Thesis no.:MSEE-2016-54

On energy consumption of mobile cloud gaming using GamingAnywhere

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This thesis is submitted to the Faculty of Computing at Blekinge Institute of Technology in partial fulfillment of the requirements for the degree of Masters in Electrical Engineering with Emphasis on Telecommunication Systems. The thesis is equivalent to 20 weeks of full time studies.

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Abstract

In the contemporary world, there has been a great proliferation of using smart-phone devices and broadband wireless networks, the young generation using mobile gaming market is tremendously increasing because of the enormous entertainment features. Mobile cloud gaming is a promising technology that overcome the implicit restrictions such as computational capacity and limited battery life. GamingAnywhere is an open source cloud gaming system which is used in this thesis and calculate the energy consumption of mobile device when using GamingAnywhere.

The aim of the thesis is to measure the power consumption of the mobile device when the game is streamed from the GamingAnywhere server to GamingAnywhere client. Total power consumption is calculated for four resolutions by using the hardware monsoon power monitoring tool and the individual components of mobile device such as CPU, LCD and Audio power are calculated by software PowerTutor. The memory usage of the mobile device is also calculated by using Trepn Profiler application when using GamingAnywhere.

Based on the obtained results, it was found that there is an increase in power consumption and memory usage of the mobile device on client side when the resolution is varying from low to high. After mapping the results of the hardware with the software, it was identified that there is very small difference between the hardware results and software results from which we could estimate that the software PowerTutor can be used instead of hardware Monsoon power tool as the software is capable of calculating the power consumption of individual components of mobile device.

Keywords: Monsoon power monitoring tool, Power consumption, PowerTutor, Trepn Profiler.

Acknowledgments

I would like to thank my supervisor Dr. Yong Yao for the encouragement, help and support in the thesis with helpful suggestions. I had learnt a lot from the meetings with him. He is very good in his patience and helped me in the successful completion of my thesis work.

I sincerely thank my examiner Dr. Siamak Khatibi and Dr. Kurt Tutschku for guidance and encouragement throughout my masters.

I would like to thank Department of communication systems for providing me the opportunity to learn lot of things and to do research in my interesting field of study.

Last but not least, I would like to thank my friends Ganesh Grandhi, Phani dutt who supported me in doing my research.

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Chapter 1

Introduction

From the past few years, video gaming is one of the quickest developing business in interactive media amusement industry. Filled by the extensive scale reception of smart mobile devices, mobile game such as Pokemon Go have shocked numerous by hitting colossal number of players in a short time frame. In spite of huge development of ability in mobile devices, gaps stay between the support of mobile devices and necessities of incredible video games. High end video game scenes often need intensive graphics and high computational energy to render sensible and intuitive gaming scenes[11]. When compared to PC and console games, mobile games are less visually attractive due to its restricted requirements like graphics, memory, network bandwidth and battery limit. These attributes may push genuine gamers away from mobile games[16].

The growing popularity of cloud framework provide more storage and lots of resources in a reliable, high-performance manner. These cloud resources are advantageous to many applications and among them cloud gaming is observed as the killer application. In cloud gaming, cloud servers render, capture and transmit the game screens to the clients which are cheap configuration devices. The clients decode and presents to the game users. Cloud gaming is observed as the fastest developing game industry sector[10].

With the revolutionary of core and expansive broadband networks, many services were carried away by the remote data centers from the end devices. This is broadly referred to as cloud computing. Cloud gaming, a kind of cloud service also referred as Gaming as a Service (GaaS) is a new technology which is born by the fruitful ideas of both cloud computing and online gaming[24][25][17]. Cloud gaming renders a gaming application remotely in the cloud and streams the video scenes back to the user over the internet. Mobile cloud gaming has been prevalent in recent times due to the advancement in cloud computing and mobile communications[24]. Mobile Cloud Gaming (MCG) is a promising innovation which has been enabled to address the intrinsic confinements of mobile devices[8].

Mobile cloud gaming system has many benefits: (i) Better visual quality attract serious gamers, (ii) Lower porting cost/effort can play more games, (iii) Low battery consumption gives longer play time.

“In cloud gaming, the games are stored in the remote datacenter’s platform and are streamed to the end users devices. Onlive(web) (bought by Sony) , StreamMyGame(web), Gaikai(web) are the closed and proprietary gaming companies which offer cloud gaming services.

GamingAnywhere(web) is the first open-source cloud gaming system. It has a cross-platform functionality. It is supportable to Windows, Linux, OSX, and Android. Thus, GamingAnywhere can be used by researchers, end users, developers, service providers for setting up cloud gaming testbed. This GamingAnywhere can port the cloud gaming client to mobile devices[16][15][2].

The performance of GamingAnywhere may be game-dependent. So the three popular categories of games considered are action adventure, real-time strategy and first person shooter. Game from each category are picked and performance are calculated for each and individual games sessions[16][2][12].

The performance of GamingAnywhere can be evaluated from different views. Larger time-scale metrics are used for multiple game sessions. Smaller time-scale metrics are used for individual game sessions[9].

Mobile devices such as smartphones and tablets are battery powered and will have finite computation power. So, functioning of mobile clients on these resource-constrained devices can cause degrading in performance and heavy energy consumption. For example, the frame rate might become lesser for smooth play of game due to deficient CPU power to execute software video decoders. This might lead to diminished game quality[14].

This thesis is focused on measuring the power consumption of the mobile device on the client side while streaming the game from the server. The power consumption may vary for different resolutions which we chose at server side. So, the power consumption of mobile device is measured for different resolutions by using monsoon power monitoring tool. Power tutor, an application for Android platform devices that gives precise power consumption estimates for power-intensive hardware components that include CPU, LCD and Audio power. Memory usage is also measured for mobile device using Trepn profiler application which is designed for Android platform devices.

1.1 Motivation

From the past five years, mobile gaming has been advanced a lot. The computational load of a mobile device when playing a game, should be offloaded to server so as to save energy and time on terminal side. As a result, the cloud gaming came into existence. As many cloud gaming systems are proprietary and closed, GamingAnywhere is the only open-source cloud gaming system available for gamer, developer or service provider.

When the users are playing cloud games, the computing, communication and display on mobile devices will consume more energy which can lead to the draining of battery quickly. This avoids the users to make phone calls even. Hence, measuring the power consumption of mobile cloud gaming using GamingAnywhere is quite challenging.

These measurements can be done by using Monsoon Power monitoring tool by which we can get the consumed energy, average power, average current and average voltage of all connected devices on PC or laptop[16][14]. This thesis is motivated by the question: What is the impact on energy consumption of mobile clients when using GamingAnywhere??

