STUDY OF ENERGY EFFICIENCY IN PORTABLE DEVICES USING CLOUD COMPUTING: CASE OF MULTIMEDIA APPLICATIONS

A Thesis by

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The following faculty members have examined the final copy of this thesis for form and content, and recommend that it be accepted in partial fulfillment of the requirement for the degree of Master of Science with a major in Electrical Engineering.

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DEDICATION

To the Almighty, my loving parents, brother, uncle, and his family, for their enduring support and patience; to my friends, especially Arun, Ashwin, Chetan, and Prabhu, for incomparable advice throughout my life

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I take enormous pleasure in recognizing, with endless thanks, to all those who assisted me directly and indirectly with my experimental research.

ABSTRACT

Energy efficiency is considered an important argument when designing information and communication technology solutions. Today the use of portable devices to receive valuable services while on the move is immense. Advancements in software and hardware technology need to be assimilated, with corresponding meliorations in battery engineering. With further progress in device miniaturization, striking improvements in battery technologies cannot be foretold. Due to limited energy requirements on portable devices, changing computing power from the user end to a remote server has provided the opportunity for the evolution of cloud computing.

With on-demand self-service from cloud computing, there has been substantial growth in the number of users of portable device like laptops, netbooks, smartphones, and tablet PCs, which has resulted in a significant increase in energy consumption. The main objective of this research is to study and analyze the energy patterns between client-computing and cloud-computing-based applications that provide multimedia services.

This study renders potential solutions for cloud users and cloud service providers to choose applications based on their requirements. It provides an alternative to end users for optimal-use cloud services through battery-powered portable devices.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF ABBREVIATIONS / NOMENCLATURE

AAC	Advanced Audio Coding
ACK	Acknowledgement
ACPI	Advanced Configuration and Power Interface
ADSL	Asymmetric Digital Subscriber Line
AP	Access Point
ASIC	Application Specific Integrated Circuit
BSD	Bounded Slow Down
CDMA	Carrier Division Multiple Access
CPU	Central Processing Unit
FLV	Flash Video
FTP	File Transfer Protocol
GPU	Graphical Processing Unit
GSM	Global System for Mobile Communications
HDD	Hard Disk Drive
HTML	Hyper Text Markup Language
ICT	Information and Communication Technology
IE	Internet Explorer
IP	Internet Protocol
ISO	International Organization and Standard
LAN	Local Area Network
LCD	Liquid Crystal Display
MAC	Media Access Control

NIC	Network Interface Card
NIST	National Institute of Standards and Technology
OS	Operating System
PDA	Personal Digital Assistant
PON	Passive Optical Network
PSM	Power Saving Mode
RAM	Random Access Memory
RDP	Remote Desktop Protocol
RFB	Remote Frame Buffer
RTT	Round Trip Time
SATA	Serial Advanced Technology Attachment
SLA	Service Level Agreement
SNR	Signal to Noise Ratio
SWF	Shockwave Flash
TCO	Total Cost Ownership
TCP	Transport Control Protocol
TFT	Thin Film Transistor
UDP	User Datagram Protocol
USB	Universal Serial Bus
VCEG	Video Coding Experts Group
VDSL	Very-high-bitrate Digital Subscriber Line
VM	Virtual Machine

LIST OF ABBREVIATIONS / NOMENCLATURE (continued)

VNC	Virtual Network Computing
VoIP	Voice over Internet Protocol
WiMax	Worldwide Interoperability for Microwave Access
WXGA	Wide eXtended Graphics Array

CHAPTER 1

INTRODUCTION

1.1 What is Energy efficiency?

Growth in knowledge and ideas by humans has provided them a comfortable life. Energy is required in every aspect of day-to-day living. Our bodies need energy to complete day-to-day tasks. Energy is required to drive to the office, to work with computers, to cook food, etc. Energy has become a basic entity in the present world. As the world continues to crave technology, it needs more energy and resources. In modern technology, energy is seen as a precious resource during the design and implementation of prototypes. Therefore, efficiency is viewed as a main factor in design. *Energy efficiency means consumption of energy in a way to provide enhanced services or to process a task with less resource utilization by achieving efficiency* [1] [2]. It involves the conscious development of all working methods and production ideas that squander less energy, while maintaining the same rate of yield. The use of renewable energy will also lead to significant energy savings, which is another way of using energy in an efficient manner.

1.2 Why Cloud Computing for Energy efficiency?

With technologies such as Fourth generation (4G), Third generation (3G), Code Division Multiple Access (CDMA), Wireless Fidelity (Wi-Fi), and Worldwide Interoperability for Microwave Access (WiMax), mobility has grown rapidly along with the Internet to provide services on the move. These devices need sufficient energy or power to provide user access to them for a significant amount of time. Currently, the Internet is in a stage of evolving in the direction of cloud computing, a technology which is transforming the computing landscape. Cloud computing is changing the way technology is deployed over the Internet and the way in which the economics of computing is considered [3]. Cloud computing provides most of the requirements as used in traditional computing—from computing power to computing applications, infrastructure, and business to personal collaboration. Services can be delivered to the end user at any given time or location. Tasks and services moving towards cloud computing means portability/accessibility on the move, efficient use of computing resources, an eco-friendly environment, increase in reliability and scalability, reduced costs, etc.

1.3 Energy Consumption of Portable Computing Devices

Commonly used computing devices, such as desktop Personal Computers (PCs), laptops, mobile phones, music players, and other miscellaneous devices like pagers, global positioning systems, etc., are used by almost everyone because they are low in cost and easily available. It has been estimated that at the end of 2009, there were around 170 million laptops in use [4]. With each laptop used for 8 hours a day consuming about 30 watts per hour, the total energy consumed in a year would be approximately 14.8 trillion watts. Mobile phones (4.1 billion) are the largest number of portable devices in use around the world [5] and include Personal Digital Assistants (PDAs), high-end phones, and low-end phones, where the energy consumption can vary from 1,000 mw to 1,250 mw. Considering mobile phones being used for 10 hours a day and an average energy consumption of 1,100 mw, then over a year, 16.4 trillion watts of energy would be consumed. With 33.3 million netbook users [6], energy consumption is around 15 to 35 watts per netbook [7]. On an average with 5 hours of usage per day, 1.5 trillion watts is consumed in a year. Tablet PC consumes up to 20 watts of energy and users are increasing every year, with 10.2 million presently; therefore if used for 5 hours a day, per year, they consume 0.15 trillion watts of energy. Finally, there are about 250 million Apple iPods, 5 million Microsoft Zune players, and 300 million other music player devices. On an average they will be used up to 10 hours a day and if the power consumed by these devices is around 0.25 watts, then 50 billion watts would be consumed over a year.

The pie chart in Figure 1 provides a clear picture of how energy consumption is distributed among different devices. Although it can be seen that laptops are consuming most of the energy, compact devices like mobile phones, netbooks, and tablet PCs account for more energy consumption than laptops. Therefore, compact devices are being preferred over laptops. Users of tablet PCs and netbooks will exceed users of laptops by the year 2013 due to services available over the Internet [8]. In the meantime, the applications developed and infrastructures implemented are attempting to become more eco-friendly in order to save as much computing energy as possible on both the user end and the server end. Experts view cloud computing as a major solution for green computing and for energy savings [9].

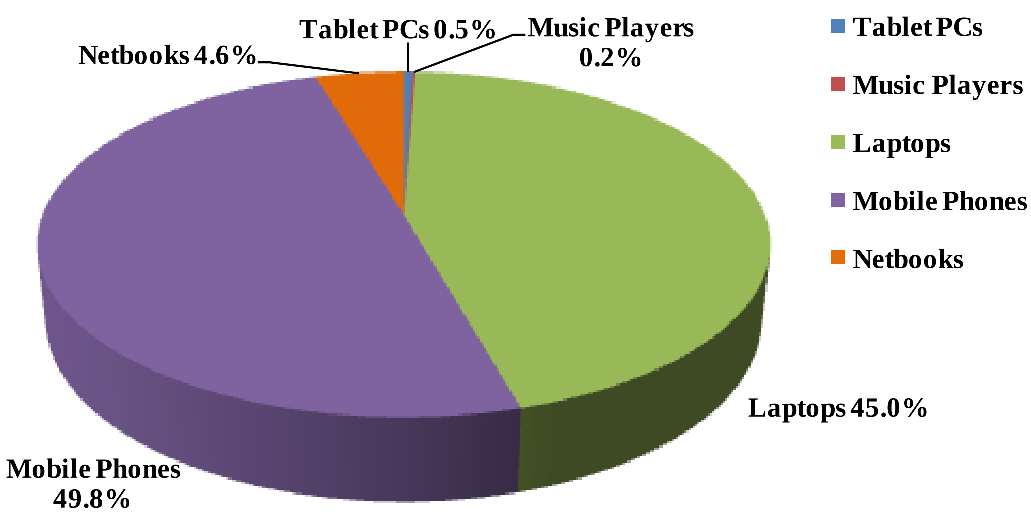

Figure 1: Energy consumption of portable devices

Green computing is the efficient and eco-friendly use of resources in the computing environment. Green computing deals with sustainable techniques of manufacturing and designing servers and networks, taking into consideration parameters such as energy consumption, power utilization, alternative technologies, etc. Energy and power constraints play a major role in green computing.

1.4 Problem Description

Cloud services can be delivered to the end user as a service whenever and wherever it is required. For an end user, most computing privileges are solely provided on the cloud. Control over computing on the cloud is done with the help of communication applications provided by the cloud service provider. In the present stage of cloud computing, data and programs are run on a web browser, which is also known as web computing [10]. The browser provides an environment similar to that of a current desktop. There are many advantages to web computing: low computer cost, improved performance, and reduction in software costs. Data on the cloud can also be shared, and collaboration with multiple users can occur in real time. This is an advantage for business applications. It is also possible to have access to all personal data on the move, making it pointless to carry anything in hand. As cloud computing is emerging, considerable research is being conducted on its implementation, maintenance, security, and service. But the end user must still spend energy on obtaining the service or executing tasks on the cloud. The energy spent locally depends on what the user is trying to accomplish over the cloud. The main intention of the research work in this thesis was to study and compare the energy it takes for accessing data locally on a portable device via local client computing, like a laptop, and for accessing multimedia over the cloud.

1.5 Contribution

In this thesis, real-time experiments were conducted for accessing multimedia data locally on the laptop and over Wi-Fi, and for accessing similar multimedia information over the cloud. A comparison of different software platforms, common multimedia formats, and in popular cloud client applications provides an idea on how the energy is being consumed by the client. This opens up opportunities in analyzing energy consumption and to specifically work on improving multimedia codecs and cloud client applications on different platforms like the closed-source Microsoft Windows and the open-sourced Linux-based Ubuntu Operating Systems (OSs). Further detailed analysis of cloud-based results between these two operating systems provides an opportunity to create an enhanced platform and applications for the end user, in order to contribute more energy-efficient cloud computing and client computing.

1.6 Organization of Thesis

As mentioned previously, this thesis delivers a detailed analysis of the energy patterns of a client laptop over cloud computing in the case of multimedia traffic. Chapter 1 presents a foreword to the concept of energy efficiency, why cloud computing is an energy efficient solution, and energy consumption of portable devices around the globe. Chapter 2 explicates the motivation behind the thesis. It renders an analysis of the energy breakdown of components of a client laptop. Chapter 3 provides a literature survey on energy-efficient wireless networking, multimedia access based on buffer management and a traffic-shaping mechanism to save energy, and thin-client computing. Chapter 4 contains thorough information on the evolution of computing, cloud computing, different architectures of cloud computing, types of cloud services, cloud client computing, cloud applications, and types and applications of multimedia. Chapter 5 presents the experiments and an analysis of the results. Chapter 6 concludes the thesis and presents suggestions for future work in the area of energy-efficient cloud and client computing.

CHAPTER 2

MOTIVATION

Since cloud computing is evolving daily, organizations are interested in providing end users with services that have mobility. Today, there is an exponential growth in the use of laptops for computing and communication. Over the past two years, desktop sales have been taken over by laptops worldwide. Furthermore, studies indicate that laptops have a stake in approximately one percent of the overall global energy consumption. However, the present battery technology in laptops can provide energy only for a few hours. Therefore, the end user should be aware of how to minimize the energy drain on portable devices by knowing which components are consuming significant amounts of energy. To achieve this goal, it is significant to study the power consumption of each component. Further research in later chapters will provide valuable information, even for the cloud service provider to decide which application will provide extended service to the end user. In this work, the power consumed by each component of a modern laptop was systematically studied. A brief description of the hardware and software setups, a detailed explanation of the procedure and graphs explaining each component, and finally the limitations and breakdown of components will be explained.

2.1 Hardware and Software

The laptop used was an IBM Lenovo SL400 with a 14-inch display with Ubuntu 9.04 operating system (OS). The processor included an Intel® Core ™2 Duo processor with an operating frequency of 2.4 GHz. The Wide eXtended Graphics Array (WXGA) Thin Film Transistor (TFT) active matrix used as the display technology supported a 24-bit color feature (16.7 million colors). The processor also included a memory of 2 Gigabytes (GB) and a hard drive storage capacity of 160 GB. It also supported 802.11 a/b/g/n Wi-Fi technologies for wireless communication with an optical Digital Video Disc plus Read-Write (DVD+RW) drive. The laptop was powered by a standard six-cell lithium-ion battery. Direct measurements were done for the hard drive and the Input/output (I/O) ports. A simple digital multimeter was used to obtain direct readings, and the other readings came from the "state" of the battery.

2.2 Procedure

2.2.1 Hard Disk Drive

With a storage capacity of 160 GB, the disk supported 7,200 rotations per minute (rpm). It was internally connected with a 22-pin Serial Advanced Technology Attachment (SATA) connector, and a 22-pin SATA extension cable was used to facilitate the obtainment of readings from the multimeter. To study the power consumption, standard read, write, and copy operations were performed using a 697.9-megabyte (MB) Ubuntu International Organization for Standardization (ISO) image file, and correspondingly, battery readings were noted to estimate the effect of hard disk utilization on the battery drain. From Figure 2 it can be seen that the read-write operation with maximum brightness consumes more milli watt hours (mWh) of energy, and Table 1 shows the direct measurements of different operations.

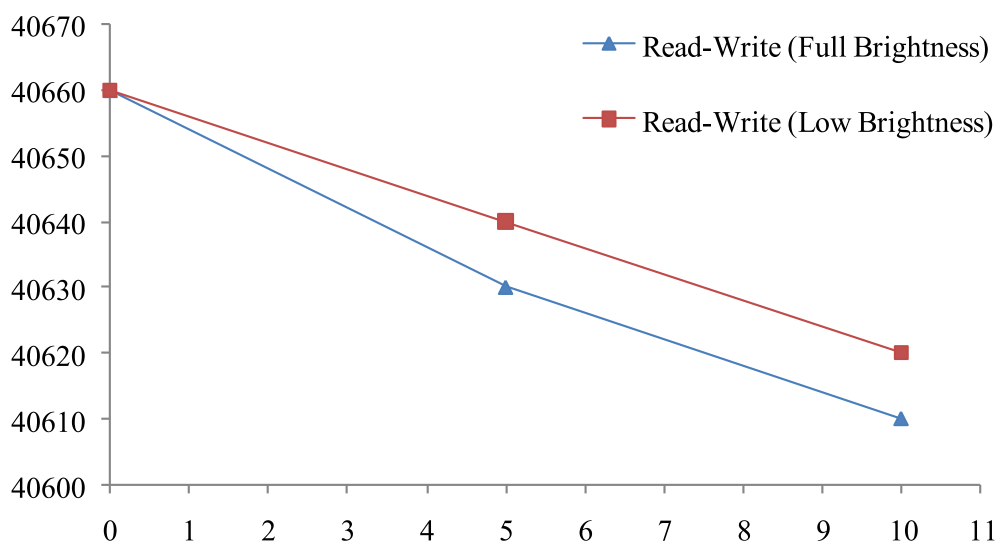

Figure 2: Time (sec) vs. energy (mWh) for read-write operation

TABLE 1

DIRECT MEASUREMENTS FOR HARD DISK DRIVE

Operation	Power Consumed (W)
Idle	2.13
Read	2.73
Write	3.32
Copy	3.37

2.2.2 LCD Display

Battery statistics for the laptop were obtained with the aid of a built-in Advanced Configuration and Power Interface (ACPI) procedure from the Ubuntu operating system. A different approach was taken here. The Hard Disk Drive (HDD), optical drive, and networking devices were dismantled, and the laptop was booted using a Universal Serial Bus (USB) drive. This USB drive was disconnected once the laptop had booted. The laptop needed a battery to power up the Liquid Crystal Display (LCD), Central Processing Unit (CPU), and Random-Access Memory (RAM). In this scenario, the CPU and RAM took a very minimal amount of energy since nothing was being processed.

