Cloudifying Desktops – A Taxonomy for Desktop Virtualization

Completed Research Paper

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ABSTRACT

Compared to traditional desktops, the implementation of desktop virtualization can leverage cost reductions and enable desktop access via mobile devices. Consequently, researchers and practitioners increasingly focus on virtualized desktops and Desktop as a Service (DaaS). However, a consistent definition for these technologies and the related delivery models does not exist yet. Therefore, we conducted a literature analysis which revealed that optimized resource allocation and performant DaaS infrastructures are the primary topics in research. Afterward, we developed a taxonomy to categorize extant virtual desktop delivery models and propose a holistic definition as theoretical framework for DaaS.

Keywords

Desktop virtualization, Desktop as a Service, Cloud computing

INTRODUCTION

Enabled by virtualization as technology for dynamic provision of server resources (Hwang and Wood, 2012; Sharma and Sood, 2011a), cloud computing enjoyed a lot of attention of research and practice in recent years (Erdogmus, 2009). As part of this development, enterprises migrated their traditional desktops to virtualized desktops and thus leveraged cost savings and reduced administrative effort (Miller and Pegah, 2007). For example, in 2010 Royal Bank of Scotland moved 55,000 users to virtualized desktops to reduce costs and to enable their employees to work from home (Williams, 2011). Although the idea of using thin clients in a host environment evolved already in the 1990s (Richardson, Stafford-Fraser, Wood and Hopper, 1998), virtual desktops recently gained momentum fostered by cloud computing. Sridharan, Calyam, Venkataraman and Berryman (2011) analyzed potential drivers for using virtualized desktops such as increase in utilization of mobile devices or reduction of underutilized distributed desktops. In the same line of research, Shu, Shen, Zhu, Huang, Yan and Li (2012) emphasize that Desktop as a Service (DaaS) and the transformation of traditional desktops into the cloud have become a focal point in research. However, although these examples illustrate the relevance of this topic, a clear distinction between the different virtual desktop deployment models is still missing. While providers such as Citrix subsumes three models to its desktop virtualization solution XenDesktop (Virtual Desktop Infrastructure (VDI), Hosted Shared Desktop or Terminal Server based Desktop, Local Streamed Desktop) (Citrix Systems Inc., 2012), VMware describes its solution VMware View as *"on-demand desktop services out of the cloud"* (VMware, 2011). Likewise, extant literature offers differing definitions. Beaty, Kochut and Shaikh (2009) define desktop virtualization as operating systems (OS) or applications migrated from local devices of the user to a remote data center. Furthermore, they note that DaaS is a "natural evolution" of the desktop virtualization paradigm delivered out of the Desktop Cloud. In contrast, Calyam, Patali, Berryman, Lai and Ramnath (2011) refer to DaaS as "virtual desktop clouds (VDC)". To elaborate on the shortcoming of conflicting descriptions for desktop delivery models, we conducted a structured literature review on desktop virtualization and subsequently derived a taxonomy. Essentially, our research questions are:

RQ1: What is the current state of the art of research on desktop virtualization?

RQ2: How can different delivery models of desktop virtualization be classified in a meaningful way?

The remainder of this paper is structured as follows. First, the literature background on cloud computing and desktop virtualization is given. Second, the research method applied to answer the research questions is described and results of the literature analysis are presented. The third part elaborates on the taxonomy for the virtual desktop delivery models before the last part discusses the findings of our paper and outlines limitations and future research.

THEORETICAL BACKGROUND

Cloud computing

Being one of the fastest developing technologies, (Erdogmus, 2009; Sharma and Sood, 2011a, b; Wang, Kurze, Tao, Kunze and Laszewski, 2011; Zhang, Cheng and Boutaba, 2010) cloud computing emerged from existing technologies such as grid computing (Foster, Zhao, Raicu and Lu, 2008; Sharma and Sood, 2011a), utility computing, and distributed computing (Hwang and Wood, 2012; Weiss, 2007). Cloud computing can be defined as: *"ubiquitous, convenient on-demand network access to a shared pool of configurable computing resources"* (Mell and Grance, 2011, p. 6). Typically, the services provided are categorized into three major service models. Infrastructure as a Service (IaaS) comprises IT infrastructure, e.g., data or processing storage and networks (Durkee, 2010; Mell and Grance, 2011). Platforms for development purposes can be accessed via Platform as a Service (PaaS) (Foster et al., 2008). Finally, applications and software can be purchased as Software as a Service (SaaS) via different devices (PC, Smartphone, etc.) (Durkee, 2010; Zhang et al., 2010). Recently, based on these service models, new models such as Desktop as a Service (DaaS) emerged (Beaty et al., 2009).