1.2 Aims and Objectives

The main aim of the thesis is to study the energy consumption of mobile device for mobile cloud gaming using GamingAnywhere. The measuring of total power and also power of the individual components of mobile device is also a main goal in the research work. To achieve this aim, GamingAnywhere based mobile cloud gaming environment needs to be configured where a setup is to be established that includes a GA server and GA client. Then monsoon power monitoring tool hardware and software are to be installed. The main objectives of this thesis are as follows.

- Understand the GamingAnywhere system and its implementation with the mobile.
- The computation load of mobile device when playing the game, should be offloaded to the server so as to save the energy and time on terminal side.
- Perform a detailed study on Monsoon power monitoring tool which gives average power, current, voltage and consumed energy and also to understand the various features in it.
- Set up the experimentation environments for criterion of evaluation.

- A black box need to be used to create an isolated environment for avoiding any external disturbances while measuring the energy consumption of a mobile client using monsoon power monitoring tool.

1.3 Research Questions

1. What is the impact on energy consumption of mobile clients when using GamingAnywhere for different resolutions?
2. What is the power consumed by each component of the mobile device using GamingAnywhere for different resolutions?
3. How does, the results generated by monsoon power monitoring tool map with the results generated by an android application?
4. What is the memory usage of the mobile device using GamingAnywhere for different resolutions?

1.4 Research Methodology

1. In the early phase of our research, thorough study of GamingAnywhere is done and then a detailed study on monsoon power monitoring tool, the power consumtion to be evaluated.
2. In the next stage, installation, configuration and implementation of GamingAnywhere testbed is studied and done where GA server and GA client are installed in our PC and mobile respectively.
3. The study on power tutor application to measure CPU, LCD, audio power and study on Trepn profiler application to measure the memory usage of mobile device on client side.
4. The tools used for evaluating the performance are studied and analyzed how to configure them.
5. Different experiments are conducted under different scenarios in different environments.
6. Results are noted and observed and later analyzed. Based on final results, conclusions and recommendations are provided.

1.5 Thesis Outline

Chapter 1: Introduction briefly explains about the cloud gaming and mobile cloud gaming technologies and how they are getting prominent these days. GamingAnywhere an open cloud gaming system depiction is also mentioned. A brief description about the Hardware monsoon power monitor and android applications PowerTutor and Trepn profiler were quoted in the introduction section.

Chapter 2: Background describes about the video gaming and its antiquity. A brief overview of cloud gaming and existing cloud gaming systems were explained. After that, the architecture of GamingAnywhere is described and explained with the help of the figures.

Chapter 3: Related Work comprises of the contributions by other authors who had done their work on topics such as cloud gaming, GamingAnywhere, energy consumption of mobile device. It depicts about their implementations and how it motivated research.

Chapter 4: Methodology gives a comprehensive demonstration of the approach. It explains about the experimental test bed and design of GamingAnywhere. Monsoon power tool, PowerTutor and Trepn profiler descriptions and explains about their working in thesis.

Chapter 5: Results and Analysis section displays the collected data in tabular and graphical format. It depicts the different experiments conducted in the thesis and analyze the results. In-depth reasoning is given about the obtained results.

Chapter 6: Conclusion and Future work section concludes the thesis. It outlines the results and also give the suggestions for the future work that can be done.

1.6 Split of work

This section illustrates the distribution of work among the thesis partners.

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Table 1.6.1: Split of work

Chapter 2

Background

2.1 Video Gaming

Single – player computer games began spreading with adoption of PCs in the 1980s. With the expansion of the internet and networked society, computer games progressively incorporated multiplayer features. As mobile gadgets are being increased, mobile games came to the real world. Recently, the growth of cloud computing has quickened the ascent of GaaS. The GTA IV computer game collected $310 million within a span of 24 hours around the world in April 2008. The video game industry is anticipated to reach $82 billion by 2017. Indeed, in depressed economy also, video gaming industry growth has been increased by 16%. The famous game distributor Electronic Arts earned 40% of income through online. This shows that video games are not only for entertainment but also intensely rely in online infrastructure. The cloud gaming technologies majorly have social gaming, multiplayer online games and many cloud services. Cloud services (for example, XBOX live) are just intended to increase the functionalities of user gadgets with social networking and finite storage with server access[25].

2.2 Overview of Cloud Gaming

Cloud computing has extremely changed existing operations and business models of IT industry due to its unparalleled versatility and reduced expenses of capital and hardware support. Existing applications, from file sharing to multimedia streaming, have encountered an awesome benefit from cloud computing platforms, in terms of system/framework efficiency and its ease of use. The advancement of cloud computing extends to allow offload complex tasks like intensive graphics 3D rendering to the cloud. This has turned the possibility of cloud gaming into a reality and significantly facilitates the development[28]. Fig 2.1 shows the overview of cloud gaming

Since 2009 to present, cloud gaming is referred as: “Cloud gaming is an online gaming where games and their logics are stored in the servers and the video game scenes are streamed back to the thin client over the Internet. The thin client is responsible for displaying the video from the cloud rendering server as well as collecting the player's commands and sending the interactions back to the cloud[22][24].

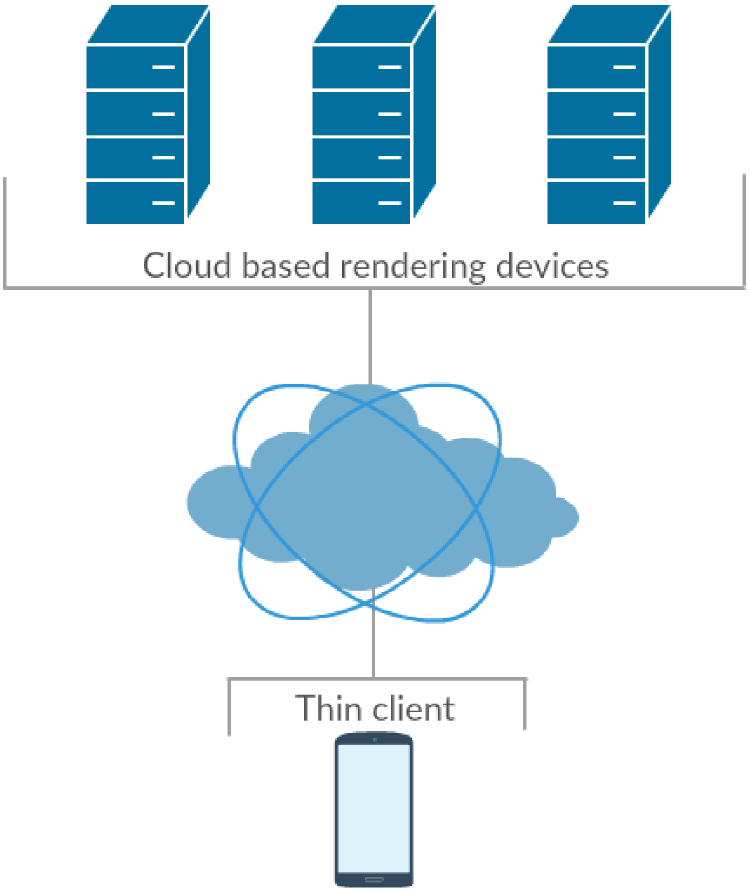

Figure 2.1: Cloud Gaming Overview

2.3 Mobile Cloud Gaming

Mobile cloud gaming is a new and promising technology for the cloud-based delivery of video games to mobile devices in a platform-independent manner. These mobile devices can be smartphones and as well as tablets.

