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An energy consumption model for virtualized office environments

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ABSTRACT

The increasing cost of energy and the worldwide desire to reduce CO_2 emissions have raised concerns about the energy efficiency of information and communication technology. Whilst research recently has focused on data centres, this paper identifies office environments as significant consumers of energy. Office environments offer a great potential of energy savings, given that office hosts often remain turned on 24 h per day while being underutilized or even idle. This paper describes a virtualized office environment that virtualizes office resources to achieve an energy-based resource management. The resource management stops idle hosts from consuming resources and consolidates utilized services on office hosts. In particular, this paper develops an energy consumption model that is able to estimate the energy consumption of hosts and networks within virtualized and ordinary office environments. The model is used to prove the energy efficiency of the suggested approach analytically and to evaluate it using a discrete-event simulation.

1. Introduction

The energy consumed by data centres runs into billions of euros [1,2]. Therefore, various solutions have been suggested to reduce the need for server hardware and energy consumption. Nowadays, service virtualization and consolidation, for example, are widely applied to data centres, and also cloud computing has been introduced as an inherently energy-efficient data centre architecture [3]. However, it is not only data centre equipment that consumes energy within enterprises and public administration bodies. End-devices located outside of data centres are also contributing to a large portion of IT-based electricity consumption [4]. According to a report commissioned by the German government [5], the energy consumption of IT equipment in German enterprise office environments summed up to about 6 TWh in 2007. This amounts to 68% of the energy consumption caused by data centre equipment (about 9 TWh) in the same year. These numbers indicate that office environments are a highly lucrative area in which to save energy.

Within office environments, especially, office hosts contribute significantly to IT-related energy consumption. On the one hand, there is a large number of such hosts because each employee typically has his/her own host. On the other hand, office hosts are often turned on without being utilized by a user. Often, office hosts remain turned on 24 h a day. Even if such hosts are mostly idle (CPU usage of 0%) during the time they are running, it is important to see that they still consume a considerable amount of energy. Measurements that have been performed at the University of Sheffield [6] show that typical office hosts which are idle still consume 49–78% of the energy that they need when they are intensely used, leading to an immense waste of energy. However, it is not only idle hosts that waste energy. Even when users access hosts, the hosts often remain underutilized in terms of CPU load by typical office applications, as text processing, web browsing, or mailing do not significantly utilize current office hosts. This indicates that idle and underutilized office hosts provide a high potential of energy savings.

Several approaches have been suggested that deal with the high energy consumption of hosts in office environments, ranging from the enforcement of office-wide power-management policies (e.g., KBOX[1]) to thin-client/terminal server (e.g., Citrix XenApp[2]) or virtual desktop infrastructure (VDI) solutions (e.g., VMWare View[3]), where the user's services are consolidated within the data centre. However, whereas the consolidation of office services on servers is successfully applied these days, a consolidation within the office environment has not yet been considered. This paper describes the architecture of a *virtualized office environment* and suggests an energy consumption model for office environments.

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1 KBOX: http://www.kace.com/solutions/powermanagement.php.
2 Citrix XenApp: http://www.citrix.com/XenApp.
3 VMWare View: http://www.vmware.com/products/view.

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The architecture achieves both an office-wide power management and the consolidation of services on office hosts. The suggested energy consumption model is able to estimate the energy consumption of hosts and networks within office environments. The model enables the energy-related comparison of ordinary and virtualized office environments, considering the energy-efficient management of services. Based on this model, this paper shows that the suggested virtualized office environment consumes significantly less energy than ordinary office environments in various user and office scenarios.

The remainder of this paper is structured as follows. Section 2 discusses related power consumption models. Section 3 describes the energy-efficient virtualized office environment architecture. Section 4 suggests an energy consumption model for office environments. Section 5 analytically proves the energy efficiency of the suggested virtualized office environment and illustrates its energy consumption, based on a discrete-event simulation. Section 6 concludes this paper.

