Echo reply messages [9]. However, ICMP packets are often filtered out, and other techniques may be used to learn about connected hosts e.g. TCP, UDP or ARP Pings. More complex host discovery techniques can return machines’ MAC addresses, operating systems, service names and network cards’ vendor information.

Figure 2. NetBem system overview illustrating the interaction between the VLAN activity monitoring tool and applications for energy efficiency.

Table 1. Illustration of the information returned by the *nmap* script for each machine discovered on the VLAN.

IPv4 address	MAC address	Network card vendor
137.43.154.57	00:50:FC:32:3B:DF	Edimax Technology
137.43.154.59	00:1A:4B:24:A3:0F	Hewlett Packard
137.43.154.65	00:23:32:DB:5C:62	Apple
137.43.154.68	00:23:DF:8D:A7:00	Apple
137.43.154.69	00:1A:80:D7:48:88	Sony
137.43.154.70	00:08:74:AA:92:38	Dell Computer

Within this work, network monitoring is performed using *nmap*, a free and open source utility for network exploration or security auditing [10], and *nbtscan*, a command-line tool that scans for open NETBIOS nameservers on a local or remote TCP/IP network [11]. Other tools performing similar tasks may be interchanged for similar results.

3.2.1 *nmap* host discovery

nmap offers commands to discover how many hosts are up on a VLAN. *nmap* version 5.20 was installed on a Ubuntu machine, and a program was developed in *Processing* [13] to execute the *nmap* command line periodically and discover connected hosts in the various VLANs. The *Processing* program generates a .csv file containing the information retrieved with *nmap* i.e. MAC address and IP address of machines active at a given timestamp.

Furthermore, organisationally unique identifier (OUI) are assigned to each company manufacturing Ethernet devices; network cards' MAC address prefixes are therefore associated to vendor names. *nmap* self-generates network cards' vendor information, matching retrieved MAC addresses with the list of OUIs available online [12], and they are added to the output file. Table 1 shows an example of the information returned by the *nmap* script.

3.2.2 *nbtscan* for NETBIOS nameserver scanning

A NetBIOS name is a unique identifier, which NetBIOS services use to identify resources on a network running NetBIOS over TCP/IP. NetBIOS names do not have to match the machines' host name, but often the NetBIOS name is created while the operating system is being installed, having the host name and the NetBIOS name based on the entered computer

name. Therefore, gathering NETBIOS names of connected machines may give additional information about users owning the machines, if machine identification is desired and access to a *MAC address/machine owner* lookup table is not available. In general, access to private computer networks in office buildings requires machine registration from the user, providing the VLAN administrator with such lookup table.

nbtscan is a command-line tool that scans for open NETBIOS nameservers on a local or remote TCP/IP network, and was installed on a Ubuntu machine for querying NETBIOS names. It operates on a range of addresses instead of just one, making it useful for retrieving NETBIOS information on the office building's VLANs.

3.3 NetBem overview

Monitoring the electricity consumed by networked business equipment requires the interaction of individual system components, illustrated in Figure 2 with the *VLAN activity auditing*, *equipment consumption look-up tables*, *building's power measurement* and *applications* components. VLAN activity auditing is automated with no supervision required from the user, apart from the provision of the building's VLAN configuration i.e. IPv4 address ranges to scan (1), as well as information where to store the output information e.g. credentials for a remote database or location where to store output results locally. Running the *Processing* network auditing program launches a single execution of *nbtscan* and the execution of the *nmap* script at a given frequency over the specified VLANs—one script execution per minute was chosen to avoid network overload while preserving fine-grained monitoring (2). Two local .csv files containing network information about machines discovered on the network are generated (3). The files are processed with Perl scripts to derive the VLAN network information of interest i.e. *MAC address/machine owner* lookup table and list of machines active on the VLANs at a given time, (4) and (5). Results are stored in the location as specified by the user (6). Applications make use of the data by connecting to the local file or the remote database. Two application exemplars, detailed further in Section 4 use such information to annotate electricity readings of the building captured at the same time (7),

Figure 3. (a) Network auditing tools return the number of client machines connected to the Ethernet VLAN of the university department; (b) The power consumed by the machines is estimated and reported against the measured overall building's power consumption.

and to further estimate associated costs and identify potential cost savings, (8) and (9). Such applications require readings of the buildings' electricity consumption (10) and access to lookup tables providing business equipment typical power consumptions (11).