Mobile cloud gaming is defined as communal gaming utilizing smartphones that access the cloud as an outer source for working of gaming scenarios and their interactions, and also to empower the extreme features like cross-platform operations and battery saving[8].

The research on mobile cloud gaming brings the rich gaming applications on hand held mobile devices which are energy constrained. While most of the mo-bile devices are capable in present days, the battery technology is not that much improved at the pace of memory and processor technologies. With the help of some estimations, it was identified that doubling the clock speed consumes eight times more power than the usual. This makes the running of computationally intensive applications on the mobile device. Processor is the enormous constraint for smart-phone devices where approaches to offload the computation load to the servers from devices have emerged. The best approach to offload the computa-tional load is by using the mobile device as a thin client which means that the mobile device is used as a dumb display and control device and handling the large computational load on the server side. This type of approaches are called mobile computation offloading approaches and there are many approaches that are prevailing nowadays [18].

2.4 Existing Cloud Gaming Systems

Cloud gaming has obtained a lot of significance and so many companies showed interest to provide several cloud gaming services. In 2012, Sony computer entertainment attained Gaikai which was founded in 2008[1]. It is the earlier lead company to provide cloud gaming services. Sony computer entertainment has built up a high quality and rapid cloud streaming platform that helps in rapid delivery of games and more associative services to the customers over the web. The main disadvantage in using Gaikai is that it does not tablets and digital TVs on the client side.

There is an another cloud gaming service called Onlive game from Onlive corporation which invented high graphic applications that are available for all devices such as laptops, PCs and tablets. For handling these type of high resolution applications, H.264 encoder is configured o n t he s erver s ide. H owever, it uses Virtual machines on server side which in turn gives two streams. One stream is for gaming in the real world which is said to be the live stream and the other stream is for recording the game sequences likely said to be media streaming[3].

StreamMyGame is a closed cloud gaming system which is quite similar to Onlive is only software game streaming solution that plays the Microsoft games remotely on Linus and Windows platforms with great number of users. However, the system layout cannot be examined as this is a closed cloud gaming system[28][5].

GamingAnywhere is the only cloud gaming system which is open to all. Compared to the remaining closed cloud gaming systems, GamingAnywhere utilizes the video streaming methodology for lower loads on the client side[15]. GamingAnywhere includes extensibility, portability, configurability and openness. It embraces a modularized plan. Video and audio capturing which are platform dependent segments and platform independent segments such as network protocols and codecs can be effortlessly changed and supplanted. Game users can utilize their gadgets with heterogeneous designs to access GamingAnywhere and so it can be ported to any platform. Modern platforms can be effectively upheld by supplanting the platform dependent segments in GamingAnywhere. A vast number of implicit video and audio codecs are supported by GamingAnywhere. It has given all possible configurations to the game users so that they can try the combinations of the parameters in different situations.

2.5 Architecture of GamingAnywhere

GamingAnnywhere comprises of two components. They are GamingAnywhere server and GamingAnywhere client.

2.5.1 GA server

The selected game runs on the game server along with an agent. The agent is a thread injected into the selected game. The first requirement of the agent is to capture the video and audio frames that are produced by the chosen game and encode the frames using chosen codecs[18]. These frames are delivered to the client via the data flow. The second requirement is to communicate with the game dynamically. As the user sends actions from the client, the server must behave, as though it was the user and must re-play the received input events[18].

The server operation involves two main mechanisms to capture game screens. The first mechanism performs a screen capture of the entire desktop periodically, then extracts the particular region associated with the game screen. After this, the second mechanism is that the video frame data is obtained from the graphic rendering buffer[18]. This method is executed by using the hook function of DirectX APIs. By using the Window Audio Session API, the audio frames were captured for the game sound. After getting the audio and video frames on server side, the encoding is done by utilizing the libavcodec library. Then the encoded information is streamed to client from the server. Fig 2.2 shows the architecture of GamingAnywhere

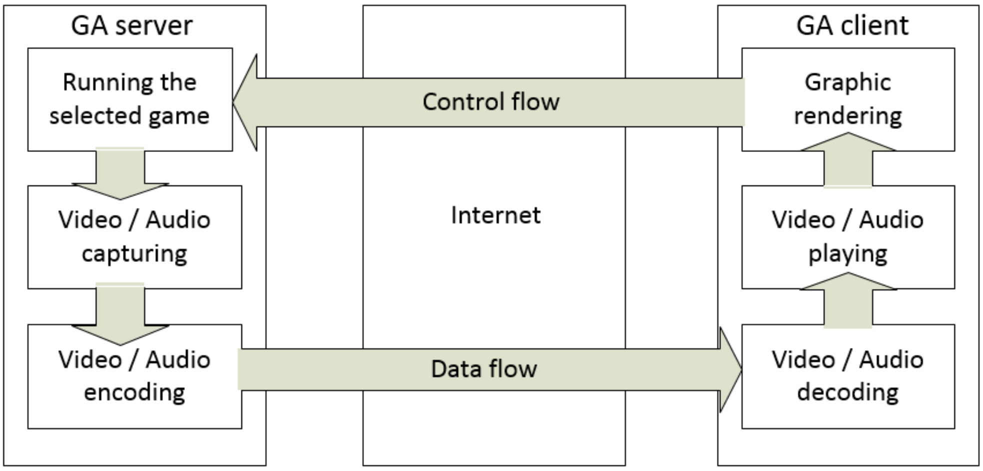

Figure 2.2: GamingAnywhere system Architecture

2.5.2 GA client

The GamingAnywhere client decodes the information which is streamed from the server and render the video and audio frames. For decoding, the GA client also utilizes libavcodec library. Zero-buffering mechanism is used by the decoder. This mechanism is used to reduce the effect of delay while playing the game[18].

SDL library is designed to provide the real time rendering of the decoded video frames through Direct3D and OpenGL. The SDL library precisely read and render the encoded audio frames. After that, SDL library also take the user inputs such as the tapping of the touchscreen on mobile and the pressing of keys on keyboard and moving the mouse in case of Windows and linux. After capturing the user inputs, they are sent to server side from the client side through control flow.