Desktop Virtualization and DaaS

With the rise of virtualization technologies desktop virtualization gained enterprises' attention as an opportunity to save costs by consolidating multiple desktops to one server (Cristofaro, Bertini, Lamanna and Baldoni, 2010; Miller and Pegah, 2007). In this context, users remotely access a desktop environment via devices such as thin clients while data processing is centralized in a data center (Beaty et al., 2009). Remote protocols, e.g., Remote Desktop Protocol (RDP), Virtual Network Computing (VNC), Remote Graphics Server (RGS), or Citrix Independent Computing Architecture (ICA), enable the connection between the virtual desktop and the user's device (client) (Miller and Pegah, 2007). Moreover, with cloud computing evolving it was possible to provide desktop virtualization out of a cloud (Kroeker, 2009) which is often referred to as DaaS (Beaty et al., 2009). Compared to virtual desktops, DaaS offers additional mobility and flexibility to its users (Beaty et al., 2009; Kroeker, 2009).

RESEARCH METHOD – LITERATURE REVIEW

To evaluate the state of the art of research on desktop virtualization and DaaS we conducted a structured literature review and used the recommendations of Webster and Watson (2002) for identifying and structuring the analysis. In so doing, we screened eight information system (IS) journals from the Senior Scholars' Basket of Journals of the Association for Information Systems (AIS) and of different IS conferences. As cloud computing emerged around 2007 (Buyya and Ranjan, 2010; Youseff, Butrico and Da Silva, 2008) we limited our search to the period from January 2007 to January 2013. However, as DaaS is relatively new, the result of our search was rather sparse. Thus, we additionally searched via databases such as ACM-DL, IEEE*Xplore*, EBSCOhost, and GoogleScholar for relevant papers and included years before 2007.

Subsequently, to check the relevance of these papers, we read their abstract and introduction (Webster and Watson, 2002). Table 2 in the Appendix presents the 31 publications considered as relevant results of our literature search after this pre-selection. The search terms used have been derived previously from extant literature. Further, we searched for terms which we found in the results (see table 2 in the Appendix).

STATE OF THE ART OF RESEARCH ON DESKTOP VIRTUALIZATION AND DAAS

Classification of DaaS in the Context of Mobile and Service Oriented Technologies

To delimitate DaaS from related technologies, we visualized them in figure 1 based on the results of our literature search. In so doing, we differentiated the technologies by their mobility which we evaluated using insights given by Lu, Li and Shen (2011) as well as Fernando, Loke and Rahayu (2013) and by their service orientation according to Deboosere, Vankeirsbilck, Simoens, De Turck, Dhoedt and Demeester (2012), Lai, Song and Lin (2010) as well as Sridharan et al. (2011) as an adequate criterion for clustering these technologies.