2. Related work

The *constant power model* predicts a constant power consumption [7], regardless of a certain utilization of a host $P^h = C_0$, where C_0 is the mean power that is consumed by the host when it is utilized by typical applications. The *linear CPU dependent model* predicts the power consumption according to the host's CPU utilization [1]. The power consumption is estimated by $P^h = C^h_{\text{idle}} + W^h_{\text{cpu}} * l^h_{\text{cpu}}$, where C^h_{idle} models the power consumption of a host when it is idle, W^h_{cpu} is a CPU weighting factor that maps CPU utilization to power consumption, and $0 \leq l^h_{\text{cpu}} \leq 1$ is the CPU utilization of the host. The *CPU and disc utilization model* predicts the power consumption of hosts similarly to the linear CPU dependent model, while also taking the utilization of the disc into account [8]. The power consumption is estimated by $P^h = C^h_{\text{idle}} + W^h_{\text{cpu}} * l^h_{\text{cpu}} + W^h_{\text{disc}} * l^h_{\text{disc}}$, where W^h_{disc} is a disc weighting factor that maps disc utilization to power consumption and $0 \leq l^h_{\text{disc}} \leq 1$ is the disc utilization of the host. *Disc I/O and transfer models* consider the dynamic power consumption of the disc by using the number of I/O requests or the number of disc transfers as parameters. The *CPU, disc, and network interface card utilization model* considers the CPU, hard disc, and network interface card as the main consumers of power [9]. The power consumption is estimated by $P^h = C^h_{\text{idle}} + f_{\text{cpu}}(l^h_{\text{cpu}}) + f_{\text{disc}}(l^h_{\text{disc}}) + f_{\text{nic}}(l^h_{\text{nic}})$, where $C^h_{\text{idle}} = C^{\text{cpu}}_0 + C^{\text{disc}}_0 + C^{\text{nic}}_0$ models the power consumption of a host with idle components, l^h_{cpu}, l^h_{disc}, and l^h_{nic} model the utilization of the different devices, and the functions f map the load of the devices to power consumption. *Performance counter models* additionally look at performance counters [10] of the system, as far as available (e.g., the amount of instruction-level parallelism, the activity of the cache hierarchy, or the utilization of the floating-point unit). Also, power consumption models of distributed architectures have been suggested: Vereecken et al. [9], for example, have suggested a *thin client/terminal server model* that is an end-to-end power consumption model concerning the thin client/terminal server paradigm. Seo et al. [11] suggest a *component/connector model* that can be used to predict the power consumption of different architecture styles (e.g., client/server, peer-to-peer, publish/subscribe).

Of all the models discussed, the linear CPU dependent model [1] is adopted to office environments in this paper. It represents a simplistic and easily computable approach that allows us to estimate the power consumption of ordinary and virtualized office environments. This approach does not impose the need for information about detailed utilization of the components or complex mappings of load to energy consumption. Furthermore, Rivoire et al. [7] have found that the linear CPU dependent model is able to estimate the power consumption of hosts within 10% mean accuracy, which is suitable for estimating an office's power consumption. Also, the network model, as it is described in [9], is a suitable candidate to be adopted to office environments. It aims at office environments and represents a simplistic and easy computable solution without complex mappings of load to energy consumption that provides good accuracy [9].

3. A virtualized office environment

The working environment a user finds when he/she powers on his/her office host is called a *personal desktop environment (PDE)* in this paper. A PDE typically consists of the operating system, applications, and the user's personal configurations. Users are able to access their PDE locally within the office,and they are also able to access it remotely (e.g., via remote desktop software) from outside the office. Hosts that are turned on within the office environment are called active in this paper; suspended (hibernated) hosts and hosts that are turned off are called passive. Office hosts are not only active while being locally accessed by users. They are also often turned on without users sitting in front of them. This happens for short time periods, e.g., if users are in meetings, make telephone calls, or have lunch or coffee breaks. It also happens for longer periods of time.

- *Remote access*: Users access their host from their home or they access it from a customer's office, when they are working externally. In this case, users leave their host turned on to be able to access it remotely. Remote access is often needed to access office-specific applications and personal data that are not accessible from outside of the office (e.g., email accounts, text documents, addresses of customers, data in data bases, or special office/graphics/business applications).
- *Overnight jobs*: Users run jobs overnight (e.g., downloads). Also, administrators often run overnight jobs such as nightly backups or virus scans.
- *Carelessness*: Users forget to turn their hosts off when they leave the office or users do not want to power them up the next morning.

Webber et al. [12] analyzed 16 office sites in the USA, and they reported that 64% of all investigated office hosts were running during nights (only 4% had switched to a low-power state) and 36% had been turned off manually. This means that there is a high potential of energy savings that can be exploited by stopping idle hosts from consuming energy and by consolidating the PDEs utilized within the office.

To enable an energy-efficient management of PDEs and hosts, PDEs are virtualized based on system virtualization and a peer-to-peer (P2P) overlay within the virtualized office environment. Each PDE is encapsulated within a virtual machine (VM) to enable migration and consolidation. Similar to hosts, PDEs in VMs can be turned on (active PDE) or be suspended/turned off (passive PDE), where only active PDEs consume resources on hosts. Passive PDEs, in contrast, reside on the hard disc of a host, without consuming further resources. The P2P overlay logically interconnects active office hosts and establishes a distributed management that enables the mediation of PDEs and office resources. The P2P overlay consists of management instances that are encapsulated within VMs (similar to PDEs). Each management instance (MI) is responsible for the management of a set of hosts within the office environment, where only active hosts are the peers of the P2P overlay. This virtualization approach provides the flexibility to perform energy-based management within the office environment. The MIs allocate PDEs to hosts, stop unutilized PDEs from consuming resources on hosts, and consolidate utilized PDEs