2.5.3 Interaction between the GamingAnywhere server and client

In GamingAnywhere, the control flow and data flow establish the interaction between the GamingAnywhere server and client. For handling the control flow and data flow, the libraries such as libavformat and live555 are used on both sides[18]. The audio and video frames were streamed to the client from the server by using two ways. One is by transmitting RTCP/RTP packets through the RTSP over TCP and the other way is by transmitting the RTP packets over UDP. The GamingAnywhere client handles protocols such as RTSP/RTP corresponding to the method used on the server side.

Chapter 3

Related Work

Authors of [13] elucidated that internet only provides better effort services and game users are hard to please. Despite researchers are improving cloud gaming systems but the existing cloud gaming systems were unable to reach the researchers ideas as they are closed and proprietary cloud gaming systems. So, Authors of [13] have presented first open source cloud gaming system GamingAnywhere, an extensible, configurable and portable cloud gaming system. It can be used by the service distributors for developing services in cloud gaming and the game users to organize their own cloud gaming system. Authors of [13] had demonstrated GamingAnywhere system with one GamingAnywhere server and four GamingAnywhere clients and then they have compared the response delays of GamingAnywhere with the closed and proprietary cloud gaming systems StreamMyGame and OnLive. The authors also concluded that GamingAnywhere cloud gaming system can help the multimedia research community to establish and develop more cloud gaming systems in future.

Authors of [16] used GamingAnywhere and conducted experiments in cloud gaming to quantify satisfaction of users. They have used both PC (Windows OS) and mobile (Android OS) clients for their experiments. User studies are conducted i.e gamers are called and played different games on both clients for one minute and evaluated their gaming experience. The evaluation is based on the aspects like smoothness, graphics and control given on a scale of five-level MOS. Each game session is varied with four different parameters like bitrate, frame rate, resolution and delay. Authors used games like Limbo, Mario Kart 64, Super Mario 64 and Super Smash Bros. Their experimental results show that users are more satisfied with the graphics on mobile devices compared to desktops and in case of smoothness PC is slightly higher, also more satisfied with the control quality on desktops. They also shared their experience of GA client to Android OS. They also analysed and explained which parameters affect the above aspects.

Authors of [27] described about PowerBooter which is an automated power model construction. This is a technique that use the knowledge of discharging behavior of a battery that helps in monitoring the power consumption and power management is also controlled simultaneously. It requires no outer estimation equipment. Authors also illustrated about PowerTutor which is an android application is a power management tool that measures the power for each component of the mobile device. For online power estimation, PowerTutor uses the model developed by PowerBooter. PowerBooter is helpful for the software developers and mobile users to develop power models for the latest and upcoming mobile devices as each mobile variant will have distinct properties of power consumption and so it needs distinct power models. For embedded systems, PowerTutor is helpful to select the better power efficient software. Authors of [27] had also used Monsoon FTA22D power meter for power measurement. The monsoon power meter gives a stable voltage to the mobile device connected to it and samples the power consumption for 5KHz. They also run the another program simultaneously which controls the mobile device power consumption. So, they considered it as rough values and had run a second program where the readings are logged at high frequencies to catch the many changes of variables that indicate the system state.

Authors of [23] illustrated that mobile phone power monitors are used to know the properties of energy of the phone components that consume more energy for example, WiFi and cellular radios. In analysis they concluded that cellular radios consume more energy as signal strength affects the energy consumption. Authors of [23] also depicted that introducing the phone power monitoring to every system on mobile devices is the better approach. They also illustrated the alternative approach where calculating the energy consumed by modelling each component's energy consumption and then activity of the components can be monitored. PowerTutor which is a monitoring application of the PowerBooter which performs the same. The benefit in modeling is that hardware is not necessary. The main disadvantage of models is that the power is measured only when the CPU is active. The Authors of [23] illustrated that this research main goal is to introduce the monitoring tool BattOr to the research community and streaming the power measurements to the laptop while phone connected to BattOr.

Authors of [14] elucidated that game users are allowed to play games on mobile devices by using mobile cloud gaming. The analysis of client performance and energy consumption plays a prominent role in attracting and retaining the game users. In order to do so, the authors of [14] have used GamingAnywhere which is an open source cloud gaming system. Authors conducted the experiment and found two best researches that are mobile cloud games save 30% of energy when compared to mobile native games and the other one is bitrate, resolution and frame rate affect the decoders resource consumption and also found that frame rate impose more impact. In the experiment, authors have used UseMon and CurrentWidget applications to measure the CPU utilization by UseMon and current, voltage by CurrentWidget which are then used to find the energy consumption.

Authors of [19] described that mobile cloud gaming is the latest approach for the cloud based delivery of games to the mobile phones in a platform independent style. Authors have considered a service model considering energy consumption, latency and cost. Measuring the latency consists of many categories such as the game pipeline latency, the encoding and decoding time span and latency of network. In the experiment, network latency is measured by considering the common WiFi and cellular networks. From the analysis of latency, authors depicted that latencies somewhat increase when there is a slight increase in geographical distance which help the cloud gaming distributors to build datacenters close to the customers. Authors of [19] concluded that mobile cloud gaming based on UMTS will have some advantages on a local game execution on latest mobile devices having powerful hardware.

Authors of [20] described that the mobile phone applications that are rapidly using cloud computing to overcome the resource limitations of smartphone devices. The computationally expensive duties are offloaded to the cloud servers and the mobile application just interacts with the remote server via a network connection. This connection is established by remote display access. In the paper [20], the authors addressed the remote display access with focus on power consump-tion of mobile devices. They analyzed different remote access solutions such as GamingAnywhere (GA), Virtual Network Connection (VNC) and Remote Desktop Protocol (RDP). The authors concluded that the power consumption and bandwidth utilization is high for GA when compared to VNC and RDP. The power consumption is measured by using Monsoon power tool and PowerTutor which helped our research in calculating power consumption for different resolu-tions.

Authors of [18] illustrated about remote cloud gaming in which the game is rendered and executed in the cloud and streaming of audio and video is done on user side. In remote cloud gaming, it approaches to use edge clouds where the games will be played without need of installing any kind of infrastructure on end users at homes. It is done by keeping the network delays to the latency sensitive games low. Game companies are presently using this kind of remote cloud gaming as a substitute to traditional download and install games so as to support anti-piracy protection. In the paper [18], authors had done a research on power consumption by proving that mobile phone users can save up to 32% of power by using remote gaming rather than using native app for playing. The overall prototype is based on GamingAnywhere where they had also integrated gamepad for controls. Authors measured and analyzed the power consumption both with 2D and 3D games.