With the brightness of the LCD at maximum, appropriate battery statistics were recorded from the ACPI procedure every minute for an hour. The experiment was then repeated with a minimum level of brightness. White and black colors were used as the background display.

As shown in Table 2, the power consumed was 15% more during maximum brightness compared to minimum brightness, and the black background consumed more power than the white background. This could be due to the twisted nematic effect of the LCD display [11]. The black background consumed 3.96% more energy than the white background. Figure 3 shows how the battery capacity was reduced with maximum and minimum brightness levels. Placing the brightness at maximum level dropped the battery capacity almost exponentially.

TABLE 2

POWER CONSUMPTION OF DISPLAY

Operation	Power Consumed (W/min)
Black Background	0.210
White Background	0.202
Default Background (Full Brightness)	0.207
Default Background (Low Brightness)	0.180

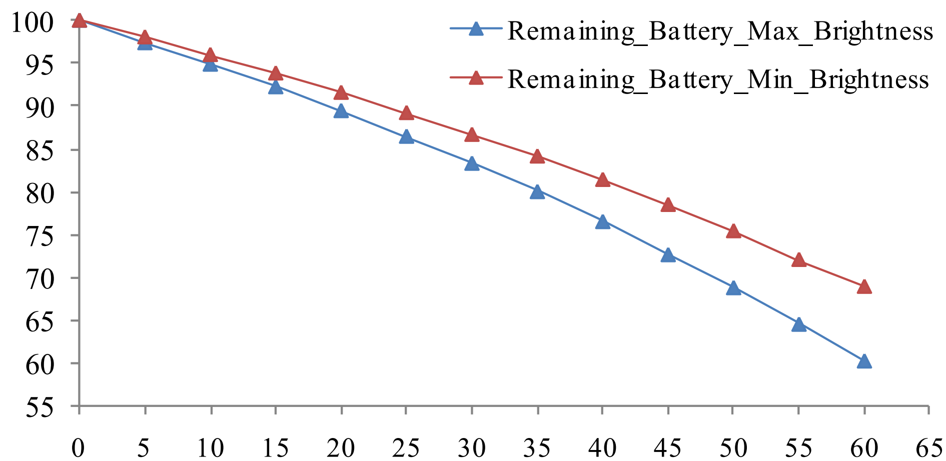

Figure 3: Time (min) vs. remaining battery capacity (%) for LCD display

The above experiment was repeated with red, blue, and green backgrounds, which are the basic colors in nature. It can be seen in Figure 4 that all three colors consumed the same amount of energy, which is evident from the overlapping graphs.

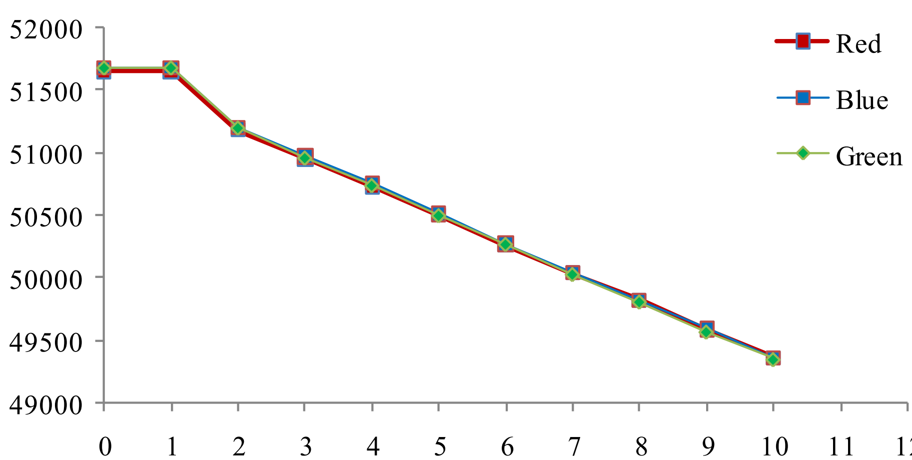

Figure 4: Time (min) vs. remaining battery capacity (%) for red, blue, and green backgrounds

2.2.3 Graphics Card

The laptop was loaded with a NVIDIA GeForce 9300M GS graphics card with 256 MB of onboard memory. Three-dimensional (3D) games were played with the Wi-Fi turned on and later with the Wi-Fi turned off. The 3D game played over the Wi-Fi was Evony, and the 3D game played locally on the laptop, without Wi-Fi, was Warezone 2100. Also, a two-dimensional (2D) game, like Solitaire, was played for comparison with the 3D games. Figure 5 compares the three stages of stress on the graphics.

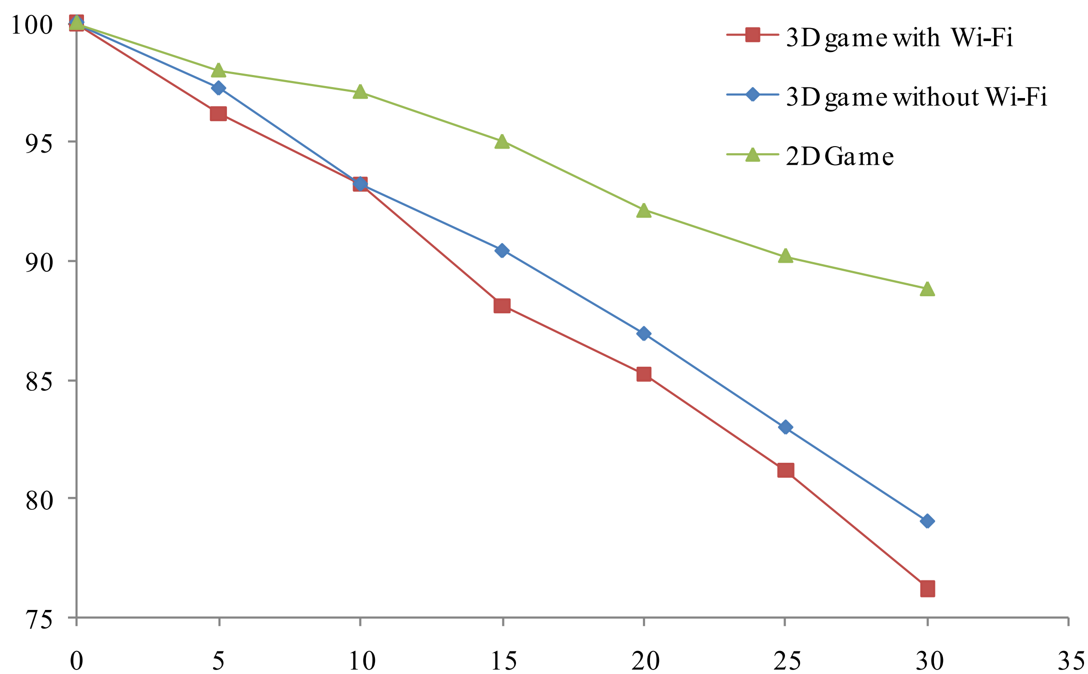

Figure 5: Time (min) vs. battery (%) for graphics card

2.2.4 Wireless Card

The wireless Local Area Network (LAN) standard IEEE 802.11g was used for testing the laptop, with a transmission rate of 54 Mbps. The applications tested were the File Transfer Profile (FTP) and Skype-based voice chat. An Ubuntu ISO image file was downloaded to identify the power consumption of both applications. Figure 6 shows that voice chat consumed a significant amount of energy.

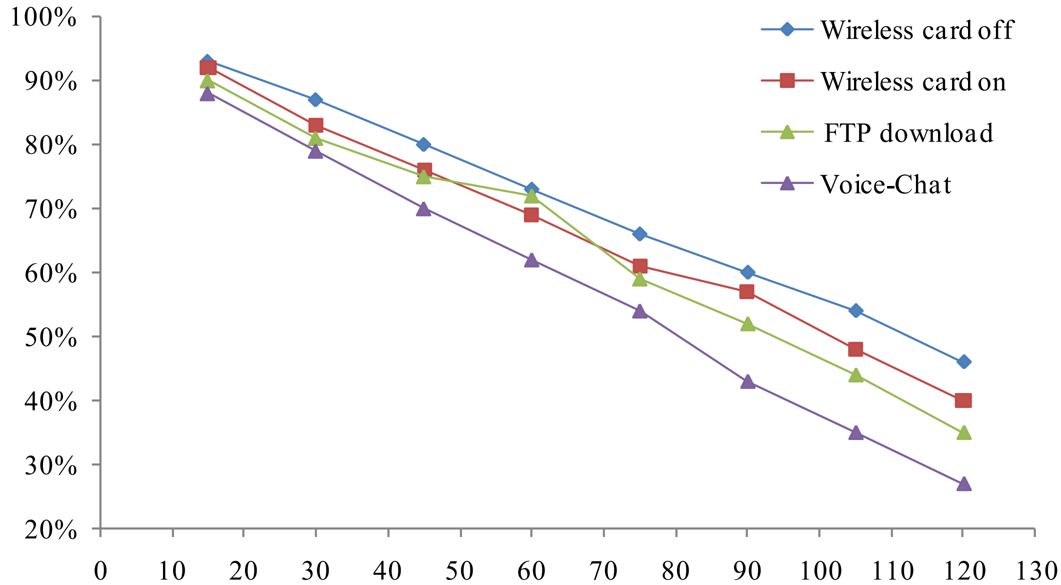

Figure 6: Time (min) vs. battery (%) for wireless card

2.2.5 Optical Drive

A DVD-RW drive is capable of writing and reading with a speed of 8x and 16x. Experiments were done on the read and write operations. Here, a small amount of data (600 MB) was tested on different brightness levels of the LCD display. One observation showed that not only did low brightness consume less energy, but the write operation also consumed less time to complete the task. Both the read and write graphs are provided in Figure 7.

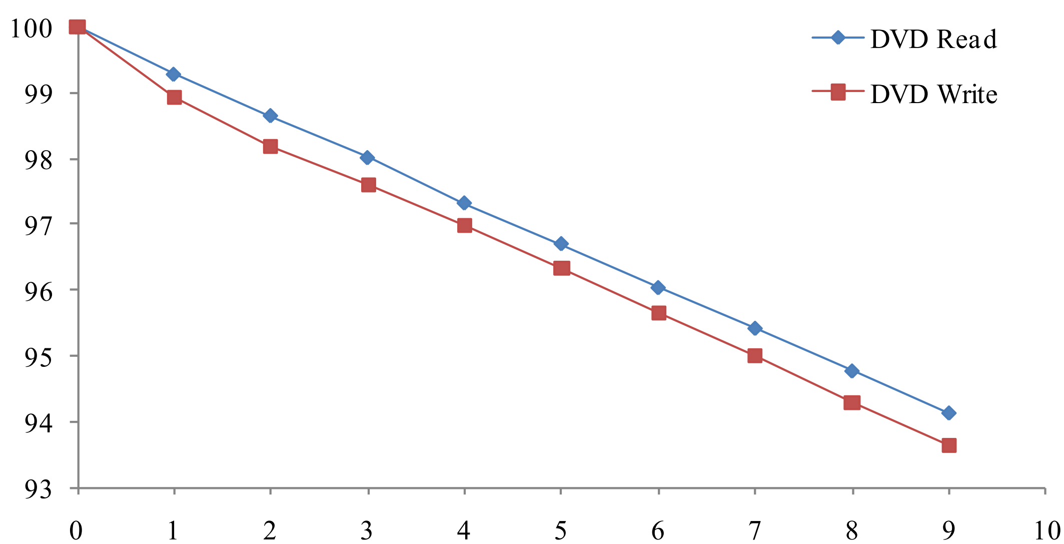

Figure 7: Time (min) vs. battery (%) for optical DVD-RW drive

2.2.6 I/O Ports

The first experiment went a step beyond in calculating power consumption for the input/output ports. Energy consumption of the USB port was measured by playing a movie continuously for an hour using a flash drive. The remaining charge on the battery was observed every five minutes, and the readings were tabulated. Results of this experiment show that energy consumption from USB devices differs only slightly when compared to energy consumption for the entire system, or “standard laptop” scenario. Some USB devices that are connected to a laptop can shorten the battery life dramatically by pulling the charge from the battery. A USB extension cable was used to measure the power consumption in some popular USB devices: iPhone, flash drive, external HDD, portable HDD, and optical mouse. A multimeter connected across this extension cable measured the power consumption readings, as shown in Table 3.

TABLE 3

POWER CONSUMPTION OF DIFFERENT USB DEVICES

Device	Power Consumed (W)
iPhone	2.475
Portable HDD	1.881
Mouse (idle state)	0.270
Mouse (working mode)	0.1485
4 GB Flash Drive (idle state)	0.297
4 GB Flash Drive (during data transfer)	0.445
External HDD (with external power source)	0.098

2.2.7 Bluetooth

Bluetooth is an open-standard technology that can be used to transmit data for short distances. The laptop in this study did not have an onboard Bluetooth available to measure the power, so an external standard Bluetooth version 2.0 was used to measure the power consumption. The transmission and reception results of both versions are shown in Figure 8.

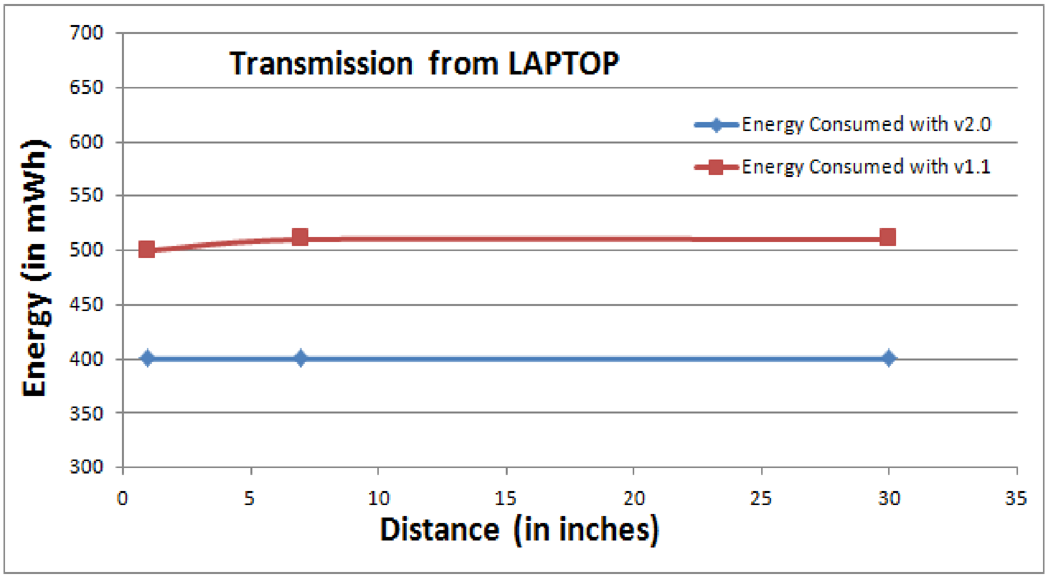

Figure 8: Distance (in) vs. energy consumed (mWh) during data transmission

In wireless communication, data reception consumes more energy than data transmission due to continuous sniffing of the medium by the receiver antenna for any probe signals. This can be inferred in Figure 8 and also in Figure 9, where it can be seen that the reception is consuming more power. As shown, Bluetooth version 2.0 is more energy efficient than version 1.1, which shows improvement in the technology.

