An Evaluation of the Power Consumption and Carbon Footprint of a Cloud Infrastructure

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Submitted in partial fulfilment of
the requirements of Edinburgh Napier University
for the Degree of
Msc Advanced Networking

School of Computing

December 2010

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Abstract

The Information and Communication Technology (ICT) sector represent two to three per-cents of the world energy consumption and about the same percentage of GreenHouse Gas (GHG) emission. Moreover the IT-related costs represent fifty per-cents of the electricity bill of a company. In January 2010 the Green Touch consortium composed of sixteen leading companies and laboratories in the IT field led by Bell's lab and Alcatel-Lucent have announced that in five years the Internet could require a thousand times less energy than it requires now. Furthermore Edinburgh Napier University is committed to reduce its carbon footprint by 25% on the 2007/8 to 2012/13 period (Edinburgh Napier University Sustainability Office, 2009) and one of the objectives is to deploy innovative C&IT solutions. Therefore there is a general interest to reduce the electrical cost of the IT infrastructure, usually led by environmental concerns.

One of the most prominent technologies when Green IT is discussed is Cloud Computing (Stephen Ruth, 2009). This technology allows the on-demand self service provisioning by making resources available as a service. Its elasticity allows the automatic scaling of the demand and hardware consolidation thanks to virtualization. Therefore an increasing number of companies are moving their resources into a cloud managed by themselves or a third party. However this is known to reduce the electricity bill of a company if the cloud is managed by a third-party off-premise but this does not say to which extent is the power consumption is reduced. Indeed the processing resources seem to be just located somewhere else. Moreover hardware consolidation suggest that power saving is achieved only during off-peak time (Xiaobo Fan et al, 2007). Furthermore the cost of the network is never mentioned when cloud is referred as power saving and this cost might not be negligible. Indeed the network might need upgrades because what was being done locally is done remotely with cloud computing. In the same way cloud computing is supposed to enhance the capabilities of mobile devices but the impact of cloud communication on their autonomy is mentioned anywhere.

Experimentations have been performed in order to evaluate the power consumption of an infrastructure relying on a cloud used for desktop virtualization and also to measure the cost of the same infrastructure without a cloud. The overall infrastructure have been split in different elements respectively the cloud infrastructure, the network infrastructure and end-devices and the power consumption of each element have been monitored separately. The experimentation have considered different severs, network equipment (switches, wireless access-points, router) and end-devices (desktops Iphone, Ipad and Sony-Ericsson Xperia running Android). The experiments have also measured the impact of a cloud communication on the battery of mobile devices.

The evaluation have considered different deployment sizes and estimated the carbon emission of the technologies tested. The cloud infrastructure happened to be power saving and not only during off-peak time from a deployment size large enough (approximately 20 computers) for the same processing power. The power saving is large enough for wide deployment (500 computers) that it could overcome the cost of a network upgrade to a Gigabit access infrastructure and still reduce the carbon emission by 4 tonnes or 43.97% over a year and on Napier campuses compared to traditional deployment with a Fast-Ethernet access-network. However the impact of cloud communication on mobile-devices is important and has increase the power consumption by 57% to 169%.

Table of Content

List of Figures

Acknowledgements

My first thanks goes to Professor William J. Buchanan, my supervisor for all the help, assistance and valuable advices he has provided for this project.

Additional thanks goes to Sofyane Khedim for his thoughtful advices, for having lend his Ipad and for having allowing me to performed tests on his Cloud infrastructure. Its help have had a major importance for the project.

I also have to thanks Matin Riedler for his mathematical expertise which have permitted to simplify equations through the use of a Floor function allowing the graphical representation in the evaluations.

Acknowledgements

Chapter 1 Introduction

1.1 Context

In January 2010 the Green Touch consortium composed of sixteen companies, research labs and service provider, led by Bell's Lab and Alcatel/Lucent announced that in five years the Internet could be running by a thousand times less energy than it actually uses. The Information and Communication Technologies (ICT) sector's total power consumption represent two to three per-cents of the global energy cost and is responsible for approximately the same percentage of GreenHouse Gas (GHG) emission. According to (Alexander Hellemans, 2010) this percentage could be reduce by ninety-nine per-cents if the technologies where used efficiently, in a power aware fashion. There is also an environmental concern, indeed increasing use of communication system and devices will increase the ICT percentage of the global energy cost and related Greenhouse Gas (GHG) emission. Therefore the ICT sector could become an important factor in the global warming issue. According to (Stephen Ruth, 2009), IT-related electrical costs represent 50% of companies' electricity bill. Therefore if companies know how to reduce their electricity bill and saves money they would probably highly consider implementing networks and systems in a power efficient way.

Moreover the sustainable office in Edinburgh Napier University is committed to reduce its carbon footprint by 25% on the 2007/8 to 2012/13 period (Edinburgh Napier University Sustainability Office, 2009). Indeed the university published a report in association with the Carbon Trust in March 2009 presenting its Carbon Management Plan detailing the commitment to reduce the carbon footprint which was 6,664.6 tonnes of CO2 emitted in 2009. In the report it can be seen that to reduce the carbon footprint by reducing the electricity use the university should deploy Innovative C&IT solutions.

1.2 Background

Cloud computing is a concept which offer to anyone the deployment of IT solution without owning the actual infrastructure. Therefore processing power and resources are made available as a service and renting on demand. There is an increasing interest toward cloud computing technologies. Indeed more and more companies are moving their data systems and application in a cloud (Hakan Erdogmus, 2009). Even Greenpeace have published a report about cloud computing and its potential to reduce GHG emissions (Greenpeace International, 2010). Indeed cloud computing is usually mentioned in the Green IT context (Stephen Ruth, 2009). This could be seen has contradictory as cloud involves servers and data-centres which require a lot of energy. Usually cloud computing means locating resources outside the boundaries of the companies, therefore is the power consumption reduced or just moved? One of the main raison why Cloud computing is considered as a green is because of the elasticity that it offers. Indeed cloud computing allow servers to cope to the demand by increasing the resources allocated and reduce them according to the load. This allows physical hardware to be turned into a power saving sleeping mode if the load is low(C Develdet, 2008). Furthermore virtualization, is a key concept for cloud computing and allow several Virtual Machines to run on the same physical hardware allowing server consolidation. Therefore servers are more likely to run at 100% of their CPU utilisation. Indeed a server in idle state consumes about 66% of its maximum power utilisation (Gong Chen et al, 2008).

Cloud computing might also change how the network is use. The network infrastructure ties everything together, but will be even more important with extensive use of cloud applications. Indeed with the resources moved in data-centres, what was being done locally will be done remotely. Therefore the network might require some changes (Aaron Weiss 2007). Indeed the network will have to be more robust and required bandwidth upgrade. A fast-Ethernet network might have to be turned into a full gigabit network. However the energy cost of the network is not usually mention when cloud computing is said to be a green technologies. Does this mean that the network is already power-efficient with a negligible cost comparing to the cost of the cloud infrastructure?

Because calculation power is moved into data-centre or cloud servers, the end devices do not need to need a huge amount of processing resources to run CPU intensive application enhancing the utility range of mobile devices which are limited by their battery and processing capability. (Aaron Weiss, 2007)(Greenpeace International, 2010). However as it enhance the usability of those devices it will at the same time increase the load on their network interfaces which represent a major portion of the device power consumption (Vijay Raghunathan et al, 2004)(Yuvraj Agarwal et al, 2005)and (Trevor Pering et al, 2005). However the impact of cloud application on the power consumption of mobile devices does not seem to be widely discussed.

1.3 Aims and Objectives

The aim of this project is to evaluate the power consumption of an entire cloud infrastructure used for desktop virtualization and to estimate the power saving compare to a physical desktop deployment. This project has a scientific interest as it should complete the literature in the area of cloud computing and network infrastructure when power consumption is discussed. But at the same time it also has an interest for Edinburgh Napier University because as mention previously the university is committed to reduce it carbon footprint partly by deploying innovative C&IT solution and also because the project has been performed using equipment deployed on campus. In order to achieve these overall aim three objectives must be achieved gradually:

- Critically evaluate the power consumption of Cloud Computing and Network infrastructure as well as discussing the impact of cloud computing communications on battery-powered mobile-devices by reviewing the literature.
- Design and implement experiments which should measure the power-consumption of servers use to build a cloud, desktop PCs, network equipment and the impact of cloud communication on mobile devices. The experiments reproduce when possible a behaviour as close as possible as cloud activity.
- Conduct the final evaluation which should allow the comparison of the differences of

power consumptions between a cloud infrastructure and desktop power consumption and the difference between a cloud communication and a regular communication on the batteries of mobile devices. This objective required the completion of an analysis the data collected during the experiment in order to extract conclusions. The evaluation should consider different deployment sizes and estimate the carbon emission.

1.4 Report Layout

The remaining of this report is organised as follow:

- **Chapter 2 – Literature Review:** This is a critical review of the literature in the area of cloud-computing, network topology and battery powered devices focussing on the power consumption. The aim of this part is to discuss the cloud-computing as a green-technology and outline why this project exist.
- **Chapter 3 – Tests Design:** This chapter present what the experiment should outline and define the data that need to be collected. Choices about how the experiment should be performed are also justified. The methodology used in the experiment is introduced but is presented in more details in the next chapter because the methodology had to adapt to the deployed solutions.
- **Chapter 4 – Implementation and Methodologies:** This chapter present the implementation of the different experiments and the technology and tools involved. The methodology depends of the range of tools available for each technology; therefore the methodology use for the data collection is presented in more details in this chapter.
- **Chapter 5 – Result Analysis:** This is an analysis of the result collected during the experiments. This analysis permits the extraction of relevant data and produces some initial conclusion which will then be used in the evaluation.
- **Chapter 6 – Evaluation:** This chapter should achieve the overall aim of this project by evaluating the carbon footprint of a complete network and system infrastructure comparing the differences between cloud deployment use for desktop virtualization and a deployment involving only desktop computer over different period.
- **Chapter 7 – Conclusion:** This chapter provide a summary of the project outlining the main findings as well as providing a critical evaluation of the project and directions for future work are proposed.

Chapter 2 Literature Review

2.1 Introduction

The aim of the literature review is to critically evaluate cloud computing as a green technology in order to evaluate its potential saving by investigating the literature. This also includes an evaluation of the literature concerning network power consumption and research about power efficiency in network infrastructure. This part outlined the missing information about cloud computing as a green technology and should introduce why the work done in this thesis fit within the literature and tries to extend it. Therefore the literature review is split in two main parts.

The first part concerns the cloud computing including a short background. Then the possible carbon emission reduction by the use of cloud solution is discussed. Virtualization is a key concept for cloud computing and the power reduction depend on the virtualization overhead. Therefore virtualization and it impact on the power consumption should also be discussed. Private cloud or cloud deployed by a company for it only is also discussed with the introduction of lightweight device which are used for virtual desktop are presented and discussed.

The second part concern the network infrastructure and mainly the present the main area where power is wasted and could be saved by implementing power-awareness on the equipment, on the topology design and on the network protocols. It also discusses the impact of the network interfaces on wireless devices and mainly its impact on mobile devices. Cloud applications might enhance the capabilities of mobile devices but their utility will still be impacted by their battery life-time which could be highly reduced by the cost of cloud communication.

Then a critical discussion will present as an overview the chapter and outline the main gap in the literature and justify this project.

2.2 Cloud Computing

In a term of carbon footprint, the literature is highly considering cloud computing as one of the greenest technologies (Stephen Ruth, 2009) (Greenpeace, 2010). This fact could be seen contradictory as cloud computing involve data-centres which, themselves, require a huge amount of energy. Indeed data-centres are actually consuming 0.5% of the total electricity generated (James W. Smith, 2009) with their servers, fans, air conditioning, power supply and so on. So how is it supposed to reduce the carbon footprint? Migrating to a cloud architecture suggest that physical server are replaced by virtual servers in a data-centres. Companies might decide to migrate to a cloud architecture where they do not own the hardware and this will reduce their energy cost, management cost and hardware ownership cost. Therefore the processing resources seem to be move somewhere else but are still running somewhere. So even if the company adopt a cloud solution reduce its electricity bill that does not directly allow a conclusion about a global energy saving.

After a brief background about cloud computing and virtualization, this section investigate why cloud computing is considered as a green technologies, and what is the impact of virtualization on the power consumption? And then a discussion about cloud computing as a way to save energy will conclude this section.

2.2.1 Background

2.2.1.1 Cloud-Computing

The National Institute of Standards and Technology (NIST) defined cloud-computing by five characteristics which are on-demand self-service, broad network access, resource pooling, rapid elasticity and measured service. In other word this allow a consumer to provision computing capabilities without requiring any human interaction from anywhere on the internet while the provider's computing resources are assigned and reassigned to a customer or another. Examples of resources include processing, memory, storage and virtual machines. The capabilities offer can in some cases automatically adapt the demand and appear unlimited and be released when the demand decreased. The pricing scheme is based on a service level agreement depending on the resources used and the duration of its use, the resource's usage is monitored and the customer pays for its usage. For instance with the Amazon Elastic Compute Cloud (EC2), customer can establish a configuration template for their Virtual Machines (VM), such as memory, numbers of processing cores, storage spaces. The VM can be created and destroy on demand, scaling up or down following the demand and the need and considering web-based application, capable of handling a sudden surge of visitors.

There are three services model:

- Cloud Software as a Service (SaaS): The consumer uses the provider application running on a cloud infrastructure. Usually the application is accessed through a thin client such as a web-browser and can be accessed from a wide range of user devices (mobile phone, PDA and so on). The consumer can only configure a limited set of parameters and does not control nor manage the cloud infrastructure.
- Cloud Platform as a Service (PaaS): The consumer deploys an application on a cloud infrastructure that he does not own, control nor manage. The application language has to be supported by the cloud infrastructure.
- Cloud Infrastructure as a Service (IaaS): The consumer has access to processing resources storage space and other fundamental computing resources. Therefore the consumer is able to deploy operating systems, to control and manage its allocated computing resources (storage, processing, memory and so on) however the consumer is not able to control and manage the cloud infrastructure.

Those service models are usually represented as a layer model with services standing as layers between the client and server. The client layer represents computer hardware or software relying mainly on cloud application such as a computer, phones, operating system, and browser and so on to deliver cloud services. The server layer represent computer hardware or software designed and optimized to support cloud services, for instance multi-core processors, cloud specific operating system. The layer model is represented in the figure 1 :

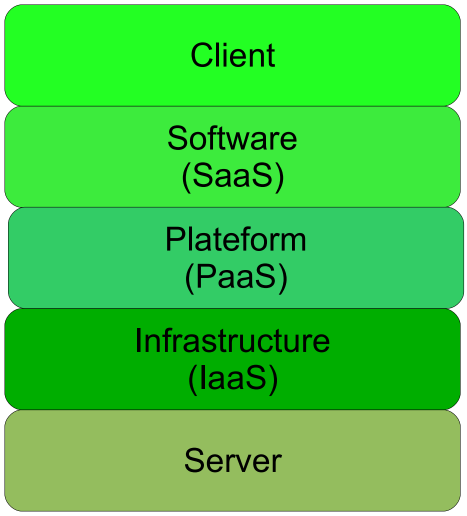

Figure 1: Layer representation of the cloud service models

There are different deployments model for cloud infrastructure:

- Private Cloud: The cloud is deployed for one organisation only, but the cloud can be managed by a third party on or off-premise.
- Community Cloud: The cloud is deployed for several organisations which will share the cloud. In this deployment model the cloud can be managed by a third party or an organisation, on or off-premise.
- Public Cloud: The cloud is managed by a cloud provider which made available the cloud infrastructure to the general public. The cloud provider is an organisation selling cloud services (cf the three service models mentioned earlier).
- Hybrid Cloud: The cloud is composed of least two clouds (private, community or public). This model could be deployed for instance when a company wants to benefit of the scalability advantage of a public cloud but also wants to keep the privacy of its data and application under control in a private cloud.

However cloud computing has been made possible by improvement in computing hardware mainly processor and an old computing concept which is virtualization. Indeed the term “virtualization” has been invented in the 1960 and is a key concept for cloud computing:

2.2.1.2 Virtualization

Virtualization creates a software version of a resource. Therefore software executed in a virtualized environment does not run directly on the hardware but on a software layer which present a software version of the resource. The software version of the resource or the virtualized resource should behave exactly as the original hardware one. Resources can be memory, hard-drive, CPU, network cards, or even addressing spaces in the case of Virtual Private Networks (VPN). Virtualization in data-centres is used to run concurrently several Operating System (OS) on a single hardware. In this case virtualization hides the fact that the resources are shared, each OS believed that it has its own resources. Even if each OS is isolated, they could communicate with each other through a virtual network which will also be emulated by the software. There are different ways of achieving virtualization but usually a hypervisor creates the virtual operating platform and allow the guest OSs to run on host hardware. A hypervisor also manage and monitor the Virtual Machine (VM) created and is also called a Virtual Machine Monitor (VMM).

There are two types of hypervisors, usually refers as type 1 and type 2. Type 1 hypervisors such as VMware ESXI, Citrix Xen Server, KVM, and Microsoft Hyper-V Server and so on, runs directly on the hardware as a thin abstraction layer. Whereas Type 2 hypervisor such as VMware Server, Sun Virtual Box and Microsoft Virtual PC and so on runs on a host operating system as a software. The operating layer difference results in virtualization efficiency differences. Type 1 hypervisors are preferred in data-centres because they provide higher performance efficiency, availability and security whereas type 2 hypervisor is cheaper and less restrictive thus it is preferred on a client system where performance efficiency is not the main goal. The figure 2 shows a layer representation of those two different approaches, it shows that hypervisor type 1 directly runs on the hardware whereas type 2 run on an operating system.

Virtualization leads to several benefits. The main one would be the server consolidation which allows the optimisation of hardware utilisation by placing several VM on the same hardware and to reduce the energy consumption by shutting off unused servers. This directly leads to lower server investment and maintenance cost because of less physical server thus increasing the space utilisation efficiency in server room or data-centres. Virtualization can also be seen as a test platform for instance to test new versions of software on the hardware they will be running on without affecting the actual system. As the VM are independent and isolated between each other, the same hardware can be used to run different operating system type (Microsoft, UNIX, Mac, and so on). Furthermore as a typical server workload usually show peak with low and high utilisation, virtualization can improve resources use through dynamical resource provisioning. Finally virtualization allows system cloning on demand thus improving system flexibility and elasticity.

Virtualization is a key concept for cloud computing, indeed Charles King, Principal analyst at Pund-IT clearly said that “without virtualization there is no cloud - that's what enabled the emergence of this new, sustainable industry”.

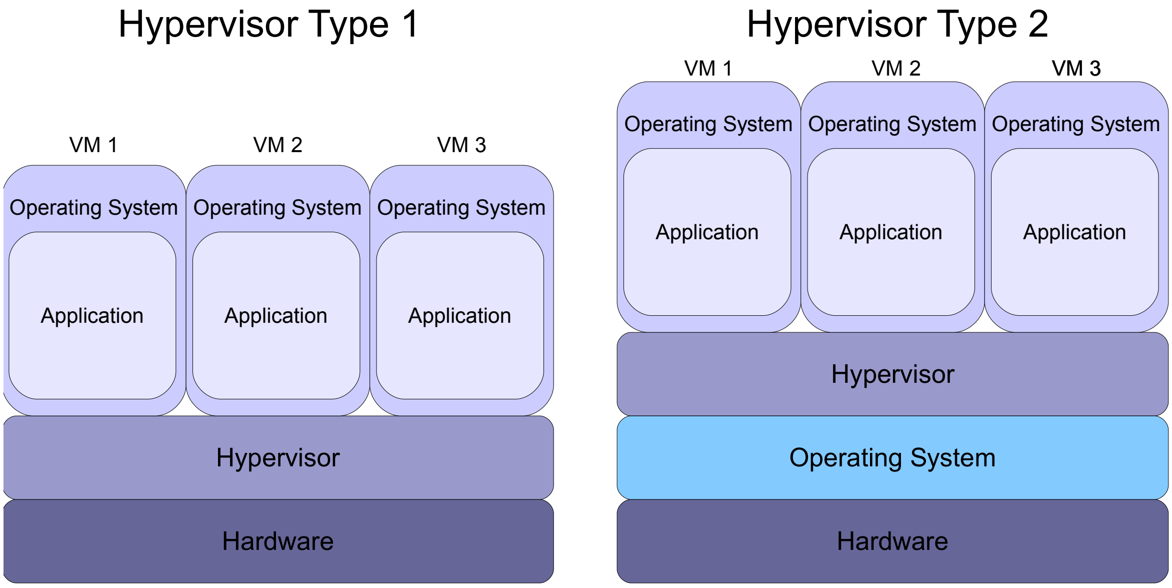

Figure 2: Layer representation of virtualization

2.2.2 Greenhouse Gas Emissions

Greenpeace have published a report in March 2010 entitled “Make IT Green: Cloud Computing and its effect on Climate Changes”. After introducing the last Apple device Ipad and how this device relies on a cloud based infrastructure, the report focuses on the incredible power consumption of data-centres and mostly on their Greenhouses Gas (GHG) emissions. Even if their definition of cloud-computing is simplistic and blurry a main idea is raised. They observed an average 9% increase in the number of data-centres server per year since 2002 and they predict this trend to continue till 2020, however they also looked at the importance of energy sources for data-centres and this effect on GHG emissions. Indeed a way to reduce the GHG emissions and carbon footprint while coping with the increasing demand of energy is to use renewable energies for instance the new Yahoo data-centres powered by hydroelectric power-plant. Greenpeace also challenge the ICT sector leaders (Google, Yahoo, Facebook and so on) to reduce their carbon footprint in order to use their influence in the industry sector to invest in renewable energies. Along with this idea Michael Dell said in Forbe magazin “I have always believed that IT is the engine of an efficient economy; it also can drive a greener one” (Forbe Magazin, December the 3rd 2009).

The figure 3 which represent the repartition of greenhouse gas emission in the IT sector shows that server farm and server represent only 14% of the total GHG emission of IT and PCs and peripherals 49% in 2007. Their estimations is that the network infrastructure will consume less and emit less GHG by 2020 but that end device will then represent 57%. For their estimation they admit that by 2020 PC ownership and mobile phone will quadruple from what it was in 2007. However their values come from a study made in 2008, technology is changing quickly specially in IT. It makes it impossible to know if in their estimation they considered potential new technology or if they admit that a data-centre has more chances to be powered by green energy. Therefore with technology such as lightweight PCs and cloud computing the tendency should be different.

One of the concept of cloud computing is that the processing resources are located on the cloud provider and not on the customer device. That why Greenpeace was introducing the Ipad in their report as a kind of end-device with theoretically low power consumption, and limited processing resources which entirely rely on web application and cloud computing resources. Therefore the end device is not power angry in contrast with a desktop. And most of the calculation is achieved in data-centres. GHG are reduced only if the cloud provider is supplying its data-centres with renewable energies and optimize it energy utilization. But this suggests that the data-centres are being built in a sustainable way.

Therefore cloud computing could reduce the emission of GHG but does this mean that the electricity can be wasted if it is from a renewable source? Indeed new data-centres are created because it follows the general tendency of the internet to grow but also because data-centres are saturated and cannot provide enough power for new servers (Stephen Ruth, 2009). Therefore data-centres should also improve their power management infrastructure in order to optimize existing data-centres (Xiaobo Fan et al, 2007). The research is highly considering virtualization to improve power efficiency in data-centres (Liang Liu et al, 2009) (Ripal Nathuji,2007).

	Emissions 2007 ($MtCO_2e$)	Percentage 2007	Emissions 2020 ($MtCO_2e$)	Percentage 2020
World	830	100%	1430	100%
Server farms/Data Centres	116	14%	257	18%
Telecoms Infrastructure and devices	307	37%	358	25%
PCs and peripherals	407	49%	815	57%

$MtCO_2e$ = Metric Tonne Carbon Dioxide Equivalent
$GtCO_2e$ = Gigatonne Carbon Dioxide Equivalent

Figure 3: IT repartition of greenhouse gas emission (Greenpeace International, 2010)

2.2.3 Impact of Virtualization on the power consumption

2.2.3.1 Potential Energy Saving with virtualization

In non virtualized web-based services or applications, the servers are always located on the same hardware (the hardware can host multiple applications), if replication is needed then new hardware is required however it also provide location transparency. In a virtualized environment the hardware represent a shared resources and is not explicitly dedicated to one (or multiple but always the same) application. Therefore this allow to cope the demand easily for instance if an application is highly demanded and required more resources, then this application can be replicated, with a load balancing mechanisms to handle the demand. In the same way if an application is not highly demanded its resources can be reduced following the load and eventually some hardware can be powered off (C Develdet, 2008). This ability to start services on demand and to switch them off suggest that energy saving is achieved only during off-peak time (Xiaobo Fan et al, 2007), when the servers are not extensively used. In fact considering data-centres, which are designed for worst-case scenario with servers capable of handling peaks of high load and are therefore overpowered. High load peaks might occur infrequently, according to Aaron Weiss data-centres might used 99% of their resources during business but this occur ten percent of the time. Consequently most of the time some servers might be in idle state and still generating heat (Aaron Weiss, 2007). Indeed the real saving is achieved when the hardware is powered down or in sleeping mode, (Gong Chen et al, 2008) have measured that the power consumption of two different processor and the power consumption in idle state is over 66% of its peak power consumption as shown in the figure 4 representing the energy consumption of two devices equipped with different processor. Accordingly with (Xiaobo Fan et al, 2007), they measured between 60 to 80% depending on the hardware type.

If cloud computing and virtualization can allow a smart migration of virtual machine and make sure that running physical hardware uses most of the time 100% of its resources, therefore server can be power down and ideally some part of data-centres (James W. Smith, 2009). Dedicated servers cannot be use for anything else when they are not used or fully use, therefore energy is wasted and even more energy is wasted to cool them down. In large data-centres it is estimated that 50% of the energy bill cover the cooling needs alone. Consequently it can be concluded that it is more efficient to have less hardware running but having them using as much of their resources as possible instead of having multiple different hardware running at low utilization.