Chapter 4

Methodology

4.1 Experimental Setup

The experimental setup comprises of a server, a client on pc, a client on mobile and monsoon power monitoring tool. GamingAnywhere server and client is established on a Windows 7 desktop having Intel quad core processor with 4GB RAM. The GamingAnywhere mobile client is installed on Samsung I9100 Galaxy SII having dual-core 1.2 GHz Cortex-A9 and super AMOLED Plus touchscreen with 217 pixel density running Android v4.1 (Jelly Bean). The monsoon power monitoring tool hardware FTA22D gives the robust power measurement for any lithium powered mobile upto 4.5 volts and maximum of 3 amps or lower. The GamingAnywhere mobile client and client on desktop were connected to the server by means of 802.11 wireless LAN and Gigabit Ethernet LAN, respectively. Fig.4.1 shows the experimental setup[16].

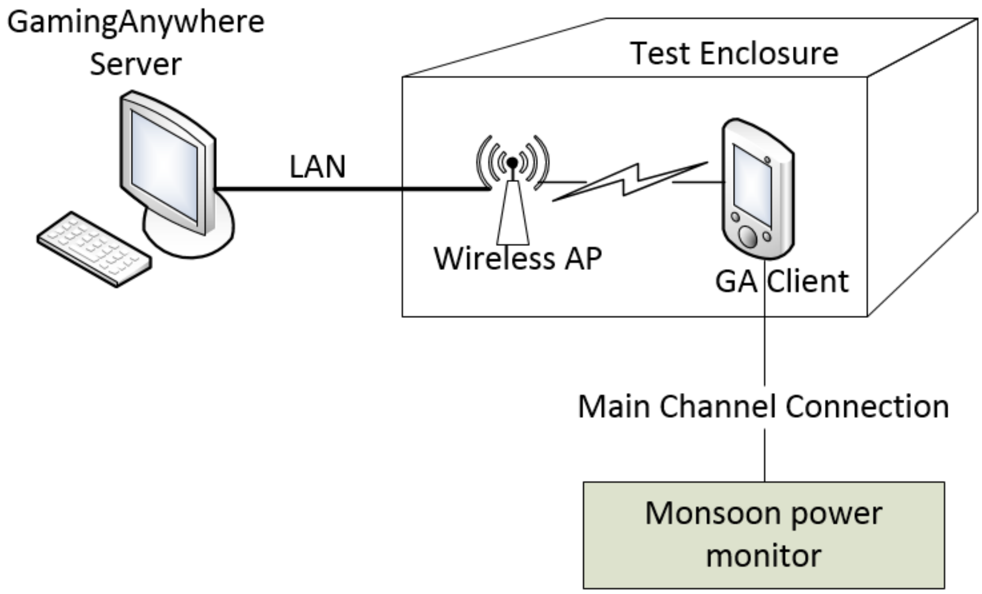

Figure 4.1: Experimental test-bed

The GamingAnywhere server which is outside the test enclosure streams the game to the GamingAnywhere client which is inside the test enclosure. The user inputs from the GA client are streamed back to GamingAnywhere server. The GamingAnywhere server and GamingAnywhere client were connected to the same wireless LAN which is inside the test enclosure. In the experiment, wireless LAN is used rather than using 3G/4G because the test enclosure used in the experiment won't allow the outer signals to come inside the test enclosure. So, 3G/4G signal gets weak when it enters the test enclosure. Here, test enclosure is used to avoid the external disturbances.

The Monsoon power monitoring tool which is outside the test enclosure is having three channels. They are Auxiliary channel, Main channel and the USB channel. Here, Main channel connection is used to connect the Mobile device to the Monsoon power monitoring tool. Main channel connection is the only possible connection to find the accurate power consumed by the mobile device. In the experiment, battery of the mobile device is removed and voltage positive"+" and negative"-" terminals of the mobile device are connected to the positive"+" and negative"-" terminals of the Monsoon power monitoring tool by means of copper wire respectively.As shown in the fig.4.4, USB 'A' cable is connected from the front of the Monsoon power monitoring tool to the mobile device and USB 'B' cable is connected from the front of the Monsoon power monitoring tool to the computer which helps in viewing the data in the Monsoon software GUI and also to set the value of Vout which is supplied to the mobile device from Monsoon power monitoring tool. All the current provided to the mobile device is from the main channel of the monsoon power tool.

The PowerTutor and Trepn Profiler are the two android applications installed on the mobile device. CPU power, LCD power and Audio power are calculated using PowerTutor and memory usage by Trepn Profiler.

4.2 Experimental design

4.2.1 GamingAnywhere server

When the GamingAnywhere is launched, its modules such as Audio source, Video source, RTSP server and input replayer were also launched. The input replayer and RTSP server waits for the incoming clients. If once the process was initialized, the video source and audio source were kept to idle. The encoder threads are launched when the client get connected to the RTSP server and then the encoder should send a notification to the respective module that it is waiting to encode the frames that are captured. Then the Video and audio frames are captured by the source modules when more than one encoder get to work. The encoded video and audio frames are generated all at once[15].

4.2.2 GamingAnywhere client

GamingAnywhere client presents the real time game screens and dispatch them as encoded video and audio frames. The client consists of two strings one is used to render video and audio frames and the other is used to handle user inputs[15].

GamingAnywhere client on mobile is established by installing android application called GA client on mobile. Fig 4.2 expose the GA client software architecture[16] and Fig.4.3 shows the game screen of Assault cube. The application is coded in java but few components are carried out as loadable shared objects in native C and C++.