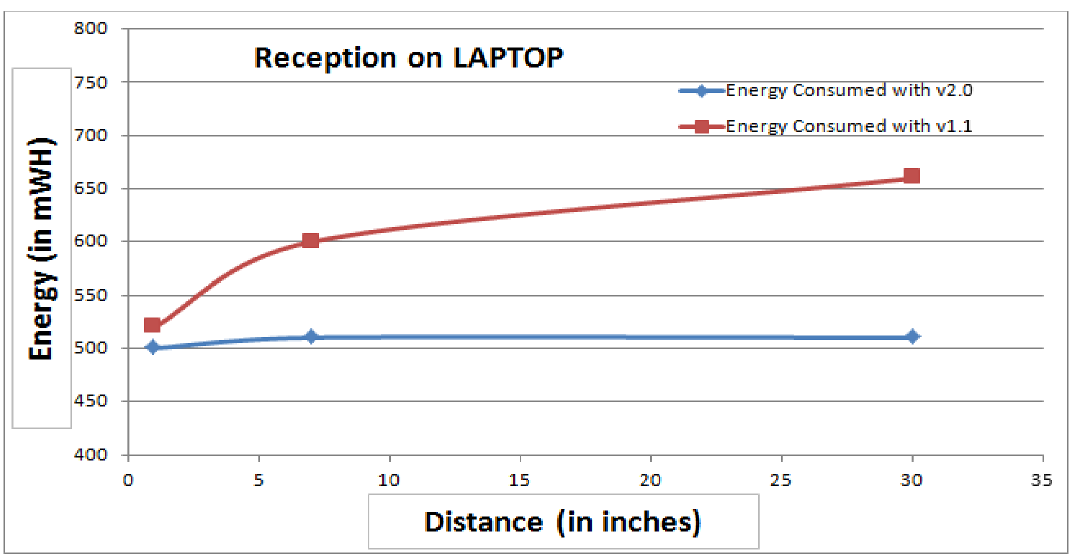

Figure 9: Distance (in) vs. energy consumed (mWh) during data reception

2.3 Discussion of Results

This section discusses the component-wise breakdown of all the hardware and which part of the device consumed significant power during different scenarios. Results were obtained for some components, like CPU, RAM, graphics, and exhaust fan power, but other components were integrated into the motherboard of the laptop and hence, termed "Rest" in the pie charts, meaning rest of the system.

Figures 10 and 11 show graphs of the energy percentage breakdowns for an idle system with minimum and maximum brightness, respectively. Although the "Rest" of the system comprised a greater percentage, it is evident that the increase in the rate of power consumption for the LCD display during maximum brightness is twice that during minimum brightness. In the idle state with minimum brightness, the total system power was 12.04 Watts, compared to 14.88 Watts during maximum brightness.

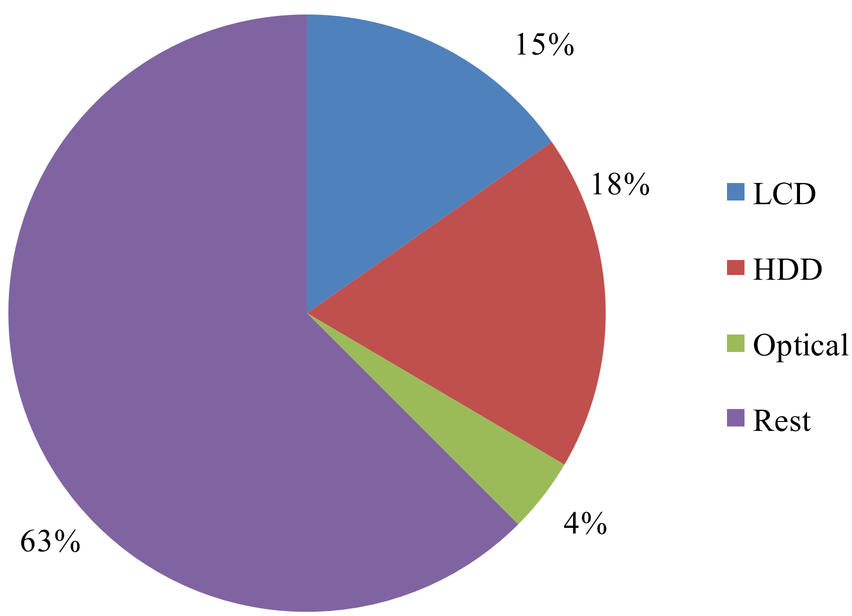

Figure 10: Power consumption breakdown of idle system with minimum brightness

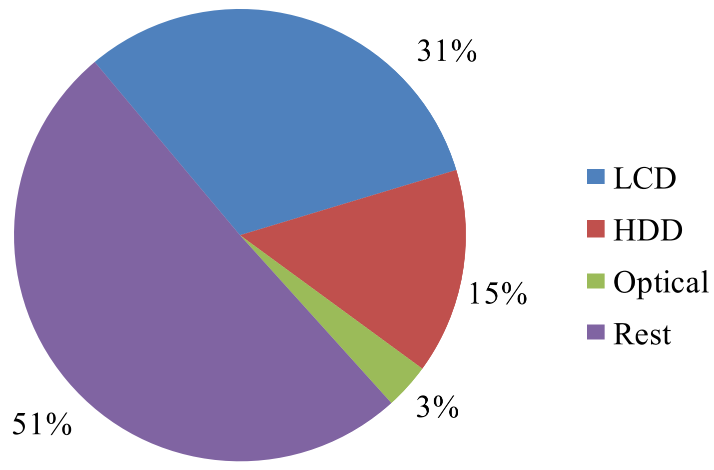

Figure 11: Power consumption breakdown of idle system with maximum brightness

The copy operation on the hard drive consumed 3.38 Watts of power, as shown in Figure 12. This hard drive was comprised of a tiny motor that spins the magnetic disks. Here, the major part of power consumption occurred while the disks were spinning, in order to seek data at a faster rate. By using solid state drives and low-rpm disks, a considerable amount of power can be saved. In section 2.2.5, it was mentioned that the optical drive took less energy during the read operation than during the write operation, when burning 700 MB of data at a speed of 16x. The optical drive consumed 6.05 Watts of energy from the total system power of 20.88 Watts. This is represented in Figure 13.

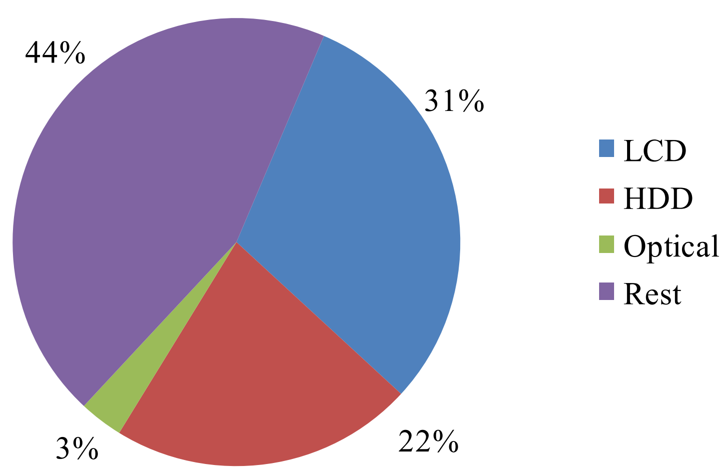

Figure 12: Power consumption breakdown during copy operation on hard drive

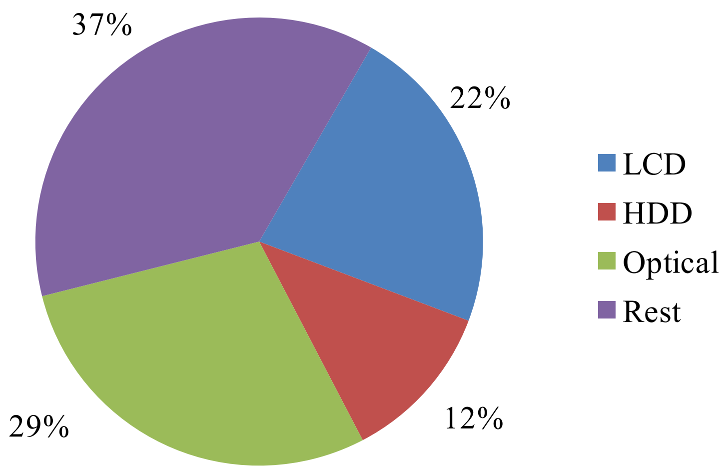

Figure 13: Power consumption breakdown when burning data on optical drive

A wireless Network Interface Card (NIC) was also tested with data and voice-based applications. Voice over Internet protocol (VoIP) communication consumed more energy than data transfer, and the wireless NIC consumed an overall power of 4.18 Watts from the total system power of 19 Watts. This breakdown is shown in Figure 14.

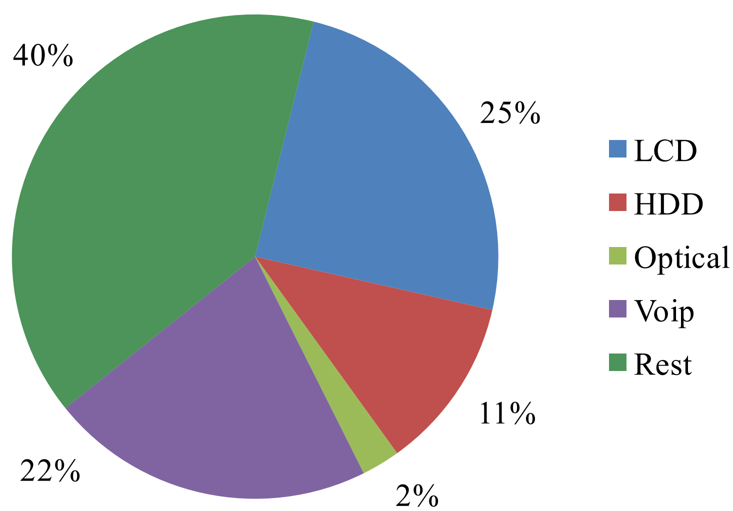

Figure 14: Power consumption breakdown for VoIP

2.4 Limitations

The accuracy of these experiments varies due to some factors. When using the multimeter to measure the currents through and voltages across the devices, there could be a marginal error of 3mA due to external factors like interference, multimeter cable resistance etc. As mentioned in the results section, power consumed by a few of the components was calculated with the subtractive method because of the device's integrated parts, which did not provide a feasible way of measuring their power consumption.

2.5 Conclusion of Analysis

From the above analysis, it was possible to obtain component-based energy consumption for some major components. It can be inferred from the results that the wireless card, LCD display, CPU, and graphics card consumed a significant amount of the laptop's energy.

CHAPTER 3

LITERATURE SURVEY

Part of the motivation for this thesis was the contention that a wireless NIC card is one of the prime consumers of energy in mobile devices. A basic VoIP communication consumed more than 22% of the battery capacity. Some of the areas researched in order to find a way to improve the energy efficiency of communication technology have been in power-controlled wireless communication, an efficient Medium Access Control (MAC) protocol, directional antennas, and application layer-controlled data management.

3.1 Energy Efficient Wireless Networking

One of the reasons for a wireless card being a power-hungry component of wireless communication is because power is radiated in all directions, even though the destination lies at a single point. The majority of currently used mobile devices employ omni-directional antennas, which radiate power over 360 degrees, thus causing interference issues and a directional waste of power. The goal of Amiri Sani et al. [12] was to address these problems by presenting BeamSwitch, a multi-antenna model designed to communicate directionally and efficiently by concentrating radiation in the right direction. Even though their design was a multi-antenna system, only one antenna at a time was used. It also employed a low-power transmit mode to transmit data and receive its acknowledgement (ACK) packet. This design worked on two key modules: antenna assessment and next antenna. The antenna assessment module determined the available Signal-To-Noise Ratio (SNR) threshold value and whether it was the same threshold value suggested by the current antenna used in communication. Meanwhile, the next antenna module provided information about the antenna to be used for data transmission. This prototype was tested with High-Definition (HD) video, file transferring using FTP, and also remote access using the Remote Desktop Protocol (RDP). BeamSwitch improved both communication quality and energy efficiency when there was 90 degrees/second of rotation for all of the above three benchmarks. The authors observed up to 20% improvement in FTP throughput and 20% less energy consumption in bit-reduction for the HD video. However in the case of 360 degrees/second rotation, there was a slight degradation in communication. Finally, their overall evaluation demonstrated that the concept of BeamSwitch improves energy efficiency by 20% of the 802.11 wireless NIC card with close and sometimes better quality in communication than traditional systems with omni-directional antennas. The authors noted that this would produce even more effective results with cellular networks.

Energy efficiency was also achieved from the research performed on long idle periods in wireless networks with a little cooperation from applications and network devices. Energy consumption can be reduced during short idle time or intervals that are part of the communication process but which are not in reach of the 802.11 Power-Saving Mode (PSM). These idle intervals are often seen as the result of a gap required during the communication of high data rate between 802.11 interfaces and also, limitations set in the wired link. To overcome these delays and make use of idle-time intervals in improving energy efficiency, Liu and Zhong [13] proposed a framework called Micro Power Management (μPM), a mini-feature to the 802.11 interface to enter power-saving modes between MAC frames without any interruption in data traffic flow. They noted that the power consumption on 802.11 interfaces was reduced by placing communication in a sleep or idle state, often for several microseconds. This could introduce frame delay to the upper Transmission Control Protocol/Internet Protocol (TCP/IP) layers but was handled by employing a history-based calculation to adaptively and statistically guess future-frame delays. The calculation employed a simple operation technique, whereby the

802.11 interface entered an idle period longer than the listening cycle, according to μPM; then the interfaces woke up and slept very often, based on the ongoing communication. The μPM incorporated a power management scheme that was synchronized with the power-saving mode and predictable idle periods. It communicated to the Access Point (AP) before going into the idle state by setting an unused bit in the control field of the last frame sent to the AP. Upon receiving the last frame, a cooperative AP did multiple retransmissions when sending the next frame in order to make up for any lost frames while the μPM was waking the interface. This could impact the throughput of other users who are communicating via this AP. Simulations on Network Simulator 2 (NS2) and in a practical setup [13] proved μPM to be an effective solution. In order to evaluate the μPM, the authors tested different types of benchmarks, such as audio, video, RDP, FTP, and browsing over Internet Explorer (IE). Overall, they found a 30% reduction in the energy spent when μPM and cooperative AP worked in tandem, with no difference in the data-loss rate.