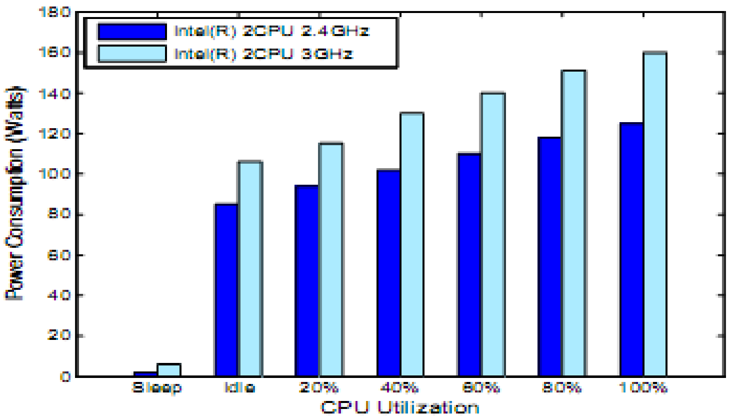

Figure 4: Power consumption depending of the CPU utilization (Gong chen et al, 2008)

Research seeking to reduce power-consumption of data-centres highly focuses on virtualization by integrating power management mechanisms into virtual machines. For instance (Ripal Nathuji,2007) have proposed an approach to optimize power management in virtualized technologies. Their idea is to allow virtualized machine to access a set of soft version of the hardware power states. This virtual power infrastructure allows an improved online power management. They measure using XEN hyper-visor a minimization of power consumption up to 34%. Another research group, (Liang Liu et al, 2009) have proposed the GreenCloud architecture which uses the live migration of Virtual Machines (VM) feature of XEN. They addressed several issues such as when to trigger the migration and how to intelligently select the physical machines for an optimal VM placement. They measured a saving of 27% of energy when applying their GreenCloud architecture.

2.2.3.2 Virtualization Overhead

Virtualization adds an extra processing layer on the hardware and therefore adds a power overhead. Indeed to allow other operating system to run on the same hardware the Virtual Machine Monitor (VMM) is required. This processing overhead depend of the virtualization solution and of the component used to achieved the virtualization. Indeed (Pradeep Padala, 2007) have compared the overhead of two different virtualization solution, Xen which is hypervisor-based virtualization and OpenVZ from OS-level virtualization. The overhead on the response time and on the CPU is show in the figure Erreur : source de la référence non trouvée. To run their experiment they run several instances of an auction workload called RUBis. They showed that the XEN overhead is approximately twice the overhead of Openvz and become overloaded sooner. However it is important to note that their experiments do not allow an evaluation of the overhead of virtualization because they only compare the overhead of two different virtualization technologies. They did not make a comparison of the differences of response time and CPU utilisation of physical server running the same architecture. Also the overhead differ too much between the two solutions, therefore overhead seems to depend on the virtualization solution. Nevertheless this show that virtualization generates an overhead and depending on the solution selected this overhead can be important. OpenVZ require less CPU consumption than XEN, therefore it should handle a higher number of instance for the same CPU utilization and as seen before the CPU utilisation is directly related to the power consumption therefore OpenVZ should be more power efficient. However Xen has a bigger overhead but it allows a greater flexibility than Openvz (mostly in a term of type of OS supported). But this has been done in 2007 with XEN 3.0.3 and the development in cloud computing has really improved quickly in the past few years, the actual XEN version is 4.0.0 which should have less overhead and in the same way Openvz could also be more flexible nowadays.

However a new question comes out. Does the virtualization overhead imply that to reproduce a physical architecture of data-centres into a cloud new hardware is needed? Indeed virtualization adds an overhead but also use the resources more efficiently. For instance according to (Pradeep Padala, 2007) most server in data-centres are running under 30% of their capacity. As mentioned before, a server in idle state consume 60% of its maximum power consumption therefore it is best to have less server running at a higher level of their capacity (Gong Chen et al, 2008). So if the overhead related to virtualization is low enough to use the same hardware it should be more interesting for company as their energy would be used more efficiently. Perhaps if the overhead is too high new hardware would need to be added to the actual infrastructure, implying increase in investment cost and power consumption. A more realistic approach to answer this question would be to consider the cost of turning an existing architecture not involving virtualization to cloud architecture. It is probably easier and cheaper in a long term to re-build a new infrastructure, optimized for cloud computing, from scratch. Indeed because it will be easier to manage, with low management cost and cheaper has the new hardware tend to be more power efficient also a server replacing another is two to five time more powerful (Emmanuel Besluau at silicon.fr, 15 juin 2009).

However to optimize the efficiency and at the same time to reduce the power consumption it is important that the virtualization overhead is low as possible. And as technologies are constantly evolving, constant performance analysis of the latest solution is suitable to allow cloud administrator to deploy the best solution.

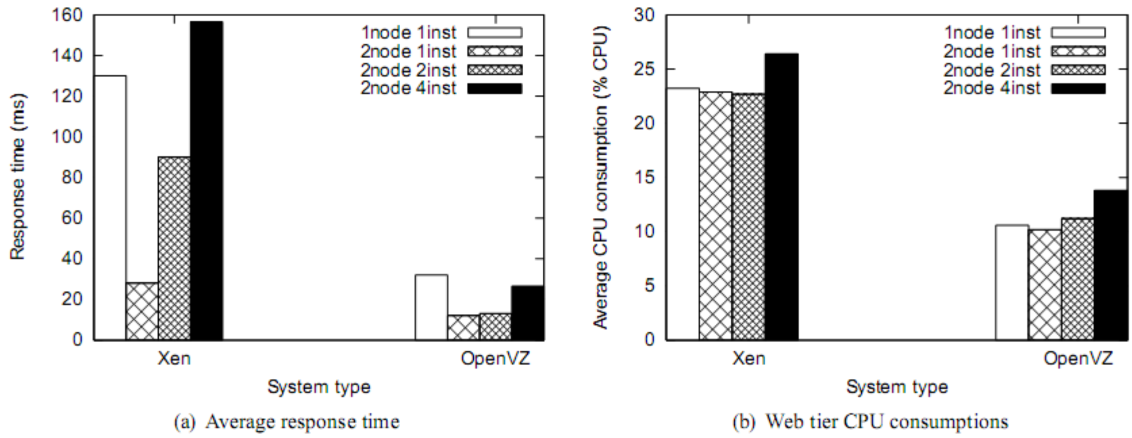

Figure 5: Overhead depending on the number of node and number of instance of a software per node and the virtualization solution (Pradeep Padala, 2007)

2.2.4 Private-Cloud

There are some privacies concern about cloud which might slow down its wide adoption. Indeed it require a high degree of trust, the data which were stored at home on personal computer or for a company inside their offices will now be located in data-centres on an infrastructure that they do not own (Aaron Weiss, 2007) (Anu Gopalakrishnan, 2009). The research is highly focusing on how to secure and manage identity in the cloud. For instance proposing trust management system and authentication model based on Kerberos for the authentication (Paul D Manuel et al, 2009) for PaaS, a closed-box execution environment which guarantees a confidential execution of VMs (N Santos et al, 2009) for IaaS or using the Security Assertion Mark-up Language (SAML) for secure browser based authentication (Meiko Jensen et al, 2009) for SaaS. But if companies still do not want to allow a third party to hold and manage their data for them they can choose to implement a private cloud. In this deployment scenario the cloud can still be manage by a third party on or off-premise. If the cloud is deployed on the premise the company will have to cover the investment and management cost as well as for the power consumed. It might not be the cheapest option be company might do it for greater security and control. However what is the electricity saving? The hardware utilisation should be optimised thanks to virtualization but what the saving really is hard to know. The literature in this area seems to lack of measurement between virtual server architecture and physical server architecture.

In a term of cost, migrating to private cloud is interesting for large business companies but not for small company. Indeed David Floyer, co-founder of Barometrix an IT advisory company, published an article on wikibon.org which had a great community rating by the professional community. In this article he showed that private clouds are more cost effective than public cloud for companies with revenues greater than $1Billion. Small enterprises will find public cloud attractive, the larger companies are able to create private cloud with the same business characteristic but with more control and governance and increase security. Also larger company might take advantage of public cloud for tactical use such as to facilitate sharing between offices and employee in a hybrid-cloud deployment. And private cloud is more cost effective for really important applications specific to the company and deployed as SaaS.

Another reason to deploy a private cloud on the premise would be to use lightweight desktop client. The idea would be that any employee's computer will be a combination of Vms in the private cloud and a lightweight client to access it. The VM already have the storage and processing resources so what therefore the client only need a network interface to access the VM and human interfaces device such as screen, keyboard and mouse. Therefore the power consumption is reduced at every employee computer and the processing resources are centralized making it easier to manage the power and even updates. In fact lightweight client could be use with any deployment model as far as the network can handle it.

2.2.5 Lightweight Client

The idea behind thin clients is to move processing resources, storage space and even software in the cloud. Everything becomes a service and if a VM can be access remotely there is no need to process anything on the device except for standalone application. Perhaps gaming and applications with a really small refreshing time which could produce a high load on the network might be preferred on a computer with good processing capabilities. In most of cloud applications the only software needed on the client is a web-browser, or a VNC client (Virtual Network Computing) to access VMs. Some VNC clients are web-based and just require a web browser such as ThinVNC or RealVNC. Some application for devices such as the apple IPods and IPads and other PDA also exist. Software development companies already proposed some lightweight version of their software, for instance Adobe propose an online Photoshop and a light version of the video suite Première which is normally quite processing intensive. The software may contain only the basic functionalities but might be enough for the average customer. The migration to thin clients might take time, for instance for home usage just the time to realise that the living room desktop computer has not been switch on for months because everything that the average customer need to do can be done from anywhere and from any devices with an internet connection and a web-browser. This is why greenpeace was introducing the IPad as relying only on cloud and the potential to reduce people carbon footprints. The wide tactile screen of the IPad combines all the human interaction device such a mouse and keyboard and its processing power is in the cloud. Large screened tactile devices could enhance cloud adoption according to Tony Bradley at pcworld.com called “office productivity in the cloud” (5th of April 2010) with the Ipad but he also argues that it might be a bit limited as a business tool however he was looking forward remote desktop solutions which are now available.

Portable tactile device can be a good business tool but should not replace desktop PC for office use, developers, architect or any professional which would be more efficient with a mouse and a keyboard. The company WYSE propose thin clients which replace the desktop central unit (Wyse, 2010). Their idea is that if virtualization is working for servers, it should also work for desktop, which outnumber servers by a factor a hundred as seen in “the death of the PC” forbes.com (Lee Gomes, 12.10.09). Most of their products only have for a (or several) screen, keyboard, mouse, network card and a thin OS such as windows CE or windows XP embedded or some thin Linux distribution. Those clients consume less than 15 watt but they also have some lightweight client which do not run an OS and consume less than 3W (Wyse, 2010). Their thin client cost between $50 to $200 in opposition to a $1000 desktop PC with latest components and consume in average 150W. Also it is supposed to reinforce the security as no malware or virus can be installed on the client, and the management of update is made easier on the VMs because they are all at the same place. Even if switching to virtualized desktop is expensive the maintenance cost is a lot lower (Lee Gomes, 12.10.09). Furthermore centralizing processing power in the cloud liberates user from having to choose the machines hardware (Aaron Weiss, 2007) which might be a good argument for people who do not have a special interest in computing and just need access machines.

2.3 Network Infrastructure

The network infrastructure consumes powers. In order to reduce this energy cost it is important to understand what are the main elements of the topology which consumes power and how is this power consumed. By understanding the power consumption behaviour on a network topology it should be possible to adjust it in order to make it more efficient. According to the work of (Joseph Chabarek et al, 2008) about power awareness in network routing and topology, they measured that the power variation between an idle state and a 75% load of the total bandwidth of the link is only 2 % on a Cisco 12000. They estimated a 10% difference if the router was fully loaded but they have not measured it. Therefore the load is not the main factor of the electricity consumption of the router. Furthermore the work of (Priya Mahadevan et al, 2009) titled “A benchmarking Framework for Network Devices” where they have benchmarked different switches, routers and access-points have confirmed that the load of the equipment only has a small impact on the power consumption (under 5 %) neither the packet size or the number of entries in the TCAM (Ternary Content Addressable Memory) use for fast-lookup have a small impact. Moreover according to the work of (Sergiu Nedevschi et al, 2007) most of the energy in networks is wasted because firstly networks are designed to handle worst case scenario which is theoretically more than peak time load. Secondly the energy consumption of the network remains almost the same during peak time and idle state because the load of the router has a really low impact on the electricity consumption. The network infrastructure need to be adjusted in order to have a low consumption when the network is not highly demanded and also the consumption should be reduced during peaks. The work of (Joseph Chabarek et al, 2008) has also outlined three main areas where power-awareness is needed in order to improve the power efficiency and awareness of wired network, namely the network equipments or system design, topology design and finally the network protocols design. These three areas are closely related between each other and can fit most of the research done in the wired network power efficiency field and are therefore used in this section as the main frame to discuss the related work of this area. But for this project another part is added which is the impact of network interface on battery-powered mobile device has it could be an issue.

2.3.1 Power-awareness on the equipment

2.3.1.1 Energy measurement on the Equipment

In 2007 it was estimated that the energy consumption of the network equipment of the Internet represent 1% of the consumption of broadband enabled countries (Jayant Baliga et al, 2007) estimated at 6.15 TWh/ yr in the USA (Chamara Gunaratne, 2008) but this could increase with networks becoming faster. Indeed in their previous study (Chamara Gunaratne et al, 2005) have measured that the cost of an active interface on a Cisco Catalyst switch 2970 depends of the speed or data-rate of the link. For instance enabling a 100Mb/s interface results in increasing the switch consumption by 0.3 Watt and 1.8 W for a 1Gb/s interface. Depending upon whether the medium is copper or fibber a 1Gb/s link consume 1 or 2 W (Maruti Gupta et al, 2007). However it is also possible to express the cost of a link, for instance in a report of the Energy Efficient Ethernet (EEE) group which is a team of the IEEE, it is mention that a 1Gb/s copper link cost 2 to 4 W, which is twice the cost of the interfaces on one end, and for a 10Gb/s copper link the cost is 10 to 20W (Bruce Nordman, 2007). This power variation is due to the energy required to operate at those speeds and is dissipated at the physical layer. Considering a switch, the cost of the entire interface can represent 20% of the total electric cost of the switch (Maruti Gupta et al, 2007). Therefore some of the energy dissipated in a 1Gb/s or 10Gb/s link can be seen as wasted if the link is not fully used for instance during night time when the network is less loaded. The biggest waste is probably on access switches in companies' networks which are generally connected to desktop computer in sleeping modes. As networks are becoming faster, most of the 100Mb/s links will probably be replaced by Gigabit links, increasing the energy consumption's percentage of network equipments from 1% to 4% up to 10 % of the global electric consumption (Rodney S. Tucker, 2008).

The actual tendencies of the research in this field is not to reduce the electric cost of Gigabit interface but to turn them into sleeping mode (Maruti Gupta et al, 2007) (Frederic Giroire, 2010) as well as other router components such as line cards (Joseph Chabarek et al, 2008) (Sergiu Nedevschi et al, 2007). Another tendency is to dynamically adapt the rate of the interface (Bruce Nordman, 2007), (Sergiu Nedevschi et al, 2007). But this will be discuss later in this section has it is more related to protocols than the equipment's hardware.

2.3.1.2 Possible Energy minimization Approaches

In their paper (Maruti Gupta et al, 2007) have turned their attention to LAN switching and more precisely they studied LAN switches behaviour and turned various components of the switches to a sleep mode. They have shown earlier that because this is the most deployed device on a network, LAN switches has the higher energy cost (Maruti Gupta et al, 2003). It is also the devices which waste the more power as it is usually connected to end devices which have a long inactivity time. Their approach is to turn the interface in a sleeping mode during inter-activity period based on increasing timers. As there are no sleeping modes for switch's interfaces they derived some from the Advanced Configuration & Power Interface (ACPI) open specification which differ depending if packet are buffered or drop during sleeping and produce a mathematical model. Several issues are raised by their study.

Firstly depending on the sleeping mode chosen they show that some ARP and Hello packet from various protocols (CDP, OSPF and so on) might be dropped if the destination port is sleeping. To solve this issues (Chamara Gunaratne et al, 2005) propose a proxy type of approach. A proxy implemented, in the switch and on Network Interface Controller (NIC) of desktop, could answer trivial request such as ARP request, hello packet and other ‘keep alive’ messages without having to wake up the entire device or interface for the switch. They measured on a university network an average of six packets per second during night time on switch link, and there approach should handle 91% of those packets. (Mark Allman et al, 2007) has based their theoretical estimation on an architecture involving the poxying mechanisms proposed by (Chamara Gunaratne et al, 2005).

Secondly for redundant links with VLAN and multiple STP instances running on switches, some of the aggregate link will never be shut down even with a really low utilisation. Therefore they suggested re-calculating the spanning tree during the night after having shutting down some of the redundant links.

Thirdly in order to have the best performance the switch will require hardware that support sleeping as well as an appropriate sleeping mode on an interface basis or line card. Indeed they considered in their study modular switches assuming that line-cards represent the part of the device with higher complexity as this is where the processing power is usually pushed and this would be the most suitable part of the device to implement the sleeping.

Finally they also estimated through a mathematical model that the overall impact on the performance would be low for the amount of energy saved. The energy saving can be achieve for load of the link only up to 5% because of the inter-activity period. However (Sergiu Nedevschi et al, 2007) mentioned that (Maruti Gupta et al, 2007) approach cannot be efficient on 10Gb/s link because even at really low utilisation (less than 5%) the inter-activity period is too small (>15µs) so sleeping will be used only if a “buffer-and-burst” approach is used meaning that the load on the link is controlled by the device. They suggested that sleeping methods are used with dynamic link rate-adaptation mechanisms for higher energy saving.

However (Priya Mahadevan, 2009) in their benchmarking work have shown that a line card with four Gigabit Ethernet port consumes 100 W or approximately a fourth of the entire switch. The entire line card should also be considered to go to sleep as suggested by (Sergiu Nedevschi et al, 2007), (Joseph Chabarek 2008) and (Frédéric Giroire et al, 2010)

2.3.2 Power-awareness on topology designs

2.3.2.1 Measurement

In Power Awareness in Network Design and Routing (Joseph Chabarek et al, 2008), have started their research by investigating the tendency of power requirement of router with line card. They explained that with the speed rate of line-cards increasing, their power requirement increase as well as the router chassis. However the power efficiency of router has started to plateau implying that heat dissipation demands increase and will nearly reach the limits of air cooling methods therefore more expensive liquid cooling methods will be required for each network Point Of Presence (POP). They believed that it is possible to reduce the power consumption by implementing power-awareness in topology design and protocol design. They measured the consumption of two widely used Cisco router, a 7507 with seven 1Gbit/s slot and a 12008 with ten 4Gbit/s slot with different line-cards. The first conclusion of (Joseph Chabarek et al, 2008) is that it is better to reduce the number of chassis and to maximize the number of line-card per chassis from a power aware point of view. Indeed (Priya Mahadevan, 2009) have benchmarked different routers and line-cards. They explain that the power consumption depends on the number of active port and the speed of those interfaces on the line-cards which is the same behaviour as with a switch interface except that the line card also include some processing component. For instance a four-port G/bits line card consumes 100W, which represent approximately a fourth of the Cisco 12008 chassis (measured 430W by (Joseph Chabarek et al, 2008)).

One of the main conclusions of (Joseph Chabarek et al, 2008) is that being aware of power consumption while designing network topologies can result in significant power reduction. For instance using a line card only for redundant links, as this line-card could be in an idle state most of the time however some modification are still required on network protocol design.

2.3.2.2 Possible Minimization approaches

In their work (Frédéric Giroire et al, 2010) followed (Joseph Chabarek et al, 2008) idea by presenting through a simplified architecture the problem of minimizing power by improving the network topology. Through a mathematical analysis on a set of existing backbone topology they showed that at least a third of the interfaces can be spared for usual demands. Considering interfaces as a four-port G/bits line card which consumes 100W they showed that if effective sleeping mechanisms were used this would represent a 33MW/year saving per topology. The increase of the route length would be in average 27% which can be tolerable on some network. Each router should normally be more loaded however their work is based on the fact that the load of a router only has a small impact on its energy consumption and that the dominating factor is the number of switched-on network elements (router, line card, interfaces and so on). They presented the Toy example in the figure 6[1]. Where α represent the Demand/Capacity ratio, for instance if each node are connecting to each other and they are all sending one unit therefore α should be equal to 2. $\overline{d}(D)$ represent the average route length and DP(D) the number of edge-distinct path (representing the fault tolerance) and D being the all-to-all demand. The graph in the extreme left of the figure is the non simplified topology and the one in the extreme right the most simplified one with the higher gain of network equipments. The graph in between shows a small impact on the route length and the fault tolerance.

Nevertheless to maintain the robustness and reliability of the network fast waking up mechanisms and improved routing protocols are required. Their work seems to be the first studies which aim to reduce the power consumption by applying energy-efficient routing solutions.

1 The figure comes from a presentation made by Joanna Moulierac the 22/03/2010. Joannna Moulierac is a member of Frederic Giroire's team MASCOTTE and is also a member of its project DIMAGREEN.

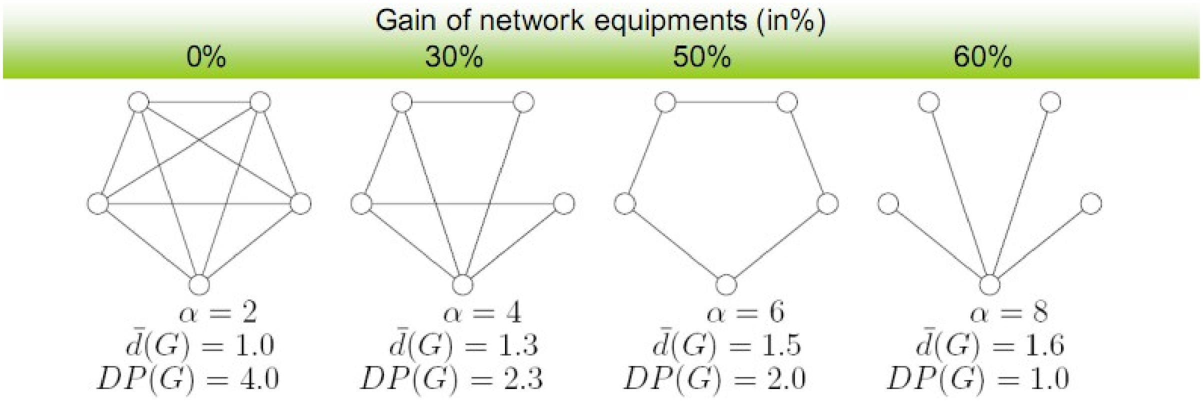

Figure 6: Gain of Network equipment depending of the number of link in a Star topology (Joanna Moulierac, 2010)

2.3.3 Power-awareness on network protocols

The Institute of Electrical and Electronics Engineers (IEEE) has created in 2007 a study group named Energy Efficient Ethernet (EEE) (Bruce Nordman, 2007). This group is working on the definition of the new standard 802.3az which define energy efficient mechanisms for the 802.3 standards. The EEE focuses mainly on dynamically adapting the rate of the interface which was also suggested by (Sergiu Nedevschi et al, 2007) in order to save power during low link utilisation. The standard is not available yet however there is a set of objectives on the EEE website which outline what the standard should be able to achieve. It appear that the standard should define a protocol which will coordinate transition to or from a lower level on consumption mainly on reducing the rate of the interface. During the transition the link status (up or down) should not change state during the transition. And this change of state should be done in a transparent way without any frame lost or corruption. This standard should be applied to a wide range of physical standard such as 100Base-TX (Full Duplex), 1000Base-T (Full Duplex), 10GBase-T as well as standard which are use to interconnect line-card to the system also know as Backplane Ethernet such as 10GBASE-KR, 10GBASE-KX4 and 10GBASE-KX.

However it is not specified if the standard will allow placing an interface or a line card in a sleeping state. Indeed it was suggested by (Joseph Chabarek et al, 2008) and (Frédéric Giroire et al, 2010) in order to adapt the topology in a power-aware fashion when the network utilization is low. Therefore this will have to be managed by the routing protocol which could have to include metrics such as network utilization. (Joseph Chabarek et al, 2008) also have suggested adapting the method of (Chun Zhang et al, 2005) which is a heuristic method to generate routing table based on traffic matrices except that the route could be selected based on a power-aware constraints. This is a new concept where routing protocols do not select the path based on the shortest path or fastest path but on an energy-efficient basis, at least during low network utilisation time. The power saving could be important as it includes most of the mechanisms proposed in the literature.

2.3.4 Wireless interfaces on mobile devices

The use of Cloud applications could lead to increase of the load on the network leading to bandwidth upgrade and therefore the network infrastructure will consume more energy. It is all the truest if power-awarness solutions, such as those mentions previously, are not used. However what is the effect on the device especially on mobile devices which are battery-powered? Indeed cloud application might also load their network interfaces especially if remote desktop application are used. Cloud will enhance the capabilities of mobile devices but their utility will still be impacted by their battery life-time. The communication system of a mobile device with one interface represents a major portion of the system total power consumption (Vijay Raghunathan et al, 2004). Furthermore Personal Digital Assistant (PDA) and Smartphone are increasingly equipped with multiple wireless interface such as Bluetooth, WIFI, GPRS and so on making the communication system even more dominant (Yuvraj Agarwal et al, 2005). (Trevor Pering et al, 2005) have made a power profiling of a multi-interface mobile devices that they build and they measured 70% of power of the hand-held device goes to the communication system. The research in the field is trying to reduce the consumption of unused interface by trying to define when an interface should be preferred to another and to turn into sleep the unused interfaces (Trevor Pering et al, 2005) (Trevor Pering et al, 2006). Their idea is to use most efficiently all the interfaces available for instance by making use of the Power Saving Mode (PSM) of Wifi 802.11b when high bandwidth is not required or by using only Bluetooth for small range connectivity therefore they designed rules and policies. They obtained a reduction of 50% power consumption for the communication system of the device. This optimized the power utilization of the device by selecting the most appropriate interfaces and turns of the other or put them into a sleeping mode. However an interface transmitting data will still consume more than an interface in idle state and the cloud might extensively use one interface over a long time. Indeed as shown in the figure 7 from (Trevor Pering et al, 2006) showing the power consumption of wireless interfaces during an idle state and a transmission state. A Wifi interface consumes three to four time more when transmitting. In the same way as the literature is considering to save power on networks when the link are not extensively used the literature focuses on optimizing the power consumption of interfaces in the idle state and when interfaces are not used. The main issue is that the cloud will enhance the power and extend the range of application of mobile devices increasing the data exchange of those devices, especially with remote desktop or remote software. Therefore the battery lifetime will be highly decreased with extensive use of cloud. Therefore it is important to evaluate the impact of cloud applications on mobile devices.