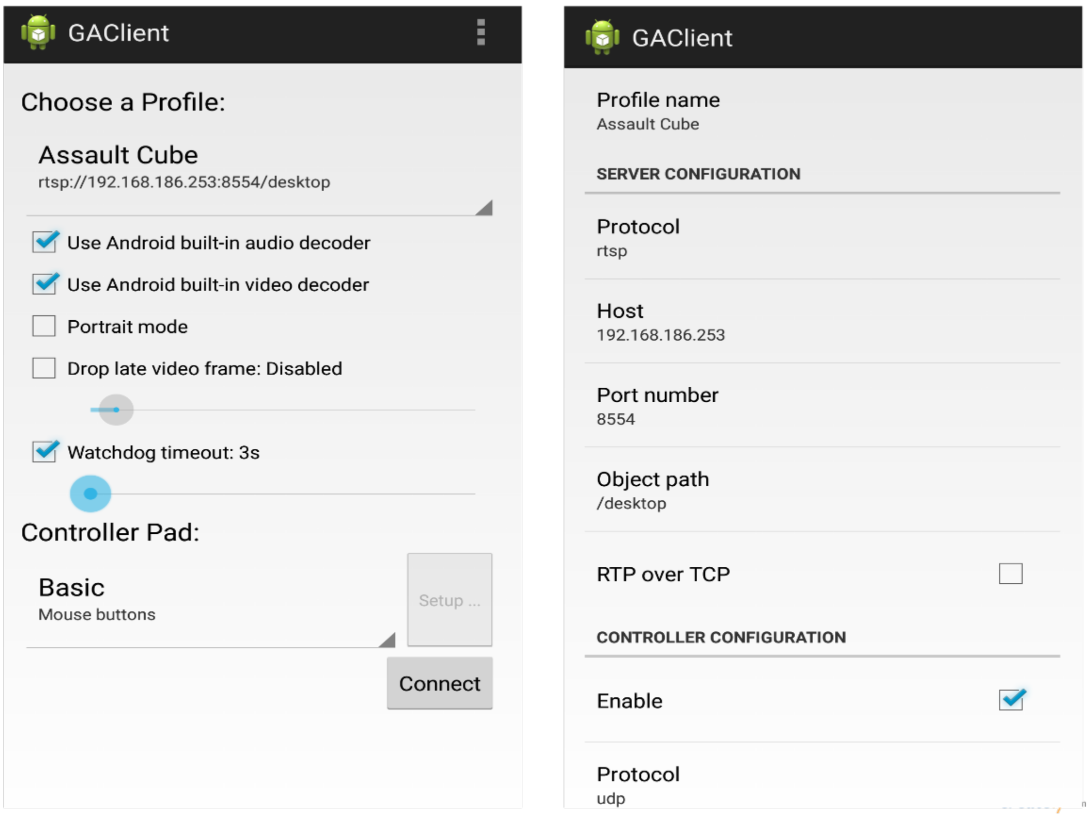

Figure 4.2: GA Client mobile application

Figure 4.3: Assault cube game running on mobile device

4.2.3 Monsoon power monitoring tool

The monsoon power monitor hardware and software gives a vigorous power estimation for the mobile devices. The software and the hardware can be able to figure out the power estimation for the devices that uses up to 4.55v battery.

The software developers and electrical engineers can use this hardware to evaluate the performance of the mobile devices. The monsoon power monitor can measure data on main, USB and Auxiliary channels. But, for the mobile device to measure the power consumption, main channel connection is the best possible way for the accurate results[21]

Fig. 4.4 shows the front view of the Monsoon power monitoring tool. The main channel connection is established by connecting the Positive and negative terminals of the power tool to the Positive and negative terminals of the mobile device respectively. On behalf of the configuration setup, the Vout is set to 4.0v and battery capacity to 1650mAh. Vout is supplied to the mobile device to power it as the battery is removed from the mobile device in the main channel connection.

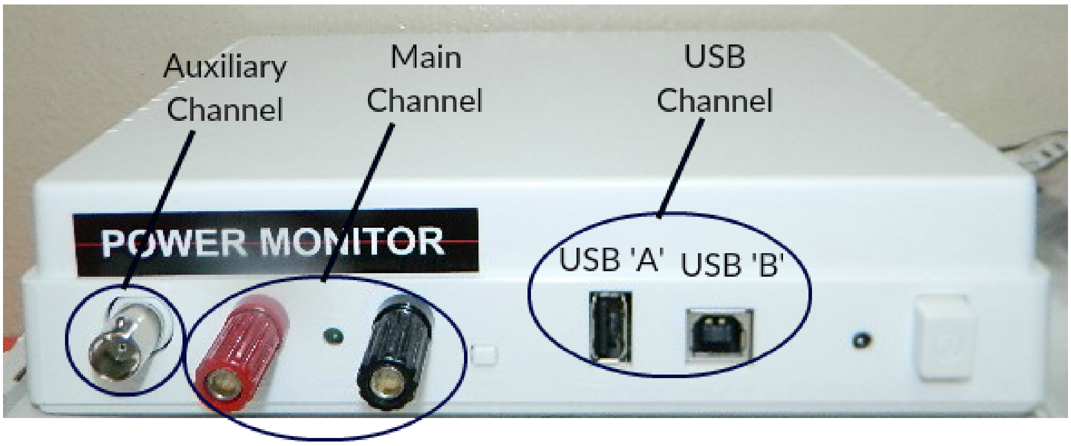

Figure 4.4: Assault cube game running on mobile device

4.2.4 PowerTutor

PowerTutor is an android application that shows the power consumed by major system components for example, CPU, LCD and Audio. This application permits the software developers to see the effect of design changes on power efficiency. The normal users can also use this application to check how their usage is affecting the battery life. This application model gives power utilization estimates within 5% of real values[26][4].

4.2.5 Trepn Profiler

Trepn profiler is an application designed for android devices. This application is an on-target power and performance profiling application for mobile phones[7]. Trepn profiler is capable of viewing real time view of CPU cores and memory usage. In our research, Trepn profiler is used to get the memory usage of mobile device[6]. The memory usage calculations were taken when the game is streaming from the GamingAnywhere server to GA client.

4.2.6 Shielded Test Enclosure

Shielded Test Enclosure is often called as Black box. It is used to avoid external interference in the network.The test enclosure used in our experiment is Ramsey STE3000FAV. It is standard with 6 outlet 230 volt power strip. It has built-in high resolution camera that can record Audio and Video. It is provided with high efficiency RF gaskets and RF foam liner that helps in avoiding external interference.

In the thesis, the wireless AP and mobile device are enclosed in the test enclosure as shown in the Fig 4.1. the mobile is placed inside the test enclosure to isolate from outer signals. Then the game is streamed from the server to GA client and then the power consumption and memory usage calculations were taken for the mobile device which is inside the black box. The test enclosure is designed in such a way that it enables the connection between the inside components with the outside components. So, the connection can be established between the mobile device which is inside the test enclosure and the Monsoon power monitoring tool which is outside the test enclosure. The advantage of using test enclosure is that it avoids the outer disturbances that comes inside the black box and disadvantage is that only wireless LAN is the possible network connection as 3G/4G signal gets weaker inside the test enclosure.

4.3 Experimental Procedure

The experimental setup consists of a GamingAnywhere server, GA client on the mobile device and Monsoon power monitoring tool. In this research, the game Assault cube is considered to be streamed from server to the client as it is the best adventurous game where the game is suitable to analyze the performance of the mobile phone in many aspects such as resolutions, power consumption etc. Once the streaming is started from the server to the client, the inputs from the mobile device on client side is sent to the server. While the game is being streamed, the power consumption of the mobile device on the client side is measured by using the hardware monsoon power monitoring tool which is connected to the mobile phone. Simultaneously, the results such as CPU, LCD and Audio power from the PowerTutor application and memory usage from Trepn profiler were also taken which are installed on the mobile device.

