Energy-Efficient Office Environments

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***Abstract*—The rising costs of energy and the world-wide desire to reduce CO_2 emissions has led to an increased concern over the energy efficiency of information and communication technology. Whilst much of this concern has focused on data centres, also office hosts that are located outside of data centres (e.g., in public administration or companies) have been identified as significant consumers of energy. Office environments offer great potential for energy savings, given that computing equipment often remains powered for 24 hours per day, and for a large part of this period is underutilised or even idle. This paper investigates the energy consumption of hosts in office environments, discusses the potential of energy savings and proposes an energy-efficient office management approach based on resource virtualization, power management, and service consolidation. Different virtualization techniques are used to enable management and consolidation of office resources. Idle services are stopped from consuming resources on the one hand and (underutilized) services are consolidated on a smaller number of hosts on the other hand.**

I. Introduction

Energy efficiency of information and communication technology has become an important topic in companies and public administration – the bottleneck of costs has changed. While hardware costs are decreasing on the one hand, costs of energy are increasing on the other hand. In addition, there are world wide efforts to turn IT green, (e.g., CO_2 emissions need to be reduced). Data centres are well known and often discussed consumers of energy. Koomey [1] reports a doubling of energy consumption from 2000 to 2005 of volume, mid-range, and high-end servers in the U.S. and worldwide. The power used by data centres and computer networks [2] runs in the billions of euros. Although this is mostly related to data centers, a similar tendency can be expected for computers outside of data centres. End devices are contributing to a large portion of the electricity consumption growth according to a 2006 survey commissioned by the EU [3].

Office hosts that are located outside of data centres contribute significantly to the overall IT energy consumption, simply because of the high number of such devices – in offices usually each employee has his own host. Office hosts, however, are often underutilized (in terms of CPU load) or not used at all (while being switched on). There are short term periods where hosts remain turned on without being used, e.g, if users are in meetings, do telephone calls, have lunch or coffee breaks. Additionally, office hosts often remain turned on on a 24/7 basis. Such hosts are running due to several reasons: Jobs might be scheduled over the night (e.g., security updates, or backups). Hosts are also often left switched on, because users require access to them remotely. Remote access typically happens from the users home or when users are working externally (e.g., at a customers office). Remote access is needed in such cases to access applications and data within the office environment. The user finds his working environment exactly in the same state in which he has left it, even the cursor in an opened text document is in the same spot as before. The user may need access to email accounts, personal data, or applications (e.g., special software with access to databases that is not available outside of the office). Apart from such reasons, some users simply forget turn off their hosts, when they leave the office.

Webber et al. [4] have analyzed sixteen sites in the USA and reported that 64% of all investigated office hosts were running during nights. Furthermore, even when office hosts are in use, they are often underutilized by typical office applications, e.g., mail clients, browsers or word processing. It is important to see that idle hosts (CPU usage of 0%) and underutilized hosts consume a considerable amount of energy, compared to computers that are turned off, without providing any added benefit. Measurements that have been performed at the University of Sheffield on hosts that are typically used as personal computers [5] show that idle office hosts still consume 49% to 78% of the energy that they need when they are intensely used.

Several approaches have been suggested that deal with high energy consumptions of hosts in office environments (see Section V). Such solutions range from the enforcement of office-wide power-management policies to thin-client approaches, where users share resources on terminal servers. As an extension to power-management solutions and opposed to data-centre based terminal-server approaches, this paper suggests a combination of office-wide power management with the consolidation of services in office environments. The key technology for this approach is the virtualization of services. The office environment is virtualized, based on system virtualization peer-to-peer approaches to enable resource sharing. The number of simultaneously running hosts in the office environment is reduced, while the utilization of hosts is raised. This enables a major reduction of the overall energy consumption within the office, without significantly decreasing quality or quantity of provided services.

II. A Managed Office Environment

When a user powers on his host in a common office, he finds his usual working environment. Within this paper this working environment is referred to as a *personal desktop environment (PDE)*. This typically consists of an operating system, applications, and the user's personal data and configurations. Although, in common offices often roaming profiles are available (see Section III), the PDE as a whole is fixed, i.e., it is bound to a certain host in the office. When the PDE is turned on/off, also the host is turned on/off and vice versa. Users are able to access their PDE locally within the office or they may also be able to access it remotely from outside the office.

In the managed office environment, PDEs are additionally used as *mobile services*. Mobile services are freely movable within the office environment (between physical hosts) and are used to achieve service consolidation. When the user is not physically using his office host, his PDE can be decoupled from the host and be migrated to another host for energy reasons. Several PDEs can be provided by a single host. Therefore, a user's host is not necessarily turned on when a user remotely utilizes his PDE – the PDE may be provided by a different host.