Interface	Low-Power Idle	Active Tx
WiFi Cards		
*Cisco PCM-350**	*390 mW*	*1600 mW*
Netgear MA701	264 mW	990 mW
*Linksys WCF12**	*256 mW*	*890 mW*
Bluetooth		
BlueCore3	5.8 mW	81 mW
*BlueCore3**	*25 mW*	*120 mW*

*Figure 7: Power consumption for various wireless network cards. Values taken from data-sheet except those marked wit a * (Trevor Pering et al, 2006)*

2.4 Chapter overview and critical discussion

The IT infrastructure represents fifty percent of the electricity bill for a company. Supposing that companies relocate their servers in the cloud, or in data-centres or just using virtualization for server consolidation. In addition they adopt virtualized desktop and thin client. The electricity bills should be reduced, but to which extent? Company could choose to deploy their own private cloud, where the power management should be optimized but this is cost effective for large business companies only. Indeed the company still have to cover the investment and management cost. Smaller companies might still deploy server consolidation for their own and specialized application using virtualization but they might consider private cloud managed by a third party. If it is said to be cost effective because of power reduction there are no scientific studies which allow a real estimation of the energy saved by migrating to a cloud.

Moreover, in the case of moving the processing resources to data-centres, is the overall or global energy consumption really reduced? It seems to be just relocated from the company to the data-centres, in fact following the processing resources. Data-centres already consume 0.5% of the total energy produced. Cloud computing might highly increase this percentage. However this should as well reduce the overall GHG emission because data-centres have better chance to optimize their energy utilisation and make use of renewable and sustainable energies to optimize their benefit. In order to optimize their data-centres and the cloud infrastructure, cloud provider should select the technologies which offer the best capabilities with the lowest overhead. Indeed the higher the overhead is, the lower the number of instance of VM can be launched on the same hardware, and more hardware result in higher energy consumption. However in an environmental point of view the use of cloud in data-centres should be greener. It should also reduce the overall energy consumption because the hardware utilisation is optimized thanks to virtualization.

But then this relocation of processing resources will add a load on the networks. Therefore is the network ready? (Aaron Weiss, 2007). Indeed company, and ISP will have to upgrade their network because what was being done locally will be done remotely relying on the network infrastructure even more. In some case even office software will run on servers in data-centres.

Studying the literature on power-awareness on network infrastructure has permitted to identify how the power is consumed and how it could be optimized. Indeed three main areas have been identified where potential saving in a term of energy can be achieve. Researches focussing on the power consumption on the network equipment or device have shown that there is a waste of power when on network link when they are not fully used. This waste increase with the speed of the unused link as a 10 Gigabit link can consume 10 to 20 Watt in opposition to a 100 megabit link which consume approximately 0.6 watt. Instead of trying to reduce the consumption of the link, it is better to reduce the waste of the link when the link is not used by shutting them down or turning them in a sleeping mode. This have several issues especially because some network protocols keeps a state of the link by sending periodically Hello messages which would be lost if the interface is sleeping. Some minimization approaches suggest proxy-like approach where the device is aware that the link is working but does not send packet over the link. Other suggests recalculating the topologies during the night for instance a power-aware STP protocol but it is not designed yet. But mainly it require power aware hardware which support sleeping mode in order to turn an interface or an entire line card into sleep. But protocols also need to be adjusted to adapt the topology when the network is not overloaded. For instance routing protocol which recalculate the topology using a power consumption metric during the night as suggested by (Joseph Chabarek et al, 2008) and (Frédéric Giroire et al, 2010). But the protocols have to be redesigned. The first power-aware standard which should be implemented soon is the IEEE 802.3az which should allow interface to adapt their speed-rate depending on their load. Nevertheless the cost of the network infrastructure has to be included when considering the energy cost of a solution involving the network because it cost is non-negligible.

The cloud will enhance the capabilities and functionalities of the device and might change how users behave with it. Indeed they might use those devices more and more instead of using a laptop or a desktop. This will save energy because those devices should consume less power however the battery time might become an issue. Therefore another concern is the impact of the network interfaces on hand-held devices which are battery powered. Indeed the extensive use of cloud applications will increase the data transfer. The communication system of those devices already represents a major portion of the device power consumption. Furthermore those devices usually include a different interface with advantages to each other. Research in this field is trying to optimize the use of those interfaces by improving the selection process of an interface to another and keep other interfaces to sleep.

In a general way it appears that power is wasted because network and network device are designed to handle a maximum but are not able to adapt their consumption depending of the load. The ideal case would be a network device where its power consumption is highly dependent of its load. Indeed if the power consumption depends only of the load, there is no power waste.

2.5 Conclusion

This chapter have review the literature concerning power consumption in the area of Cloud-Computing, network infrastructure and battery powered devices. This chapter has also presented why cloud computing is considered as a green technology and this has been critically discussed.

There are different deployment schemes for cloud infrastructure. The greener one would be a cloud provider managing the hardware in data-centres because then they can choose to use sustainable and green energies. However the idea is that cloud can be green if the energy consumption of computing calculation is centralized in green data-centres and virtualization adds power efficiency to hardware utilisation. But this does not evaluate the reduction of the global electricity consumption, this does just say that it can be greener.

However the literature focusing on cloud and its power consumption never consider the electric cost of the network. Indeed the network infrastructure ties everything together and will need some upgrades to support cloud technologies. Therefore the energy utilisation of network infrastructure has been studied. It appears that network topologies and equipment are usually not designed in a power aware fashion and that energy is wasted when the network is not fully used. Research is trying to improve the power efficiency on network topologies, equipment and protocols. But the cost of the network infrastructure should be included when discussing the cost of cloud computing when important upgrades are required. Furthermore cloud computing might enhance the use of mobile device which will benefit from external processing resources. However this will load interfaces on mobile devices which are the major portion of the power consumption on those devices and might highly reduce their autonomy.

Therefore this literature reviews have outlined some of gap in the literature about cloud computing and power consumption. For instance, cloud is said to be green depending of the source of energy of the data-centres, but what is the impact of cloud computing on the power consumption for a company and does it reduce its carbon footprint if the company deployed its own cloud on the premise. Virtualization should help to optimized server utilisation and allow a saving during off-peak time but again what is the actual saving? Some benchmarking studies of network equipment have been made but should be mentioned when discussing power saving on the cloud. And finally cloud computing might develop even more the use of mobile device but the impact of cloud computing on the portable devices is not well studied.

Chapter 3 Tests Design

3.1 Introduction

The literature review have outlined that previous work in the area of cloud computing and green IT does not permit to determine what is the actual saving of moving toward a cloud architecture to replace a set computer into lightweight end-devices and virtual machines (VM). This study will try to achieve that by considering a simple deployment scenario. When cloud computing is used to virtualized a pool of computer, for instance a university lab or a small office deployment. This will consider virtualization environments and cloud deployment of VMs. The experiments should also interest the university as it is trying to reduce its carbon footprint and this lab will evaluate a virtualization cloud which could be deployed on campus and could reduce its carbon footprint.

In order to produce study as complete as possible, the experiment should also consider the network infrastructure. Indeed the literature review have outlined that the network infrastructure's energy cost is non-negligible. The study should consider wired and wireless access-point; however impact on the core layer of the network is not covered in this project.

In the same way as the network infrastructure will be considered the impact on the end device will also be evaluated. Ideally a range of devices should be considered including smart-phone and tablet PC with low processing resources in order to have a better idea of the impact on the cloud on the battery time.

The aim of this chapter is to present the experiments performed. The design of the different experimentation is really important to identify which data will be used and analysed in the result analysis and permit the evaluation of the different technologies. The different choices concerning how the experiments are performed are also justified.

3.2 Experimentations

3.2.1 Aims of the experimentations

The aims of the experimentation is to generate useful data in order to evaluate what is the energy consumption for a cloud deployment including end device and network infrastructure and to compare the energy cost to a traditional deployment. This should allow to quickly evaluating the power consumption of a deployed cloud if the number of elements (servers, network equipment and end-devices) is known. The data should be the power consumption or energy used by the device tested (network equipment, server, end device and so on) and will have to be converted in order to obtain the carbon footprint for each technology tested. However there is not a unique cloud deployment scenario, each cloud should be deployed according to a set a requirement which will differ from a deployment scheme to another. It is obviously impossible to try every deployment scenario as the list probably is infinite. Therefore to make the study more relevant and not to specific to one cloud deployments the architecture will be broken in several components as shown in the figure 8. The result could complete the literature in any of the field concerned by the elements when energy consumption is involved. The experimentation should consider a simple case, when a server is used to virtualize a pool of computer, for instance a university lab, with ten to twenty computers. The cloud offers great possibilities for learning if used for virtualization indeed with virtual images of operating systems, the same desktop computer could run any operating systems (from Microsoft, Apple or any Unix distribution) required if the images are installed on the virtualization server. The images of the VM could be pre-installed in a special states making easier de deployment of a tutorial lab. The experiment should consider the energy of the end-device, the network infrastructure and virtualization servers. But it should also consider different type of end devices (mobile and battery powered, desktop, lightweight desktop, tablet, smartphone and PDA), different network equipment (wireless access-points, wired switches and routers) and different servers. It is important to note that if the cloud is managed by a third-party, the carbon footprint of the company could be seen has reduced despite the fact that it is just move and that the cloud provider is handling it.

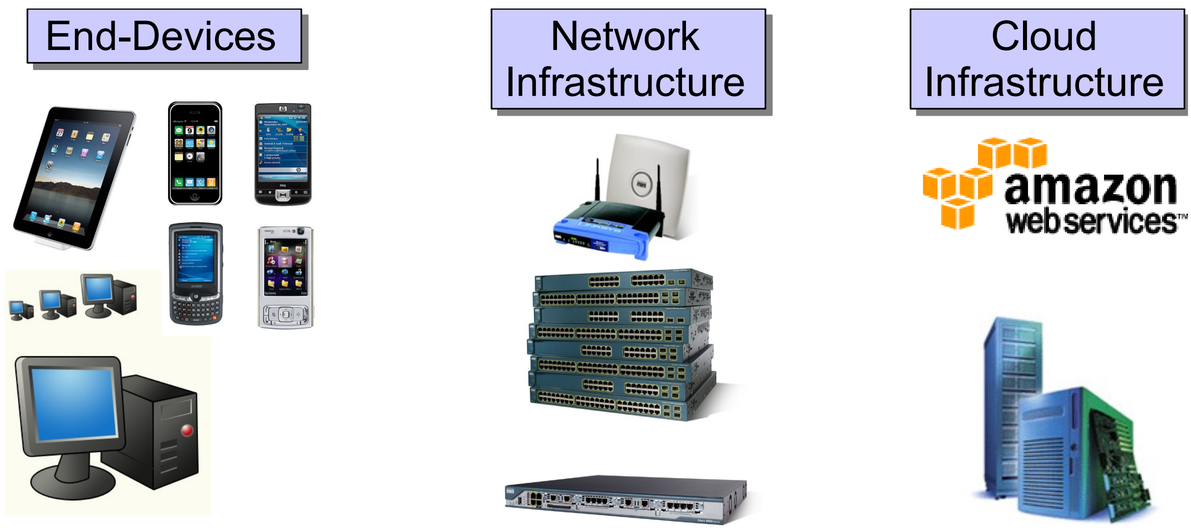

Figure 8: Component considered for the experiment

3.2.2 Data collection

The data collected should be the energy used or in some case the power required by the equipment tested. The difference between the energy and the power is fundamental. The energy represents the electricity used over a period. It is usually expressed in Watt per hour (W/h) and gives an idea of the entire amount of energy used. The power is the energy used over a one second period and is expressed in Watt (W). If the power is constant than the energy used over a period is equal to the power measured times the period. In most of the experiment the power should be a relevant metric however for experiment involving battery-powered devices it will be important to know the amount of energy accumulated during the charging time of the battery. Then evaluate how long it takes to discharge the battery. If the discharge time is constant therefore the power is the energy divided by the period. Therefore a power and energy monitor device should be used. There are two main kind of power monitor device. The most common one needs to be installed between the plug and the power cable; therefore it requires unplugging the device. The other type of device have a sensor which should be wrap around the cable, it measure the magnetic field around the cable and deduct the intensity of the power in the cable. Ideally a device selected should not require unplugging the wire as this would mean shutting down some server if they do not have a redundant power supply. The device should be as accurate as possible.

3.2.3 Carbon foot-printing and conversion factor

According to the UK Carbon Trust the carbon footprint represent the amount of greenhouses gas emission caused by a particular activity, organisation, event, and person. Therefore the carbon footprint can be undertaking by performing a GHG emission assessment. This project should use the carbon footprint to compare the physical lab and a virtual lab in a cloud. The carbon footprint is a relevant metric for whoever feels concern about the environment. Napier Edinburgh University in association with the Carbon Trust published in March 2009 a Carbon management program which presents the commitment of the university to reduce its carbon footprint by 25% on the 2007/8 to 2012/13 period (Edinburgh Napier University Sustainability Office, 2009). Therefore the university should be quite receptive if this project produce a GHG emission assessment of a standard computer lab and an assessment of this same lab but virtualized using the carbon footprint as a metric.

To calculate the carbon footprint a conversion factor is needed. The conversion factor allows estimating how much carbon dioxide is emitted for an amount of energy. It is usually expressed in gramme (or kilogramme) of Co2 per Watt (or Kilo-Watt) hours. The amount of carbon dioxide depends on the source of energy (coal, oil, natural gaz, fuel and so on). Each energy sources have a different conversion factor as illustrated in the table presented 9 showing value originally from Defra's GHG conversion (Carbon trust, 2009). Electricity provider companies usually sell energy which comes from a mix of different sources therefore an average conversion factor has to be calculated. The average conversion factor use in this project is the same as the one use in the Napier Edinburgh University Carbon management plan (Edinburgh Napier University Sustainability Office, 2009) which has been calculated by the Carbon Trust and will be used in the evaluation is equal to:

$$0.057 kg/kWh$$

Fuel	Units	$kgCO_2e$ per unit
Grid electricity[1]	kWh	0.544
Renewable electricity[2]	See footnote 2	See footnote 2
Natural gas	kWh	0.184
	therms	5.391
LPG	kWh	0.214
	therms	6.285
	litres	1.497
Gas oil	tonnes	3498
	kWh	0.277
	litres	3.029
Fuel oil	tonnes	3229
	kWh	0.266
Burning oil	tonnes	3165
	kWh	0.247
Diesel	tonnes	3201
	kWh	0.253
	litres	2.669
Petrol	tonnes	3172
	kWh	0.243
	litres	2.331
Industrial coal	tonnes	2338
	kWh	0.313
Wood pellets	tonnes	121.5
	kWh	0.026

Figure 9: Energy Conversion Factor originally from Defra's GHG Conversion (Carbon trust, 2009)

3.2.4 Desktop PC energy consumption

One of the first experiments should be a benchmarking of the desktop computers used in Napier University at Merchiston campus. This should give an idea of the saving of a cloud used to virtualized operating system accessed through a thin client. The saving will be the power of the cloud divided by the number of instances running in addition with the consumption of the thin client minus the power consumption of a regular desktop PC. The screen will not be considered for this experiment as desktop thin client require a screen as well. However the screen can also be benchmark to compare the power saving of mobile device which include a screen. The screen power consumption should be constant. According to (Xiaobo Fan et al, 2007) and (Gong Chen et al, 2008) the power consumption depend of the CPU. They noticed that a server in idle state consumed between 60 to 80% of its maximum energy consumption. Therefore this experiment will permit to determine if this is also the case of desktop PC. The methodology followed will be the same as (Gong Chen et al, 2008) which is to increase the CPU load and to measure the power consumption. This requires a tool to set the CPU utilisation to a wanted value and a power monitor device. The tool used is presented in the implementation because it depends on the test platform and some of the tests have been adapted to an environment which was already set up.

3.2.5 Cloud Energy Consumption

Another experiment is the benchmarking of the power consumption of server or servers used to achieved virtualization in a cloud. However this experiment is really delicate as depending on the server used the power consumption will differ as well as the maximum performances. Ideally several servers running the virtualized environment for the cloud should be measured. A small server which could allow the virtualization of four to ten VM instances which would have the same characteristic of the desktop computer benchmarked in the Desktop PC experiment. Also it would be interesting to measured “data-centres type” servers which would offer higher performances in order to compare to the smaller virtualization server. This would allow comparing if somehow the power consumption is related to the number of VM instances and may be allowed to define a footprint of a VM. Indeed the fact of running one VM might or might not have the same increase of energy on the small server and on the bigger one. Unfortunately no experiment of this type seems to have been performed in the literature even-though (Pradeep Padala, 2007) have compared the impact of different virtualization solution and measured the CPU utilization depending on the number of instances. Therefore the methodology will be similar, this means to say starting a VM and measured its energy consumption depending of its virtual CPU utilization and then to start another one and so on and the power will be monitored during the experiment.

Ideally the power monitor device should not require restarting the server. Some monitor devices wrap around the power wire and do not require to unplug the device will be preferred. Otherwise if the server has a redundant power supply, one of the power supplies should be unplugged to install the power monitor device and plugged back in than the other power supply should be unplugged during the entire duration of the experiment.

Also it is important to note that a characteristic of virtualization deployed in a cloud is the architecture of the cloud as presented in the figure 10. It always included a controller also called a front-end server which is used to optimised the allocation of resources, the client initially access the cloud through the front-end which normally has networks interfaces and offers routing functionalities. Indeed the controllers must be connected to the network infrastructure and in the case of a small cloud where all the servers are on the same rack, it might also be connected to the other servers. Virtualization servers running hypervisors are usually referred as back-end servers. Back-end servers represent the core of the cloud; a same instance of VM is not always started on the same virtualization servers and might be dispatched across several servers. The cloud infrastructure is what gives the elasticity to the cloud. The back-end servers are the most important to measure; controllers are expected to have stable power consumption because their CPU is less stressed than back-end server.

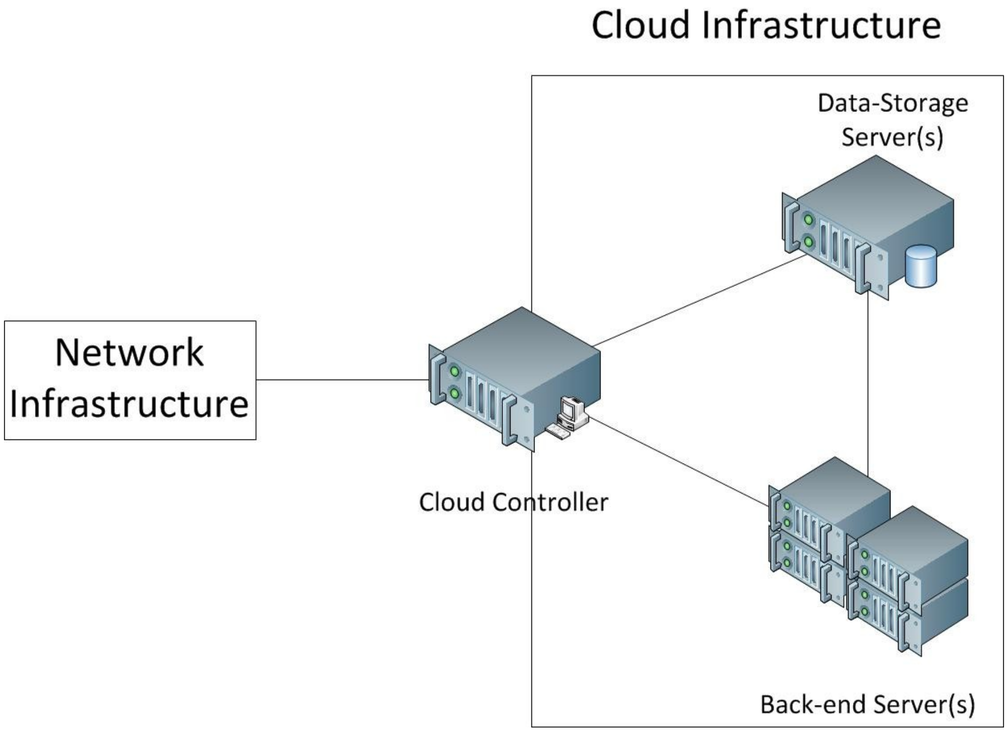

Figure 10: Key elements of a cloud infrastructure

3.2.6 Power Benchmarking of Network equipments

This experiment should include as many network devices as possible. Depending on the Device type the experiment might differ. The range of device should include network switches, router and wireless access-points. (Priya Mahadevan, 2009) have used a number of metric in their power benchmarking framework, only the most representative of those metric will be used because some of the metric they used are not relevant for this experiment. Indeed their aim was to identify what was the most efficient device and what influence its power consumption, the aim of this project experiments are to find the footprint of the device which could be used in order to estimate the global energy consumption of the cloud. Therefore the metric used should be:

- Rated maximum power. This is used to make sure that the experiment was correctly performed. The measured maximum power should be as close as the rated maximum power.
- Measured maximum power
- Measured idle power

Another metric will be used which was not used by (Priya Mahadevan, 2009) is the cost of an individual network interfaces for network switches. This metric will be used to confirm result presented in the literature review such as the power consumes by a Gigabit interface (which was said to be around 2W). This will make possible the estimation of the percentage of energy consume by all the network interfaces on the device. However the methodology used for each experiment might differ because the power consumption of the different devices might be influenced by different factors. The methodologies are explained in the implementations part of the report. However this experiment will not accurately measure the power of the cloud but benchmark the power consumption of equipment which can be used to connect to the cloud.

The result of the test should allow to easily estimating the consumption of the network equipment involved in the interconnection of a virtual lab connected to desktop and mobile devices such as the topology presented in the figure 11.

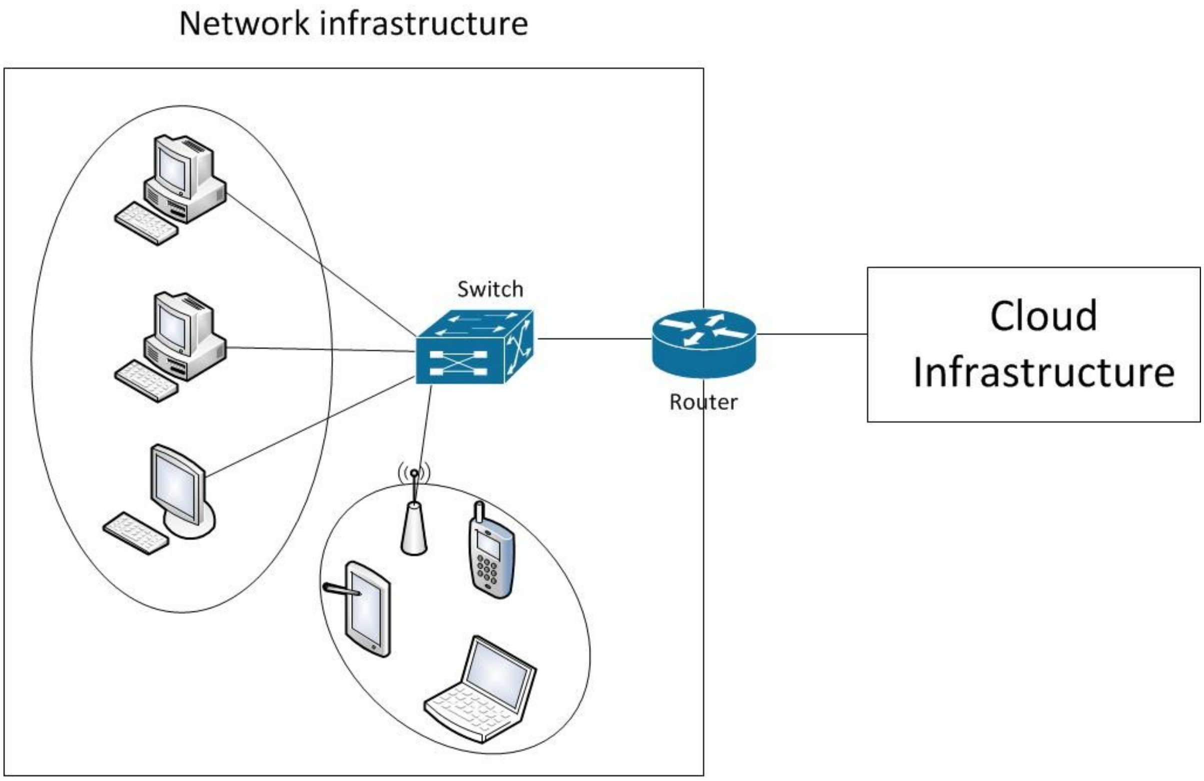

Illustration 11: Access-Network infrastructure of a virtual Lab in a cloud

3.2.7 Energy consumption of mobile Devices

This experiment should show the impact on a cloud application on the device. According to (Vijay Raghunathan et al, 2004) and (Trevor Pering et al, 2005) the communication system of the device is the main actor of the power consumption of the device especially with devices equipped with several interfaces (Yuvraj Agarwal et al, 2005). However to make sure that all devices are tested in the same way all the devices should be equipped with at least a Wi-Fi interface. One of the applications of cloud computing is to remotely access a virtual computer located in a data-centre. Therefore all the processing is achieved in the cloud and the instruction and result of operation are sent to the end device. It has been chosen to evaluate the impact of accessing a VM from a mobile device. The communication should be authenticated; this will generate an important data exchange. But also the device should receive the screen display remotely which should also generate an important data-exchange. This could also represent a device accessing any software and receiving only the display and sending execution information to the remotely located software. Indeed only the amount of processing differs but it is done remotely so the impact on the device does not matter as far as it receives the display and sends information. Mobile devices considered are those with low processing resources which can make great advantages of virtualization and cloud computing. Therefore the device considered should be smart-phones and tablet-PCs as they are replacing PDA. Notebook will not be considered because the battery time really depends on the processor and other components.