Fig 4.5 shows the environmental test bed with GamingAnywhere server streaming game to the GA client which is inside the test enclosure. While streaming the game, the power consumption of the mobile device is calculated by connecting the mobile device to Monsoon power tool which is outside the test enclosure through main channel connection.

In the experiment, the power consumption of the mobile device is calculated by both the hardware Monsoon power tool and software PowerTutor. This is due to the reason that the hardware finds the total power consumed by the mobile device whereas the software PowerTutor calculates the power consumed by each component inside the mobile device such as CPU, LCD and Audio power.

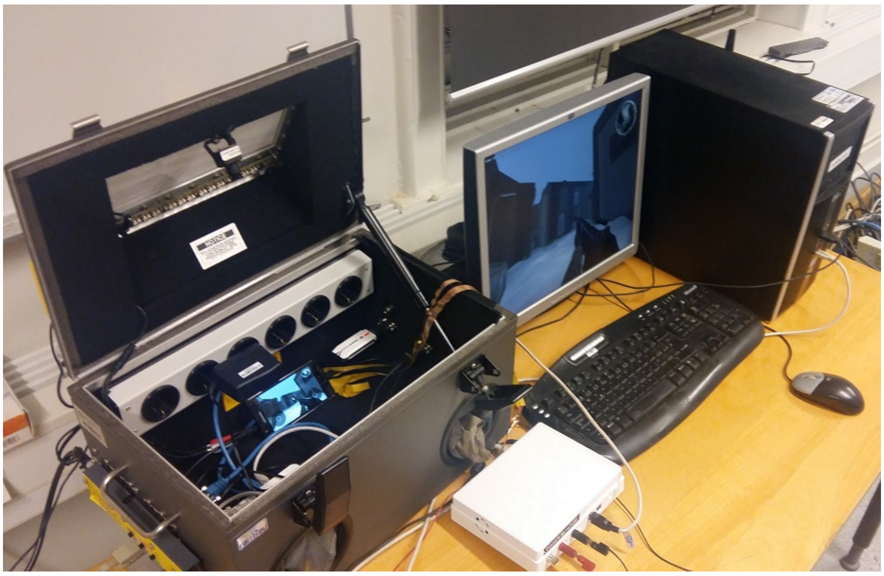

Figure 4.5: A Demonstration of experimental setup

Chapter 5

Results and Analysis

This section gives a brief description on the outcomes acquired in the experiment which was specified before. The outcomes acquired depicts the impact on power consumption of mobile client when using GamingAnywhere. Average power is found out for the mobile device by using monsoon power monitoring tool. CPU, LCD, Audio power and total power have been found out by using PowerTutor and memory usage by Trepn profiler. The results were taken for every 10 minutes for 40 times. Monsoon power monitoring tool is a hardware tool whereas PowerTutor and Trepn profiler are the android applications. From the collected data, standard deviation and confidence intervals for 95% are found out.

The experimentation was done in the following scenarios independently:

- Resolution: 640 x 480; 30fps for every 10 min for 40 times.
- Resolution: 720 x 576; 30fps for every 10 min for 40 times.
- Resolution: 800 x 600; 30fps for every 10 min for 40 times.
- Resolution: 1024 x 768;30fps for every 10 min for 40 times.

The reason for considering these resolutions is because they are mostly used and most of the games support these resolutions only and we stream Assault cube game in our thesis as it is the best adventurous game and so the game is suitable to analyze the performance of the mobile device in many aspects.

5.1 Monsoon power monitor calculations

When the game is streamed from server to the client i.e., from GamingAnywhere server to GA client. The power consumption of the mobile device which is on the client side is calculated for every 10 minutes for 40 times by using monsoon power monitoring tool which is outside the test enclosure connected to the mobile device inside the test enclosure.

Resolution	Total Power	Standard Deviation	95% CI
640 x 480	1257.95	5.274605612	1.634587178
720 x 576	1320.64	6.621304698	2.051925879
800 x 600	1408.25	6.789716281	2.104116211
1024 x 768	1461.36	7.423048565	2.300384313

Table 5.1.1: Power consumption calculations by monsoon power tool

The results were generated in the Monsoon power tool software as a csv file from which the average power is taken. Table 5.1.1 Shows the average power and its standard deviation and 95% confidence interval(CI) for each resolution.

5.2 PowerTutor calculations

PowerTutor is an android application used for calculating CPU, LCD, Audio power and also total power. When the game is streamed from GamingAnywhere server to GA client, the PowerTutor application which is installed on the mobile device on client side calculates the total power simultaneously for every 10minutes for 40 times.

The results from the PowerTutor is logged to a text file. Then the text file is analyzed and total power for each resolution is taken into an excel file where the standard deviation and 95% confidence intervals(CI) are found out.

Tab 5.2.1 depicts the total power and its standard deviation and 95% confidence intervals.

Resolution	Total power	Standard Deviation	95% CI
640X480	1198.72	6.073833728	1.882265986
720X576	1266.42	5.982898229	1.854085301
800X600	1356.05	5.504089761	1.705703746
1024X768	1417.98	5.730853245	1.775977186

Table 5.2.1: Power consumption calculations by PowerTutor

The summation of CPU, LCD and Audio power gives the total power consumed by the mobile device when the game is streamed. But in the analysis, LCD and audio power stands constant at 650mW and 382mW respectively. CPU power is the only parameter that has been changed for each resolution. Table 5.2.2 depicts the CPU power calculated by the PowerTutor application when the game is streamed from GamingAnywhere server to GA client.

Resolution	CPU power	Standard Deviation	95% CI
640X480	166.87	6.073833728	1.882265986
720X576	234.76	5.982898229	1.854085301
800X600	324.60	5.504089761	1.705703746
1024X768	386.59	5.730853245	1.775977186

Table 5.2.2: CPU Power calculations by PowerTutor

5.3 Trepn profiler calculations

Trepn profiler is an android application used in this thesis to calculate the memory usage of the mobile device when the game is streamed from GamingAnywhere server to GA client. Trepn profiler is installed on mobile device and memory usage calculations are taken simultaneously for every 10 minutes for 40 times while taking power consumption values. The memory usage values are logged into a text file. The text file is analyzed and taken into an excel file and then its standard deviation and 95% confidence intervals were found out. Table 5.3.1 depicts the memory usage of the mobile device and its standard deviation and 95% confidence intervals.