Mobile devices have the option of communicating using technologies like Wi-Fi, Global System for Mobile Communication (GSM), CDMA, Bluetooth, etc. To handle all of these technologies, battery requirements must also be met. Among the above-mentioned technologies, Wi-Fi is the least efficient. Marcu et al. [14] analyzed Wi-Fi, Bluetooth, and GSM technologies when used for different purposes. They presented a monitoring application that collected power usage statistics of the CPU, Wi-Fi module, and battery. Their application also showed logging and profiling capabilities. The authors provided relevant details on the energy consumption of a Wi-Fi module of differing data block sizes, varying distances through obstacles, and with and without encryption. One of their important observations was that VoIP over GSM is more energy efficient than Wi-Fi. This paper provided the necessary details proving that Wi-Fi is a power-hungry component and needs application-level control to increase its power efficiency.

3.2 Energy efficiency for Multimedia Services

Experiencing multimedia over wireless networks is common these days. Due to large amount of data being exchanged over the air, the energy consumed by mobile devices is very high. This depends, however, on the type of audio or video being streamed. If the multimedia application running on the client and the wireless network interface card work in concert together with controlled data transmission and reception, a considerable amount of power could be saved. One of the main impacts on energy consumption when running multimedia data with wireless streaming is the cost of the data stream that is received. A high-compression technique like the MP3 digital audio encoding format is less power consuming than MP1 or MP2 formats, which use a lower compression technique. Bertozzi et al. [15] proposed a power management idea using an NIC off mode while the client controlled the streaming of multimedia data that was in progress from the server or source. The basic approach here was to turn off the NIC when the frames were played back until a threshold was reached in the buffer level on the client. A buffer-management policy in place accommodated the need of the NIC to minimize the switching activity (ON/OFF) and for the requirement of the audio chip not to run out of data or buffer. When the buffer level hit a low water-mark level, the network interface card was informed by the application to request more data from the source to refill the buffer. When buffering reached a certain required level, the NIC was turned OFF. Here it was assumed that the client could control the data exchange whenever necessary. Simulation results showed that when the available bandwidth was less, buffering needed to be increased, and that with this simple method, 25% power efficiency compared to standard 802.11 techniques could be accomplished.

In the work mentioned above, the client was trying to control multimedia data reception and transmission by implementing buffer management. Chandra and Vahdat [16] explored different ways to transmit data packets in order for the client to enter a low power-consuming state. Reducing the fidelity or quality also decreased the amount of data to be streamed under low-bandwidth conditions. Therefore, this could reduce the total energy consumed. The authors showed limitations of the MAC-level power-saving mode in IEEE 802.11 for an isochronous stream of multimedia data. By keenly observing the streaming requirements, the MAC level mode did not perform properly enough to offer any energy savings for streams above 56 kbps. The authors proposed a server-controlled traffic-shaping mechanism, which offered energy savings for different video-stream formats. This idea was tested on Microsoft Real-Time, and QuickTime versions for bandwidth streams of 56 kbps, 128 kbps, and 256 kbps. The scenarios were repeated with a single user and multiple users communicating over a single access point. Based on the delay introduced by the server on traffic-shaping policies, the media players for their respective versions adapted to these delays by reducing the stream quality. Since there was a reduction in stream quality, the energy consumption on the client in processing a low-quality video was also less. Chandra and Vahdat proved that the Traffic Indication Map (TIM) interval and wait time could affect the client's energy savings. In this way, 83% energy savings was achieved on the client end due to intelligent control over the fidelity of the streams. This research also contributed to handling the delay during low-quality streams, scheduling mechanisms by operating systems, and making use of AP to avoid network issues.

The rapid growth of the Internet has shown an increase in the number of users accessing the web through wireless networks. However, the wireless NIC card is one of the power-consuming devices, so when accessing the web, considerable Transmission Control Protocol

(TCP) and User Datagram Protocol (UDP) connections exist. Krashinsky and Balakrishnan [17] analyzed TCP performance for web-based communication and its impact on energy consumption. They provided details on how the IEEE 802.11 power-saving mode with a static protocol can lower the performance with an increase in Round Trip Time (RTT). They also proposed the Bounded Slowdown (BSD) protocol, which is a type of PSM that adapts dynamically to sleep intervals based on past activities so that the RTT is not increased by a factor x, where x is a parameter of the protocol that exposes the performance trade-off between reducing energy and latency in a probable manner. To overcome fast RTT delays, the network interface stayed awake for a short interval when the link was active. Then, less energy was consumed in listening to the beacons by backing off and only listening to fewer beacon signals when network activity was minimal. The only confinement with this approach was that the PSM protocol worked at a link-layer without any knowledge of higher layers. In this way, the PSM, i.e., BSD protocol reduced the web page retrieval up to 64% of normal value, whereas energy consumption was reduced by 14% on the client device.

3.3 Energy Management in the Cloud

Cloud computing has been acclaimed as the future paradigm for local and Internet computing. This will bring a rapid change in the approach for Information Technology (IT) and business activities among many organizations. So when the need for computing, resources, and applications is satisfied over the cloud, the requirements for energy and efficiency could be a challenge.

Many users compute on the cloud with different applications, based on the requirements. A few applications, such as e-mail, online Word, etc., require less computing power than multimedia applications. Therefore, based on the computing power required for a user, an application will be run accordingly on the required Virtual Machine (VM). Li et al. [18] used an approach to enable the migration of an application between different VMs, in order to manage the CPU load and energy usage efficiently. In this approach, known as an EnaCloud, the VM was used to encapsulate the application, and then later, the VM was migrated from one physical server to another without interrupting service. To decide where the application should be placed based on the departure or managing-events application, a heuristic energy-aware algorithm was implemented. This algorithm also took care of optimizing frequent VM migrations due to resource resizing. The EnaCloud model was developed in the Python programming language and implemented in a virtual computing environment called iVIC, which uses Xen as the hypervisor. Experimental results of this algorithm proved that energy savings up to 13% could be achieved. Even when VM migration was performed a number of times, the energy used was minimal. With this schema of dynamically placing the application on different physical servers, a possible solution to save energy for cloud platform was provided.

As discussed previously, the cloud computing platform has the potential to dynamically modify the provisions and configurations of computing physical devices or VMs, since modern computing devices have the ability to operate over a range of CPU frequencies with different power levels, which is one of the advantages in handling different types of applications. There exists the possibility of choosing a specific set of frequencies at which applications can be run by consuming optimum power. Abdelsalam et al. [19] created a proactive provisioning mathematical model for power management of devices that are available for services and can undergo management changes according to requirements. This model also considered hardware failures over a time function under constraints of Service Level Agreements (SLAs) that can regulate application performance as needed. For this model, the authors considered gateway and load balancers as having access to job scheduling and power-optimizer information, which is a feasible assumption. With these features, the model also allows administrators to compute the optimum number of servers and frequencies at which they should operate and to extend it to include any type of application handling. The authors provided relevant plots showing that energy savings up to 74% can be achieved using this model. They also considered a scenario when 5% over-provisioning is needed. Finally, this model was adapted to handle discrete values of frequencies instead of depending on continuous function.

3.4 Energy Savings via Thin Clients

Along with cloud computing, energy-saving solutions for clients is also very important. Much research has been conducted on thin client applications in the past few years. Thin client computing is executed on a server, and the client can control a session on the server using a specific application like Virtual Network Computing (VNC), UltraVNC, X11 Window System, etc. Thin clients are also seen as a solution to minimizing equipment costs and increasing manageability.

The present generation of Information and Communication Technology (ICT) is considering energy efficiency when designing any solutions. Virtualization is seen as one way to increase energy efficiency. This can be realized through grid or cloud computing. Vereecken et al. [20] analyzed the opportunities available in saving energy via the thin client concept. A linear mathematical model was considered to compare the power consumption between a desktop PC and a thin client. The authors opted for a desktop PC with an Intel® Core ™2 Duo CPU and a WYSE S10 [21] thin client device. With the linear mathematical model, they proved theoretically that the thin client setup consumes considerably less energy than a desktop PC. The analysis was done when the devices were in either of two states—active or passive—and communicating over three different networking technologies—ADSL2, VDSL2, and PON. In the active state with all three technologies, the thin client consumed 66% to 101% less energy than the desktop PC. In some cases, passive-state devices could be completely shut down or put in an idle state, but this did not occur in most cases, due to the requirement that services must be provided to users all the time. If the device was not in use or had a very minimal load, then it could operate in a reduced network power mode. These results showed that thin clients consumed 93% less energy than desktop PCs.

Energy consumed by thin clients is much less compared to the traditional way of computing. A white paper by Greenberg and Anderson [22] from WYSE technologies discussed Total Cost Ownership (TCO) reduction with thin clients' usage. They compared the power consumption of three WYSE-developed thin client devices against two desktop PCs. Three proprietary thin clients were intended for office productivity: web-based and locally computed applications. The authors compared different parameters and found that thin clients consumed much less power than desktop PCs. They provided the power readings for thin clients and PCs with and without display, and found that desktop PCs consumed three times more energy than thin client devices, without display, and twice the energy when display was used. Their plots showed that with an integrated display, thin client devices consumed considerably less power. The authors also projected the energy requirements for networks using both thin clients and desktop PCs and found that thin clients needed only one seventh the cost of power required for PCs. The energy consumption in a large-scale business environment was 50% less than that of desktop PCs. With this research analysis, Greenberg and Anderson provided relevant data to prove that thin clients are more energy efficient than PCs.

Simoens et al. [23] proposed a cross-layer approach between a wireless link-layer and a Virtual Network Computing Remote Frame Buffer (VNC-RFB) application, which could potentially save power. They noted that 37.7% of the total power on a mobile device is consumed by the wireless platform itself and that a continuous network connection can also reduce the power efficiency in the case of thin-client usage. The authors followed a cross-layer approach between a wireless link-layer and an application for saving energy over a thin client. In this cross-layer solution (XCTRL), they considered wireless platform components, such as baseband performance, power amplifier of the wireless platform, analogue front end, digital platform, and MAC goodput to create a power and performance model. Based on the decisions obtained from this model, they are used for optimum communication. To compare the results of this model, the authors chose a maximum throughput policy via a Downlink Burst Profile Control (DPBC) algorithm, which is a legacy state of the art method. They covered three major office scenarios: typing, static browsing, and dynamic browsing, which are used often. The authors aimed to save energy by optimizing data transmission and implementing the sleep mode often after communication. When simulated, this algorithm showed up to 14% reduction in the power consumption of the above scenarios.

As mentioned in the previous paragraph, the VNC-RFB protocol was proven to save power as a thin-client application. It is an open-source, simple protocol for remote access of the Graphical User Interface (GUI). Simoens et al. [24] uplifted this VNC-RFB protocol to a video-streaming mode and transmitted the images of a multimedia application to the client. Depending on the level of change in motion or movement of image, the pixels changes were relayed to the client either through the VNC-RFB protocol or by way of video streaming in H.264 format. This model was like a hybrid thin client protocol. To achieve this, of the authors used an image-rendering application on the Graphics Processing Unit (GPU) hardware of the server. Any change in the image or pixels on the server GUI also resulted in a change on the client side. A heuristic decision was made, based on whether changes in the display mode at the client side should be via the VNC-RFB protocol or video-streaming mode. When the amount of change in the image or pixels on the server was seen to be above a threshold level, communication of the multimedia data switched to the video-streaming mode. It also made sure that the mode being displayed did not change often. The authors analyzed bandwidth, CPU, and delay parameters with this hybrid implementation. When many changes were seen with successive frames, then the video-streaming mode was selected in order to save CPU usage; otherwise, the VNC-RFB protocol was streamed for the client. This model shows that VNC-RFB is an efficient way to optimize multimedia experience at the client end.

With the above survey, it is evident that energy efficiency is crucial at every aspect, not only for the Wi-Fi module but also when there are numerous TCP connections for accessing the web, streaming multimedia data, accessing remote devices, accessing and managing the cloud, etc. With the present scenario, the Internet has expanded so much that it is possible to access it from anywhere in order to obtain relevant information. Cloud computing is seen as the future of managing productivity applications, entertainment, and gaming. Currently, with current available wireless technologies, it is not clear how to access the cloud so that it results in power efficiency and decreased battery usage. Cloud computing technology is still new but is available for a few applications. Chapter 4 provides a view on what cloud computing is and how it works.

CHAPTER 4

CLOUD COMPUTING AND CLIENT COMPUTING

4.1 History of Computing

Computing has significantly influenced the fields of engineering, science, business, as well as our daily life. Currently, as most everyone needs and uses computing devices for many purposes. Computing will further evolve in the future for benefit of mankind. *Computing can be defined as the systematic execution of process and transforming the information in meaningful manner.* For instance, the instructions on a computer program are carried out with an execution process. Computations are executed by instructions, triggering a sequence of actions on the machine. These actions provide expected results as per instructions. Computing has other definitions, which are more specific depending on the context in which it is used.

The entire history of computing spans a longer period of time than the history of modern computing technology and the history of computing hardware combined. The history of computing started with the abacus, and then moved to the concept of numbers. Following that, there was binary computation, which caused a digital revolution leading to the modern computing era. The story of modern computing started four decades ago with the invention of transistors. This led to the development of personal computers, laptops, mobile phones, and tablet PCs, etc. Along with these, the Internet grew abundantly to support computing services.

There are many computing models, some of which are still in use and others that are being phased out. The client-server model of computing is one of the oldest ways of communication with a repository, and it still exists today. In this method, client types are service requestors, and servers are providers of service. This model has the advantage of serving multiple clients but lacks robustness, thus leading to overload issues and increased installation of server hardware. A pictorial representation of the client-server model is shown in Figure 15.

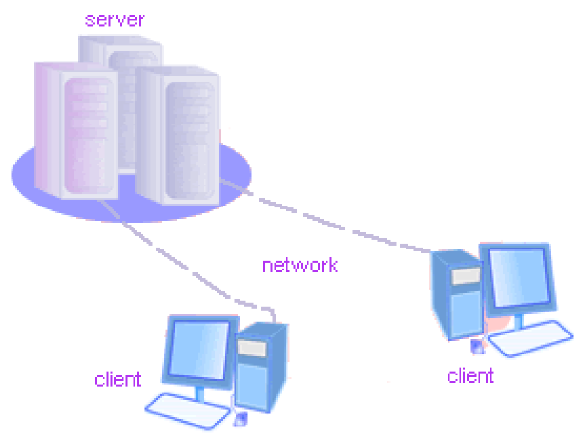

Figure 15: Client-server model (courtesy code.google.com)

Then later emerged a group of computers called mainframes. They are shown in Figure 16. Mainframe computers are quite powerful compared to normal server workstations, which are used by large organizations to perform complex calculations, run critical applications, and process bulk data. This began in 1960 and to this day is still being implemented. Mainframes can replace a large set of servers and provide equivalent service. However, today, so-called virtualization reduces the complexity of mainframe implementation.

Figure 16: IBM mainframe computers (courtesy IBM)

In the late 1990s, a new approach called grid computing was proposed. Here, computing is performed by making use of computer resources from multiple domains at the same time to achieve a common goal. The resources are heterogeneous, loosely coupled, and even spread over a geographical area. Grid computing is like a super virtual computer [25] composed of many network computers coupled together to perform a task. This concept is also referred to as a type of distributed computing. It has the advantage of making more cost-effective use of available computing resources without using a large amount of computing power. Grid computing has applications under high-energy physics, weather studies, biology applications, and earth observations.