To evaluate the electricity consumption of mobile devices, the energy will be used. Indeed the battery accumulates electricity while charging. This electricity is stored and release during the device utilisation. Therefore the amount of electricity accumulated is known and represent the energy. The utilisation time of the device with battery fully charged should allow evaluating the energy utilisation and will give an idea of the power consumption. The amount of battery remaining should be monitored periodically; this will permit to evaluate the tendency of the energy utilisation. 20 minutes should give an accurate enough graph. If the tendency is linear than the power consumption will be constant and can be deducted by divided the energy by the period. If it is not linear the power consumption will be evaluated on shorter period. The power consumption will also to be compared to the power consumption under normal use of the Wi-Fi interface. Therefore the discharging time of the device under normal Wi-Fi use has to be known to deduct the power consumption. The autonomy under Wi-Fi use should be given on the device constructor web-site. Therefore all the data to find are:

- Charging power (Watt)
- Charging Time (hour)
- Energy: E (Watt/hour)
- Autonomy Wi-Fi (hour)
- Autonomy Cloud (hour) it will have to be measured
- Power Consumption Wi-Fi (Watt)
- Power Consumption Cloud (Watt)

3.3 Conclusion

The experiment will evaluate the impact of cloud application on the different element involved, and should allow to deduct the power consumption of a deployed cloud used for virtualization The cloud server when tested should be able to re-create a university lab, or a pool of ten to twenty virtual machines and representing a small cloud use mainly for virtualization. All the experiment will require a power and energy monitor device which should be as accurate as possible and in some case not require unplugging any wire.

First the power consumption of a few desktop computers should be measured. This is to have an idea of the eventual power saving of several VM running on the same hardware. As presented previously the power consumption of a computer depends of its CPU utilisation, therefore the power will be measured on a desktop with a different load on the CPU, and this is the methodology followed by (Gong Chen et al, 2008). Therefore the next step will be to evaluate the power consumption of a server which virtualized a number of VM instances.

But in order to have a complete measure of the consumption of the cloud the electricity consumption of the network architecture should also be measured. This is expected to vary depending on the type of device (Router, Access-Points and Switches) and the model. If cloud facilitates the use of mobile devices, wireless access-points might replace wired switches. The power consumption of wired switches is expected to depend on the number of active interfaces and their speed. The result will give an idea of the footprint of individual equipment and help the estimation of the power consumption of architecture.

The communication sub-system of mobile devices is the main factor of its power consumption and is crucial as their battery is directly affected therefore affecting the usability of the device. Cloud application should constantly refresh the screen display as software is executed remotely and the communication might be authenticated and secure generating an important data-exchange. The impact of cloud application will be evaluated by measuring the discharge time of the battery of mobile devices accessing cloud applications. But the amount of energy accumulate of the devices will have to be known.

All the result will have to be converted in order to obtain the GHG emission of those technologies using the conversion factor of Napier University. In the next chapter the set of tools and the test platform set up for each experiment is introduced. The methodology used will be also be presented in more details as it is sometimes depends of the technology. This will present exactly how the data have been collected.

Chapter 4 Implementation and Methodologies

4.1 Introduction

The experiments have been designed in the previous chapter. It has permitted to clarify the aim of each experiment. The experiments should evaluate the impact of cloud computing on servers used to create a cloud, on the network infrastructure and on mobile devices as there is a potential energy saving if heavyweight end device are replaced by lightweight end-device. This should allow to conclude if a virtualized lab is more power efficient than a physical lab but also to easily estimate the consumption of an actual deployment with a given number of router, server and end devices such as the topology suggestion presented in the figure 12. Also the result obtained has to be converted in order to have the carbon footprint which will be essential for the evaluation.

In the previous chapter the data to gather has also been identified. Even if in most of the case the power utilisation will be the main metric, each experiment might consider power variation depending on another factor. For instance power consumption depending on the CPU utilisation for desktop PC and servers, number of interfaces for network device, or wireless interfaces utilisation for mobile-devices and so on.

Each experiment involved specific equipment and technologies. The methodology used for each experiment highly depends on the experiments and the technologies tested and are therefore presented in this part. Indeed some experiments involved a special set of tools, or monitoring tools which are specific for a technology. This part is composed as followed. Firstly the power and energy monitor device selected is presented and its selection justified. Then the different experiments performed are presented one by one.

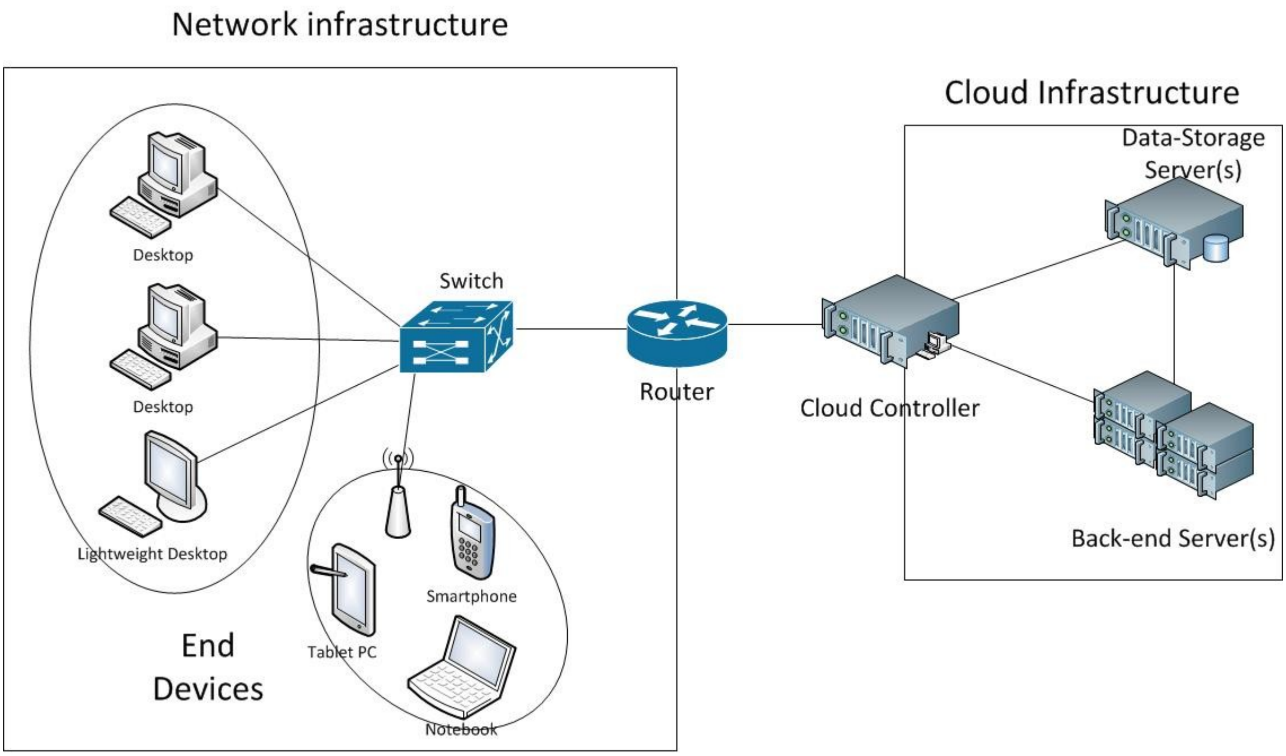

Figure 12: A virtual lab topology's suggestion and all the element involved

4.2 Energy and power monitoring device

In the previous section it has been stated that ideally the monitoring device should not require unplugging the equipment tested. Indeed experiments on cloud involve servers which are already running and should not be unplugged. Therefore energy monitors which do not require to unplugged where the first choices. The Efergy E2 wireless sensor has been tried. A sensor has to be clipped around the cable, and sends data wirelessly to a display monitor and the data can be downloaded on a computer. However this device has been tried and is not suitable to measure individual appliances. Indeed it supposed to measure the power of an entire house and should be placed on the feed cable of the electricity meter. It seems that it is measuring the magnetic field around the wire. The magnetic field is not equal to zero when it is leaving the electricity meter because the positive and negatives charges are separate, positive charges goes in the feed cable and negative in another one. However an appliance connected to the home electricity circuit needs both the positive and negative charges, which are both connected to the plug. Therefore between the plug and the appliances both positive and negative charges are in the same cable. The magnetic field of measured with the sensor was almost always around zero probably because the negative field cancelled the positive one.

Therefore a plug-In and energy monitor has been selected. It has been bought in an electronic store. The device selection has been made primarily on its accuracy, 0.2% whereas the other devices in store had an accuracy over 2% and sometimes 10%. The device selected is shown in the figure 13. Consequently for the experiment the topology will be split and each elements will be measured separately because some cloud are already deployed for test in Napier University but some of the element cannot be unplugged.

Figure 13: Plug-in Energy and Power monitor device

4.3 Desktop PC energy consumption

The aim of this experiment is to evaluate the power consumption of a few desktop computers. Those results will then be compared to result from the cloud experiment in order to evaluate the saving of virtualization. However the power consumption depends on the type of processor and its utilisation. It would be impossible to try every processor available on the market therefore only computer available in Napier University on Merchiston campus especially in labs and in the Jack Kilby Computer Centre (JKCC). On this campus mainly three different processors are used in desktop PC:

- In room C27: Computer's motherboard are equipped with two Intel 4 running at 3,20Ghz each
- In JKCC PCs are equipped with two different configuration, one Intel Core 2 duo CPU E8400 a 3GHz or one Intel Core 2 duo CPU 6420 at 2.13GHz.

The CPU utilisation has varied from 0 to 100% with a 5% increase at a time providing an accurate graph and giving the power used during idle state and during full utilisation. The software CPUKiller3 has been used. This software uses the processor and allow the user to enter the percentage of utilisation the CPU should be using. The figure 14 show the interface of the software, the scroll bar allow setting the CPU to a certain percentage of utilisation and the actual CPU utilisation is given by the graph.

Another way to load CPU but not gradually is to use a ping flood. Ping flood is Denial of Service (Dos) attack which consists in overwhelming a host with ICMP requests. A new ICMP request is sent as soon as one ICMP reply is received, instead of waiting the default 1 second period. It normally only works if the attackers has more bandwidth than the victim. However it is possible to perform a ping on a loopback interface, meaning that the host is flooding himself. The CPU utilisation goes straight to 100%. This method will be used on Linux VM which cannot run the CPUKiller3 software as it is only supported on Windows. However as said before this method does not allow to increase the CPU utilisation gradually. The command to perform a ping flooding on Linux host is:

```
root # ping -f 127.0.0.1
```

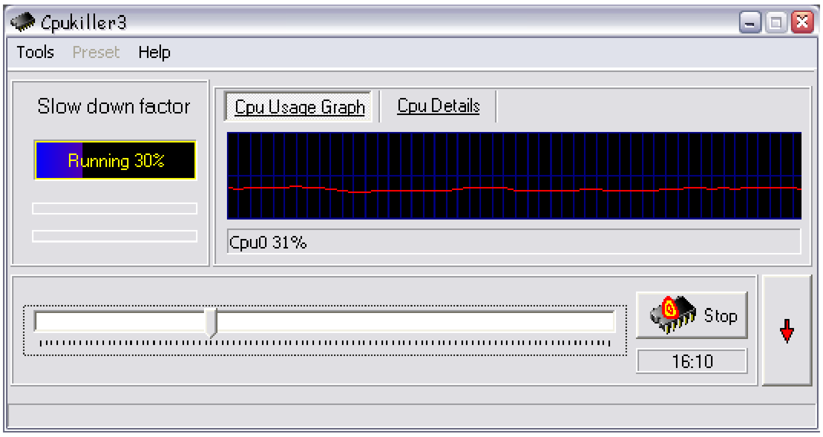

Figure 14: CPUKiller3 interface setting CPU utilisation at 30%

4.4 Cloud power consumption

The aim of this experiment is to evaluate the power consumption of a cloud infrastructure use to create a virtualized pool of computer. This experiment is looking at the power consumption depending on the number of VM instances running. Virtualization allows the allocation of a certain amount of resources to each VM. However the power consumption depends on the CPU utilisation.

The methodology used is as follow: Each VM had a virtual processor and its clock frequency has been set in advance. One VM has been started and its CPU utilisation has been increased gradually until it reaches 100%, exactly as for the desktop PC experiment. When a VM is using its entire virtual processors a new VM has been started and its CPU has been increased and so on. The global CPU utilisation has been monitored as well as the power consumption of the server.

Each instances of VM had a virtual processor running at least at 2GHZ and 2Mb of Ram. This is has been decided because this represents a decent amount of processing resources. Also on each of the cloud tested each processor were multi-core with each core running around 2 GHz therefore each VM would have the power of a core for itself. The experiment has been conducted on two different clouds:

- A Test Cloud: XEN 3.4.2 as the hypervisor on Dell Power Edge T310 equipped with one Intel Xeon X3430 quad-core, 2.40 GHz/core and 12 GB of memory. The controller is Open Nebula 1.4 running on a Dell Power Edge T110 with a one Intel dual-core E6500, 2.93 GHz/core and 2048 Mb of memory. The power supply of the hypervisors is non-redundant therefore it will have to be shut down to place the device. VMs were running Windows XP.
- A Production Cloud: VSPHERE 4.1.0 as the hypervisor on R410 on a Dell Power Edge R410 with two Intel Xeon E5520 quad-cores, 2.27 GHz/core and 16Mb of memory. The controller is running on a Dell Power Edge R410 with two Intel Xeon 5504quad-core, 2GHz/core and 12GB of memory. The power supply of the hypervisor is redundant; one of the power supplies will be removed while the device is being installed. VMs were running an Ubuntu 10.4.

In the VMware cloud the data storage and databases are located on different server or

Network Attached Storage (NAS), this is not the case for the small XEN cloud used for the test where the data storage is made directly on the virtualization server. The figure 15 show the network map of the VMware cloud deployed. It shows logical connection between networks and the different element of the cloud. The server 146.176.166.69 is the virtualization server measured; the server 146.176.166.65 and 146.176.166.67 are other virtualization servers. Each server has it own data-server and they all shared one data-server named Shared Data-Store.

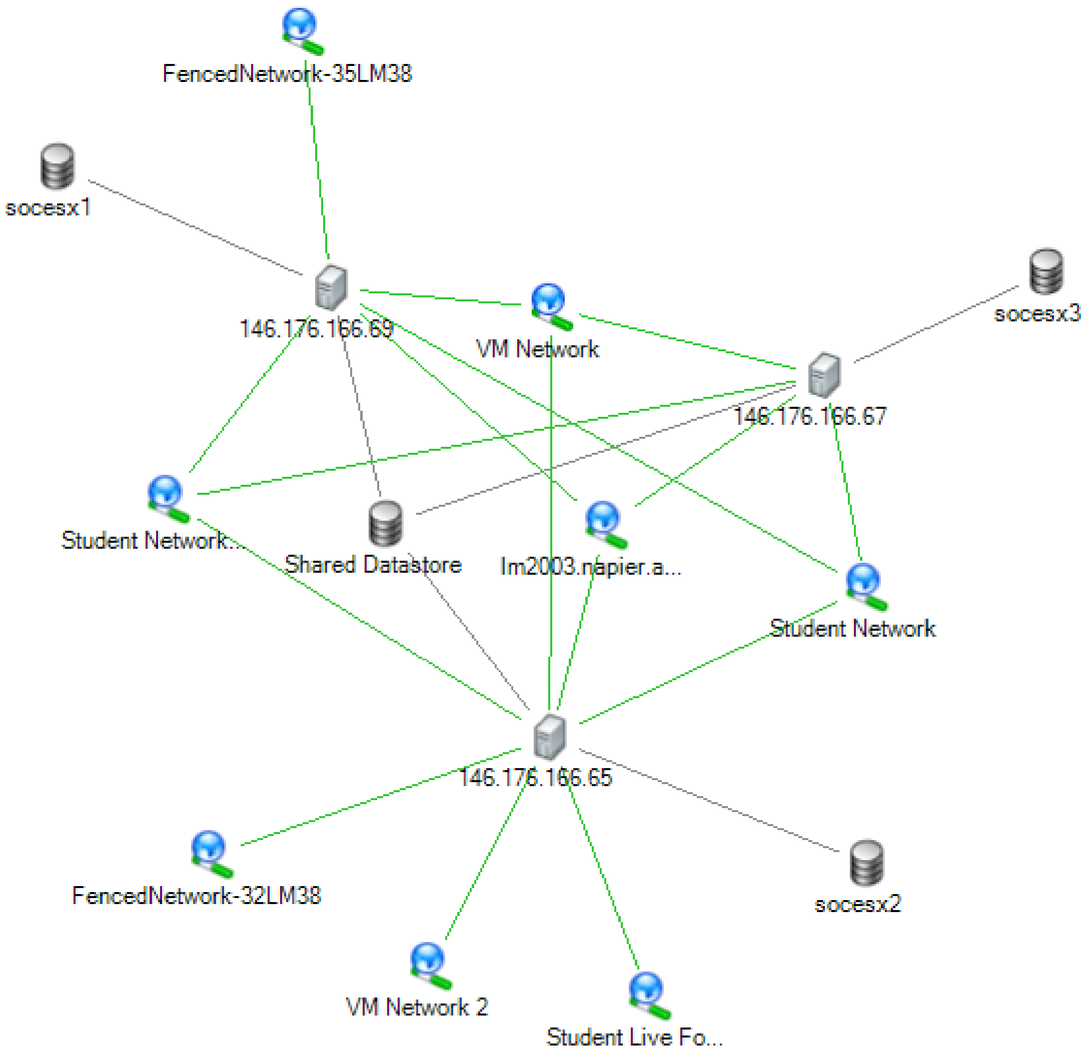

Figure 15: Network map of the VMware cloud

4.5 Power Benchmarking of Network equipments

The aim of this experiment is to power benchmark as many network equipment as possible, which could be used to interconnect end-devices to the cloud. As it is not possible to unplugged devices that are in used on the Napier Merchiston campus only equipment available to networking student have been benchmarked, this are equipment in room C28. This experiment gives an idea of the power consumption of those equipments. The experiment considers network switches, routers and wireless Access-points (AP). This experiment does not accurately measure the power of the cloud but benchmark the power consumption of equipment which can be used to connect to the cloud.

4.5.1 Network switches

The main factor of the energy consumption of a network switch should be the number of network interfaces and their speed-rate according to (Maruti Gupta et al, 2003), (Chamara Gunaratne et al, 2005) and (Priya Mahadevan, 2009). The test benchmark access-layer switches. Those switches could be used to connect desktop lightweight clients to the virtual lab in a cloud. In order to find the maximum power consumption all the interfaces of the switches must be connected. The load of the switch only has a small impact therefore no traffic will be injected in the switches. For each switch considered, three switches are used to measure the power of one of them. Their interfaces are connected to each other creating a loop and then STP is deactivated. This create a broadcast storm, every switch forward the broadcast message on all of his port except the one which has receiving the broadcast, the message is forwarded indefinitely on every port as explain in figure 16 except that every port is connected. All the interfaces are used and this represents the measured maximum power. The power is measured before the entire interface are in used and during the broadcast storm. The broadcast storm is running for some times but the power consumption become stable after a few seconds meaning that a maximum is reached.

If the power consumption increase continuously the test might not be appropriate because this would mean that something else is needed more power to work correctly such as a processing component. The broadcast storm will use every interface instantaneously. The power is measured on one switch at a time.

Four models of access switches will be benchmarked:

- Cisco Catalyst 2950 Serie: 24 fast-Ethernet interfaces and 2 Gigabit interfaces
- Cisco Catalyst 2960 Serie: 24 fast-Ethernet interfaces and 2 Gigabit interfaces
- Cisco Catalyst 3550 Serie: 24 fast-Ethernet interfaces and no Gigabit interfaces
- Cisco Catalyst 3560 Serie: 24 fast-Ethernet interfaces and no Gigabit interfaces

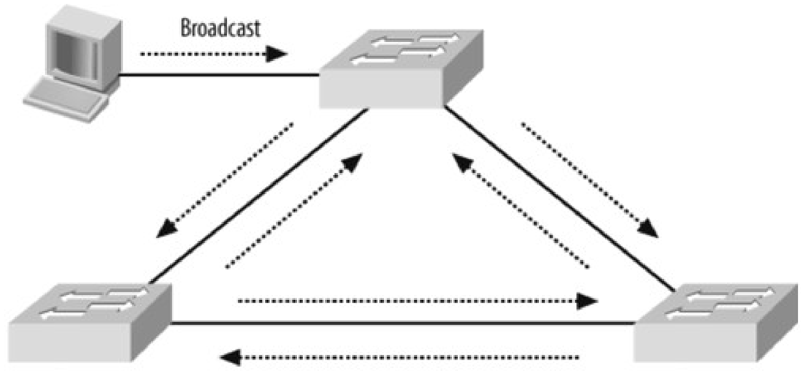

Figure 16: Broadcast Storm with three switches

4.5.2 Routers

As core router are not considered in this experiment because core router will always be needed without the cloud. Furthermore it is difficult to evaluate the impact of the cloud on a core router because every cloud deployment will be different. Therefore smaller router will be benchmark, ideally routers with Gigabits interfaces. To benchmark the router the power is measured when none of the interfaces is used, this is the measured idle power and then when the interfaces are up. Then traffic will be sent at the maximum rate of the interfaces and should go from one interface to the other a return.

If the measured maximum power is under the rated maximum power and the difference is important this would mean that the router is not correctly loaded. But the result show a power consumption close enough to the maximum rated.

Unfortunately only one type of router is made available to student in room C28 and does not have Gigabit interfaces:

- Cisco 2811 Series with two Fast-Ethernets and no Gigabit interfaces

Traffic is sent on one interface to the other one. The speed-rate of each interface is changed in order to evaluate the cost of 10Mbps interfaces and of a 100Mbps interfaces. However according to (Chamara Gunaratne et al, 2005) the cost of a 100mbps interfaces should be 0.3watt therefore the cost of a 10Mbps interfaces should be smaller and depending on the power variation of the device, the monitoring device might not be able to appropriately measure the difference.

4.5.3 Wireless access-points

Wireless Access-Points (AP) have also been benchmarked. There is two types of AP, APs standing alone (heavyweight) or APs managed by a controller (Lightweight). Lightweight AP would be the preferred solution for a deployment however it is still interesting to measure the difference of power consumption of an AP in different modes. It was expected that the lightweight AP consumes less power than the heavyweight which should do more things.

However this is not the case and a hypothesis is proposed in the result analysis. If lightweight access-points are deployed WLAN controller is needed. The Controller and the AP communicate using the LightWeight Access Point Protocol (LWAPP) and allow the centralization of the AP management but require a constant communication. The figure 17 present a deployment suggestion for a lab providing operating systems and processing resources virtualized in a cloud and using wireless AP. The easiest deployment would be one using lightweight Ap (marked LAP1, 2, 3, 4) a controller (marked WLC) which usually is a module in a switch. Therefore the entire topology includes a switch with a controller and a router and several Aps. Different parameters should also be changed during the test such as:

- Power transmission
- Type of 802.11 network (A,B, and G)
- Security (Wep, WPA2) when traffic is generated

  After all the experiment the estimation power consumption of the scenario presented in the figure 17 will be possible.

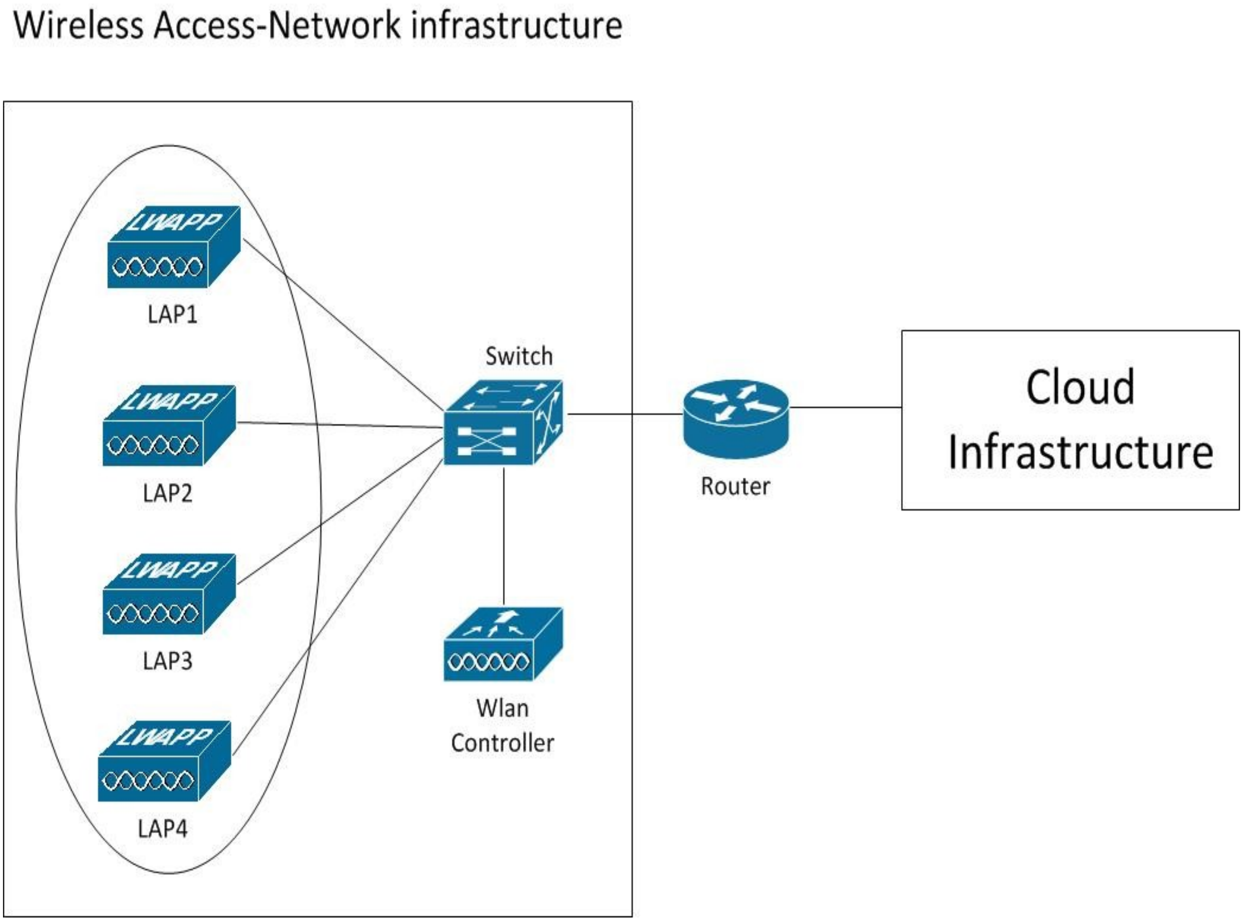

Figure 17: Wireless infrastructure's suggestion

4.5.4 Traffic Generation

To measure the power consumption of router and AP which are forwarding traffic, traffic needs to be generated. The traffic has to be as real as possible. The Lincoln Laboratory of the Massachusetts Institute of Technology (MIT) makes available a sample of traffic (DARPA data set) they captured over a 22 hours period on the MIT network (Lincoln Laboratory, 2009). The offers several samples some contains attacks they generated and are mostly used to evaluate and tune Intrusion Detection Systems (IDS). For this experiment the content of the sample must be diversify and use wide range of protocol (UDP and TCP) therefore one of the attack free sample has been selected. To replay the traffic, three tools are used on a Linux machine.