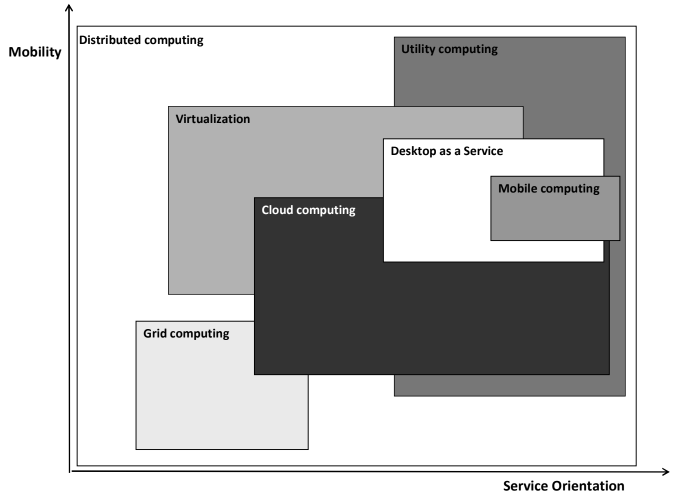

Figure 1: Classification of DaaS

As depicted in figure 1, DaaS is essentially based on cloud computing and virtualization. Moreover, DaaS overlaps with utility computing which can be accounted for by service orientation which both technologies have in common (Buyya, Yeo and Venugopal, 2008). However, with the convergence of mobile and cloud computing, research and practice will increasingly focus on DaaS (Deboosere et al., 2012; Lai et al., 2010; Sridharan et al., 2011). Please note that the rectangles in figure 1 are used for purposes of presentation only and are not necessarily of relative proportions to each other.

Literature Overview on Virtual Desktops and DaaS

After this first classification, we further assessed the publications found to identify those eligible to elaborate on our first research question regarding the current state of research on virtual desktops and DaaS. According to the concept-centric approach of Webster and Watson (2002) and informed by Palvia, Mao, Salam and Soliman (2003), we clustered the analysis by authors, their major topic of analysis, and applied research method (see Table 3 in the Appendix for details).

A major role in extant research can be assigned to the optimal allocation of resources and the development of DaaS infrastructure and software environments (Beaty et al., 2009; Lai et al., 2010; Li, Jia, Liu and Wo, 2013; Sridharan et al., 2011). Associated with the optimal resource allocation authors such as Bila, de Lara, Joshi, Lagar-Cavilla, Hiltunen and Satyanarayanan (2012), Calyam et al. (2011), Hwang and Wood (2012), or Shu et al. (2012) were interested in increasing the performance of virtual desktops. With regard to DaaS infrastructure, Alexander, Hicks, Dick, Hacker and Stockman (2012) and Kibe, Koyama and Uehara (2012) investigated feasibility and technical limitations of DaaS in experimental implementations. Moreover, other authors examined user experience and satisfaction while using DaaS, for which they developed benchmarks (Berryman, Calyam, Honigford and Lai, 2010; Miller and Pegah, 2007) and applied them (Calyam et al., 2011; Deboosere et al., 2012). Further researchers focused on the advancing convergence of cloud and mobile computing (Lu et al., 2011). Especially in times of increasing usage of mobile devices the relevance of virtual desktops increases as it offers a high degree of flexibility and mobility. In this context, research aimed at reducing power usage of mobile devices for instance by moving CPU-intense tasks (e.g., display rendering) into the cloud (Deboosere et al., 2012; Lu et al., 2011). Finally, another focus of research was on DaaS architecture (e.g., Sharma and Sood, 2011a, b).

Comparison of Traditional and Virtual Desktops as well as DaaS

To elaborate on our second research question, we first analyzed the differences and similarities of traditional desktops (without virtualization), desktop virtualization and DaaS. Table 1 depicts these three environments and differentiates them by characteristics such as network protocol, end user device, user experience and lists the relevant publications.

Technology / Characteristic	DaaS	Desktop virtualization	Traditional desktop	Reference
Network Protocol	Heterogeneous, based on protocols of Desktop virtualization	RDP, VNC, ICA, RGS, PCOIP	-	Miller and Pegah (2007); Beaty et al. (2009); Kroeker (2009); Lai et al. (2010); Lu et al. (2011); Kibe et al. (2012)
User Device	Mobile or local devices (e.g., Smartphone Notebook)	Thin Clients, Fat Clients	Local computer	Alexander et al. (2012); Beaty et al. (2009); Cristofaro et al. (2010); Deboosere et al. (2012); Kibe et al. (2012); Kroeker (2009)
Environment for Operating System	Cloud	Terminal server	Local computer	Beaty et al. (2009); Cristofaro et al. (2010); Lai et al. (2010)
Environment for Applications	Cloud	Terminal server	Local computer	Beaty et al. (2009); Cristofaro et al. (2010); Lai et al. (2010)
Management Costs	low	low	high	Beaty et al. (2009)
User Experience	high	medium	-	Beaty et al. (2009); Deboosere et al. (2012); Sridharan et al. (2011)
Security of data and applications	medium	high	medium	Beaty et al. (2009)