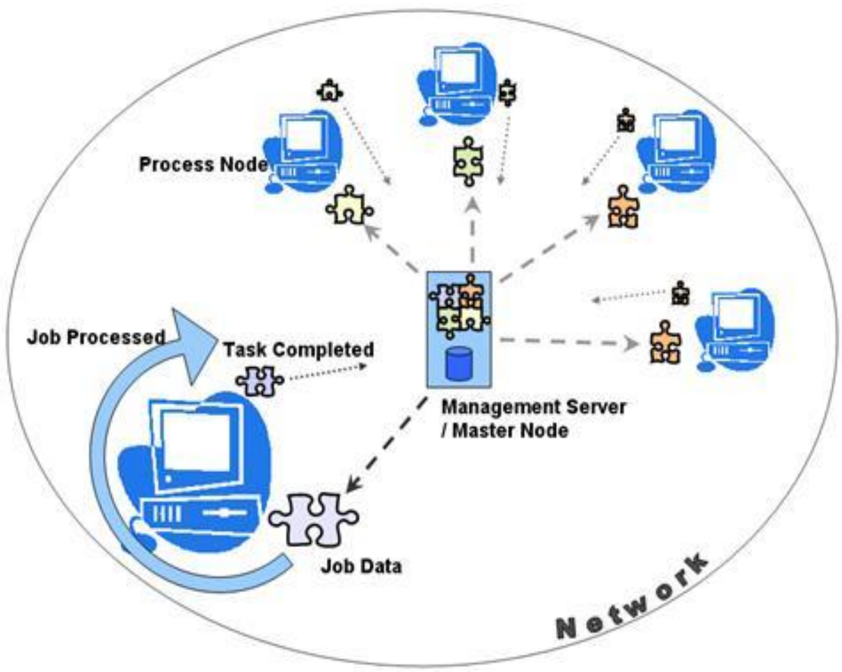

Figure 17: Grid computing view (courtesy askyourpc.com)

A few years ago, a solution was proposed to address architectural problems. Service-oriented architecture (SOA) is a technology framework strategically built to allow all relevant interested systems in and out of an organization, and to share and access necessary services.

In the landscape of computing, the word cloud is capturing everyone's attention. Cloud computing is a present-day trend and also seen as the future technology of Internet communication. All operating systems, applications, and services like Ubuntu, Microsoft Office 2010, and web browsers, are being designed to ensure that they are compatible with cloud architecture for future implementation and usage.

4.2 Cloud Computing

4.2.1 Definition of Cloud Computing

A standard definition for cloud computing provided by the Information Technology Laboratory of the National Institute of Standards and Technology (NIST), Information Technology Laboratory so far:

> *Cloud Computing is a design or an approach to provide any time commodious access to a network which holds a common syndicate of resources that are configurable are per user's need (e.g., servers, network, storage services and applications,) and the same used resources can also be planned and released instantly, with no management effort or minimal interaction of cloud provider* [26].

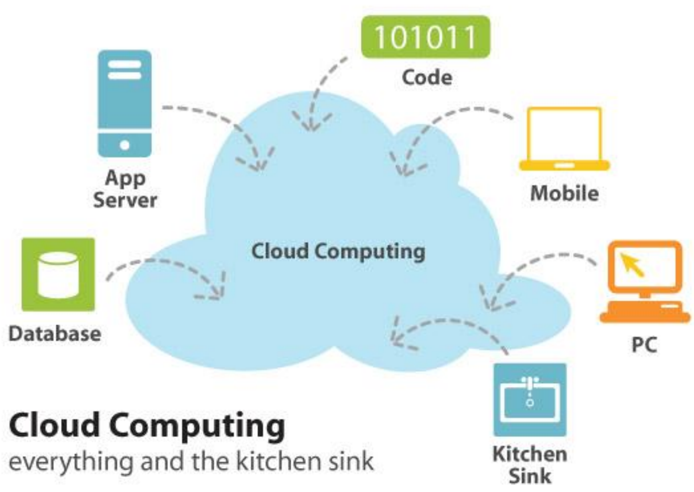

Figure 18: Cloud computing (courtesy briankeithmay.com)

Cloud computing technology implementation is composed of three computing models, four cloud architecture models, and five significant characteristics [27]. Following are the characteristics of cloud computing:

- *On-Demand Self Service:* Based on the client or end-user requirement, the computing capabilities, such as storage, server, etc., can be provisioned anytime, whenever needed, and without or with very minimal interaction of the cloud service provider.
- *Ubiquitous Network Access:* Accessing into the cloud over the Internet or network can be done via standard ways that promote use of thick-client platforms or heterogeneous thin clients like VNC and XWindow from devices like laptops, PDAs, mobile phones, and tablet PCs. This enables the mobility feature for end users to access the cloud on the move. A web browser is a popular way of accessing cloud applications today.
- *Location Independent Resource Pooling:* In cloud computing, resources are served in a pool of hardware using a maintenance model. Here, the different virtual and physical resources are assigned dynamically as per-consumer demand. The end user will not have knowledge of the provided resources' cloud location. This is advantageous when it comes to mobility requirements. Resources can include the CPU, VMs, and storage.
- *Rapid Elasticity:* The capacity and capability of resources as requested by the consumer or end user can be provided quickly, i.e., scaled up and released when the request is low. However the user will not see any limit, as it appears to be an infinite amount and can be purchased at any time in any quantity as needed.
- *Pay per Use:* The cost or fee for the end user is charged using a metered service based on the amount of resources being used. Inside the cloud, the user may utilize bandwidth, storage, software, etc. The provider and user have an agreement on billing services.

4.2.2 Cloud-Computing Models

Considering these characteristics as explained, cloud computing can take full advantage of this service-oriented approach by focusing on statelessness, modularity, low coupling, and interoperability [28]. Many small and large business executives are attracted to the idea of cloud computing. But few organizations need a private architecture and services that work solely with their requirements. Some need commonly used public services. A few need the benefits of public services as well as private services for internal operations and a traditional datacenter for remaining services. Therefore, organizations will approach different architectures based on their requirements. Most companies are investigating cloud computing technology because of unresolved issues relative to the privacy and security of data. Another main reason for cloud computing is to manage precious investments in a more efficient way. However, all types of cloud-computing deployment approaches are different. Some of them are as follows:

- Private Cloud
- Public Cloud
- Community Cloud
- Hybrid Cloud

These deployment models will be built either internally or externally in an organization network.

- *Private Cloud:* In this cloud, the infrastructure or the architecture is owned or leased by a single organization and is dedicated to that particular organization. A private cloud is a vastly virtualized data center, which can be located inside an organization's firewall. It can be a pool of private resources dedicated to a company by the cloud provider and designed to handle specific tasks. A few key characteristics of the private cloud are,
    - ✓ Automated management tasks.

- ✓ Computing capability for internal clients in their own way.
- ✓ Provisioning of software and hardware resources as per requirements.

- *Public Cloud:* This type of cloud provides general services for all users over the Internet. It will have a limited provisioning of resources, but conditional provisioning can also be present. Services provided in a public cloud are for common usage like e-mail, file sharing, video sharing, etc. They can be accessed via web applications or web services. Some of the key features are as follows:
  - ✓ Development and testing of standardized applications for users.
  - ✓ Incremental usage of computing capacity dynamically.
  - ✓ Less costly in terms of disaster shunning.
- *Community Cloud:* The infrastructure in a community cloud is shared by multiple organizations to address a specific group or community that has shared concerns to develop technology, a product, or an application with shared ideas. The architecture is designed by a combination of grid-computing prototypes, percepts of digital ecosystems, and follows green computing standards along with compatibility with the true Internet [29]. When large organizations want to work in collaboration to develop an open-source technology, this type of cloud provides a perfect platform and environment. A community cloud has its own pros and cons:
  - ✓ More privacy in the development of proprietary ideas between organizations.
  - ✓ Difficulty and challenging in the cloud design.
- *Hybrid Cloud:* The composition of two or more clouds, as mentioned above, is considered a hybrid cloud. All of these clouds are bound together by a standard or proprietary method that enables service portability with respect to data or application.

Organizations with this environment manage and provide some services internally and others externally.

A pictorial representation of private, public, and hybrid cloud models is shown in Figure 19.

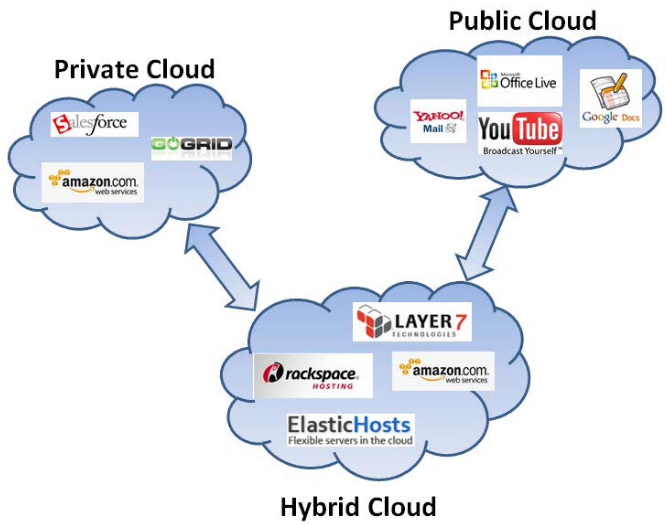

Figure 19: Cloud computing models

4.2.3 Cloud Computing Services

With these deployment models in place, cloud computing has different computing models. Services can be any type, and they need the proper infrastructure to support the task execution without any issues. The different services [28] provided over a cloud are shown in Figure 20.

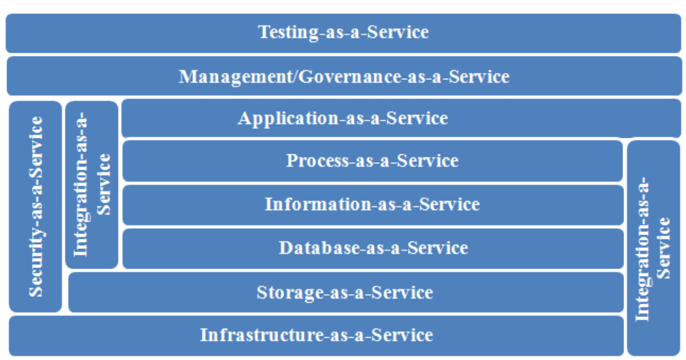

Figure 20: Cloud computing service components

Of the eleven services shown in Figure 20, three of them are very important and are shown in Figure 21:

- Software-as-a-Service (SaaS)
- Platform-as-a-Service (PaaS)
- Infrastructure-as-a-Service (IaaS)

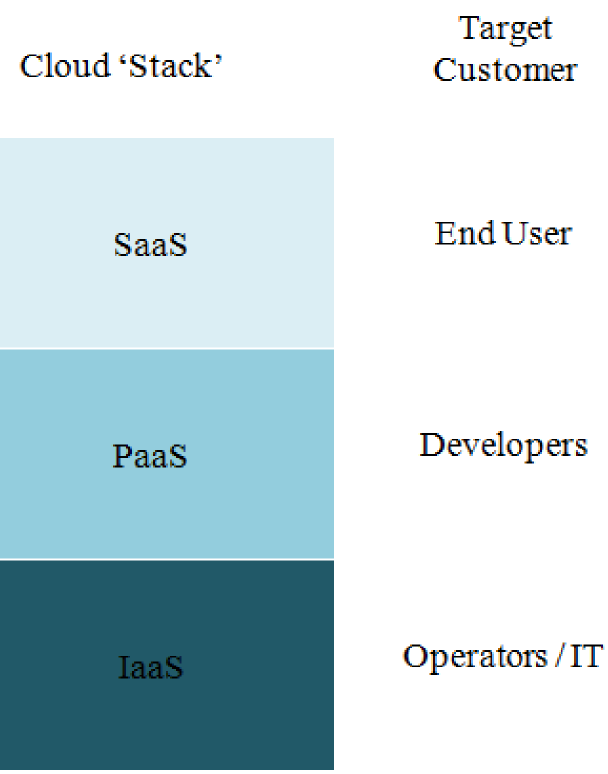

Figure 21: Cloud computing stack

- *Software-as-a-Service (SaaS):* In this type of service, the application hosted by the cloud service provider is delivered over the web to the end user and is known as software as a service. Services will be running over the cloud as the user, from his/her location, attempts to execute the application. This is the end layer on the cloud where data will be handled and is typically implemented through a browser. Few organizations may have their own proprietary applications to provide service for them. Applications such as Google Docs, Office Live, and Zoho Docs fall under this service.

- *Platform-as-a-Service (PaaS):* This service is a combination of a software set that is available for the developer to build or develop an application for both software and runtime. It is a service or platform that offers a development environment for an application, database, storage, testing, and so on, which can be used to provide cloud-ready business solutions. Here, the provider delivers more service than the infrastructure. A simple example of platform-as-a-service can be Windows or UNIX. Other examples are Google App Engine, Etelos, and Qrimp.
- *Infrastructure-as-a-Service (IaaS):* This service, which is an underlying base for both platform and software services, provides the support for computing hardware and virtualization technology to handle and manage resources. It builds the bridge between two endpoints for remote access of computing resources. The end user can rent computing resources and pay for services on the basis of usage. The user can also get dynamic scaling of resources; when more resources are required, they are always available. Many large organizations like Cisco, Juniper, VMware, and EMC, who have expertise in technologies like networking, virtualization, and storage, are collaborating to provide solutions at this service level.

Cloud computing is being deployed by most organizations, as it is touted as an energy-efficient technology, but it is still in the beginning stages. As mentioned in the literature survey, much research is currently taking place to provide ways to save energy on the cloud, such as dynamic management of resources, load balancing traffic between different datacenters, etc.

4.3 Cloud Client Computing

As described in the chapter on motivation, the hardware used in cloud client computing is a laptop that supports both Linux and Windows platforms. The research in this thesis made use of open-source applications, proprietary software, and multimedia formats for real-time experiments. Brief information of these data is provided in further subsections.

4.3.1 Operating Systems

In this thesis, two major platforms, namely Microsoft Windows and on open-source Linux-based Ubuntu, were analyzed for energy efficiency.

- *Microsoft Windows:* The Microsoft Corporation is the leading developer of a PC-based operating system. Windows 7 is the latest version and is the most advanced OS ever built on a Windows platform with advanced features like touch recognition, virtual disk support, improved computing performance, less boot-up time, kernel improvements, and better power management than its predecessors. The power-management provides the hardware to operate in low-power mode across several technologies. As mentioned in Chapter 2, the display consumes a significant amount of power. Windows 7 has adaptive display brightness, which reduces power consumption. Windows 7 consumes up to 20% less power than Windows Vista, which is a major improvement. Windows 7 on a PC draws 15.6 Watts compared to 20.5 Watts drawn by its predecessor Windows Vista [30].
- *Ubuntu:* Ubuntu is a popular Linux-based open-source OS developed by Canonical Limited. Ubuntu's share of Linux-based desktop computing is about 50%, indicating that many users have Ubuntu as their Linux platform. Ubuntu has similar features as Windows 7 rich graphics display, word processor, battery management, ACPI, etc. The latest stable release 10.10 has a faster boot-up and shut-down time than Windows 7.

4.3.2 Cloud Clients

A cloud client is comprised of computer hardware and compatible software, which depends on cloud computing for delivery applications that are designed specifically for cloud services delivery [31]. The cloud client is an interface that builds communication between the end user and the cloud. Clients can be either hardware or software. Some hardware-based cloud clients are discussed briefly below:

- *Thick Clients:* These are simply desktop PCs, full-fledged laptops, Apple MACs, etc. They contain many I/O devices, such as interfaces, memory, hard-drive, etc. They are fully featured, fully functional devices.
- *Thin Clients:* Thin clients have only the required components for specific tasks. They can have input and output interfaces, display, and networking components. They do not have a hard drive, software, or OS installed on them. They connect to a server to execute programs and tasks. Some examples of thin clients are VNC, RealVNC, WebOS, and XWindow.