Firstly the sample has to be prepared. The client-side traffic and the server-side traffic must be recognized and split this will help the third tool which will have to send the traffic. Indeed the traffic will be sent faster because no more calculation will be made to recognize the client-side and the server-side traffic. The tool tcpprep can perform this action. In bridge mode the DAPRA data set (DARPA.pcap) can be separated in client and server-side traffic, the calculation information are placed in the input.cache file.

```
tcpprep --auto=bridge --pcap=DARPA.pcap --cachefile=input.cache
```

Secondly the DARPA.pcap file needs to be rewrite in order to adapt the traffic to the test platform. Indeed now that the client and server side traffic has been identified it has to be sent to the host in the experiment. Tcprewrite can modify all the IP addresses in the DARPA.pcap file using the input.cache file previously created. This will create a new file rewrited_DARPA.pcap containing only the client/server traffic identify previously. The sending endpoint (which will play the client taffic) is 10.0.0.1 and the receiving one is 10.0.0.2 (playing the server traffic).

```
tcprewrite –endpoints=10.0.0.1:10.0.0.2 –cachefile=input.cache
--infile=DARPA.pcap --outfile=rewrited_DARPA.pcap --skipbroadcast
```

Thirdly the traffic has to be sent on the network. The tool tcpreplay can replay an entire communication saved in a pcap file. Tcpreplay is used to replay the rewrited_DARPA.pcap, previously generated, containing only the client and server traffic. Different options can be used such as loop which define the number of time the sample of traffic is sent and --mbps which specify the data rate, the option –topspeed sent the traffic at the maximum speed supported by the interfaces and –int specify the interface to send the traffic on.

```
tcpreplay —-topspeed --intf1=eth0 rewrite_DARPA.pcap
```

The traffic has been sent using the top-speed option because in all the experiment the speed-rate of the traffic didn't have an impact on the power consumption of the devices monitored. The experiment is simple two computer need to be connected to the router or access-point and the traffic needs to be sent between them across the device. The test platforms set up for the experiment set up is presented in 18.

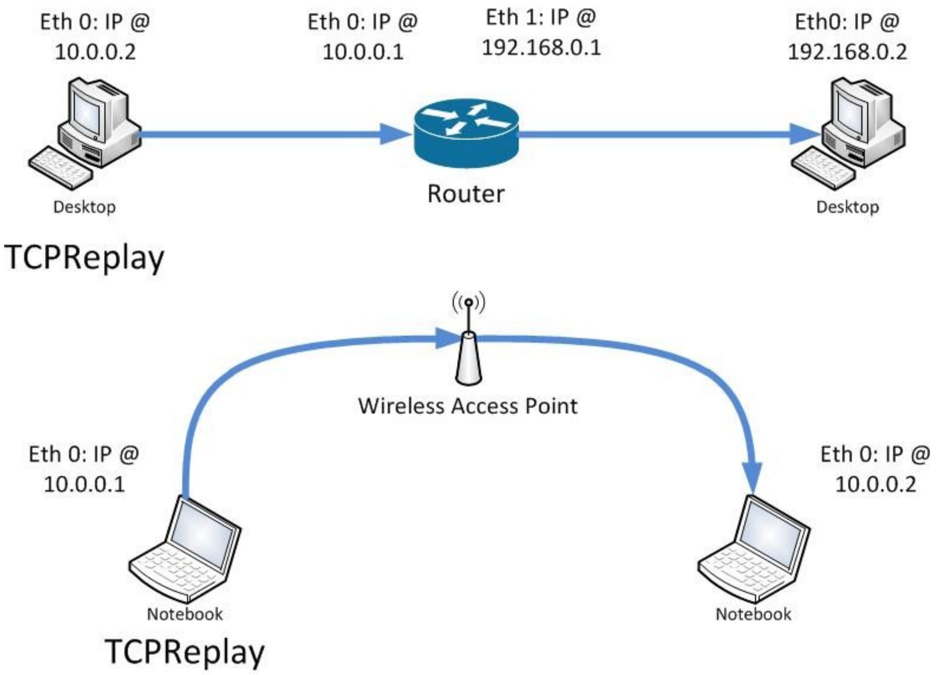

Figure 18: Traffic generation test platforms

4.6 Energy consumption of mobile devices

The aim of this experiment is to evaluate the impact of cloud computing communication on a battery powered devices. Indeed it is expected that the battery utilisation time highly decrease with the utilisation of cloud application as the communication system of the device is highly solicited. To evaluate this impact, the experiments look at how fast the energy is consumed by the device. Therefore the amount of energy accumulated during the charging time of the device had to be known. To do so, the device's battery needed to be completely empty. Then the battery-charger was plugged on the energy monitoring device during the entire charging time. This gave the amount of energy accumulated in the device. Then a simulation of a cloud application accessing a VM from the device had to run. The battery level was monitored every 20 minutes until the battery reach a low level such as 5% of battery remaining. Then all the values will be presented as a graph. The graph will permit to evaluate the power consumption of the device accessing the cloud. Also this will also give the minimum utilisation time of the device accessing the cloud; this result will be compared to the theoretical utilisation time of the device under normal utilisation using its wireless interfaces.

To simulate a communication as close as possible of the device accessing the VM, the Virtual Network Computing (VNC) system is used. VNC allow to remotely controlling a computer using the Remote FrameBuffer (RFB) protocol allowing remote access to graphical user interfaces. RFB is used in VNC and its derivatives. It is a client-server protocol, the client or viewer access the server through the TCP port 5900. After an authentication phase the viewer can send input command to the remote computer. Depending of it implementation, the server refresh the screen pixel by pixel when changes happen or by group of pixel such as VNC implementation of VNC. However for the experimentation, it is important to be sure that the communication is not uni-directional. Indeed the client should send command to the server and the server should send information to refresh the screen to the client. However the traffic as been captured during a VNC exchange showing that the communication is bi-directional even if the no command is sent from the client but the server is refreshing its screen because of all the acknowledgement and authentication frames sent. The figure 19 shows a sample of a VNC communication between a server (with the IP address 192.168.0.7) and the client (with the IP address 192.168.0.11), during the capture the client was not sending commands to the server and the communication is bi-directional. Accessing a VM in a cloud or accessing a physical machine is the same for the device because the processing is achieved remotely and the device receives the screen display and sends commands.

To perform the test, all the devices are connected to the server which is running a RealVNC server. The server reproduced a normal office use such as web-browsing and report writing just to make sure that the screen is refreshed. The screen display is sent through VNC to the clients. The RealVNC version tried was the free version and did not support encryption.

All the devices had their GPRS interfaces on if they had any but their 3G was shut down. Because it is expected that a smart-phone would always be connected to the GPRS network but not necessarily to the 3G which is power consuming. The devices tested are:

- Ipad 3G, this will illustrate the tablet PC. The VNC client used is the applications Mocha VNC Lite. Theoretical Wifi autonomy 10 hours. Charging time 2h30 at 10.6W.
- Iphone 3GS, to illustrate a smart-phone. The VNC client used is the application Mocha VNC Lite. Theoretical Wifi autonomy 9 hours. Charging time 2h15 at 5.5W.
- Sony Ericsson Xperia X10 Android 1.6 to illustrate a smart-phone but from another vendor than the previous two devices tested. The VNC client used is android-vnc-viewer. Theoretical Wifi autonomy 10 hours. Charging time 2h15 at 5.5W.

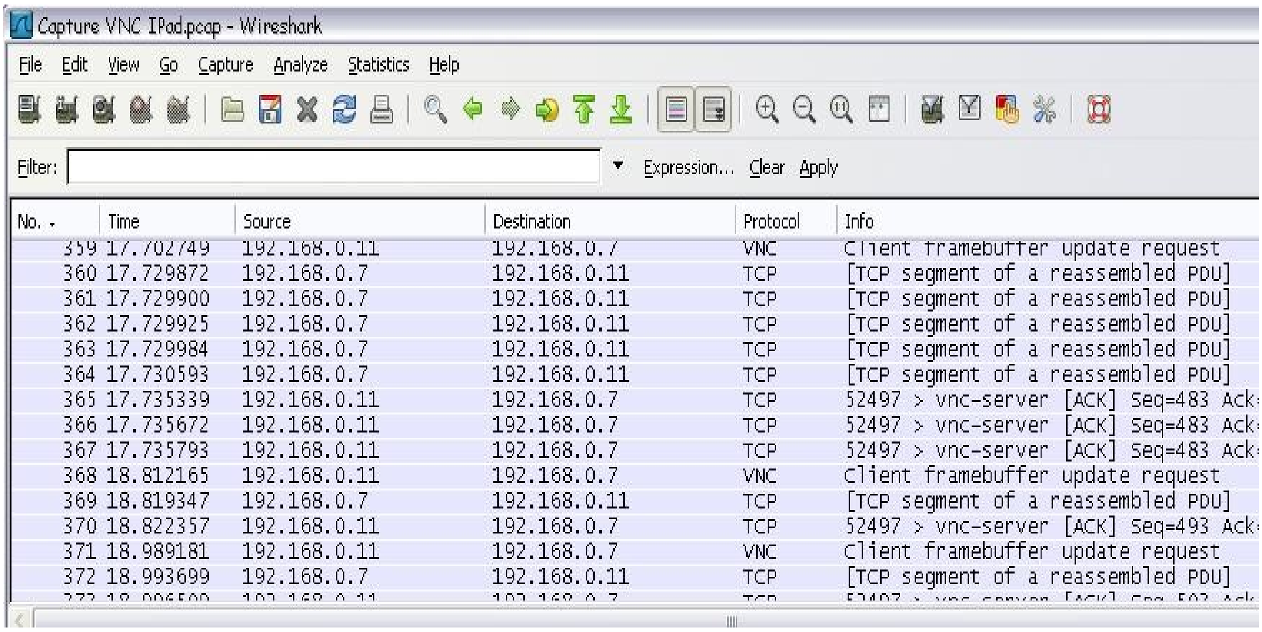

Figure 19: Sample of a VNC communication

4.7 Conclusion

In this chapter the different experiments have been presented in more details focussing on how they have been implemented. The aim of this project is to evaluate the power consumption of an entire cloud infrastructure used for desktop virtualization and to estimate the power saving compare to a physical desktop deployment. The result should allow the power consumption estimation of a deployed cloud depending on the number of network equipment, server and end-devices. However the cloud infrastructure has been split in several parts.

Because the experiment on cloud have used cloud already deployed and in use, some of the element were not measured because it would have required some shut down which were not advised. Therefore controllers have not been measured but are expected to have a fixed consumption. However the most interesting element to measure for this experiment was the consumption of back end servers. Two kinds of back end server were measured, a small one in a tour used mainly as a test platform and a more powerful one in a server-rack type which could be found in a small data-centre or on a company production network.

It was not possible to measure the actual power consumption of the network infrastructure used for the cloud however other equipment which could be used has been benchmarked. This gives an idea of the power consumption per equipment.

To evaluate the impact of cloud computing on the battery of mobile devices the experiment simulates the communication of a mobile-device accessing a VM. It is done using a VNC system, each mobile device have a VNC client and access a remote-computer which running a VM server.

In the next part the results obtain are presented and analysed. It permits to emit conclusions essential for the evaluation of the power consumption of a cloud and potential saving against a physical deployment of a pool of computer.

Chapter 5 Result Analysis

5.1 Introduction

The data collected during the experiments needs to be analysed in order to emit conclusions. The conclusions will then be used to produce the evaluation which represents the main aim of the project.

The result analysis looks through all the data collected during the experiments defined in the design on the platform presented in the implementation. First the analysis of power consumption depending on the CPU utilisation on a several desktop computer has been performed. This result will be compared to the footprint of a machine virtualized in a cloud in the evaluation. The power consumption of a virtualization server has been measured on two different hardware offering different performances. The footprint of the VM will also be compared between the two clouds. Then the result of the power benchmarking of the network equipment will be presented as a table and will mostly be used in the evaluation to give the footprint of each devices. Afterwards the impact on the battery of mobile devices accessing a remote computer will be presented and analysed. This will determine if mobile device accessing a VM is a feasible idea for everyday use considering the impact on the battery.

In this chapter the term heavyweight desktop refer to the deployment of desktop PC. It is use in opposition to the term lightweight client which defines the end device for the cloud deployment.

All the results should permit to determine if a cloud use for virtualization is more power efficient than a physical lab. All the raw data collected are presented in Appendix A.

5.2 Analysis of Desktop PC power consumption

As presented in the implementation, three types of configuration have been benchmarked on Napier University Merchiston Campus:

- PCs with two Intel 4 running at 3,20Ghz in room C27, referred as room C27
- PCs with one Intel Core 2 duo E8400 processor a 3GHz in the Jack Kilby Computer Centre, referred as JKCC type 1
- PCs with one Intel Core 2 duo E6420 processor a 2.13GHz in the Jack Kilby Computer Centre, referred as JKCC type 2

Their CPU utilisations have been increased gradually and their power monitored during the entire time of the experiment. The experiments have been performed on several PCs with the same configuration and have shown a negligible difference between them. Therefore the result shows the results of one example per configuration. The results are presented in 20.

The curves being approximately linear, it has been chosen to use a mathematical function in order to analyse them because it will facilitate its analysis. The abscissa axe will be referenced as x and f(x) will represent the power consumption for a particular value of x. Linear curves can be represented as:

$f(x)=mx+b$

The value b is the initial value and is found at x=0, this represent the computer idle state. Ideally the value should be as small as possible.

The value m is the gradient; it gives the steepness of the graph. Ideally the curves should be as horizontal as possible because the CPU is directly responsible of the power consumption therefore m should be as small as possible. "m" can be deducted if for an x given the f(x) is known. As the curves here are approximately linear but not completely the value m will be deducted when x=100 as it is the maximum on the graph. The table 1 represent the value m and b and f(100) which as permitted to deduct m and the figure 21 represent the graphical representation of the functions. It can be seen that the mathematical representation look similar to the measured value.

Configuration type	b	m	f(100)
Room C27	79.7	0.88	168
JKCC type 1	31.2	0.32	63.2
JKCC type 2	101.5	0.37	138.2

Table 2: f(x)=mx+b and relevant values

The initial value b represents the power consumption when each computer is in idle state. There are noticeable differences between each configuration. Indeed the one with the smallest initial values is the JKCC type 1 computers which consumes only 31.2 W compare to the computer in room C27 with 79.7 W (approximately 2.5 times more) and JKCC type 2 with 101.5W (approximately more than 3 times more). Therefore it would be more power efficient to have only JKCC type 1 computers on campus if those computers where to be in idle state most of the time.

The gradient "m" gives the steepness of the graph. The smaller m is, the shallower the curve is and therefore the more power efficient the CPU tested is. Indeed if the CPU utilisation does not increase the power consumption the CPU is ideally power efficient. It appear that the computer in JKCC have almost the same gradient (0.32 and 0.37) therefore it can be concluded that they are as power efficient. The main difference is their initial value which is due to something else, indeed some of the chassis in JKCC have been upgraded with a new CPU such as JKCC type 2 whereas JKCC type 1 are in new chassis probably equipped with more efficient power supply and other components. However in the room C27 configuration the gradient is the highest (0.88) which mean that for every per-cents of CPU utilisation the Wattage increase of 0.88 W, almost a Watt. The only explanation for this result would be that it is the oldest CPU tested indeed Intel Pentium 4 processor were released in 2004 whereas Intel core 2 duo started being released in 2008. The processors market is continuously improving and the power efficiency has probably been improved as well. Those processors should be removing from the campus even-though the initial value is smaller than the JKCC type 2 value.

Therefore the configuration of JKCC type 1 is definitely the most efficient, it has a recent Intel Core duo clocked at 3Ghz which is the better processor tested in this experiment and has the smaller initial power consumption and the smaller maximum power consumption therefore it is also the most power efficient. However the processor in JKCC type 2 has the same gradient but the highest initial value, therefore the processor is not the main factor of the energy consumption. As mention earlier JKCC type 2 computer has a new processor in an older chassis and other element might consumes power for instance an inefficient power supply. The computer in room C27 is the older and has the least efficient processors. Indeed it has the highest gradient and a high initial value. Again the processor might not be the only responsible of this high consumption in idle state but the gradient confirm that the processor is not power efficient and should be removed.

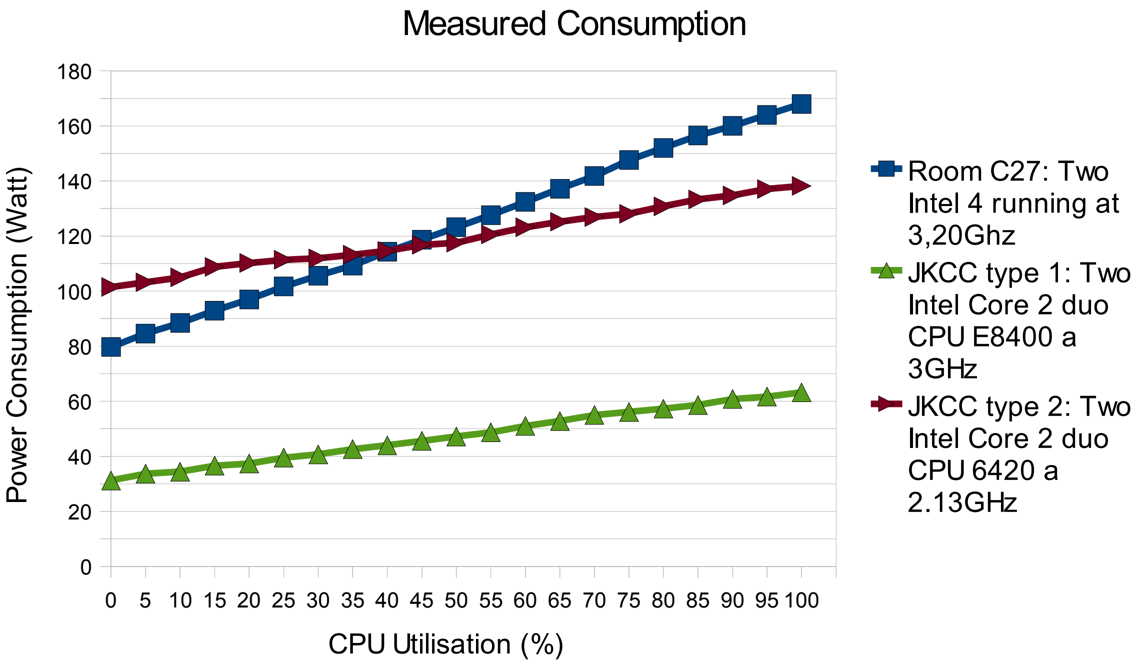

Figure 20: Power consumption of Desktop PCs depending on their CPU utilisation

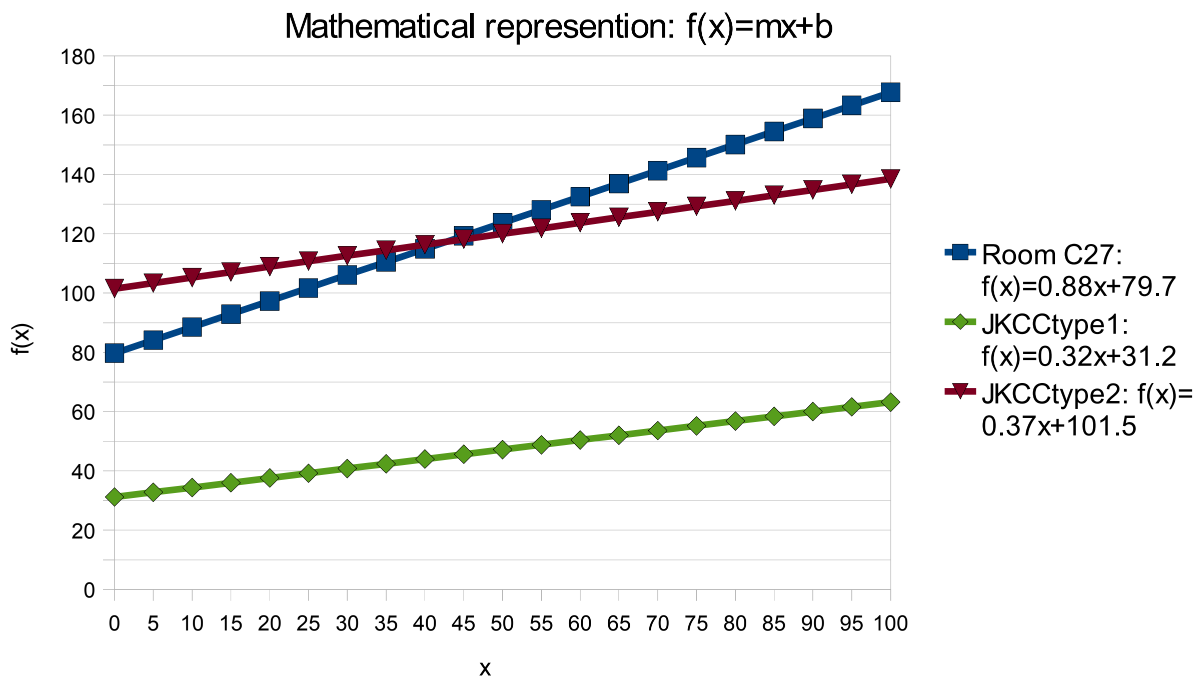

Figure 21: Mathematical representation of the Power consumption of Desktop PCs depending on their CPU utilisation

5.3 Consumption analysis of virtualization clouds

The power consumption has been monitored on two different virtualization server in two different cloud. One of the cloud is used for test and does not have huge resources but can still virtualized up to twelve VM with 1 Gigabit of Ram each. And the other one is use in Napier to provide VM. The entire cloud has been able to virtualized 35 VM simultaneously during a tutorial referred as Production Cloud.