Table 1: Comparison of DaaS, Desktop Virtualization and Traditional Desktops

The comparison in table 1 illustrates how the number of applicable *network protocols* and hence the variety of *mobile devices* accompanies the development of different technologies (from traditional via virtualized desktops to DaaS). Users utilizing DaaS can now access their desktop from multiple devices anywhere at any time (Deboosere et al., 2012). While this effect was already obvious for the evolution from traditional to virtualized desktops, the transition into the cloud fosters this change. Similarly, the *environment for operating system and applications* was transformed by migrating from traditional, local desktops via virtualized desktops to desktops in the cloud (DaaS) of cloud computing providers. Moreover, the consolidation of resources, such as desktop resources, enabled by the virtualization technology, led to a reduction of *management costs* for DaaS infrastructure compared to traditional desktops. *User experience* (i.e., the perception of the user when using the technology) was not mentioned by the authors for evaluating traditional desktops. However, it moved into their focus of interest for assessing virtualized desktops and DaaS. For example, user experience can be applied to evaluate side effects of virtualization such as actual quality of services and relative fairness of service provision for other user or groups. With regard to *security of data and applications*, virtualized desktops offer the highest level of security, compared to DaaS deployed in a public cloud or traditional desktops with limited restrictions to users (e.g., installing software or using USB ports). The rationale behind that is that virtualized desktops running in an isolated, centralized environment (VM) are easier to protect against hazardous intrusions compared to traditional desktops and thus also easier to restore. However, from a business point of view, security guidelines such as access control and password policies can likewise contribute to security aspects of traditional desktops.

TAXONOMY FOR CATEGORIZING DESKTOP VIRTUALIZATION DELIVERY MODELS

Based on this comparative analysis and to answer our second research question how to classify different virtual desktop delivery models, we derived the taxonomy depicted in figure 2. Furthermore, to substantiate the taxonomy and to identify potentially missing elements, we enhanced our categorization by insights from providers of virtual desktop solutions. As originators for our taxonomy we added the paradigm of virtualization (Miller and Pegah, 2007) to service orientation which we used already for the classification scheme in figure 1. The next column of figure 2 visualizes the different computational resources of the desktop, such as virtual machine or cloud. Moreover, the number of users per desktop or desktop instance respectively is presented in the third column of our taxonomy. On the right-hand side of figure 2, the desktop delivery models are shown with traditional desktops and DaaS as anchor points as well as different models of desktop virtualization such as

Client Hosted VM, Streamed OS, and VDI (Beaty et al., 2009; Citrix Systems Inc., 2012; Eaves and Stockman, 2012; Freeform Dynamics Ltd., 2010; Intel Corporation, 2011; Miller and Pegah, 2007).