Today, smartphones and tablet PCs are designed to be capable of replacing both thick and thin clients. They contain enough computing hardware or software to execute tasks like desktop and laptop computers. Devices like the iPhone, Blackberry, HTC, iPad, and HP Tablet PC can be used as cloud clients.

Generally, software client applications are designed to run on hardware clients efficiently in order to execute a user's tasks over the cloud. Today, the web browser is used as a cloud client to interface the cloud. Many web browsers are available for free online, and some of the more popular web browsers are Mozilla Firefox, Internet Explorer, Google Chrome, Safari, and Opera.

This thesis considered three renowned web browsers that are currently in use as cloud clients for experimental purpose: Mozilla Firefox, Internet Explorer, and Google Chrome.

Mozilla Firefox is an open-source web browser developed by the Mozilla Corporation. It uses a Gecko layout engine to display web pages. It implements most standard web features. It is the second most widely used web browser, comprising 23% of browsers worldwide. It runs on all three popular platforms, i.e., Linux, Windows, and MAC.

Developed by the Microsoft Corporation, Internet Explorer is one of the oldest browsers and has been the most widely used browser up until now. It is also known as simply IE. The latest and most stable version is 8.0. This browser has been in use since 1995. Then, its usage was 95% throughput the world; now it covers 55% of the browser market. It is supported on a Windows platform only.

Google Chrome is one of the fastest browsers available today and is making a popular name in the browser market. It was developed by the Google Corporation, and the latest version is 6.0, which supports most advanced web features. Many of the features that are unique in Google Chrome were announced by other browsers but first implemented by Google.

CHAPTER 5

MULTIMEDIA

5.1 Introduction to Multimedia

The word multimedia was first used in the year 1966 by Bob Goldstein [32] in describing a performance that was a combination of lights, music, art, and cinema. In the last three decades, the way of communication via an electronic medium has evolved in a very useful manner. Multimedia is a way to receive entertainment, education, information, etc.

With the evolution of the Internet, the view of computers has changed and is changing daily as the result of multimedia. As technology has advanced into a digital medium, multimedia has become a unique way of rendering information using pictures video, audio, and text. Multimedia can be used to improve efficiency and productivity in the workplace, educational institutions, and home for personal use.

Multimedia is a combination of different media and content. Usually it is recorded and displayed to the user. The data and content must be processed by electronic devices. Sometimes live streaming of multimedia content occurs. With the continuous improvement of audio and video technology, the main focus is on processing multimedia data to provide better quality and service to the end user. This has been a challenging task due to the processing of a high volume of data and also the requirement of computing power. To overcome this hurdle, Application Specific Integrated Circuit (ASIC) chips have been designed to compress and decompress multimedia data at the hardware level in order to attain speed and efficiency. Therefore, as the amount of data to be processed increases, accordingly, computing power must increase, which in turn leads to the consumption of more energy.

5.2 Popular Multimedia Formats

Compression and decompression in information theory is the process of encoding and decoding digital data using specific coding schemes. Compression is very useful in reducing the utilization of computing resources like CPU, memory, storage space, and bandwidth. The receiver should be aware of the sender's encoding scheme in order to process data. A better encoding scheme and an increase in compression can reduce the use of resources. In the past two decades, many encoding schemes have been proposed. Some of them are MP3, WAV, WMA, 3GP, AVI, MPEG, MP4, and MKV.

In this thesis, the energy patterns when video data was accessed online from a very popular video-hosting website, YouTube, were analyzed. YouTube is the largest video-sharing website on the Internet. During the initial stages of YouTube, the website was hosting videos encoded in H.263 using a low-quality mono MP3 audio codec. However, beginning in November 2008, YouTube started to host HD videos with an advanced H264/MPEG-4 AVC codec, whereby the user could change the aspect ratio of the video. YouTube uses an Adobe Flash Player to play the video. The video container here is Flash Video (FLV) with H.264 encoding.

5.2.1 Flash Video

Flash video is a container for video data, which can be used to render video over the Internet using an Adobe Flash Player. FLV is a the most powerful animation designing tool with a dynamic scripting engine, anti-aliasing precision, bitmap rendering, and a very light-weight advanced video and audio player. Flash-based videos can be stored in very small files to download and play quickly. This is why YouTube adopted FLV online. Most FLV files have H.263-encoded video data with MP3 as the audio codec. Beginning in 2007, FLV started to support H.264 encoding with an Advanced Audio Codec (AAC) for audio [33]. In 2003, version

7 of Adobe Flash Player started to support FLV file format; until that time, it was looking for files with Shockwave Flash (SWF) format. Beginning in 2007, Adobe proposed new file formats based on ISO MPEG4-12 standards. A flash player does not look at the extension of the file but rather checks the extension of the file. Adobe is moving from the previous FLV file format, due to functional limits in its structure when hosting the H.263/AAC codec, which could not be overcome without redesigning the file format. Flash technology has become a potent platform for developers to create more convoluted web applications. It is evolving as a great online e-learning tool for future use.

5.2.2 MPEG-2

Developed by the Motion Pictures Expert Group (MPEG), MPEG-2 is another video standard for coding and moving pictures and related audio information [34]. It is based on combining lossy video and audio data compression, in order to store them in media storage and transmit them. It is widely used as the video format for broadcasting or transmitting over cable, satellite television systems, etc. Movies that are available in DVD are in MPEG-2 format. The hardware or equipment like DVD players, television receivers, and media players are designed to support this format by default.

MPEG-2 was developed to overcome the weaknesses in MPEG-1, such as limited audio compression, poor compression for interlaced video, and no support for higher-resolution video. MPEG-2 includes two distinct parts that are related to carrying digital video data and audio. The video part supports interlaced video, a technique for ameliorating the quality of the picture in the video signal without using up more bandwidth. When there is a need for less bandwidth, this leads to processing less data on the client side, thus leading to less energy consumption in playing the video and audio. In the audio part, MPEG-2 allows coding of the audio codec up to

5.1 multichannels. MPEG-2 also supports an AAC codec, which is efficient and simpler than the MP3 codec. With the addition of some enhancements for MPEG-2, it is also used to transmit High-definition Television (HDTV) content.

5.2.3 H.264 or Advanced Video Coding

H.264, an advanced video codec for video compression, is book oriented and also has a feature with motion compensated, where accurate synthesizing of image improves compression efficiency. This codec was developed and finalized in May 2003 by the Video Coding Experts Group (VCEG) in collaboration with MPEG. H.264 coding is capable of providing good quality video at lower bit rates with a less-complex design [35]. It provides a better performance on a low bit rate network. For instance, with a minimal bandwidth of 256 Kbps, an H.264 video codec can be smoothly streamed at a rate of 356 Kbps without compromising the video quality. Due to the advantage of the lower bit rate in this codec, storage capacity for the file or the data size is also less. With less data to process, less computing power is needed. H.264 is widely used in many applications like Blu-ray discs, live video conferencing, television broadcasting, satellite broadcasting, and YouTube, as mentioned in later sections.

5.2.4 MP3 or MPEG-2 Audio Layer III

MP3, also referred to as MPEG-1 or MPEG2 Audio Layer III, is a popular digital audio encoding format that is commonly using in consumer audio storage like MP3 Compact Discs (CDs) and audio files. It is also the standard digital audio compression for music playback in most digital audio players. The audio format was developed by MPEG in 1992. Like what occurs when a compressed file is created using ZIP format, similarly, MP3 uses a technique called perceptual noise shaping in its algorithm. The compression algorithm used in MP3 is designed to compress the audio data to a greater extent, so that the file is 10 to 14 times smaller than the file that was originally created in CD format [36]. With MP3, a 36 MB audio CD file can be compressed to about 3.6 MB without hurting the quality of the audio. The processing and bandwidth needed for the data is also reduced considerably.

With these technologies in place, the energy consumption on the client is analyzed with different multimedia techniques. Chapter 6 provides the experimental setup and a comparison of results of real-time information on energy usage on the client when accessing and processing different types of multimedia.

CHAPTER 6

EXPERIMENTAL SETUP AND RESULTS COMPARISON

6.1 Methodology: Hardware and Software

The laptop used in this analysis was an IBM Lenovo SL400 with a 14-inch LCD display. The two main operating systems loaded on it were Ubuntu 9.04 and Windows 7. A detailed description of the different hardware components are listed in Table 4.

TABLE 4

HARDWARE COMPONENTS

Component	Details
Processor	Intel(R) Core(TM)2 Duo 2.4 GHz
Memory	2 GB
LCD Display	14.1" with Maximum Resolution of 1280 x 800
Battery	6-cell Lithium-Ion
Ports	4 USB ports (v2.0), Firewire
Graphics	NVIDIA GeForce 9300M GS with 256 MB Built-In Memory
Hard Drive/Optical Drive	160GB / DVD+RW
Wireless Networking	Intel 4965AGN (802.11 a/b/g/n Wi-Fi) and Bluetooth 2.0

6.2 Experimental Setup

The energy consumed in the laptop was investigated on both open-sourced Ubuntu 9.04 and closed-source Windows 7 operating systems. The battery used was a standard six-cell lithium-ion battery with a maximum charge of 51 290 mWh. On Ubuntu, the battery statistics were obtained from a file updated by an ACPI module, which provides the values on battery capacity present on the device. Windows 7 did not provide the energy readings for any built-in application; therefore, a soft battery meter, called a battery bar [37], was used to provide the same statistics as for the Ubuntu. It is important to note that all readings obtained were from real-time experiments. Simulation software or simulated data were not involved.

To study and analyze the energy pattern, two main parameters from the battery statistics were considered:

1. Battery Capacity (mWh)
2. Energy Consumed

Cloud technology is very new, and the current approach for accessing, computing, and communicating the data is done with a web browser. Google, Microsoft, and Cloudo provided some of the cloud services over the web browser. IBM, Eucalyptus, Nebula, and Amazon have their own way of cloud access for different services, but they are still in the development stages. Here, the available cloud services for analyzing energy patterns of multimedia access were considered.

In multimedia, the energy for audio and video data was studied. In both video and audio different kinds of formats, such as MP3, WMA, FLV, WMV, MPEG-II, and HD, means different ways of encoding data. The most commonly used formats, like MP3 in audio and FLV and MPEG-II in video, were considered here. For accessing audio data over the cloud, online radio was used in this thesis. With respect to video, data was accessed over YouTube by three of the most widely used browsers: Firefox, Internet Explorer, and Google Chrome. The same video was played locally on the computer using a media player with different file formats, FLV and MPEG-II.

The MP3 file was played using Windows Media Player and Movie Player, on Windows and Ubuntu, respectively. The decoding of the above formats was computed locally using commonly available software in the OS, and respective battery readings were recorded. To analyze the energy pattern when played on the cloud, online radio was experimented with in this thesis. It was available on the media players itself. A radio with the same audio characteristics of the above MP3 file details was carefully chosen. The energy consumed from the video data was analyzed more fully. Energy readings were captured for two different file formats, FLV and MPEG-II, which are widely used as standards. The data was encoded with the latest format or the H.264/MPEG-4 AVC codec. In this case, the same media players were used as those for audio format. The results obtained were compared when the same data was being accessed over the cloud using a browser.

YouTube is a widely used online video-sharing website. The video file was uploaded to this web portal and then accessed using a browser. The battery statistics were recorded when data was accessed over the different browsers, but Ubuntu supported only Firefox and Google Chrome, not Internet Explorer. As a result, interesting results were obtained.

The data required to obtain readings was ensured to be the same and constant at each time on both the Ubuntu and Windows platforms. All experiments for audio and video data were conducted for ten minutes. Battery statistics were recorded every minute in order to ensure accurate readings over that time. The trials were repeated and the results obtained were similar to each other. There was no major difference in the readings obtained on repeating the experiments.

6.3 Results

Results from the Linux-based Ubuntu and Windows platforms were analyzed and compared. During the experiments, the brightness on the laptop was at default level (30%). Wi-Fi was turned ON, only when required to access the data over the cloud. The data was computed locally on the laptop with Wi-Fi was turned OFF, to obtain a more efficient and accurate reading.

6.3.1 Comparison of Energy Consumption for Audio Data

A standard audio MP3 file format with the following details was used for the experiments:

Format:	**MPEG Audio**
Format Version:	Version 1
Format Profile:	Layer 3
Bit Rate:	128 Kbps
Sampling Rate:	44.1 KHz

A comparison of audio data when played locally and online over the cloud on Windows 7 is shown in Table 5.

TABLE 5

BATTERY CAPACITY READINGS FOR AUDIO MP3 ON WINDOWS PLATFORM

	Remaining Battery Capacity (mWh)	
Time (min)	**Audio (local)**	**Audio (cloud)**
0	51,290	51,290
1	50,950	50,850
2	50,720	50,570
3	50,480	50,300
4	50,250	50,040
5	50,020	49,750
6	49,790	49,470
7	49,556	49,190
8	49,320	48,920
9	49,080	48,670
10	48,840	48,400

The results tabulated in Table 6 were captured on Ubuntu 9.04 for audio data. From Figures 22 and 23, it can be inferred that audio over the cloud consumed more energy than audio played locally. The MP3 file played locally consumed less energy comparatively over the cloud. On Ubuntu, audio played over the cloud required more energy, which was the same case in Windows. This is because in order to receive the audio data, communication over the Wi-Fi needs more energy, compared to local computation of an MP3 file.