5.3.1 Test cloud power monitoring

Experiment on the test cloud has permitted to identify some relation between the power consumption and a VM. The server had one Intel Xeon X3430 quad-core, 2.40 GHz/core. Each VM have been allocated one core and 2 Gigabit of Ram. Therefore four VM have been started one at a time, and their CPU increased gradually. The power has been monitored every time the CPU was increase by 20%. The results are presented in table 2. The figure 22 show a graphical representation of the data collected. It appears that each curve is increasing but not steeply. The differences between each VM when their utilisation is 0% represent the maximum cost of one VM and the efficiency of the virtual CPU allocated to each VM. This value is important for the evaluation when comparing to the cost of physical machines. The cost is respectively for each VM 22W, 12.1W, 12.2W and 9.2W. The first VM has shown an abnormal increase in CPU after 80% of its utilisation however the maximum cost per VM seems to be around 11W. In the table 2 the 100% column is the starting value of the next VM meaning that the curves could be join together as one curve representing the general CPU utilisation of the server. Indeed theoretically each VM has been allocated one core of the server which only has one quad-core processor. Therefore if each VM is fully using its CPU the processor should be fully used. However this is not the case because the maximum power consumption measured was 128.3W on the same server and was not reached while performing this experience but when the server was emulating sixteen VMs. Therefore this shows that the server only pretend to allocate an entire core to the VM. It seems that the server saves resources for itself and could therefore allocate more resources than it has. The figure 23 represent the supposed CPU utilisation if the server really allocated a core to each VM, this graph is in fact the four curves of the graph in 22 joint as one curve. The first value is the idle state which is the state when no images were emulated. There is a difference between the first value and the idle state, this could be because that the hypervisor might reserve some resources to virtualize each VM confirming that the hypervisor require resources for itself and does not give all of its resources. The cost of each VM is mentioned as well as the tendency curve. However the cost per VM is 14W. The tendency is a linear function and will also be used to compare the gradient with the other cloud. It equation is:

$f(x)= 0.56x+62.5$

	0.00%	20.00%	40.00%	60.00%	80.00%	100.00%
Machine 1	60	63.5	64.4	65.2	66.2	82
Machine 2	82	85.2	88.1	88.5	89.3	94.1
Machine 3	94.1	95.9	97.5	99.2	101.3	106.5
Machine 4	106.5	104.5	106.3	104.1	106.4	115.7

Table 2: Power Consumption of the VM depending of their CPU utilisation

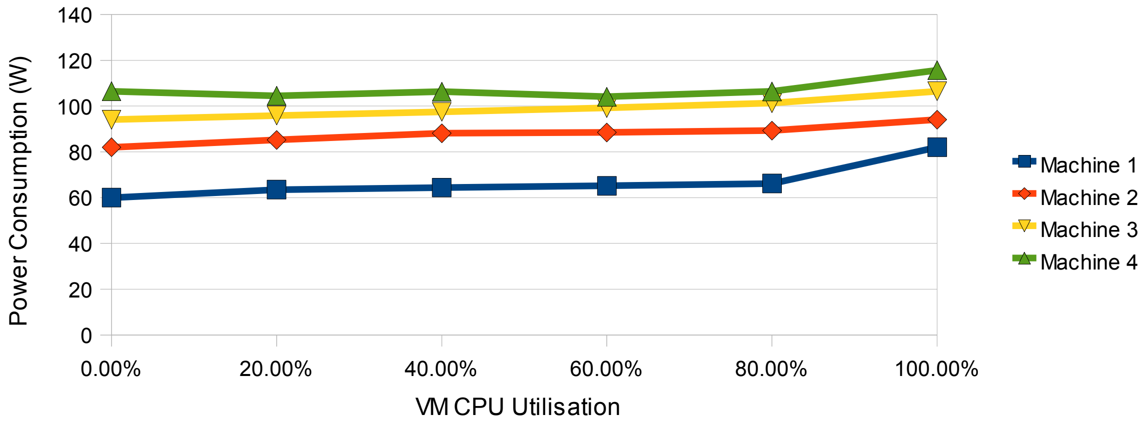

Figure 22: Power consumption of the test cloud depending of the CPU utilisation of each VM

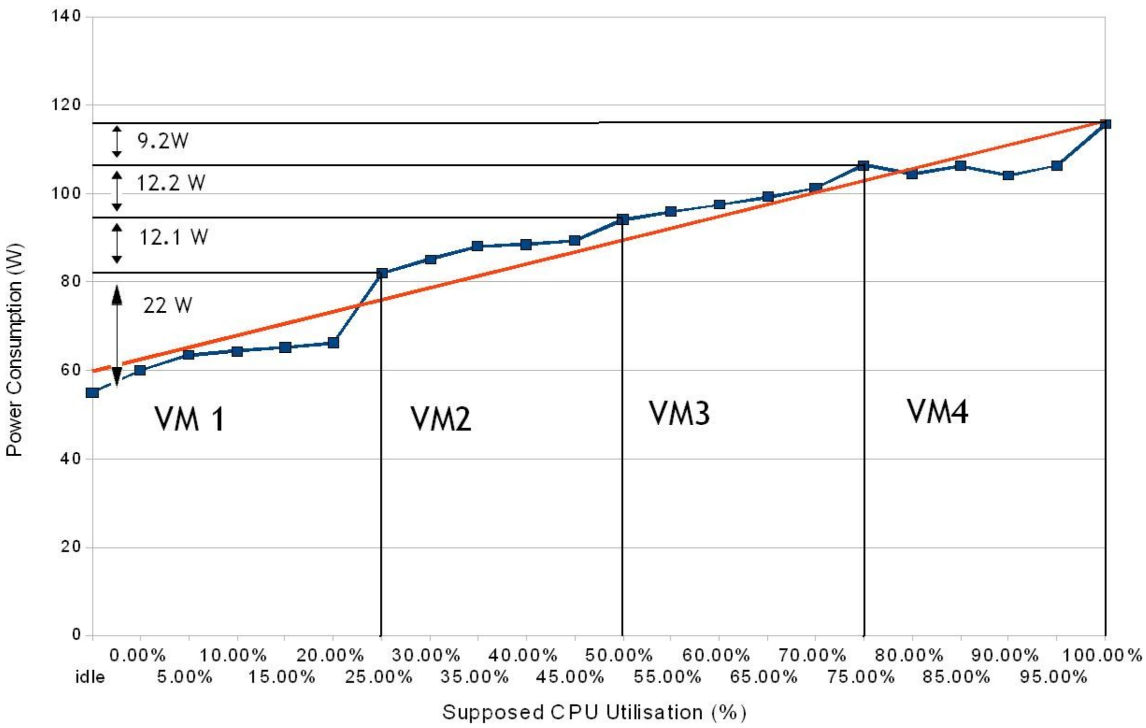

Figure 23: Global CPU Utilisation of the test cloud (Supposed)

5.3.2 Production-cloud power monitoring

The server monitored for this experience was a running on a R410 on a Dell Power Edge R410 with two Intel Xeon E5520 quad-cores, 2.27 GHz/core and 16Mb of memory. The server was in used and running VM instances which were not required for this experiment. Therefore in the result analysis it has been assumed that the resources' utilisation related to other activities than the experience was fairly stable and did not influence the result obtained. The rack-server was equipped with redundant power-supply however one device was plugged on one power supply but the other one remain plugged for the entire time of the experiment for safety reasons. Therefore the result obtained has been double up as the tension on both power supply should be the same according to the Dell Power-edge R410' technical guidebook. The server was able to virtualized eight VM with the equivalent of a core of processor allocated to each of them and 2 Gigabit of Ram. However as mentioned some other instances might have been running at the same time. The figure 24 shows the global CPU utilisation of the server. Each dot represents one VM with its CPU loaded at 100%. It has been decided to just take the measurement when the VM was fully loaded because on the previous cloud the power consumption depending on the CPU utilisation was linear. However the tendency curve is also represented. The equation of the tendency curve is :

$$f(x)=0.59x+175$$

The gradient of the curve is almost similar to the gradient of the previous curve. However the production cloud is more efficient because when the test cloud and the production reached 100% there consumption has increased respectively by 56 and 59 W but the production cloud is twice has twice as much processing resources than the test server.

Apart from the difference between the first VM launched and the second VM launched and the fifth and the sixth one, the difference between VMs is between 5 and 7 W. This represent the cost of a VM and it is smaller than on the previous cloud measured. The figure 25 shows the CPU utilisation of the server. Each VM loaded to 100% is clearly identifiable by a step equivalent to 15% or approximately 2 GHz. On this graph the power consumption equivalent from the previous graph have been added on three representative steps. This shows the cost of a VM in Watt but mainly the cost of 2 GHz in Watt which approximately 6.4W (about half the cost of the same VM in the previous cloud). However the average cost per VM over the eight VM is 7.65W. Therefore this could be used to express the cost per GHz instead of the cost of a particular VM. For instance if any VM were allocated only 1 GHz they would have had a maximum cost of 3.82W.

In this experiment the actual CPU of the server was measured and not only the CPU utilisation of each VM. It appears that the maximum could not be reach even if each VM were supposed to utilise all the resources of the server. This confirm that the server saves some resources and cannot be overloaded by a VM trying to take all its resources however the end of the graph is not as clear as the beginning probably because the server start being overloaded and try to keep resources to maintain the VM.

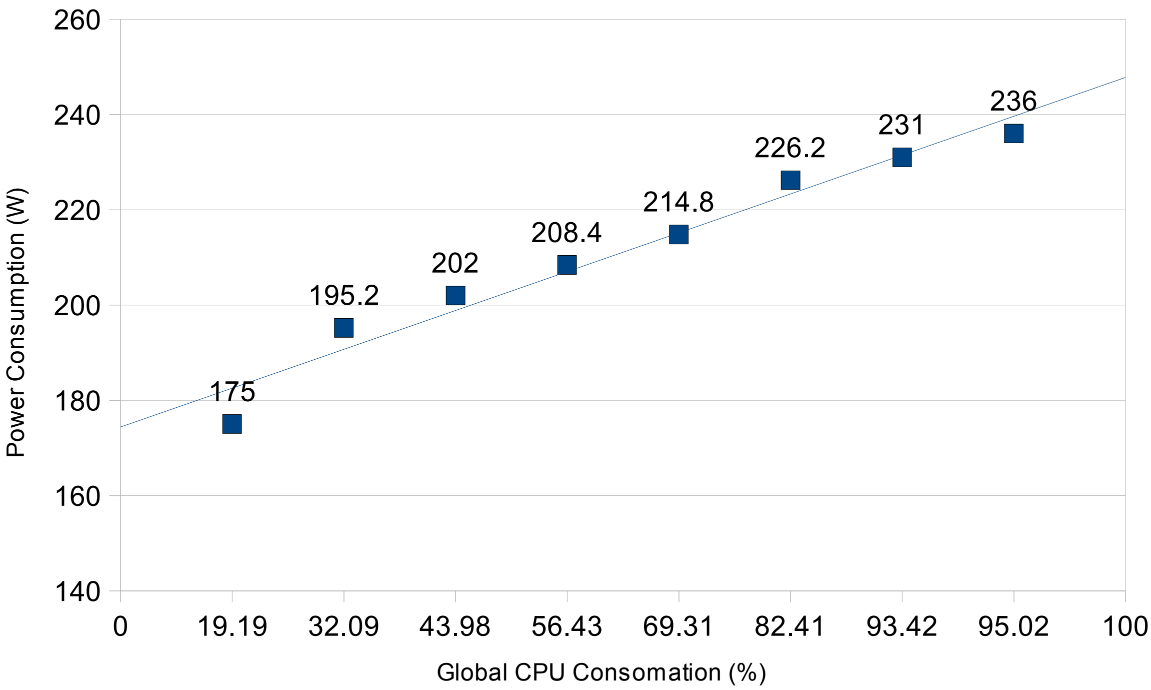

Figure 24: Production-Cloud Power consumption depending on the number of VM and the CPU utilisation

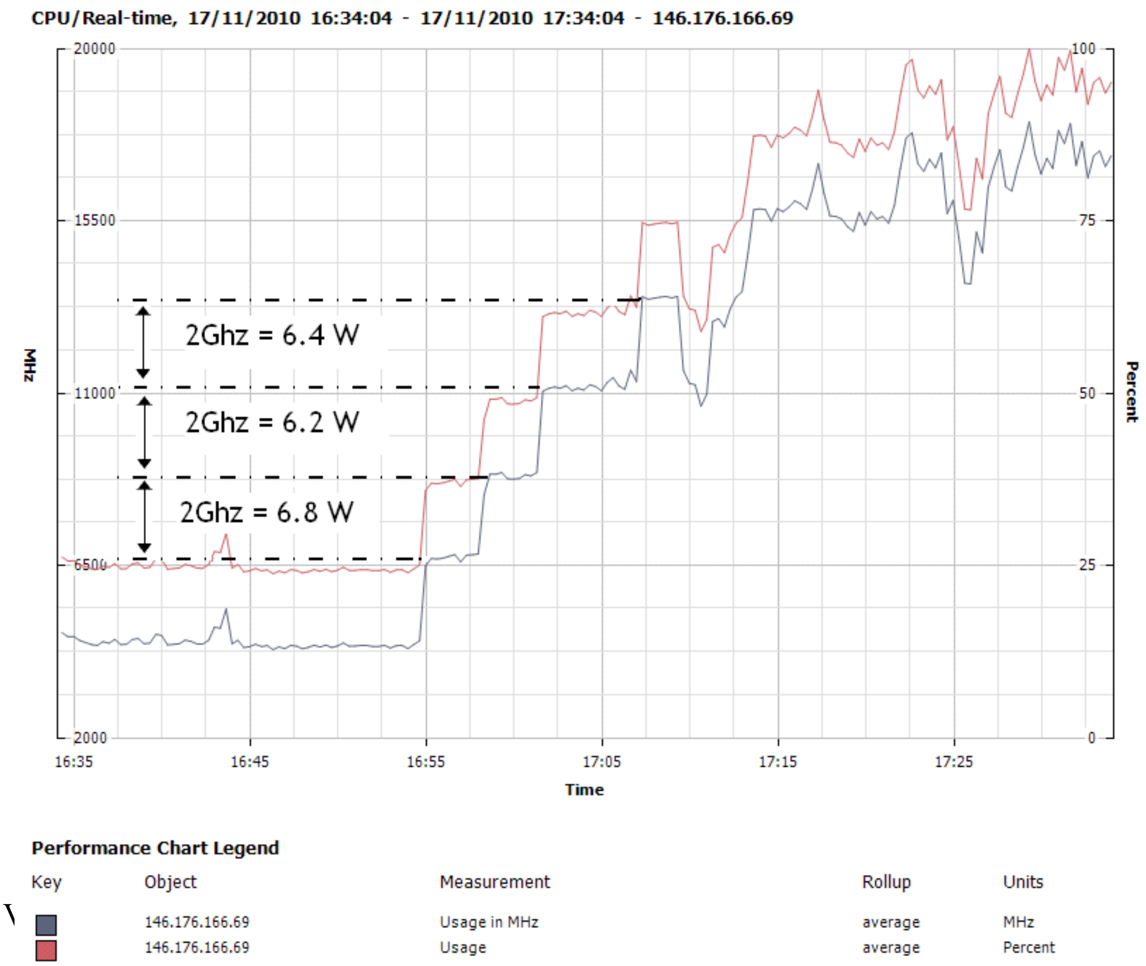

Figure 25: CPU Utilisation of the Server with VM consumption in Watt

5.4 Power benchmarking of Network Equipments

The aim of this experiment was the power benchmarking different access equipment. Therefore depending on the type of equipment the methodology was different as mentioned in the implementation.

5.4.1 Switches and Routers

The table 3 show the result of the power benchmarking of different 24 port switches and a 2811 router. Some of the switches have an additional two Gigabit interfaces. The power consumption of a 100 Mbps interface has been estimated by the difference between the idle powers and when all the interfaces were connected divided by the number of interfaces. The power consumption of Gigabit interfaces has been measured because the different of power consumption is large enough. Then the ratio of the cost of all interfaces plugged in on the total power consumption represent the percentage of electricity used to maintain the interfaces. This last information is not relevant for the router which only has two interfaces.

The analysis of the data show that a 100mbps interface on a switch consumes between 0.16 and 0.38 W and that a 1Gbps interface consumes between 1.5 and 2.2 Watt. This confirms the results obtained by (Chamara Gunaratne et al, 2005) on a Cisco 2970 (0.3 Watt for a 100Mbps and 1.8 W for a 1Gb/s link). (Maruti Gupta et al, 2007) have mentioned in their paper that the cost of the entire interface represent 20% of the cost of a switch. In the experiment value obtained varies from 10% to 40% in case of switches with Gigabit interfaces. The last column in the table does not consider the Gbps interfaces and only if the devices have only two interfaces the reduction is almost the half for the Cisco 2950-24T. Meaning that the two interfaces have an equivalent cost as the 24 others. This show that the higher the speed of the links is, the higher the cost of Ethernet interfaces are and higher the waste is if the link is not fully use. But it is also interesting to note that the smaller Ethernet cost on switches is on the 3550 and 3560 switches which offer better performances and more functionalities than the 2900 series. However on the 3550 and on the 3560 the measured maximum power consumption was 10 to 20W bellow the rated maximum power-consumption. The reason could be that some of the functionalities offered by those switches consume more power. Indeed they offer routing functionalities which can be power intensive such Cisco Express Forwarding (CEF).

The only router tried was a Cisco 2811. The cost of one interface is 0.5 W which is slightly higher than on the switches. A small power increase has been measured when traffic was sent on the router (0.3W), this confirm that the traffic load only has a small impact on the total power consumption of the device. In this experiment the configuration of the router was minimal but the maximum measured power consumption is less than 2 W from the rated maximum power consumption. Probably that a lot of services are running by default on the router and might not be always require but this would need a deeper investigation on the power consumption of routers.

Device	Rated Max Power (W)	Measured Max Power (W)	Measured Idle Power (W)	Power per 100mbps int (W)	Power per 1 Gbps int (W)	Power Int/Max Power	Power Int/MAx Power (No Giga)
Cisco 2950-24T	30	26	18.7	0.16	1.5	39.50%	22.99%
Cisco 2960-24TT-L	30	27.9	16.6	0.38	2.2	40.50%	30.54%
Cisco 3550-24	65	46.6	41.5	0.22	No Gbps	No Gbps	10.75%
Cisco 3560-24TS	45	36.5	32.8	0.2	No Gbps	No Gbps	10.14%
Cisco 2811 (router)	32 no module	29.9 (30.2 with traffic)	28.8	0.5	Not relevant	Not relevant	Not relevant

Table 3: Result of the power benchmarking of Switches and a Router

5.4.2 Wireless Access-Points

Identical Access-Points (AP) (Cisco Aironet 1200) have been tried in two different deployment. The first one using the controller (Lightweight) and the second one without using the controller (Heavyweight). Different factors have been changed and the results are presented in the table 4. The main differences between the two cases is that the heavyweight AP is consuming 7.2 Watt and its power consumption does not really change and the lightweight one consumes 9.6W in idle state but its power consumption changes slightly. It was expected that the lightweight AP consumes less power but one of the explanation could be that the lightweight AP is maintaining a constant communication with the controllers using the Lightweight Access Point Protocol (LWAPP). The results are difficult to analyse because the power consumption was not completely stable and the result presented are only estimation. The main difference is when the AP is receiving traffic, because in the lightweight case there is 0.8W difference between the idle state with 802.11b/g whereas there is only a 0.2W differences with the heavyweight. Again the communication with the controller might also be responsible of this increase.

Test	Lightweight	Heavyweight
idle (no wireless)	9.4	7
802.11a	9.9	7.3
802.11b/g	9.6	7.2
Transmission powe	9.6	7.2
Transmission powe	9.7	7.3
Traffic + Wep	10.5	7.3
Traffic + Wpa2	10.5	7.4

Table 4: Wireless Access-Points Power consumption in Watt

5.5 Discharging time of battery-powered devices using VNC communications

This experiment has involved three mobile devices accessing and controlling a remote computer using VNC. The devices involved were an Ipad, an Iphone 3GS and a Sony Ericson XPERIA X10. The battery level has been monitored every 20 minutes and the figure 26 represents the tendency of the batteries discharge. It appears that the battery discharges are all approximately linear meaning that the power consumption of the devices was constant. The devices have different discharging time but the devices are running different operating systems, application in background, have different screen sizes and battery-capacity. Therefore comparing those devices between them would be meaningless. However this graph gives an important data for the evaluation, indeed it provide the discharging time. This will be used in the evaluation to find the power consumption of those devices. Indeed the power when charging and the charging time have been measured. Therefore the energy accumulated in those devices is known and the discharging time should permit to find the power consumption. The common point between the three devices is that the tendency of the battery discharging time is linear and could be represented by the functions:

- Ipad: $f(x)=100 - 0.26x$
- Iphone 3gs: $f(x)= 100 - 0.55x$
- Xperia: $f(x)= 100 - 0.32x$

  However in a general case the VNC application have shown high delay and the tactile screens of those devices make the control of a remote computer a bit tricky. It can mainly be used for quick utilisation and improvement on the delay and the usability has to be made before the impact of those applications on the battery becomes a serious issue on those devices.

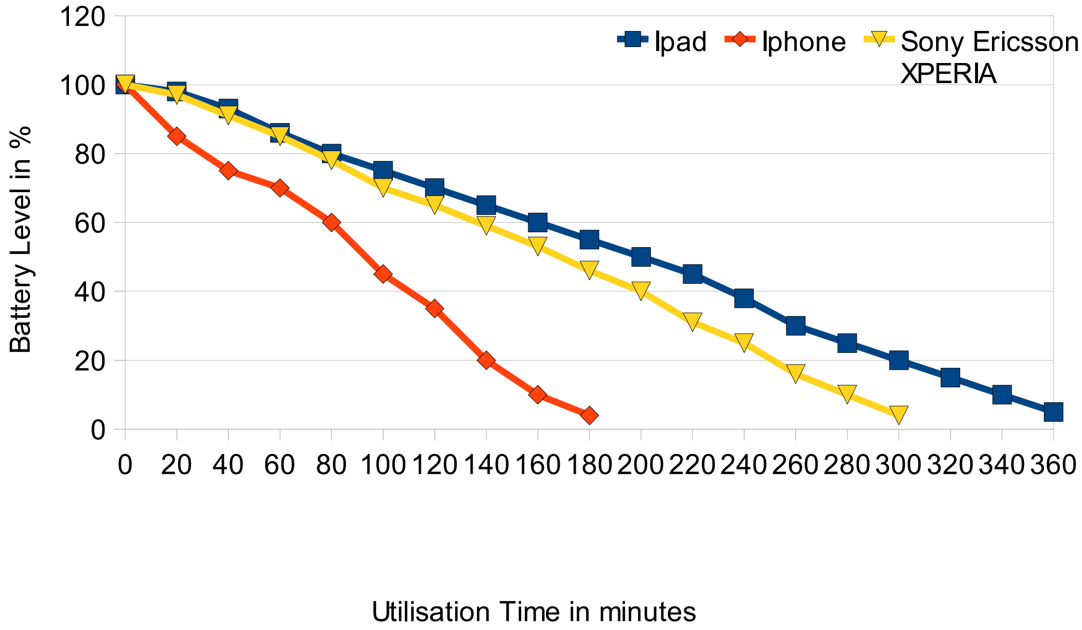

Figure 26: Battery level tendency under VNC utilisation

5.6 Conclusion

In this chapter the analysis of the result have been performed. This should have given enough information to performed the evaluation which will aim to evaluate the saving of an existing set of desktop computer into a virtual set of computer in a cloud.

Therefore the actual consumption of a few desktop computer deployed in Napier university have been made. They have shown that the most efficient configuration is the newest one because it is the most powerful one and the least power consuming. Therefore in order to save power the older computer should be replace by new ones.

The result of the cloud infrastructure have given also similar tendency on the two clouds. On each cloud the cost of a VM have been estimated and on the production cloud the power consumption per Ghz have been deducted from the result. However the cost per VM and per Ghz had not been seen in the literature review and the methodology use could represent a finding for the literature. This should allow the comparison between virtual and physical machines.

The power consumption of network have also been studied. The results are in accordance with the expectation of the literature review about the cost of interfaces(approx 0.3W per 100mbps interfaces and around 2W for a 1Gbps interface). However on the router and on the wireless access-point the power variation were really small between the different experiments.

The analysis of the power consumption of mobile-devices accessing the cloud have been performed. However comparing the result between the device would be meaningless because they have different battery-capacity and operating systems. However the evaluation will give the power consumption of those devices with a VNC communication and with a normal wireless usage.

In the next chapter those conclusions are used to performed the evaluation and achieve the main aims of this project.

Chapter 6 Evaluation

6.1 Introduction

The results of the experiment have been analysed in the previous parts. The tendency of the power consumption has been analysed when possible. The result now have to be compared in order to evaluate if the power consumption of is reduced when a physical architecture is turned into a virtual one and the saving has to be estimated as well as the difference of carbon footprint. This should also include network equipment however some upgrade would have to be made to handle the load of cloud. Fast-Ethernet switches might have to be upgraded to Gigabit Ethernet switches, but those switches have not been benchmarked in the experiments. When possible the result from the experiment will be used but if the experiment did not provide the data require, the rated maximum power of the equipment suggested will be retrieved from the internet and this would be signalled. The power consumption of mobile-device will be evaluated separately as during the experiment it has shown that it is not suitable yet to be consider as regular end-device.

In this chapter the carbon emissions of the infrastructure is estimated for different period and different deployment sizes during idle state and full-utilisation. Then a normal behaviour is proposed which represent a usage as close as possible as reel life usage and its carbon footprint is also estimated. Finally the power consumption of mobile devices is calculated.

6.2 Cloud Computing virtualization vs heavyweight desktop deployments

In this section the evaluation aim to find when cloud for virtualization is less power consuming than heavyweight desktop deployment. This will consider the power consumption depending of the number of machines deployed.

The end-device consider will be a lightweight desktop which have not been tried in this report, such as those propose by the company Wyse and are designed for cloud utilisation. Those devices consume 3W, do not run an operating system and are equipped with a Gigabit interface. Therefore 3W will be added per VM. Furthermore for each cloud one controller should be added. The controller has not been benchmarked however it is in the same chassis than the virtualization server but has smaller processors in the production cloud and has a smaller chassis and smaller processor in the test cloud. Therefore the maximum power measured on the virtualization server is used as a reference for the controller which is 250W for the production cloud and 130W for the test cloud. Even if the controller is really unlikely to run at 100% of its CPU utilisation. The storage is not considered in the evaluation because depending on the amount of data that need to be stored the power consumption might highly vary. To evaluate the consumption of the cloud depending of the number of instances the cost per VM is required. This number will be multiplied by the number of instances, referenced as n_VM. The number of instances will also multiply the cost of a lightweight desktop which is three watt. When a server is saturated a new one is needed and its cost should be included, this will be represented by a Floor function. A floor function round down a number and is use as follow in excel: FLOOR(N; P) with N the fraction to round down and P the precision. The floor function will add the power consumption of a virtualization server every time the maximum of VM supported is reached. The Precision represents the multiple to round to and will be set to 1.The values for the clouds are summarized in the table 6. The equation to estimate the power consumption is :

f(n_VM)= C+V*(1+FLOOR(n_VM/VM_max))+3*n_VM+(C_VM*n_VM)

With: C= Controller consumption; V= Virtualization Server consumption; nVM= the number of VMs; VM_max= the number of VM maximum per virtualization server before starting a new one;C_VM = the cost per VM).

Cloud	Controllers (*1) C	Virtualization Server V	Lightweight Desktop	Cost per 2.2Ghz VM C_VM	Cost per 3Ghz VM	VM_max for 3Ghz VMs
Production	250	175 W (every 8VMs : VM_max)	3	7.65W	10.43W	6
Test	130	115.7 (every 4 VM : VM_max)	3	14W	19.1	3

Table 5: Equation value for the cloud power consumption

The table 5 consider the cost of a 2.2 GHz VM which have been measured and estimate the cost of a 3 GHz machine. Therefore VM_Max has to be redefined. However this cost will be compared to the cost of desktop with a 3.3GHz processor. Only the configuration which has shown the best result in the result analysis is considered because it is more likely that computers will be replace by more efficient one. The equation which give the power consumption of the most efficient desktop depending on the number of machine is :

f(n_D)= max*n_D

With N_D= the number of desktop deployed; and max = the maximal cost of the desktop set to 63.2.