4 Experimentation

Experimentation of NetBem has been carried within the School of Computer Science and Informatics at University College Dublin in Ireland. This case study illustrates power load disaggregation of business equipment as described in Section 3, and shows how electricity data annotation and both cost estimation and savings can be assessed. The presented technique is reproducible in other office buildings where the VLAN configuration is known.

4.1 Experimental setup

Access to readings of a building's electricity consumption and knowledge of a building's VLAN configuration are essential to monitoring power loads of business equipment.

4.1.1 Acquisition of power data

Most public and office buildings have three phase power supply. Three phase power supply is delivered on three lines of power, each phase carrying the same voltage at the same frequency, but two are delayed by one-third and two-thirds of the cycle respectively. Our experimental setup includes a PC-class storage unit that receives data from a 120 Amps ZigBee-compliant 3-Phase electricity monitor, clipped to the 4-wire electricity supply of the university department. The electricity monitor measures current, voltage and the phase difference on the three phases, generating 9 electricity parameters per phase [7]. Electricity readings are transmitted every minute, and are stored in a remote SQL database, after ZigBee communication between devices. The total power

consumed is the addition of the power measured on each phase.

4.1.2 VLAN configuration

The university department has the following VLAN configuration:

- Ethernet: 137.43.154/155.x
- WiFi: 137.43.135.0/24 and 137.43.200.0/24
- Server: 193.1.132/133.x

The IP addressing setup on the wireless network is similar to the wired, with dynamic IP addresses and hostnames. Network monitoring may not work across VLANs, i.e. server machines will not be discovered when running monitoring tools from a client. Therefore, the VLANs' setup imposes that scans are run separate for each of the above ranges. The following provides some implementation details to allow experimentation of NetBem to be replicated in other office buildings.

4.2 Network monitoring scripts

The following *nmap* command line has been used for monitoring hosts connected to part of the university department's Ethernet VLAN:

```
sudo /usr/local/bin/nmap -sn -oX nmap.xml 137.43.154.0/24
```

The *-sn* argument specifies an host discovery consisting of an ICMP echo request, TCP SYN to port 443, TCP ACK to port 80, and a ICMP timestamp request. By default, ARP ping over the VLAN is also used. The VLANs' setup imposes two scripts, one running from a server and a second from a client; they are able to discover Ethernet and WiFi

clients, and Server machines, respectively.

The following *nbtstat* command line has been used for acquiring NETBIOS information about hosts connected to part of the university department’s Ethernet VLAN:

```
logsave nbtscan.txt nbtscan -s : 137.43.154.0/24
```

-s generates results in an output-friendly format and *logsave* saves the Unix terminal output into a file. A Perl script has been developed to filter out NETBIOS names and associated MAC addresses. MAC addresses and NETBIOS names are fixed; the *nbtscan* script is therefore run once at startup and anytime a MAC address returned by the *nmap* script has no NETBIOS information. A *MAC address/NETBIOS name* lookup table is built and queried to annotate electricity readings with NETBIOS names retrieved for each MAC address detected on the VLANs.

4.3 Results

NetBem has been run on the VLANs over a period of five days, capturing business equipment’s activity during working days, night-time and week-end. The following describes the results in terms of machine activity, estimated electricity consumption and identification of potential costly electricity consumers.

4.3.1 Number of active machines and estimated consumption

Figure 3(a) shows the output from the auditing tools on the combined Ethernet VLANs, indicating the activity of client machines. The number of machines powered on at night and during the week-end approaches 100, and an average of 200 machines are discovered active during day-time. Half of client machines are therefore left *on* overnight and during week-ends, which account for 75 % of the week. Such numbers are in line with those by Webber et al. [15] who found that on average, 36 % of computers are turned off at night, 4 % are in low power mode, and the remainder are active.