TABLE 6

BATTERY CAPACITY READINGS FOR AUDIO MP3 ON UBUNTU PLATFORM

	Remaining Battery Capacity (mWh)	
Time (min)	**Audio (local)**	**Audio (cloud)**
0	51,290	51,290
1	51,000	50,830
2	50,730	50,550
3	50,470	50,270
4	50,220	49,970
5	49,960	49,680
6	49,710	49,380
7	49,460	49,100
8	49,200	48,810
9	48,930	48,510
10	48,670	48,220

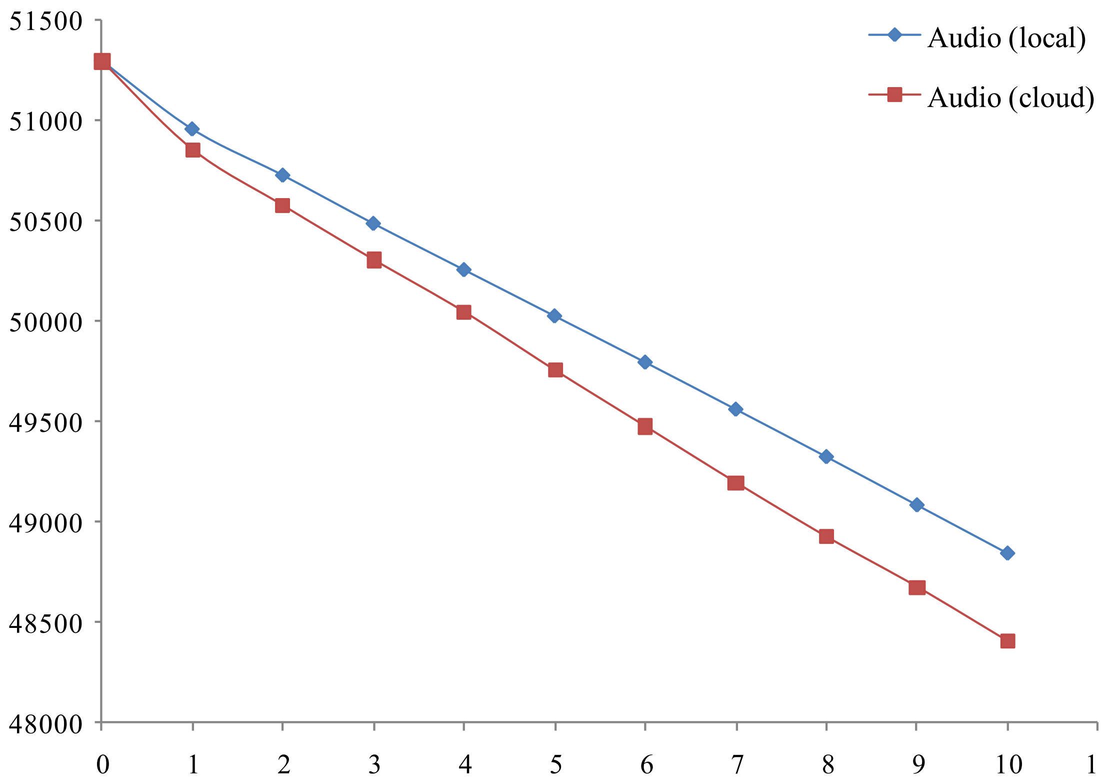

Figure 22: Time (min) vs. battery capacity (mWh) for audio MP3 on Windows platform

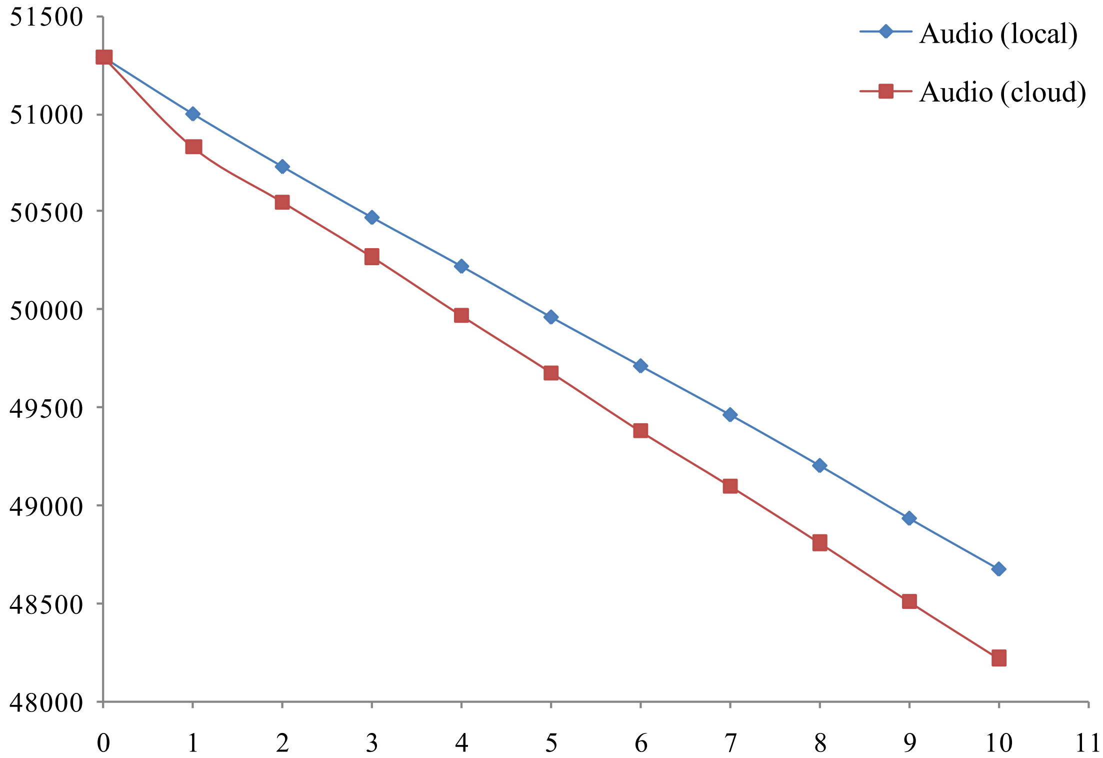

Figure 23: Time (min) vs. battery capacity (mWh) for audio MP3 on Ubuntu platform

The bar graph shown in Figure 24 outlines the energy required for audio data for all readings tabulated in Tables 5 and 6. On the average, this plot shows the energy consumed by the audio data for the above ten readings. It is obtained by taking the difference between the battery capacities at every minute.

In Windows, the cloud operation took 13.9% more energy than local computation of the MP3 file, and Ubuntu took 10.8% more energy over the cloud than local computation. Over the cloud, Ubuntu took 6.2% more energy than Windows, and even on local Ubuntu, an excess of 4.24% energy was consumed, in comparison to Windows.

It can be inferred that Windows had better energy management of audio data, either with or without cloud options. Therefore, the Ubuntu OS consumed more energy with respect to audio over local and cloud operations.

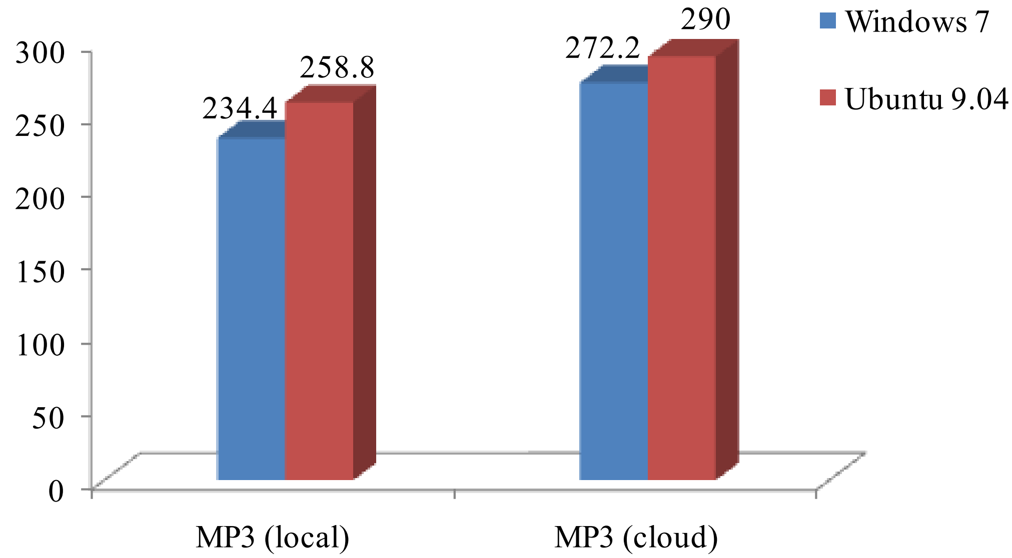

Figure 24: Energy consumption (mW) of audio data on Windows and Ubuntu platforms

6.3.2 Comparison of Energy Consumption for Video Data

As explained earlier, a detailed analysis for video data was done for two of the most popularly used formats, FLV and MPEG-II. The results were computed locally and also over the cloud on both Windows 7 and Ubuntu 9.04. The analysis was done by playing a FLV and MPEG-II video file locally with the following characteristics:

	FLV	**MPEG-II**
Format:	Flash Video	MPEG Version 2
Display Ratio:	16:9	16:9
Frame Rate:	30 fps	30 fps

The data in Table 7 shows the results for Windows 7. It is compared with the readings obtained when the data was played over the cloud on all three browsers, as mentioned previously. Figure 25 provides relevant information about battery usage for the different video formats, FLV and MPEG-II. All plots look similar in their discharge readings. The MPEG-II format video discharged less energy compared to the other formats.

TABLE 7

BATTERY CAPACITY READINGS FOR FLASH AND MPEG-II VIDEO ON WINDOWS PLATFORM

	Remaining Battery Capacity (mWh)				
Time (min)	**FLV (local)**	**MPEG-II (local)**	**Chrome (cloud)**	**Firefox (cloud)**	**IE (cloud)**
0	51,290	51,290	51,290	51,290	51,290
1	50,870	50,890	50,860	50,950	50,920
2	50,580	50,600	50,580	50,640	50,620
3	50,310	50,370	50,300	50,340	50,320
4	50,040	50,100	49,980	49,990	50,010
5	49,740	49,790	49,680	49,660	49,690
6	49,450	49,530	49,380	49,350	49,390
7	49,190	49,270	49,080	49,040	49,070
8	48,920	49,010	48,770	48,730	48,760
9	48,660	48,750	48,470	48,410	48,470
10	48,390	48,450	48,170	48,100	48,160

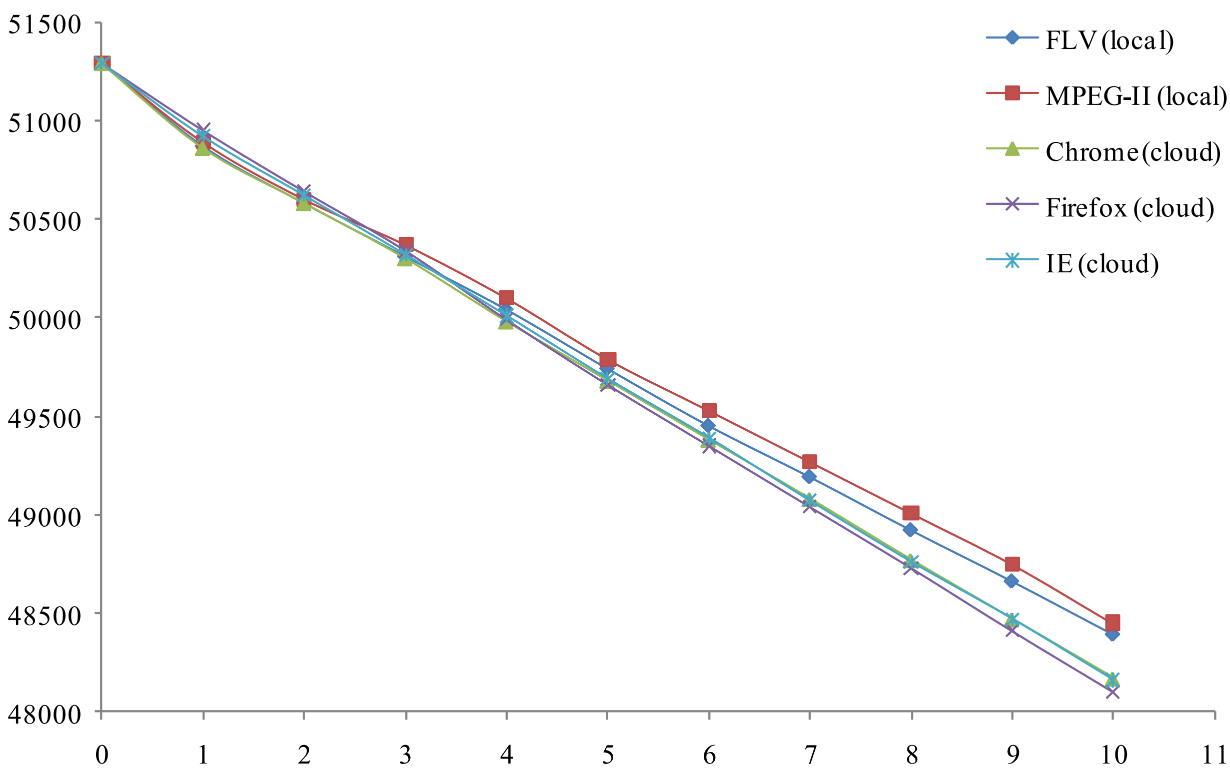

Figure 25: Time (min) vs. battery capacity (mWh) for video on Windows platform

Energy consumption of FLV was also close to that of MPEG-II. All three browsers took more energy than locally computed video formats. Of the three, Google Chrome and IE had almost similar readings. The plots for these two almost overlap each other, but Google Chrome still consumed more energy than IE communication over Wi-Fi. Buffering the video and computing it at the same time caused the browsers to consume more energy. The experiments were repeated on Ubuntu, and corresponding readings are shown in Table 8 along with a graph in Figure 26. As mentioned previously Internet Explorer was not supported on the Ubuntu platform, so there were no readings for the same. The plot clearly shows that MPEG-II showed less energy being consumed than all other video formats. In Ubuntu also, Google Chrome was more energy efficient than Firefox over the cloud. This is evident from the readings shown in Table 8.

TABLE 8

BATTERY CAPACITY READINGS FOR FLASH AND MPEG-II VIDEO
ON UBUNTU PLATFORM

	Remaining Battery Capacity (mWh)			
Time (min)	**FLV (local)**	**MPEG-II (local)**	**Chrome (cloud)**	**Firefox (cloud)**
0	51,290	51,290	51,290	51,290
1	50,870	50,890	50,860	50,950
2	50,580	50,600	50,580	50,640
3	50,310	50,370	50,300	50,340
4	50,040	50,100	49,980	49,990
5	49,740	49,790	49,680	49,660
6	49,450	49,530	49,380	49,350
7	49,190	49,270	49,080	49,040
8	48,920	49,010	48770	48,730
9	48,660	48,750	48,470	48,410
10	48,390	48,450	48,170	48,100

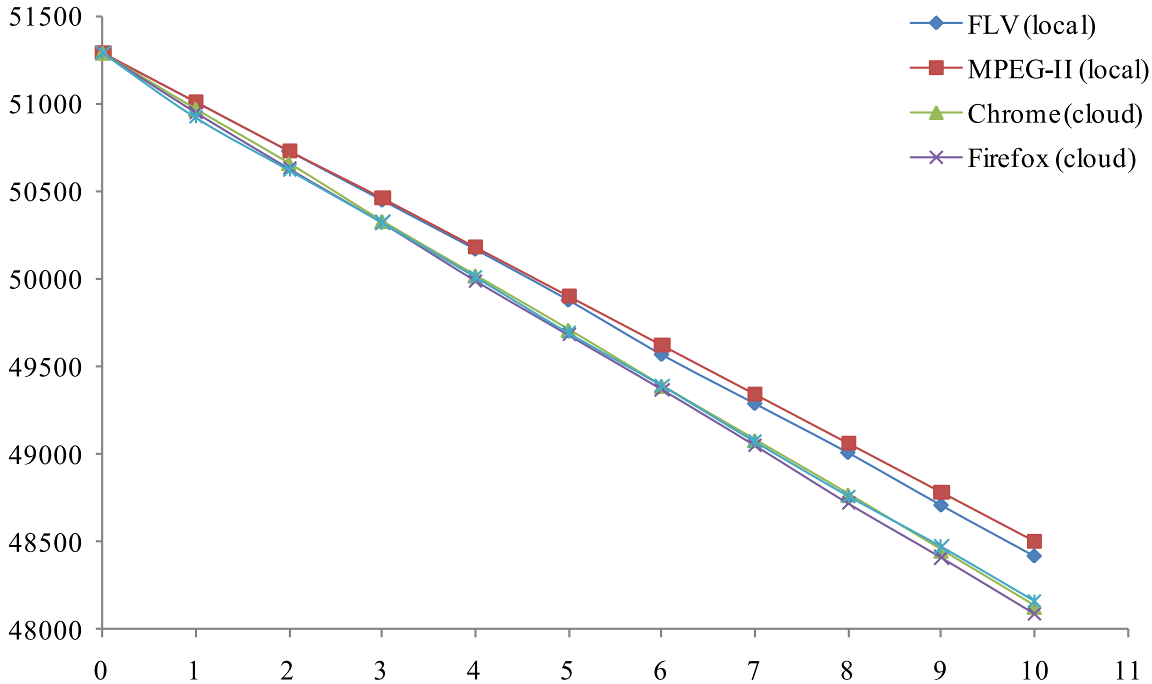

Figure 26: Time (min) vs. battery capacity (mWh) for video on Ubuntu platform

Figure 27 shows a comparison of the energy required per minute by these different entities. Calculations were done in the same way as explained in the audio section.