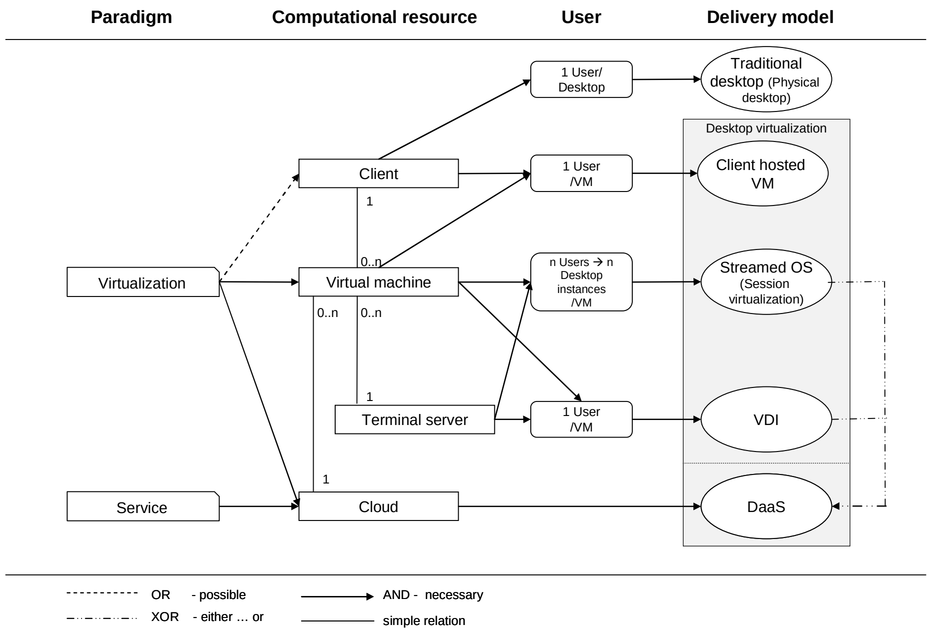

Figure 2: Taxonomy for Desktop Virtualization

With regard to traditional desktops, the virtualization paradigm is not relevant. Being hosted on a client, the traditional desktop can be accessed by one user only (Kibe et al., 2012). However, if the client runs a virtual machine (VM), a virtual desktop can be provided to one user via a Client Hosted VM (Freeform Dynamics Ltd., 2010; Intel Corporation, 2011). Taking into account a terminal server which can host multiple VMs (0..n), each of multiple (n) users can use one instance of n virtual desktops per VM via Streamed OS (Session Virtualization). Moreover, delivering one dedicated desktop per user, running on a dedicated VM on a terminal server, is called VDI (Beaty et al., 2009; Citrix Systems Inc., 2012; Intel Corporation, 2011; Miller and Pegah, 2007). For DaaS the virtual desktop is provided on a VM which in turn is hosted in a cloud (Beaty et al., 2009). Furthermore, virtual desktops of DaaS are implemented either as Streamed OS or as VDI which can be accessed from any place and any device as a service (Beaty et al., 2009; Kroeker, 2009).

DISCUSSION AND CONCLUSION

In this paper, we were interested in desktop virtualization and DaaS as technologies to enable mobile, flexible work. Thus, to answer our research questions *what* the current state of research in this field is, and *how* desktop virtualization can be categorized, we conducted a structured literature review and derived a taxonomy on delivery models for virtual desktops.

Regarding the theoretical contribution and to answer our first research question, we analyzed the papers found on desktop virtualization and DaaS (Webster and Watson, 2002). Subsequently, we evaluated them by author, result, and research method, according to Palvia et al. (2003). As a result, we found, that research is mainly interested in optimized resource allocation, avoiding underutilization of (traditional) desktops and developing a performant DaaS infrastructure. Moreover, research also elaborates on the convergence of mobile and cloud computing and the usability of DaaS. To identify criteria to categorize different delivery models of desktop virtualization and thus to answer our second research question, we derived a taxonomy based on extant literature and informed by the definitions of desktop virtualization solution providers. This taxonomy allows categorizing different delivery models in a meaningful way, which to the best of our knowledge has not been done before.

For practitioners, our paper can be used as guidance for a consistent definition for example by providers of desktop virtualization. Thus, practitioners should consider validating the terminology they use for their products and if necessary align it in accordance with our suggested taxonomy. Moreover, this categorization approach can help managers when deciding to implement desktop virtualization, to choose the best fitting technology (e.g., client hosted VM, streamed OS, VDI or DaaS).

However, the research presented in our paper also faces some limitations. First, the quantity of papers considered in the literature review was comparatively sparse and allows only limited insights. Second, the taxonomy did not undergo any empirical validation, e.g., by experts, field studies, etc. Consequently, further analysis, corrections and amendments were not possible. Third, we have not applied a theoretical lens, such as for example dynamic capabilities, which could have added additional insight regarding the contribution of DaaS in a dynamic environment.

Regarding future research, we suggest to focus on design science information system research as this has not been done in the field of DaaS yet. Using design science to develop and specify IT artifacts, DaaS could be further described (Hevner, March, Park and Ram, 2004; Kuechler and Vaishnavi, 2008). For example, lab and real world experiments should be conducted with participants executing different tasks using a DaaS artifact. These experiments could be subsequently used to technically evaluate DaaS (e.g., benchmark DaaS against traditional desktops). Moreover, business models specific to the categorization scheme should be derived. Finally, future research should concentrate on mobile-cloud-convergence, focusing on usability of DaaS on mobile devices, especially in the context of Bring Your Own Device.