The figure 27 shows the consumption depending on the number of instances. It appear that the production cloud start becoming more power efficient than a normal physical desktop deployment after 19 machines. At 30 machines the saving is less than 200 W (193.1W). Therefore before nineteen computers a regular deployment is more interesting and after 30 the saving is not impressive and therefore is not an argument to change a physical one into a virtual one, but other argument might such as manageability. The production cloud seems to never be more power efficient than the normal deployment. It is a good test platform but the server is not powerful enough to be used for production deployment. The production cloud would been more efficient after 12 machines if the CPU allocated to each VM was 2.2 but therefore it would not have been comparable. The figure 28 represents also the power consumption depending on the numbers of machine except that a wider range of machines is considered. At 500 machines the cloud the production-cloud is definitely interesting as there is a difference of almost 10kW (9935 W). Therefore the cloud is really interesting for large deployment. Furthermore if the machine were allocated 2.2 GHz the consumption would be reduced even more: exactly 15KW or almost the half of the 3.3 GHz heavyweight desktops. It is important to highlight the fact that those results show the consumption if all the machines were using 100% of their CPU. The conversion factor presented in 3.2.3 is used to determine the amount of Co2 emission (0.057kg/kWh), if the 500 machines were used during 1hour and 8 hour this would give:

Deployments	Desktop	Production Cloud (3Ghz)	Production Cloud (2.2Ghz)	Test Cloud (3Ghz)
Carbon emission in Kg (1 hour)	1.82	1.28	0.95	1.76
Carbon emission in Kg (8 hour)	14.54	9.96	7.64	14.05

Table 6: Carbon emission per deployment over a 8h period

The table 6 show the carbon emission of the different solution. If the 500 machines were deployed in the cloud with 2.2 GHz of processor and use 100% of their CPU during 8 hours, the amount of Co2 release would be 7.64 Kg of Co2 or half of the Desktop deployment. Also this evaluation show that the efficiency of the server use for virtualization really matters indeed the more powerful the server is the more efficient it seems to be as well. For a 500 PC deployment, server would probably be more powerful and the consumption should be reduced as well.

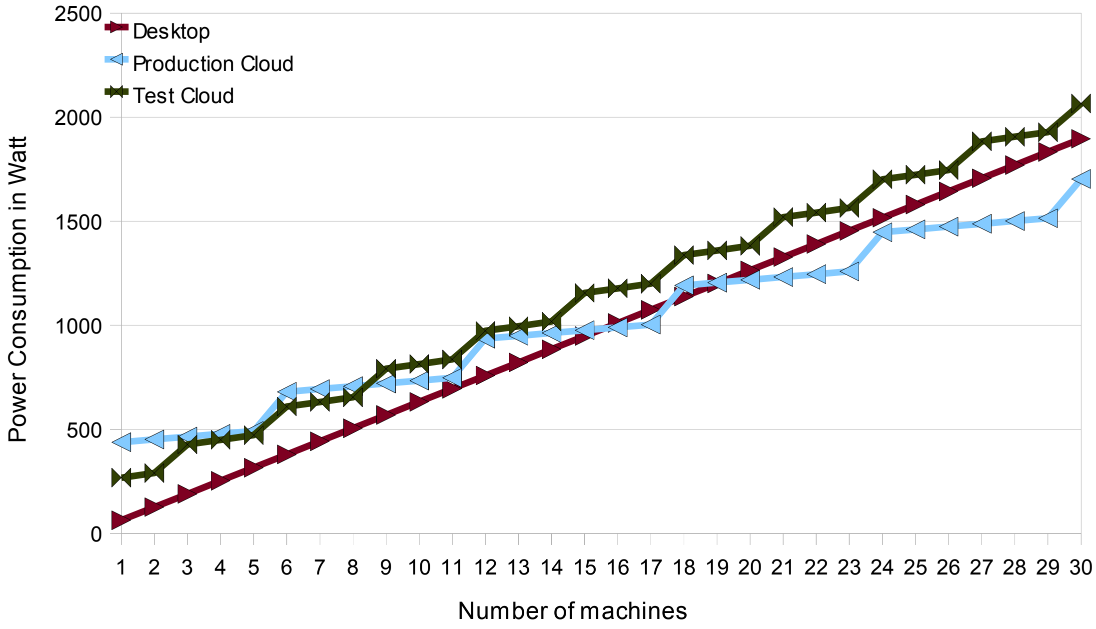

Figure 27: Power Consumption depending on the number of machines

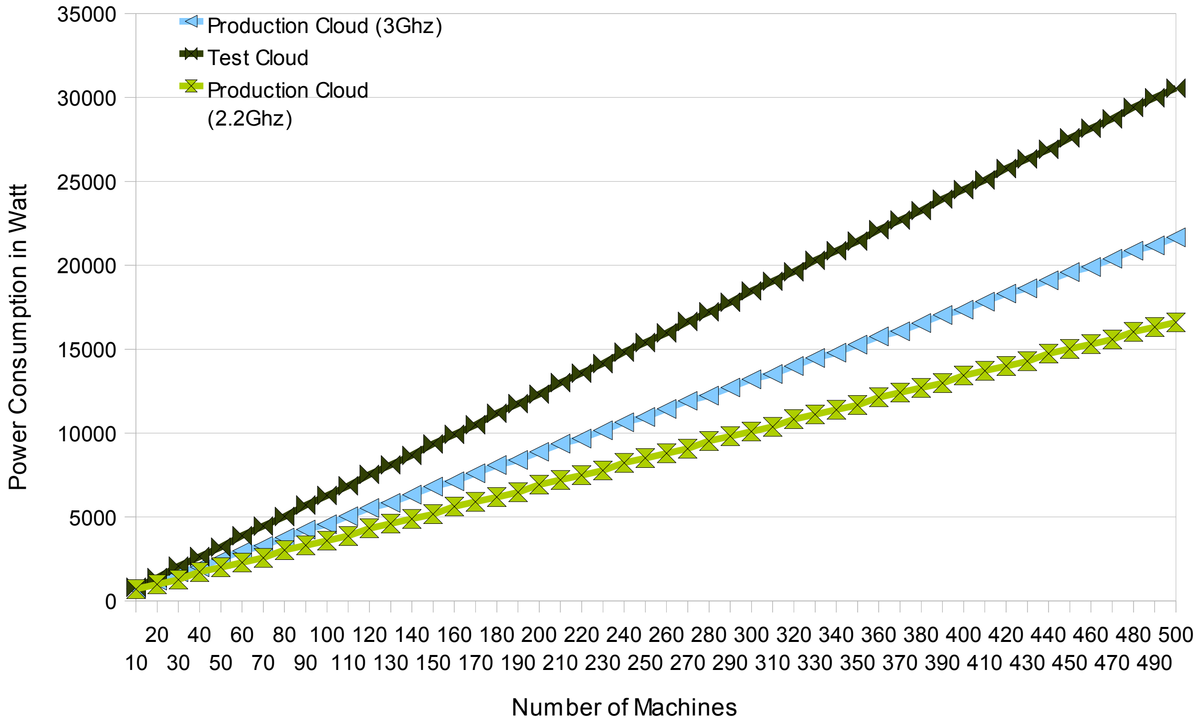

Figure 28: Power consumption depending of the number of machines bis

6.3 Network infrastructure power consumption

If lightweight client were to be deployed on an entire campus and could only use virtual images in the cloud, Gigabit Ethernet link would be preferred to interconnect them. Gigabit Ethernet switches has not been benchmarked in this project but the maximum power measured was close to the maximum rated power. Therefore for the cloud cases a Cisco catalyst 3560-48TS with 48 Gigabit interfaces will be consider whereas for normal desktop case a Cisco 3560-48PS. The power consumption is retrieved from the data-sheet available on the Cisco website and are respectively 530W and 65W. A FLOOR function can be used to represent the consumption depending of the number of client. This function adds the power of a switch every 48 client.

f(N_D)=(FLOOR(N_D/48;1)+1)*P_Switch

With: N_D= the number of desktop deployed; P_Switch the power of a switch.

For wireless deployment, the power measured on the AP 1200 with controllers will be used. Despite the fact that a 802.11n Wifi should be used for greater bandwidth and this configuration has not been measured. However the power consumption was stable in every configuration tested therefore it has been assumed that the power consumption would be the same with 802.11n. On their website Cisco advise that nor more than 24 client should connect to the same AP, however considering that the cloud require a lot of bandwidths only 12 client will be consider per AP. However this deployment is suggested for the evaluation but might not be the most appropriate one if performances is the main objectives as the bandwidth might not be enough even with a 802.11n network (270Mpbs or 300mbps respectively for frequency of 2.5Ghz and 5Ghz). The controller considers is a Cisco 5500 Series which have a maximum power consumption of 115W according to the Cisco Data-Sheets. Wireless power consumption could also be represented by a floor function which add an AP every 12 client.

f(N_D)=(FLOOR(N_D/12;1)+1)*P_AP+P_Controller

With: N_D= the number of desktop deployed; P_AP= the power consumption of one AP; P_Controller: the power consumption of the controller.

The different value use for this report is summarized in the table 7. Every deployment would need a number of routers which is relatively hard to estimate, however its cost might be negligible.

Equipment	Switch 48 Gigabit (P_Switch)	Switch 48 Fast-Ethernet (P_Switch)	AP (P_AP)	Controllers (P_Controller)	Router (P_Router)
Power Consumption	530W	65W	10.5W	115W	P_Router

Table 7: Equation values for the network infrastructure power consumption estimation

The figure 29 represents the power consumption of the network infrastructure depending on the number of machines and the network technology. Switches with 48 Gigabit would be preferred for cloud deployments. The wireless case is really unlikely to be deployed for large deployments if the end devices only rely on the cloud infrastructure. However this shows that for a deployment of smaller than 230 machines, the wired 100Mps network is less power consuming than the wireless network. But the main information that can be extracted from this graph is the fact that if the network infrastructure is being upgraded from a 100Mps network to a 1 Gbps network because of the cloud, the cost of the network infrastructure becomes not important. Indeed it represents 27% of the cloud with 3 GHz VMs and 35% of the system infrastructure with 2.2 GHz VMs. The carbon footprint of the network infrastructure over a 1 hour, 8 hours and a 24 hour period for a 500 desktop deployment is presented in the table 8. A 24h period is use to represent the fact that the network is never shut down and it consumption only vary by 2% depending of the load (Joseph Chabarek et al, 2008). Those results will be added to the cloud deployment in the next part.

Network technologies	Wireless AP	Fast-Ethernet	Gigabit network
Carbon emission in kg (1 hour)	0.032	0.04	0.33
Carbon emission in kg (8 hour)	0.26	0.33	2.68
Carbon emission in kg (24h)	0.77	0.96	7.92

Table 8: carbon emission of the network infrastructure

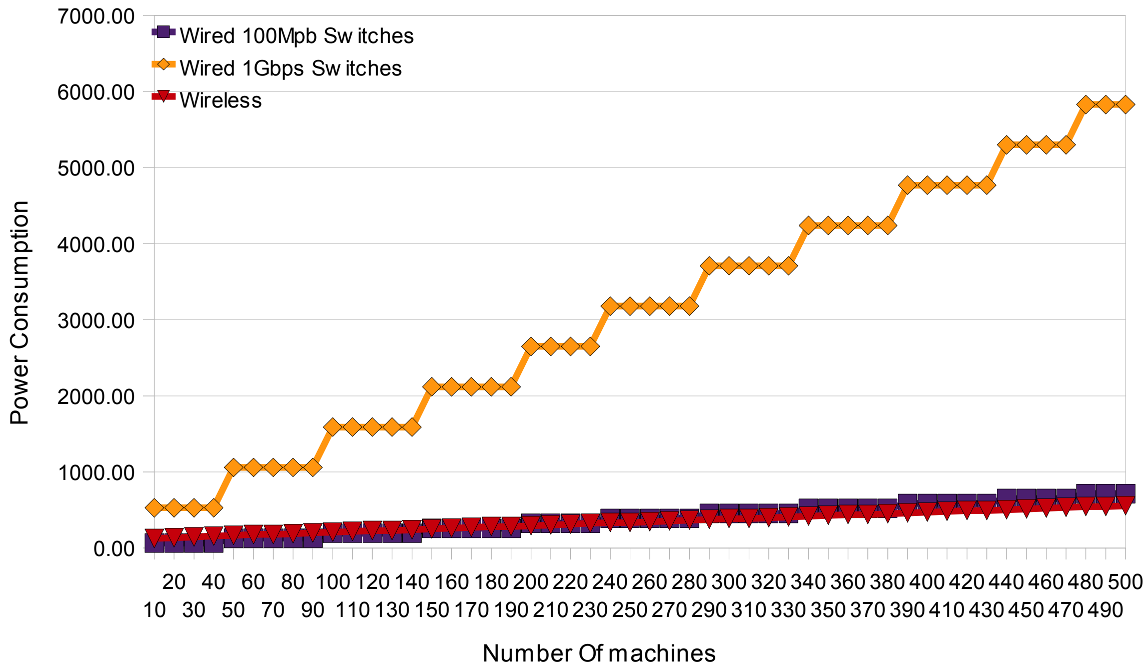

Figure 29: Power consumption of the network infrastructure depending on the number of machine

6.4 System infrastructure and network infrastructure

In this part the power consumption of the network infrastructure and of the system infrastructure (heavyweight desktop or lightweight desktop) are joined together. The Test cloud deployment is not considered as the server use are unlikely to be deploy for a large deployments. The analysis focuses on a small deployment of 30 PC and of a large deployment of 500 PC such as the Jack Kilby Computer centre.

6.4.1 Full utilisation

The part considers only the cost of machines using 100% of its CPU.

The equation representing the power consumption of the system and network infrastructure depending on the number of machine is the sum of the previous equation and is:

- For the Cloud: f(n_D)= C+V*(1+FLOOR(n_D/VM_max))+3*n_D+(C_VM*n_D)+(FLOOR(N_D/48;1)+1)*P_SwitchGiga
- For the Heavyweight Dektop:f(n_D)= D_max*n_D+(FLOOR(N_D/48;1)+1)*P_SwitchFa

With: C= Controller consumption; V= Virtualization Server consumption; n_D= the number of Machine; VM_max= the number of VM maximum per virtualization server before starting a new one;C_VM = the cost per VM; N_D= the number of desktop deployed; D_max = the maximal cost of the desktop set to 63.2; P_Switch the power of a switch (Fa= faste-Ethernet and Giga=Gigabite Ethernet switches);

The graph resulting from the equation is shown in 30. The carbon emission equivalent over a 8hour period are shown on the vertical right axe. This shows that the cloud deployment with a Gigabit network is power saving compared to a regular deployment with a Fast-Ethernet network and heavyweight desktop. The carbon emission over a 8h period if the infrastructure is fully is significant in both cases but considering a utilisation of 8 hour a day 5 days a week over year is even more important, the result have to be multiply by 240 and give:

- Cloud 3Ghz: 3,36 tonnes per year
- Cloud 2.2Ghz: 2.47 tonnes of Co2 per year
- Regular Desktop: 3.56 tonnes of Co2 per year

The results are summarized in the table 9. It considers two deployment size, a computer lab of 30 PC and a Computer centre of 500 PCs. The power consumption is in Watt and the carbon emissions have been calculated for a 1h period using the conversion factor 0.057kg/kWh. It appear that for a 30 PC lab all the deployment are consumed approximately the same amount of power (around 2kW) and have about the same carbon footprint. When considering a computer centre it appear that cloud deployment are less power intensive than heavyweight desktop. The choice of the network technology also matter. Indeed Gigabit Ethernet switches produce in general 0.3 kg of Co2 more than wireless or Ethernet technology.

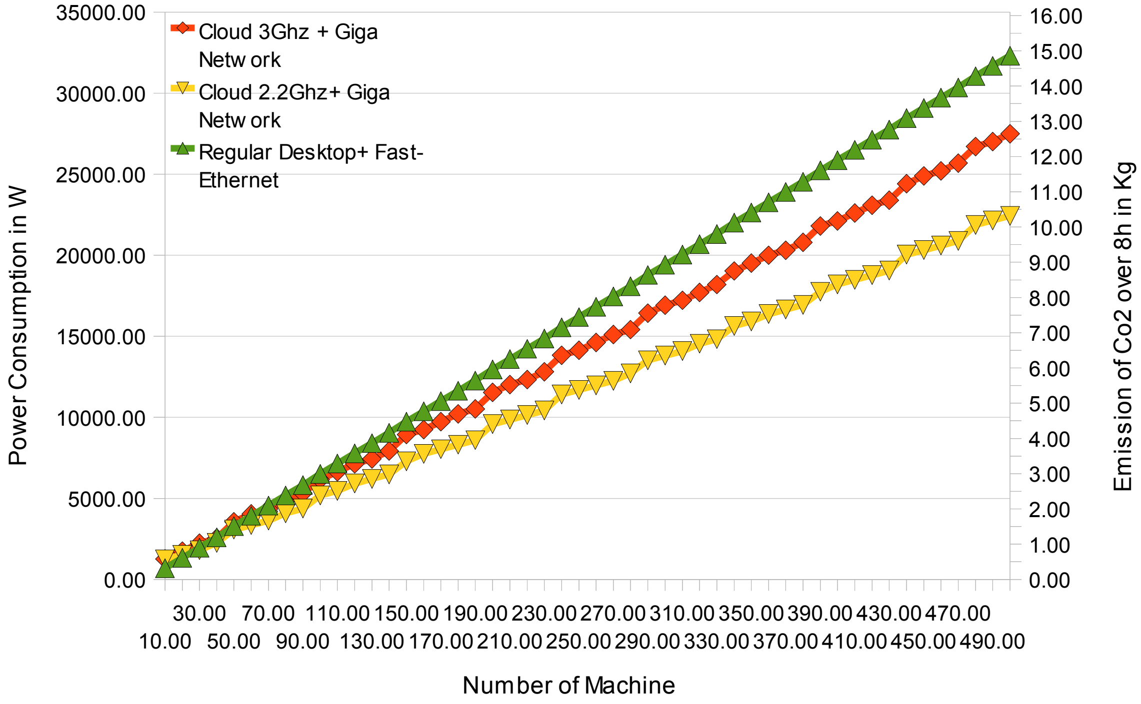

Figure 30: Power Consumption and Carbon Emission depending on the number of VM

		Lab (30Pc)			Computer centre (500 PC)		
		Wifi	Fast-Ethernet	Gigabit Ethernet	Wifi	Fast-Ethernet	Gigabit-Ethernet
Desktop	Power	2042.5 W	1961 W	2426 W	32156 W	32315W	37430 W
	Carbon Footprint	0.12 kg	0.11kg	0.13kg	1.83 kg	1.84 kg	2.13kg
Cloud 2.2Ghz	Power	1416 W	1334.5 W	1799.5 W	17156W	17315 W	22430 W
	Carbon Footprint	0.08 kg	0.07 kg	0.10 kG	0.97kg	0.98 kg	1.27 kg
Cloud 3.3Ghz	Power	1849.4 W	1767.9	2232.9 W	22221 W	22380 W	27495W
	Carbon Footprint	0.11 kg	0.10 kg	0.13kg	1.25 kg	1.27 kg	1.56 kg

Table 9: Power consumption and carbon emission over a 1h period

6.4.2 Idle state estimation

The most representative difference of power saving should be during idle state when the PC are not used (Xiaobo Fan et al, 2007). Indeed the controller should is theoretically able to turn an unused server into a sleeping mode (C Develdet, 2008), therefore the servers should have a really low power consumption. The consumption of the server in sleeping mode has not been measured but should be negligible. Therefore it should be approximately the cost of the network presented in 6.3 with the cost of the controller. However it is really important to note that this is an estimation which assume that the cost of a server in sleeping state is negligible (less than 10W)

However the network equipments are never turned into a sleeping mode except for the wireless access-point. If the cloud need a Gigabit network therefore the cost of the network become even more important. Indeed it is the same power consumption with and without traffic according to (Joseph Chabarek et al, 2008) which measured a 2% between cases with traffic sent and no traffic. The wireless infrastructure should be able to be turned into a sleeping mode and wakes up on demand. However the sleeping mode has not been measured and is not offered by every AP. Therefore for the wireless network it has been assumed that the AP did not implement a sleeping mode and the data used for the estimation are those measured during the experiment. The value of one device is the same as in the table 8 but 2% variation should be added for the accuracy due to the traffic cost (Joseph Chabarek et al, 2008).

The cost of the desktop Pc in idle state was 31.2 W according to the equation presented in 5.2 f(x)=mx+b were b was the initial value. For 30 PC the cost is 936W and for 500 it is 15600W.

The table 10 gives the power consumption of desktop in idle state in including the carbon footprint for a 1 hour period. This is an estimation because it has been assumed that the controller for the cloud turn every server in a sleeping mode and that their cost is negligible, the cost of the controller is 250 W but it is overestimated because the controller should also consumes less power. The cost of the wireless infrastructure is same as the one measured which did not implement a sleeping mode.

		Lab (30Pc)			Computer centre (500 PC)		
		Wifi	Fast-Ethernet	Gigabit Ethernet	Wifi	Fast-Ethernet	Gigabit-Ethernet
Desktop	Power	1061.5	1001 W	1466 W	16156	16315W	21430 W
	Carbon Footprint	0.06kg	0.05kg	0.08kg	0.92kg	0.92 kg	1.22kg
Cloud	Power	396.5 W	315 W	780 W	806 W	965 W	6080W
	Carbon Footprint	0.02 kg	0.02kg	0.04kg	0.04kg	0.05kg	0.35kg

Table 10: Power consumption and Carbon footprint estimation over a 1 hour period

6.4.3 Normal behaviour carbon footprint estimations

To evaluate the power consumption and the carbon footprint of a real life scenario, a normal behaviour is considered. This represent the working hours of a company with computer fully using their CPU and other hours with computers in idle state. Therefore it has been assumed that the computer are running at 100% of their capacity for eight hours and in idle state the rest of the time five days a week, the week-end the computers remains in idle state. It is an extreme case because all the computer of a company are unlikely to be running at 100% of their capacity for eight hours and probably some of the computer will be shut down instead of being just in idle state. The values are obtained from the two previous parts multiply by the number of hours. Then the value are calculated over a week than this result is multiplied per 4.34 which is the average number of week in a month and the number of month is than multiply by twelve to get the result over a year. The final results are presented in the table 11. The results are expressed in kilogrammes of Co2. The results confirm that the saving is more important for large deployments. Indeed for the Fast-Ethernet network the cloud produce 30.7% less carbon than the heavyweight desktop for a month period and 70% less over a year. The cloud saving can overcome the cost of the Gigabit network. For instance over a year the cloud with 3.3ghz VM and the Gigabit network produces 5.58 tonnes of Co2 whereas the heavyweight desktop with the Fast-Ethernet network deployment produces 9.96 tonnes of Co2 which is still 43.97% less carbon produced.

		Lab (30Pc)			Computer centre (500 PC)		
		Wifi	Fast-Ethernet	Gigabit Ethernet	Wifi	Fast-Ethernet	Gigabit-Ethernet
Desktop	Week	12.48	10.80	15.44	190.96	191.36	241.36
	Month	54.16	46.87	67.01	828.77	830.50	1047.50
	Year	649.96	562.46	804.12	9945.20	9966.03	12570.03
Cloud 2.2Ghz	Week	5.76	5.36	9.12	43.92	45.60	95.60
	Month	25.00	23.26	39.58	190.61	197.90	414.90
	Year	299.98	279.15	474.97	2287.35	2374.85	4978.85
Cloud 3.3Ghz	Week	6.96	6.56	10.32	55.12	57.20	107.20
	Month	30.21	28.47	44.79	239.22	248.25	465.25
	Year	362.48	341.64	537.47	2870.65	2978.98	5582.98

Table 11: Carbon Footprint in kilogrammes of Co2 of the different solution over a week, a month and a year

6.5 Mobile devices power consumption's

The aim of the Mobil device experiment was to find the discharging time of the device extensively using VNC communication. VNC communication has been chosen because VNC can be used to access a VM in a cloud; also the amount of data transfer should be similar to a cloud application with graphical interfaces. The discharging times of the devices have not been compared between them because the battery of the devices have different capacity, the devices are running different operating system, some did not support multitasking and some did.

The aim of this evaluation is to find the difference of power consumption between the device using VNC and the device under normal Wi-Fi usage. The table 12 list power energy and autonomy information which are essential for this analysis. The autonomy under Wi-Fi utilisation has been collected on the respective constructors' web-sites. The charging power (Pcharge) have been measured using the monitoring device, the charging time represent the time to completely charge the battery. The energy E in W/h has been deducted from P Charge and the Charging time, this represent the energy accumulated in the device. The autonomy VNC has been measured during the experiment. Pwifi and PVNC represent the power utilisation respectively when the device is using its Wifi normally and using VNC, and have been calculated from the autonomy and the Energy. For instance P_VNC=E/Autonomy(VNC) and is possible because E is constant as shown in 5.5 .The power consumption of the device under P_wifi is higher than P_VNC for all the devices tested as shown in 31.

	P charge (W)	Charging Time	E (W/h)	Autonomy (Wifi)	Autonomy (VNC)	P_wifi (W)	P_VNC (W)
Ipad	10.6	2h30	26.5	10h	6h20	2.65	4.18
Iphone	5.4	2H15	12.15	9h	3h20	1.35	3.64
Sony Ericsson XPERIA	5.6	2H15	12.6	10h	5h20	1.26	2.36

Table 12: Power, Energy and Autonomy

The Ipad has the highest consumption in both cases but have the biggest battery capacity, its power consumption has increased by 57.73%. The Iphone 3Gs is the devices which have had the highest power consumption, 3.64W which represent an increase of 169% compare to its normal consumption. The Sony Ericsson has the lowest power consumption but the use of VNC show an increase of 87% in its power consumption compare to the normal utilisation. Unfortunately the increase being different on every device it is not possible to define the impact of the cloud. But it definitely has an impact, and depending on the device, it could highly increase its power consumption, however the minimum impact measure is 57% which is not negligible. The carbon footprint of those devices over a 1 hour period is shown in the table 12, the result are expressed in g. The carbon footprint use is the same as the one in Napier University. Has it depends of the service provider; it should probably be approximately the same in Scotland and in UK.