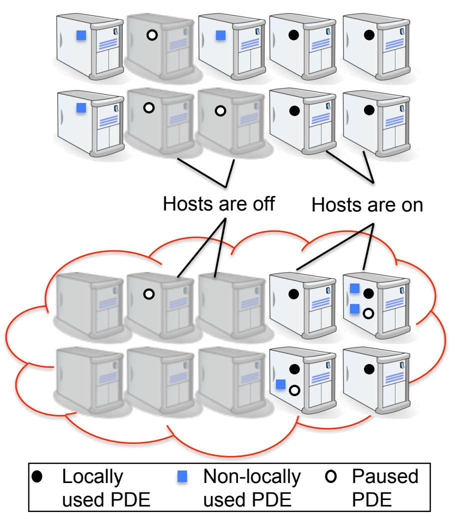

Fig. 1. Common and managed office environment

In Figure 1 the transition from a common to a managed office environment (based on PDEs) is illustrated. It can be observed in the upper part of the figure that in the common office environment the PDEs and the hosts are interdependent. Seven hosts are turned on together with seven PDEs and three hosts (with PDEs) are turned off. The situation is very different in the managed office environment shown in the lower part of the figure. Although the number of currently running PDEs is the same as before, only four hosts are actually turned on. It can be observed, e.g., that the upper right host is providing three PDEs to users simultaneously.

Based on the availability of mobile PDEs, energy efficiency is achieved in three steps:

1) Unloaded PDEs in the office environment are stopped from consuming resources. If a PDE is idle (no job is performed on behalf of its user) it will be suspended.
2) Loaded PDEs are consolidated on a small number of hosts. If a PDE is not accessed locally (the user does not physically access his office host), the PDE becomes a mobile service and may be migrated to other hosts to achieve consolidation.
3) Hosts that do not provide running PDEs are shut down to save energy.

The managed office environment has to dynamically determine an energy-efficient mapping of PDEs to hosts in the office and initiates necessary migrations of PDEs. This mapping has to fulfill contradicting goals and needs to solve a twodimensional optimization problem:

- The mapping needs to constantly maintain a **valid** configuration in the office environment to provide PDEs to users as needed. A mapping is called valid, if 1) all PDEs are located at their dedicated hosts, and 2) no host is overloaded with PDEs. Valid mappings allow all users to access their PDEs as desired, but are not necessarily optimized considering energy efficiency.
- The mapping needs to achieve energy-efficiency through consolidation, by approaching a **host optimal** configuration. A mapping is called host optimal, when it utilizes the minimum possible number of hosts to provide all required PDEs (locally or remotely) in the office.
- The mapping needs to minimize the number of migrations within the office environment because migrations are costly themselves (in terms of network traffic and interference with the users work). Unnecessary migrations need to be avoided and hosts should not be overloaded by performing several migrations simultaneously.

The architecture of the managed office environment is further described and evaluated in [6].

III. Virtualization approach

An important virtualization approach that is used in the managed office environment is system virtualization. It enables service consolidation and is successfully applied to data centres today. It can be adapted to office environments in order to achieve a similar utilization and energy efficiency of office resources. In system virtualization *virtual machines (VMs)* are created from idle resources. Full hosts are virtualized, consisting of virtual CPUs, virtual memory, virtual hard disk, virtual network interface card, etc. A VM is an imitation of a real machine in such a way that an operating system can be installed on it without being aware of the resource virtualization. The software that provides VMs is usually called *Virtual Machine Monitor (VMM)* (e.g., VMWare Server[1], QEMU [7], or Xen [8]) and is able to process several VMs simultaneously on a single host. There are several basic primitives of management functions available for VMs: create, destroy, start, stop, migrate, copy, pause, and resume VM. It