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APPENDIX

Nr.	Search Term	Results
1	**Virtualization**	Barham, Dragovic, Fraser, Hand, Harris, Ho, Neugebauer, Pratt and Warfield (2003); Border (2007); Keller, Szefer, Rexford and Lee (2010); Kotsovinos (2010); Sahoo, Mohapatra and Lath (2010)
1a	System Virtualization	Border (2007)
1b	Virtualization Architectures	Daniels (2009); Lunsford (2009); McDougall and Anderson (2010)
1c	Virtualization Technologies	Chaudhary, Cha, Walters, Guercio and Gallo (2008); Younge, Henschel, Brown, von Laszewski, Qiu and Fox (2011)
1d	Server Virtualization	Daniels (2009)
2	Desktop Virtualization	Alexander et al. (2012); Beaty et al. (2009); Bila et al. (2012); Kroeker (2009); Lai et al. (2010)
2a	Virtual Desktop Cloud	Calyam et al. (2011); Fernando et al. (2013); Sridharan et al. (2011)
2b	Desktop to Cloud	Kibe et al. (2012)
2c	Desktop Cloud	Beaty et al. (2009)
2d	Mobile Cloud Computing	Fernando et al. (2013)

Nr.	Search Term	Results
2e	Virtual Screen	Lu et al. (2011); Whiteaker, Schneider, Teixeira, Diot, Soule, Picconi and May (2012)
2f	Virtual Desktop Infrastructure (VDI)	Hwang and Wood (2012)
3	Desktop as a Service	Cristofaro et al. (2010); Deboosere et al. (2012); Eaves and Stockman (2012); Erdogmus (2009); Sharma and Sood (2011a); Shu et al. (2012)
3a	Desktop as a Service Cloud Computing	Li et al. (2013)
4	Virtual Desktop	Hwang and Wood (2012); Miller and Pegah (2007); Raj, Nathuji, Singh and England (2009)

Table 2: Search Terms and Results

Authors	Description	Method
Alexander et al. (2012)	Development and implementation of a *Cloud-based DaaS infrastructure*	Lab experiment
Beaty et al. (2009)	Provision of a *benchmark for desktop workload* and of a *framework* for optimized *transition* of traditional desktops into a Cloud	Framework, conceptional model, lab experiment
Bila et al. (2012)	Deduction of an approach to efficiently *consolidate underutilized virtual desktops*; Development of prototype "Jettison", which hibernates unused virtual desktops temporarily	Framework, conceptional model, lab experiment
Calyam et al. (2011)	Development of an utilization based *model for optimized resource allocation* in a VDC	Framework, conceptional model, lab experiment
Deboosere et al. (2012)	Quantification of *user satisfaction* via offline *benchmarks*; development of an efficient Cloud-based *DaaS architecture model* to increase user satisfaction and reduce costs	Framework, conceptional model, lab experiment
Hwang and Wood (2012)	Design of a dynamic, QoS based *scheduling algorithm* as potential factor to reduce costs and minimize VM inference of CPU-intensive tasks	Mathematical model, lab experiment
Kibe et al. (2012)	Assessment of *DaaS as insufficient for high amounts of users* and depiction of high correlation between increasing users and decreasing costs and at the same time significant performance reductions	Lab experiment
Lai et al. (2010)	Development of a *Cloud-based streaming solution* to optimize the management of physical resources; testing of the framework by simulation	Mathematical model, lab experiment
Li et al. (2013)	Development of a secure, dynamic *provisioning prototype CyberLiveApp* for collaborative use of virtual desktops and applications of multiple users in a Cloud	Framework, conceptional model, lab experiment
Lu et al. (2011)	Identification of the „*virtual display*“ as important element for the *convergence between Cloud and Mobile computing*, development of models for the provision of Cloud browser and Cloud phone via “virtual display”	Framework, conceptional model
Sharma and Sood (2011a), (2011b)	Development of a platform independent *software provisioning* architecture model for Cloud services	Framework, conceptional model
Shu et al. (2012)	Development of an efficient *DaaS prototype* for a field-programmable gate array (FPGA) based *Cloud architecture*	Framework, conceptional model, lab experiment
Sridharan et al. (2011)	Development of a *framework for the provisioning and placement* of virtual desktops based on relative fairness of quality between groups of users	Mathematical model, lab experiment

Table 3: Status Quo of Research on Virtual Desktops and DaaS