Following the identification of machines active on the VLAN and annotation of electricity readings, estimation of the electricity consumed by business equipment is calculated by applying the following assumptions: (1) an average power consumption of 40 W for business equipment during day-time (8am—8pm), and (2) an average power consumption of 25 W during night-time. These average power consumption numbers are derived from Kawamoto et al. measurements of 55 W and 25 W average consumptions [14], and taking into account the diversity of business equipment. To further increase the accuracy of the our estimation, we also performed measurements directly onto individual pieces of equipments, as shown in Table 2. Figure 3(b) illustrates the results, showing the total power consumption of the university department measured with an EpiSensor Zem-60 electricity sensor, and highlighting the estimated contribution of business equipment, on average equal to 25 % of the total load.

In order to estimate better the power consumed by business equipment, we use network cards’ vendor information returned by the *nmap* tool. A Perl script has been de-

Table 2. Power consumption in Watts (W) of office equipments measured with an EpiSensor Zem-30 electricity monitor [8].

	Active	Standby/Charged
Laptops		
Apple MacBook Pro	55	25
Dell Studio XPS 16	50	25
Desktop PCs + monitor		
Dell Optiplex GX280	120	25
Apple iMac 24"	100	50
Printer		
HP LaserJet P4015X	5000	40
Router		
Cisco Aironet 1242AG	13	/

Figure 4. Classification of machines per brand within the VLAN (top 3 brands are shown).

veloped to extract vendor card information each time the *nmap* script is executed, and calculate the percentage of machines belonging to each brand. Figure 4 shows the percentage of machines that are of Dell, Apple and Hewlett Packard (HP) brand within the VLANs; other brands are not shown because of a share percentage inferior to 5 %. Results show that Apple users are day-time users—the percentage of Apple machines increases over working hours, but more importantly this data enables a finer estimation of the business equipment contribution to the building’s power load, as we can differentiate desktop/laptop machines from routers and copiers, classifying equipment into subgroups via their network card brands. Such classification allows the attribution of appropriate power consumption to each subgroup. For instance, 3 % of machines detected on the VLAN have a Cisco brand name, and can be classified within a router/switch/bridge subgroup, with an average power consumption of 13 W, and not 40 W.

4.3.2 Identification of costly energy consumers

In some cases computers are left on to allow back-ups or maintenance to occur, but often machines are kept *on* when unnecessary. The approach taken for identifying such machines consists of processing the lists of MAC addresses of active machines generated on each iteration of the *nmap* script, to create a list of unique MAC addresses that have appeared throughout the 5-day duration of the experiment, and count how many times each address has appeared out of the

Table 3. Perl processing of data generated by the *nmap* script to identify client machines potentially consuming more than needed.

Nb of <i>nmap</i> script iterations	8537
Nb of unique MAC addresses	315
Nb of machines always on	56
Nb of machines with only day-time activity	213
Nb of machines with random night activity	46

total amount of times the script was run. Such approach allows identification of machines that are always *on*, machines that have been solely operated at day time, and machines that have peculiar pattern e.g. powered on day and night during the week but not at week-ends.

A Perl script was developed to retrieve such information, and results are shown in Table 3. The calculation of the number of machines that are found always *on* included an error margin equal to 2 % of the number of *nmap* scans to handle random errors from the VLAN monitoring tools. Almost 20 % of machines are active 100 % of the time; turning them off at night and week-end would reduce the time they spend active to 25 % of the time, and would importantly reduce the power load of business equipment. These results show that a number of machines—always-on and with peculiar pattern—can be narrowed down and identified as possible costly energy consumers.

We envisage that NetBem can empower a set of applications to generate both energy awareness and personalised recommendations to users. For example, a facility manager can be provided with an automated list of machines susceptible of wasting electricity and estimate the associated costs. With such information and basic user education programmes, via e-mailing and posters, results achieving approximately 70 %–80 % of computers turned off at night can be achieved [16].

5 Conclusions

Business equipment represents as a whole a major source of current draw in office buildings. However, the power consumed by single appliances typically inferior than 100 W is an obstacle to traditional appliance load monitoring systems; power step changes appear as noise and cannot be detected. This work proposes NetBem, a novel technique for monitoring the load associated to business equipment: network auditing tools track activity of business equipment on buildings' virtual local area networks and annotation of electricity data is made with the list of machines active at a given moment. A case study presented results from a fine-grained breakdown of business equipment power load within a University department. The load associated to business equipment has been estimated to 25 % of the overall load, and potential costly electricity consumers have been shortlisted.

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