[1] http://www.vmware.com/de/products/server

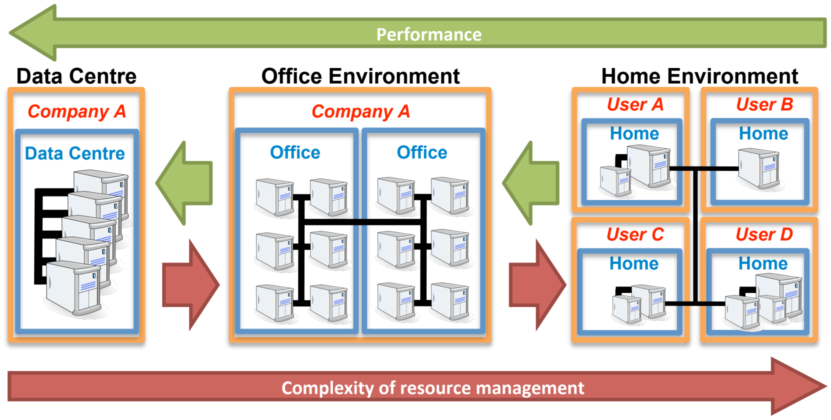

Fig. 2. Performance and complexity of resource management

is even possible to have a *live migration* [9]. This means that a service in a VM can be migrated to another host without being interrupted. A PDE, as it is described in Section II, can be encapsulated within a VM and inherits all of the VM-related features. This enables the operation of PDEs in separated runtime environments (VMs). The VMM can trigger the shut down of a host if required. Hosts can be powered up again, e.g., by using wake on LAN mechanisms[2], to boot into the VMM again. PDEs can be suspended by the VMM if they are idle and be resumed again if necessary. Additionally, when PDEs are enclosed in VMs they can be migrated from host to host, without a durable interruption of running services.

A second important virtualization approach that is needed to realize the managed office environment is based on P2P technology. Independent of the logical network that is used to interconnect hosts, the resource sharing in the managed office environment is done in a P2P manner. There is no central element that provides resources to run PDEs on, as it is available in the thin-client/terminal-server approach. Instead all of the office hosts are sharing their resources. Therefore, methods and principles from P2P overlays can be used to realize a management environment that interconnects hosts and provides mediation for hosts and PDEs. P2P content distribution networks (e.g., eDonkey[3] or BitTorrent[4]) are often used to share files among users. Such protocols provide several functions, the behaviour of which can be adapted to office environments. First, these kind of networks create and maintain an overlay network among participants that enables a logical addressing of hosts, users, and content. Second, they enable the mediation of resources and are able to bring providers and consumers of content together. Third, such networks additionally manage the access to resources, in order to achieve an optimal and fair distribution of resources among all users of the network. Concerning managed office environments, P2P overlays enable interconnection, addressing, and mediation of PDEs and hosts within the office environment. They also enable a management of PDEs and hosts based on their current states (e.g, powering off/on hosts or PDEs).

[2]http://www.energystar.gov/index.cfm?c=power _mgt.pr_power_mgt_wol
[3]http://www.overnet.org
[4]http://www.bittorrent.com

IV. Service Consolidation Obstacles

Energy-efficient consolidation of services is only achieved in data centres, today. The main reason for this is that data centres differ significantly from the other environments in terms of provided performance and the complexity of resource management. The more performant, centralized, homogeneous, and controllable an environment is, the easier service consolidation can be applied. Figure 2 illustrates the three different environments. It can be observed, that in data centres server hosts are located very close to each other, usually within a single room, and are interconnected with a high performance network. In office environments hosts are loosely coupled, distributed over several rooms and typically connected via Fast Ethernet. The home environment consists of heterogeneous and rather small networks, interconnected via asynchronous DSL connections.

Service consolidation (as it is done in data centres) can not easily be adapted to office environments. Server hosts tend to be more performant than office hosts, in terms of CPU cycles, memory capacity, and networking. This enables servers in data centres to run several virtualized services (up to hundreds) simultaneously, depending on the number of users that are using the services. Office hosts, in contrast, may run only a few virtualized services simultaneously. The high performance network in the data centre allows a fast migration of virtualized services from one host to another. Migration, however, is a problem in the office environment. Whereas in data centres usually only processes are migrated (operating system and data are typically stored on network storage), PDEs have to be migrated entirely. This leads to considerable overhead because operating system and user data and applications might sum up to several GBs of data. This issue is further discussed in [10].

Additionally resource management is less complex in data centres, compared to office environments. Whereas the data centre is a controlled environment, where only administrators have physical access to hosts, the office environment is rather uncontrolled. Users are able to power hosts on and off, unplug cables, or move hosts to other locations. Furthermore, in data centres users use their services remotely via network access, which eases up the consolidation of services. Local access to hosts, as it is typical in office environments adds hard constraints to the management of resources: Services that are used locally can not be migrated or consolidated. The physical access of users to host in the office environment additionally raises security issues. When services are migrated to achieve consolidation, employees are potentially able to copy or modify contents of other persons.