	Ipad	Iphone	Sony Ericsson Xperia
Wifi normal use	0.151g	0.07g	0.07g
Wifi VNC	0.24g	0.21g	0.13g

Table 12: Carbon emission of the mobile devices over 1 hour

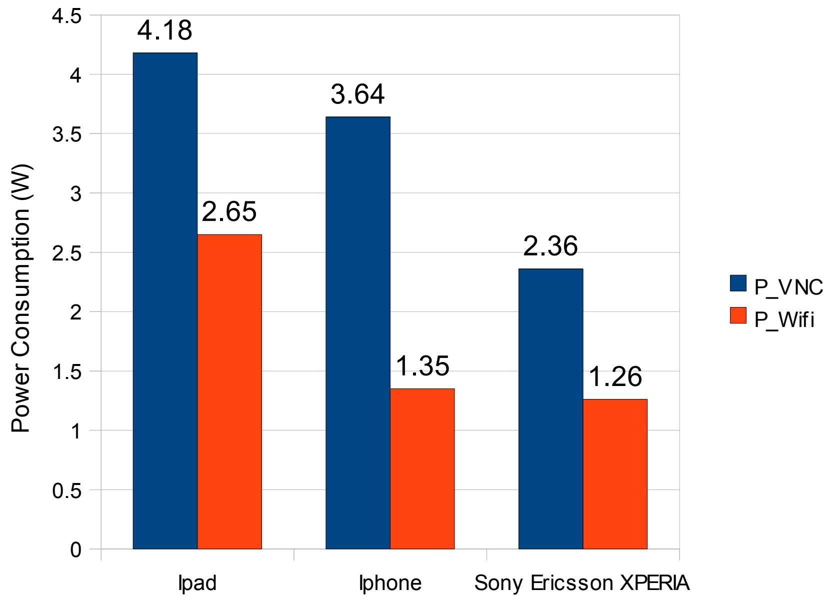

Figure 31: Power Consumption in normal Wifi utilisation and VNC

6.6 Conclusion

The information collected during the results analyses have allowed the evaluation of the power consumption of a cloud deployed for desktop virtualization achieving the main aim of this project. It appear that in general if a cloud is use for desktop virtualization it saved power compared to the same processing power deployed on individual desktop but the importance of the saving depends on the size of the pool of computer considered. For a lab of 30 machines the saving is only200 Watt if the VM are as powerful has the desktop PC. Two clouds have been tried and the power saving depends on the power of the server use to virtualized the VM. Indeed the more powerful the server is, the higher the number of VM per server will be and the higher the saving is. Also the VMs tested were allocated 2.2Ghz of processor time, but the desktop had 3Ghz therefore the power consumption for a 3Ghz VM has been estimated. It was expected that the power consumption depends on the CPU utilisation. The saving depends on the number of VM that can be virtualized on a server, therefore if the VM are less powerful, more VM could be virtualized and the saving will be higher. Also if the cloud was managed by a third party off-premise the carbon footprint would be only the carbon footprint of the network infrastructure, but it is suitable only for virtual servers and not for virtual desktop.

The evaluation has shown that the cost of the network infrastructure is not negligible especially for a high speed network. Indeed network devices used to build a high speed network consumes a lot more than Fast-Ethernet equipment. The power consumption does not depend on the loads therefore it is really important that the speed of the links become adaptive has the network never shut down. Cloud computing might require a Gigabit network if it is used for desktop virtualization. If deploying the cloud require the network to be upgrade to a Gigabit network than the saving for a 500 PC pool would be less than 5kW. However the bigger the pool of computer is the bigger the saving is. Furthermore the cloud saves a lot more power in idle state. However the evaluations have assumed that when the computers are not used they are in idle state and not shut down.

The power consumption of mobile devices has been made. This has shown that the VNC communication have a strong impact on the consumption of those devices. The VNC communication was simulating access to a VM in a cloud. The smaller impact measure was an increase of 57% for the Ipad and the biggest is169% measured on the Iphone 3Gs.

The results obtained have also been transformed to obtain the carbon footprint of the entire cloud infrastructure. The carbon footprint has been evaluated on a short period but become impressive when considered a longer one for instance a month or a year period.

Chapter 7 Conclusion

7.1 Introduction

The previous chapter, the evaluation, have shown that in general a cloud infrastructure use for desktop virtualization consumes less power than the same deployment with physical and heavyweight desktop for a number of desktop large enough (more than 20). The power is saved mainly on the system infrastructure but this could compensate the power cost of a network upgrade. However the cloud has a strong impact on mobile-devices. The aim of this project was to evaluate the power consumption of an entire cloud infrastructure used for desktop virtualization and to estimate the power saving compare to a physical desktop deployment. Therefore the aim of this project has been met.

This aim of this chapter is to explain how the main aim has been met and outline the main conclusions and findings. Additionally a critical analysis assesses the work undertaken during this project and outlines the limitation of this project. And finally directions for future work are proposed. A Gantt chart representing illustrating the project management can be consulted n the appendix B and the initial project proposal in appendix C.

7.2 Meeting the objectives

In the introduction chapters the objectives of this project have been defined as follow:

- Critically evaluate the power consumption of Cloud Computing and Network infrastructure as well as discussing the impact of cloud computing communications on battery-powered mobile-devices by reviewing the literature.
- Design and implement experiments which should measure the power-consumption of servers use to build a cloud, desktop PCs, network equipment and the impact of cloud communication on mobile devices. The experiments reproduce when possible a behaviour as close as possible as cloud activity.
- Conduct the final evaluation which should allow the comparison of the differences of power consumptions between a cloud infrastructure and desktop power consumption and the difference between a cloud communication and a regular communication on the batteries of mobile devices. This objective required the completion of an analysis the data collected during the experiment in order to extract conclusion. The evaluation should consider different deployment sizes and estimate the carbon emission.

The first objective was met by the creation of a literature review in the area of cloud computing and network infrastructure focusing on power consumptions. It appears that when discussing power consumption cloud computing and network infrastructure are discussed separately. For cloud computing, virtualization allows an efficient use of the hardware by allowing server consolidation but also to turn into sleeping mode unused server if a power management solution is used. Also cloud computing is said to be green but it is only if the cloud infrastructure is located in a green-data centre therefore this does not allow the estimation of any power saving because the resources is just moved. The network infrastructure consumes and waste power during low utilisation time, the load only has a small impact. However the speed of the link makes the differences therefore network equipment, protocols and topologies needs to be design in a power-aware fashion. Cloud communication should also have an important impact on battery-powered devices because it will extensively uses their interfaces which represent the main portion of their power consumption but the literature lakes of article in this area.

The second objective was met but the experiments have split the overall infrastructure in different parts. Indeed servers on two different clouds have been tested but their respective networks have not. Instead equipment which could be used to build the network infrastructure used by the cloud has been benchmarked. In the same way to reproduce a cloud communication on the mobile devices, VNC communications have been established on three different mobile-devices. Plugs in energy and power monitor device have been used to measure the instantaneous power consumption. Each experiment had its own methodology because the literature reviews have outlined what were the respective actors (CPU utilisation, number of interfaces in use, network traffic and so on) of the power consumption on each of the element tested. Most of the required data have been collected however due to the nature of the monitoring device some of the equipment could not be turned off therefore the missing data have been collected on the internet.

The third objective was the final evaluation of the power consumption and carbon footprint difference between a cloud deployment for desktop virtualization and a physical deployment with the same processing power. This has required a previous analysis of the data collected during the experiment in order to have the cost in power of a single VM in order to extend the result over a large range of computer. The evaluation present an estimation of the power consumption and carbon footprint of the different elements tested. However sometimes the estimation might not be really accurate because it has assumed that devices were never shut down and when the devices are used they are using their CPU at 100%. The evaluation have considered two deployment size, thirty computers representing a small lab and five hundred computers representing a computer centre such as the Jack Kilby Computer Centre. However the result of the evaluation show important difference and the cloud always consume less power than the physical desktop deployments. The power consumption of mobile devices has also been obtained, it has been deducted from the amount of energy accumulate in the battery and the discharging time. This has shown that cloud communication have an important impact on mobile devices.

7.3 Conclusions

This project has permitted to evaluate the power consumption difference between a cloud used for desktop virtualization using lightweight end-devices and normal deployment with regular desktop PC. During this evaluation a number of findings have been made.

The analysis of the power consumption depending on the CPU utilisation of different desktop computer have shown that the power consumption increase gradually with the processor utilisation in a linear fashion. However older processors are less efficient and should be replace by newer one has the power consumption increase is faster on older one. Furthermore the cost of a desktop computer in idle state can be high, it has been measured 100W for the maximum measured and whereas the minimum measured was 31.2W.

The analyses of the cost of the same VM on the two clouds tested have permitted to outline the fact that this cost depends on the efficiency of the hardware. Indeed the more powerful the hardware is the smaller the consumption per GHz is and therefore the cost of the VM is. It has been measured 11W on the test cloud and 7.65W per VM on the production cloud. The tendency of the power consumption depending on the CPU utilisation was linear the cost of a more powerful VM than the one measured has been estimated.

The cost of the network infrastructure is not negligible specially when Gigabit links are used and have to be included in the cost of the cloud because cloud will generate more traffic and will require network upgrades. However the cost per equipment depends on the equipment. However the experiment has confirmed that the cost a Gigabit interface is around 2W on a network switch whereas the cost of 100Mbps interfaces is around 0.3W. Therefore is it important that the network become adaptive and adapt to the speed of the interfaces to the load of the network which is what the norm IEEE 802.3az should standardize.

The deployment of the cloud with the same processing power as the desktop already deployed, and deployed with a Gigabit network infrastructure could represent a saving of 43.97% in carbon emission or 4383.05 Kg of CO2 over a year for 500 PC compared to the heavyweight desktop deployment with a Fast-Ethernet network. Therefore even if the cloud deployment would require a network upgrade, the saving of power of the cloud should overcome the excess of power of the network upgrade. But the saving would be even bigger if the network was adaptive. Therefore Cloud computing can reduce the overall power consumption but it depends on the servers used and also it should save power during on and off-peak.

The power consumption of mobile devices using a VNC communication has been performed. This has been compared to an estimation of the power consumption of those same devices when using their wireless interface to access the web or normal use. This has shown an increase of at least 57% and the worst case 169%. Therefore mobile-device consumes much more power when accessing the cloud compared to their normal utilisation. But the VNC client was in general not appropriate enough to be considering as a usable application. Therefore improvement needs to be done before a mobile-device is considered as a suitable end-device to access a VM. This does not mean that mobile-devices cannot be used to access every cloud applications.

And finally the evaluations on large deployment have been estimated through a mathematical function. The functions used were simple and could be used to evaluate the power consumption of other deployments by only changing the value.

7.4 Critical analysis

This project aimed to evaluate the saving in a term of power of a cloud deployment for desktop virtualization. To conduct this evaluation experiments have been designed to measure the power consumption of the cloud. However the experiments have split the infrastructure in several elements such as the network infrastructure, controllers, virtualization server, end-devices and so on. Therefore all the elements of the cloud infrastructure have never been monitored at the same time.

For instance the network equipment has been measured separately. For the network switches the number of interfaces has been the main factor of the power consumption. In order to find the maximum power consumption three switches have had their interfaces connected together and the spanning-tree protocol have been disabled. This might not be a representative test for the power consumption. However the result have been verified, for instance by making sure that the cost of the interface deducted from the difference between the idle power and the maximum power is the actual cost of an interface multiply by the number of interfaces.

Furthermore some of the devices considered in the evaluation has not been measured and the power consumption was estimated from other devices or from the rated maximum power retrieved on the data sheets available on the equipment constructors. Therefore the Gigabit switch consider in the experiment was Cisco catalyst 3560-48TS have a maximum rated power of 530W which might be too high however this device was not available for monitoring. However the maximum power measured on the Cisco 3560-24TS in the experiment had maximum power consumption 10W below the rated maximum consumption. Furthermore the rated maximum power consumption was never reached in the experiment therefore the cost of the Gigabit network might be a bit overestimated.

In the same way the controller has not been measured, it is expected that it is never fully using its processor. The controller had less processing power than the virtualization server however it has the same chassis. It has been decided to use the maximum power measured on the virtualization server as the value for the controllers. It should be an overestimation. In the same way the lightweight device had not been measured but their consumption have been retrieved from one of the company providing those devices.

However all the elements of the normal desktop deployment have been measured therefore the estimation should be close enough to the reality. Despite the fact that it has been considered that the cost of the desktop when use it the cost of the desktop when fully use. And that during the normal behaviour estimations each desktop remain in idle state for sixteen hours instead of being turned off. In the Jack Kilby Computer Centre, since this summer and Windows Vista is in used the computers goes into a sleeping mode automatically after an inactivity times.

Therefore the evaluation gives an estimation which should be close to the real consumption but it is an estimation not entirely based on measurements. The consumption of the cloud have been overestimated but still represent a saving compare to normal desktop deployment.

7.5 Future Work

Two different hypervisor were running on the different virtualization server considered for the two clouds: XEN 3.4.2 on the test cloud and on the production Cloud VSPERE 4.1.0. A performance analysis of the different hypervisors available would have to be performed on the same platform to evaluate the virtualization overhead of each hypervisor. This could also evaluate the power consumption different hypervisor virtualizing the same VMs on the same hardware. However a benchmarking framework for hypervisor should be design in order to easily perform the benchmarking when a new version is released.

The result of this study could be easily turned into software which estimates the consumption of specific deployments. The result could be set manually, for instance a user specifying the number of Pc running with their average CPU utilisation. Or the information could be retrieved automatically from a daemon running on every end-device which sends an average CPU utilisation over a period every half-hour to a server. Those data could then be used to estimate the actual power consumption. This could be a first step to the design of a power management framework which would monitor activity and turn down services, application and physical instances in order to save power when it is not fully used.

The Cisco EnergyWise technology store SNMP objects on network equipment which give information on the power consumption of those devices. A deeper investigation of the power consumption of service on a router is also required because the power variation did not vary during the experimentations and also on wireless access-points.

Wireless mesh network have the capability to turn area of the topology down if not user are using it. An investigation of the power saved by this technology compared to a traditional deployment would be really interesting.

Also these studies have only considered the power consumption cost, which is a management cost. It would be relevant for company to have an idea of the investment cost as well in order to see in how long it will take to actually save money out of the cloud.

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Appendix A

Appendix A.1: Excel data-sheets of Desktop power-consumption's

cpu	0	5	10	15	20	25	30	35	40	45	50
Room C27: two Intel 4 running at 3,2	79.7	84.6	88.4	92.9	97	101.7	105.6	109.3	114.3	118.7	123.2
JKCC type 1: Intel Core 2 duo CPU E840	31.2	33.7	34.4	36.6	37.4	39.5	40.7	42.6	44	45.6	47.2
JKCC type 2: Intel Core 2 duo CPU 6420	101.5	103.2	105	108.8	110.2	111.4	111.9	113.2	114.6	116.8	117.6
Room C27: f(x)=0.88x+79.7	79.7	84.1	88.5	92.9	97.3	101.7	106.1	110.5	114.9	119.3	123.7
JKCCtype1: f(x)=0.32x+31.2	31.2	32.8	34.4	36	37.6	39.2	40.8	42.4	44	45.6	47.2
JKCCtype2: f(x)= 0.37x+101.5	101.5	103.35	105.2	107.05	108.9	110.75	112.6	114.45	116.3	118.15	120

cpu	50	55	60	65	70	75	80	85	90	95	100
Room C27: two Intel 4 running at 3,2	123.2	127.6	132.4	137.2	141.8	147.6	152	156.5	160	164	168
JKCC type 1: Intel Core 2 duo CPU E840	47.2	48.7	51	52.8	55	56.1	57.3	58.6	60.8	61.7	63.2
JKCC type 2: Intel Core 2 duo CPU 6420	117.6	120.6	123.2	125.2	126.9	128.1	130.8	133.3	134.8	137.1	138.2
Room C27: f(x)=0.88x+79.7	123.7	128.1	132.5	136.9	141.3	145.7	150.1	154.5	158.9	163.3	167.7
JKCCtype1: f(x)=0.32x+31.2	47.2	48.8	50.4	52	53.6	55.2	56.8	58.4	60	61.6	63.2
JKCCtype2: f(x)= 0.37x+101.5	120	121.85	123.7	125.55	127.4	129.25	131.1	132.95	134.8	136.65	138.5

Appendix A.2: Excel data-sheets for Test cloud power consumption's

	0	0.2	0.4	0.6	0.8	1
Machine 1	60	63.5	64.4	65.2	66.2	82
Machine 2	82	85.2	88.1	88.5	89.3	94.1
Machine 3	94.1	95.9	97.5	99.2	101.3	106.5
Machine 4	106.5	104.5	106.3	104.1	106.4	115.7

Appendix A.3: Excel data-sheets for Deployment cloud power consumption's

CPU	0.00	3469.00	5801.00	7951.00	10203.00	12532.00	14899.00	16891.00	17179.00
CPU %	0.00	19.19	32.09	43.98	56.43	69.31	82.41	93.42	95.02
Watt		175.00	195.20	202.00	208.40	214.80	214.80	231.00	236.00
f(x)	166.60	179.65	188.42	196.50	204.97	213.73	222.64	230.13	231.21

Appendix A.4: Excel data-sheets for power benchmarking of Desktop equipment's

Device	Rated Max Power (W)	Measured Max Power (W)	Measured Idle Power (W)	Power per 100mbps int (W)	Power per 1 Gbps int (W)	Power Int/Max Power	Power Int/MAx Power (No Giga)
Cisco 2950-24T	30	26	18.7	0.16	1.5	39.50%	22.99%
Cisco 2960-24TT-L	30	27.9	16.6	0.38	2.2	40.50%	30.54%
Cisco 3550-24	65	46.6	41.5	0.22	No Gbps	No Gbps	10.75%
Cisco 3560-24TS	45	36.5	32.8	0.2	No Gbps	No Gbps	10.14%
Cisco 2811 (router)	32 no module	29.9 (30.2 with traffic)	28.8	0.5	Not relevant	Not relevant	Not relevant

Cisco AP 1200:

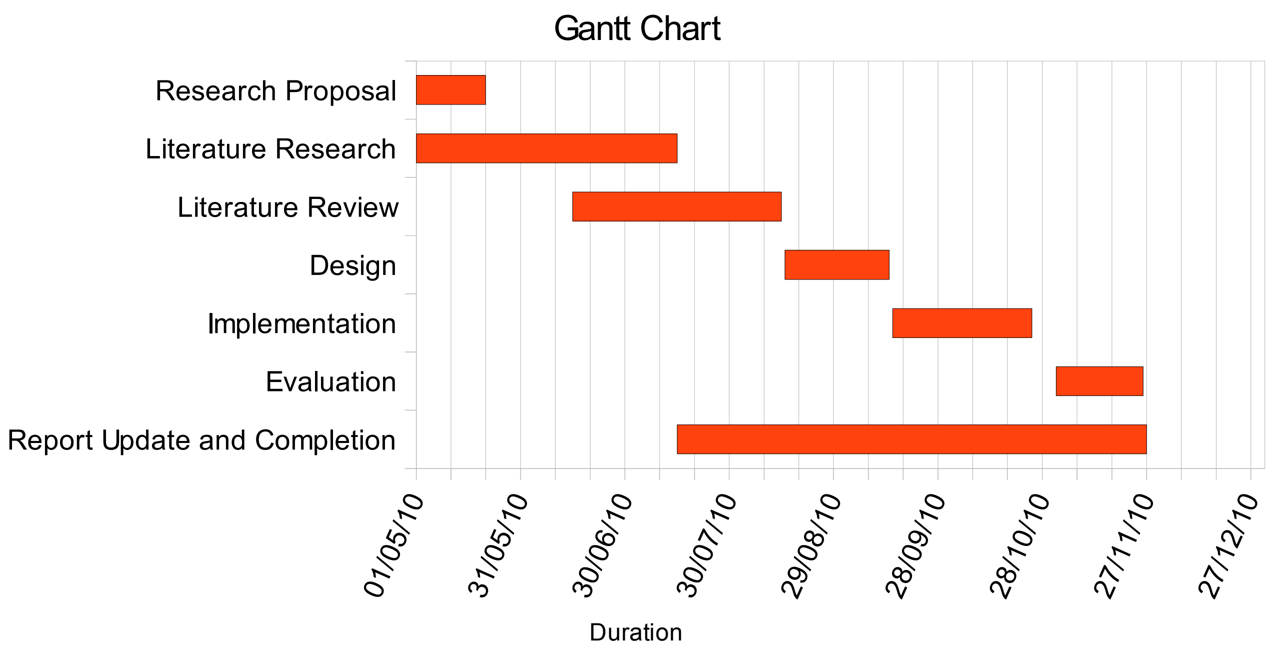
Test	Lightweight	Heavyweigh
idle	9.6	7.2
802.11a	9.9	7.3
802.11b/g	9.6	7.2
nsmission power 1	9.6	7.2
smission power 10	9.7	7.3
Traffic + Wep	10.5	7.3
Traffic + Wpa2	10.5	7.4

Appendix A.5: Excel Data-sheets for Battery consumption with VNC communications

Utilisation Time in min	0	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360
Ipad	100	98	93	86	80	75	70	65	60	55	50	45	38	30	25	20	15	10	5
Iphone	100	85	75	70	60	45	35	20	10	4									
Sony Ericsson XPERIA	100	97	91	85	78	70	65	59	53	46	40	31	25	16	10	4			

Appendix B

Appendix B.1 Project Management: Gantt chart



Appendix B

Appendix C

C.1 Brief description of the research area - background

IT-related electrical cost represent fifty percent of the electricity bill of a company, consequently helping companies to save power should be well accepted as it will reduce their expenses and help the environment at the same time (Stephen Ruth, 2009). In January 2010 the Green Touch consortium composed of sixteen companies, research labs and service provider, led by Bell's Lab and Alcatel/Lucent has announced that in five years the Internet could be running by a thousand time less energy that it actually uses. Indeed the actual consumption of Information and Communication Technologies (ICT) represent two to three percent of the world energy consumption and this could be reduced by ninety-nine percent by implementing actual technologies efficiently (Alexander Hellemans, 2010).

Therefore ICT technologies which make efficient use of power already exist they should just be used or implemented efficiently. For instance by configuring wireless equipments in a power-efficient way (*D. Coudert et al, 2009),* or reducing the number of network elements involved (links and devices) during data routing (F. Giroire et al, 2010). The use of cloud computing and virtualization is also supposed to be more power-efficient than regular server infrastructure because of the ability to start running server on-demand and to switch them off if not required (C Develdet, 2008). However this suggest that the energy saving is achieved only during off-peak time, when the servers are not extensively used and does not allow a conclusion about saving more power by having virtualized servers running on a single hardware than having those servers running on lighter hardware platform when all the services are required at the same time. Is it the same tendency as for data routing? Indeed in data-routing it has been shown that the load of a router has a small influence on its energy consumption (F. Giroire et al, 2010) and consequently it is better to used less routers and having them more loaded than having more router running less loaded. The control of the topology is also an important factor, maintaining an unused link also consumed energy because devices has to manage and control unused interfaces and link (Joanna Moulierac et al, 2010)(Mahesh K et al, 2010)(Jingcao Hu et al,2008), it is all the most true for wireless because the energy consumption is proportional to the number of transmission (A. Keshavarz-Haddad et al, 2008). Therefore simplifying a network topology by removing less loaded link should have an important impact on the energy consumption with a limited impact on route length (Joanna Moulierac, 2010)(Jingcao Hu et al,2008).

In a general way the tendency is to start services on demand, for instance a server(C Develdet et al, 2008) or network interfaces (Christine E. Jones et al, 2001)(Mahesh K et al, 2010) or even devices with the use of wake-on-LAN technologies. However the research seems to focus on wireless technology when it comes to network topology probably because of the battery consumption of end-devices, but also because of the flexibility bring by mesh networks and network sensors (Mahesh K et al, 2010). But it is actually impossible to compare two similar topologies, one involving mostly wireless network element and a second one involving only wired elements. Furthermore it is also difficult to evaluate the real energy saving realised when deploying power-efficient technologies such sleeping mode on wireless network devices. And finally the cloud computing seems to save energy for the customer but does it really reduces the global energy consumption? Usually while deploying a cloud computing architecture, the power consumption is moved outside companies boundaries but there should still be an important consumption of electricity in data-center which need to be measured.

C.2 Project outline for the work that you propose to complete

The idea for this research arose from:

A global environmentally-friendly tendency/a general trend in the IT fields to reduce energy-consumption.

The aims of the project are as follows:

- Evaluate impact of Virtualization/Cloud architecture carbon footprint compared to an architecture involving several physical servers
- Compare Wireless Network topology and Wired Network topologies in terms of energy consumption. Possibly involving wireless mesh network topology.
- Measure the energy consumption differences between a wireless topology which have been deployed in a power-efficient way and implementing some power-efficient technologies and a wireless technologies which has not.
- Based on performance evaluation and measurements, define power-efficient network design and management guidelines.

The main research questions that this work will address include:

- Is the carbon footprint of having a several physical servers bigger than having them virtualized and running on the same hardware ? How big is the difference ?
- Can actual wireless topology manage energy utilization most efficiently than wired topology?
- How much power can be saved by implementing power-efficient technologies or by configuring it in a power-efficient way.
- Which modifications should be done in terms of design and management on companies network to reduce the energy consumption?

The software development/design work/other deliverable of the project will be:

A study of some actual network technologies focusing on their energy consumption. The study will also include measurements and result analysis and propose some guidelines.

The project will involve the following research/field work/experimentation/evaluation:

This project will involve a literature review about cloud computing, wireless and wired infrastructure, mesh networks focussed mostly on energy consumption.

Experimentations aiming to compare and measure the difference of power consumption between a cloud infrastructure and a “classic” infrastructure.

Experimentations aiming to compare and measure the difference of energy consumption between a wireless network topology and a wired topology. An experimentation aiming to evaluate and measure the difference of energy consumption of a wireless topology.

This work will require the use of specialist software:

Virtualization software (such as XEN or KVM) used to build a cloud infrastructure and OpenNebula to manage virtual servers.(The actual cloud can be used as there will probably not have any configuration to perform.

This work will require the use of specialist hardware:

For the cloud computing part: A cluster of servers

For the network architecture part: Switches, Router, Wireless access-point, Wireless-mesh Access-Points.

C.3 Proposal References

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