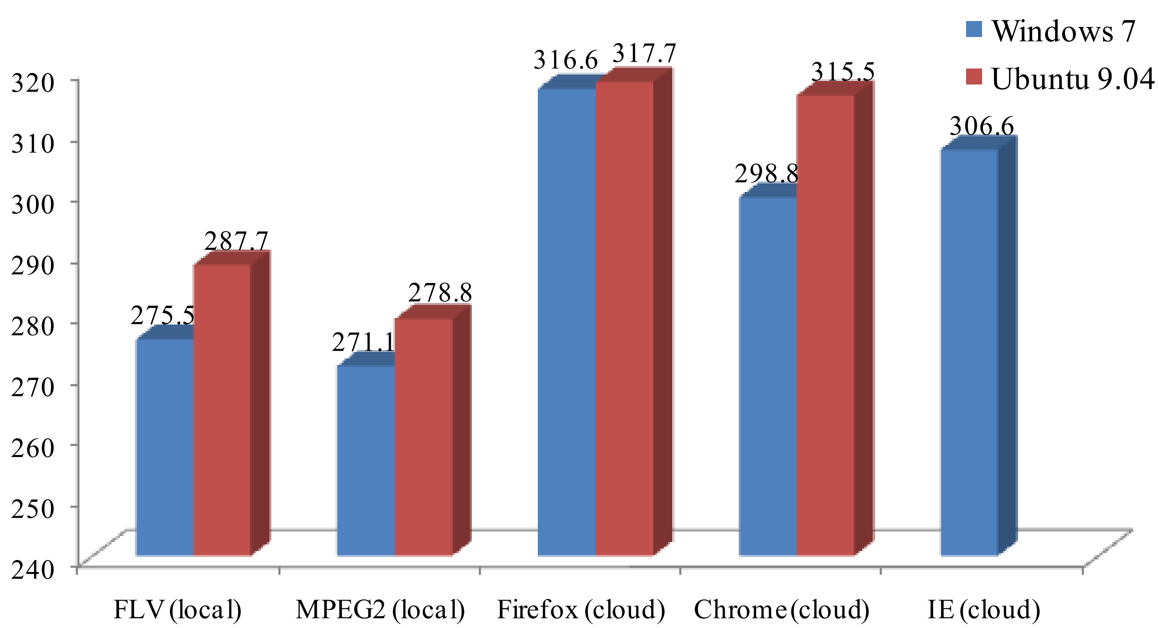

Figure 27: Energy consumption (mW) of video data on Windows and Ubuntu platforms

From Figure 27, it can be seen that in the case of video, the cloud consumes more energy than local computation, but energy consumption over the cloud using Windows is better than when using Ubuntu. Playing an MPEG-II file over Windows saves 2.8% more energy than playing it over Ubuntu. Similarly, FLV files save 4.4% of energy on Windows than on Ubuntu. Among the browsers, Google Chrome has energy savings of 6% per minute on Windows platform. It can be observed that Windows provides energy-efficient cloud access over the Google Chrome browser when compared to Ubuntu.

6.4 Analysis of Audio and Video Traffic

This section provides the results of a study on real-time audio and video traffic, which were used for experimentation as explained in the previous sections. Traffic, captured using the Wireshark application, was analyzed for packet reception and transmission over a wireless card on both Windows and Ubuntu operating systems.

6.4.1 Audio Traffic

Graphs were plotted for the number of packets being handled against time for audio traffic. Figure 28 shows the plot for Ubuntu. Here the communication was constant, and the number of packets increased at certain points, which was due to the exchange of some broadcast and keep-alive packets. The rate was around 20 packets per second. The payload size was limited to 1,448 bytes, and the TCP header was 32 bytes, with the options field used for acknowledgment packets. Usually the TCP header size will be 20 bytes, but here in the option field, the TCP timestamp was used in every packet, which added another 12 bytes of data. ACK packets with no payload were seen for every data packet received. Also, TCP window update packets were often exchanged, so the communication was very chatty, due to more energy being consumed.

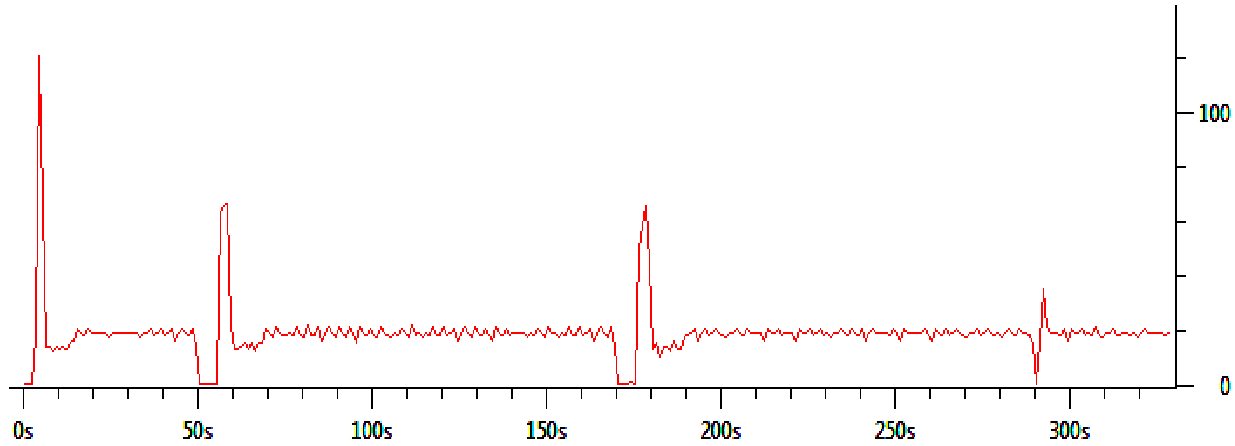

Figure 28: Audio traffic on Ubuntu platform, time vs. number of packets

In Figure 29, the plot for audio traffic on the windows platform is shown. The communication here is not as continuous as with Ubuntu. The payload size was seen at a maximum size of 1,460 bytes. However the TCP header was only 20 bytes, with no option field used at all. This is an advantage at ASIC level, since it saves some energy while processing the packet. The acknowledgement packets with no payload were not as frequent as those in Ubuntu, and a TCP window update was sent only when the window size was full during communication. Due to this, energy consumption was less on the Windows platform than on the Linux platform.

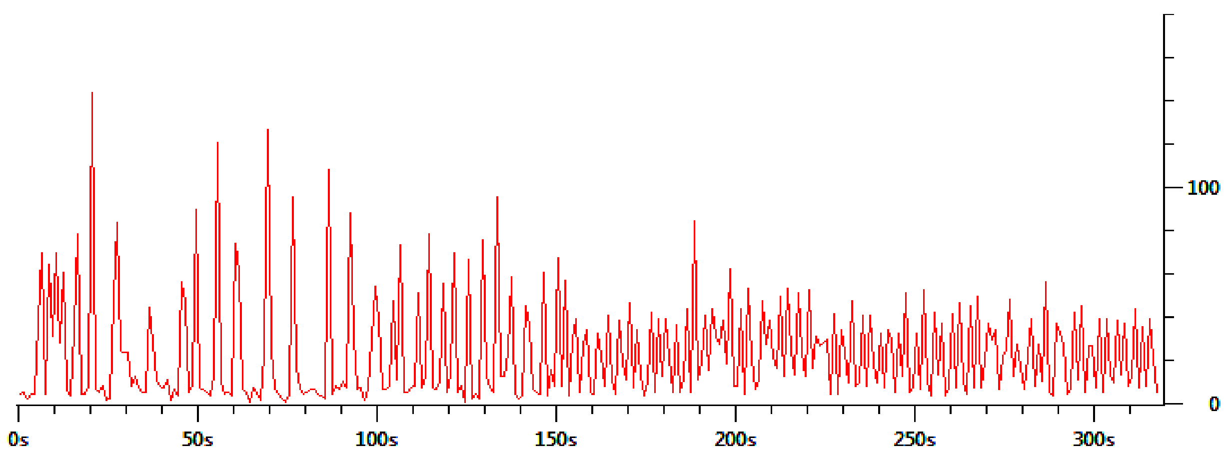

Figure 29: Audio traffic on Windows platform, time vs. number of packets

6.4.2 Video Traffic

The source for video traffic was the same at all times; therefore, the amount of data fetched each time was the same. Figure 30 shows that on the Ubuntu platform, video traffic was similar to audio traffic.

The graph in Figure 30 is similar to the one for audio traffic, and frequent spikes indicate that the increase in the number of packets at certain points was due to the greater number of ACK packets. During the entire communication, 29,948 ACK packets were seen. Also in this scenario, the packets had 12 bytes of the options field used in the TCP header for exchanging timestamp information. Due to the payload size of 1,448 bytes in every packet, there was a frequency of 70 to 80 packets every 10 ms.

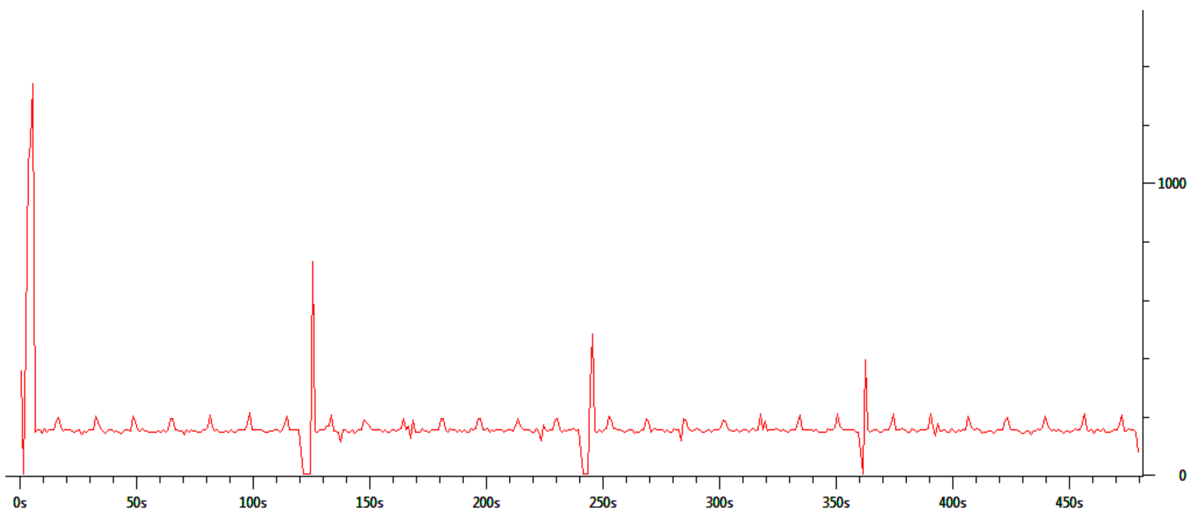

Figure 30: Video traffic on Ubuntu platform, time vs. number of packets

In the case of video traffic on the wireless card, the Windows platform was quite efficient compared to Ubuntu. The graph of this information is plotted in Figure 31. For the same data fetched, there were only 16,962 ACK packets sent, which is almost 40% less than with Ubuntu. In the TCP header, the options field was not used, which was an added advantage here. The payload size was seen to be an optimum value of 1,460 bytes in every packet. The traffic flow was smoother here, compared with 50 to 60 packets exchanged for every 10 ms of time.

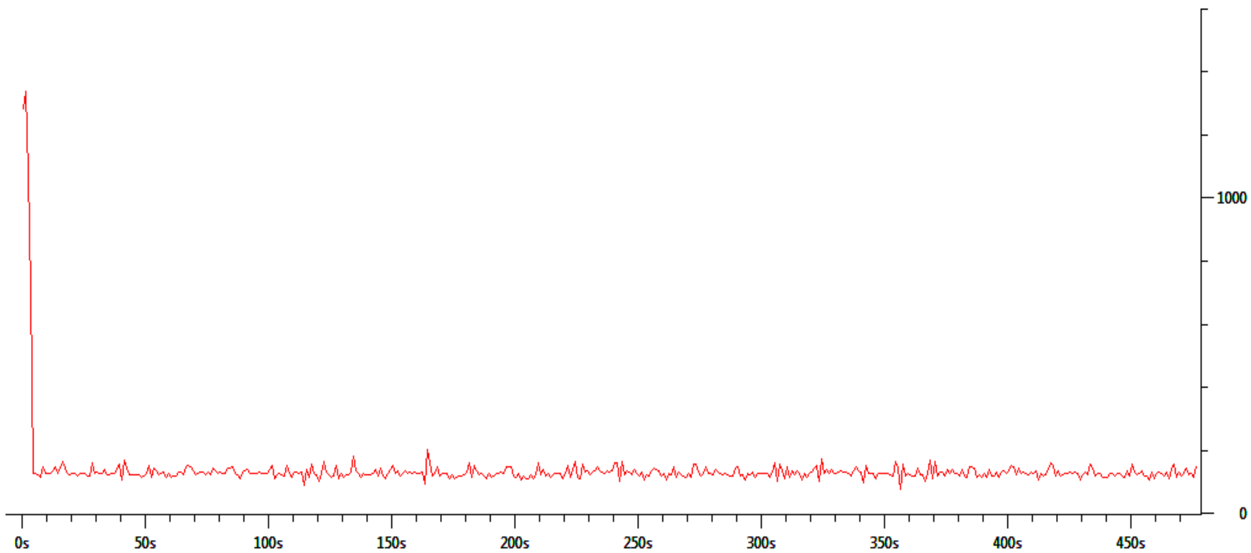

Figure 31: Video traffic on Windows platform, time vs. number of packets

Results show that local computation is more energy saving than cloud computing when accessing multimedia data. And wireless communication over the Windows platform provides a better solution than Ubuntu for communication using cloud computing. The main purpose in conducting this research was to determine which had the better trade-off-computations or communication. The Windows platform served as an energy efficient solution when compared to the Ubuntu platform for multimedia data in cloud computation.

CHAPTER 7

CONCLUSION AND FUTURE WORK

7.1 Conclusions

As explained in the detailed analysis in the motivation section of this thesis, it is evident that improvement in protocols and technology can provide an energy-efficient platform. With further research on cloud-based communication and multimedia applications, which are essential for everyone, it is apparent, that multimedia over the cloud via the Internet is still not as energy efficient as local client computation. Flash-based videos are a simple way of providing multimedia service, where further improvement is expected. When cloud computing is performed over the Microsoft Windows platform, it provides better results than does the open-sourced Linux-based Ubuntu platform for energy-efficient communication. Cloud client applications like browsers prove to be robust solutions, since they are developed to support most multimedia requirements. This study provides possible solutions for cloud users and cloud service providers to choose applications based on their requirements so that end users can expend the maximum amount of time over the cloud completing their tasks.

7.2 Future Work

In the future, this study could be broadened to include more platforms like netbooks, which are miniaturized versions of laptops. Access to the cloud started with the boom of tablet PCs like the HP Slate, Blackberry Playbook, and iPad, which is being anticipated as the next generation of netbooks [38]. Therefore, analyzing energy patterns on these devices would be another good way of understanding the efficiency of portable devices. The wave of the future is cloud operating systems, such as Google's browser-based operating system Chromium [39], where energy consumption needs to be analyzed. Flash-based videos also need to be analyzed against a new competitor HTML5, whereby multimedia services are provided with a rich feature set [40]. Also, energy patterns over wireless technologies like third generation (3G), fourth generation (4G), and the upcoming Worldwide Interoperability for Microwave Access (WiMax) could be explored.

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