It is even more difficult to approach consolidation of services in home environments [13], as they provide less performance and more resource management complexity. In office environments typically similar kinds of hosts, operating systems, and applications are used, whereas hardware and software is heterogeneous in home networks, applications and equipments depend on the flavour of the different home users. Office environment hosts are typically interconnected via Fast Ethernet, providing a symmetric up and download behaviour, whereas in home networks usually DSL-connections are applied (with different performance properties for different homes), often providing smaller upload than download performance. Data storage is realized in a completely decentralized way, there is usually no shared storage resource available between different home users. In office environments that belong to the same company there will at least be a minimum of trust among employees. In the home environment instead, services are migrated between completely unrelated users. A major obstacle that complicates service consolidation in home environments is the cost of energy. In data centres and office environments the energy is payed by a single company (probably on different expenditures). However, when resources are shared for consolidation among home users, some users will receive a higher energy bill than others – without having consumed more resources. This has to be balanced by the service management.

V. Related Work

There are several projects that provide power-management solutions for office environments. Examples are eiPowerSaver[5], Adaptiva Companion[6], FaronicsCore[7], KBOX[8], or LANrev [9]. In such approaches, office-wide power management policies are applied to office environments. Office hosts change to low-power modes, independent of user-specific power management configurations. Additionally, mechanisms are provided to wake up hosts if necessary. This way, hibernated hosts can be used for overnight jobs (e.g., backup processes) and for remote usage. Such solutions, however, rely on the capability of the host to switch to low-power modes which depends on the complex interaction of a host's hard and software. The approach presented in this paper is independent of such interaction. PDEs are suspended together with their VM without being aware of the suspension. What is more, the mentioned power-management solutions focus on idle hosts only. The solution suggested in this paper, additionally deals with the energy consumption of underutilized hosts in office environments.

Thin-client/terminal-server approaches use data-centre technology to provide energy-efficient services in office environments. User environments (similar to PDEs) are provided by terminal servers and users can access these environments via energy-efficient thin clients. Common terminal-server software products are Citrix XenApp[10], Microsoft Windows Server 2008[11], or the Linux Terminal Server Project[12]. Similar to the approach suggested in this paper, such approaches foster a resource sharing among users in the office environment. However, this approach is based of the usage of additional hardware in the office (energy-efficient thin clients and terminal servers) and PDEs are provided in a centralized way by the terminal server. Instead, the approach suggested in this paper utilizes available hosts in office environments and shares resources among them.

In [12], [13], [14] a virtualized future home environment is introduced that uses virtualization to aggregate and consolidate distributed hardware resources of home users in order to save energy. Similar to offices, also in home environments some machines are running on a 24/7 basis (e.g., media servers or P2P clients). These services can be consolidated by using different virtualization techniques in order to turn unused hosts off. In contrast to the future home environment approach, this work focuses on resource sharing in office environments as they can be found today in companies or public administration. Whereas in the future home environment separate services are virtualized (e.g., video-encoding or P2P file-sharing services) and are distributed among homes, this work suggests to virtualize user environments (PDEs) as a whole. As an important consequence, the approach in this paper envisions a seamless and transparent provision of user services within the PDE (e.g., when a PDE has been moved, the user still finds his text document open, with the cursor at the same position as before the migration). The future home environment approach, in contrast, is not transparent to the user. The user has to utilize special software that enables the envisioned migrations of services, and seamless access to migrated services is not possible. Instead the result of a service is transferred back to the user.

VI. Conclusions and Future Work

This paper has presented an architecture that manages resources in office environments in energy efficient ways. A shift from current decentralized resource management approaches (per user) is suggested to a centralized resource management approach (per office). The proposed solution extends available power-management approaches and is opposed to data-

[5]http://entisp.com/pages/eiPowerSaver.php
[6]http://www.adaptiva.com/products_companion.html
[7]http://faronics.com/html/CoreConsole.asp
[8]http://www.kace.com/solutions/power-management.php
[9]http://www.lanrev.com/solutions/power-management.html
[10]http://www.citrix.com/XenApp
[11]http://www.microsoft.com/windowsserver2008
[12]http://www.ltsp.org

center based thin-client/terminal-server solutions. It exploits available potentials of energy savings in office environments by managing office resources based on the behaviour of users. Resource virtualization technologies (system virtualization and peer-to-peer overlays) are used to suspend idle services and to consolidate underutilized services on a small number of hosts. The suggested architecture is evaluated in [10] and [6] and it is shown that that more than 70% of energy savings can be achieved in office environments, without significantly interrupting the day to day work of users.

In future work, the suggested architecture will be refined, together with an energy consumption model for office environments, based on discrete event simulation.

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