Resolution	Memory usage (kB)	Standard Deviation	95% CI
640X480	826499.83	303.30	93.9927
720X576	827462.23	222.79	69.0406
800X600	827802.30	217.64	67.4474
1024X768	828928.20	241.96	74.9815

Table 5.3.1: Memory usage calculations by Trepn Profiler

5.4 Monsoon power monitor v/s PowerTutor

The results from the monsoon power monitoring tool and PowerTutor when streming the game from GamingAnywhere server to GA client were analyzed and have been compared. The comparison describes that the power consumption values taken from the hardware monsoon power monitoring tool are slightly higher than the values taken from the software PowerTutor application. Fig. 5.1 shows the graphical comparison of monsoon power tool and PowerTutor.

The reason for the slight increase in the power consumption values by monsoon power tool is that it calculates the total power of the mobile device that includes the background processes whereas the PowerTutor calculates the power consumed by the GA client application only.

The reason for the increase in the power consumption for the change in resolutions from low to high is that the pixels will be more for higher resolutions than for lower resolutions. Each pixel needs some energy to power up. So, the higher resolutions having more pixels consume more power when compared to the lower resolutions having less pixels.

As the values of power consumption by Monsoon tool and PowerTutor is very small, we can estimate that software PowerTutor could be used for measuring the power consumption instead of Monsoon tool as the software is even capable of measuring the individual components of the mobile device.

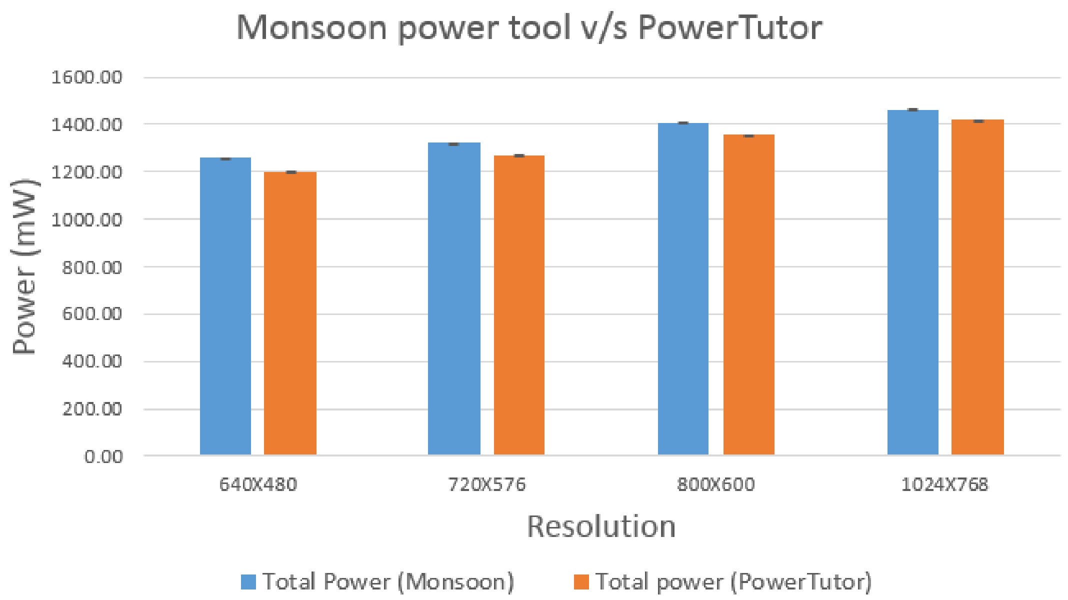

Figure 5.1: Comparison of Monsoon power tool and PowerTutor calculations

5.5 Analysis of memory usage

When the game is streaming from the GamingAnywhere server to GA client, Trepn profiler application runs simultaneously and takes the values of memory usage for each resolution. Fig. 5.2 shows the memory usage of the mobile device while streaming the game for each resolution. In the analysis, it depicts that as there is a change is resolutions from low to high there is a slight increase in the memory usage.

The reason for the increase in memory usage when there is a change in resolution from low to high is that for higher resolutions, more data is to be transmitted from GamingAnywhere server to the GA client. So, more memory usage takes place for higher resolution than for lower resolutions.

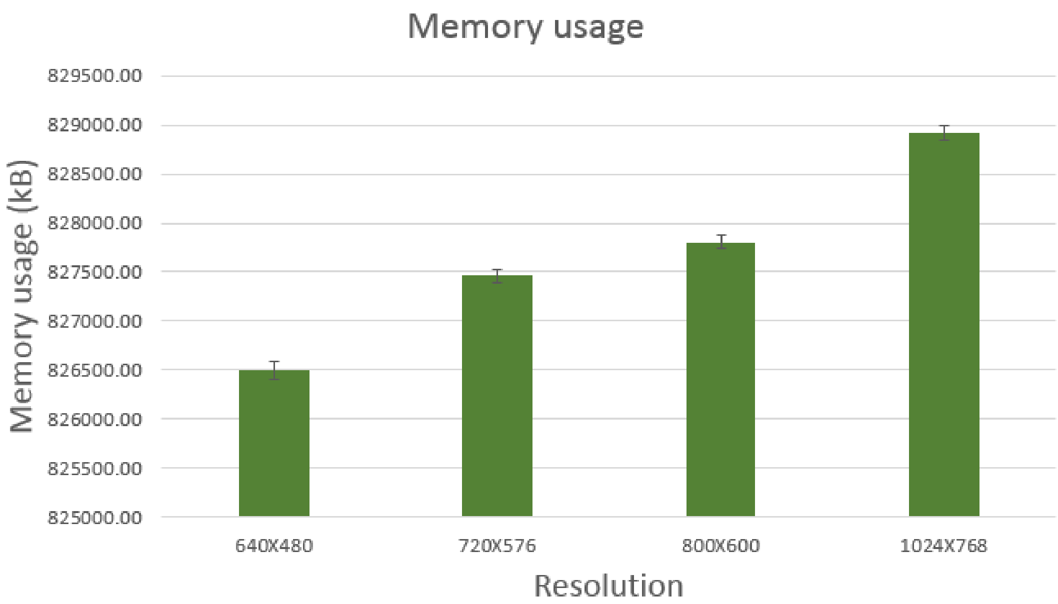

Figure 5.2: Analysis of memory usage

5.6 Analysis of CPU, LCD and Audio power

PowerTutor application runs simultaneously with the game streaming from the GamingAnywhere server to GA client. The results such as CPU, LCD and Audio power were taken at that time. Then they are logged to a text file which is then analyzed and taken into an excel sheet. Fig. 5.3 shows the average power of CPU, LCD and Audio power for each resolution. It also depicts that CPU power is varying as there is a change in resolutions but LCD and Audio power stands constant as the experiment was done by considering the ideal case.

In the analysis, it can be observed that the CPU power is increasing as there is a change in the resolution from low to high. This can be due to the increase in the memory usage of the mobile device. When more memory is consumed, CPU also consumes more power and hence the CPU power is slightly increasing with the change in resolution from low to high.

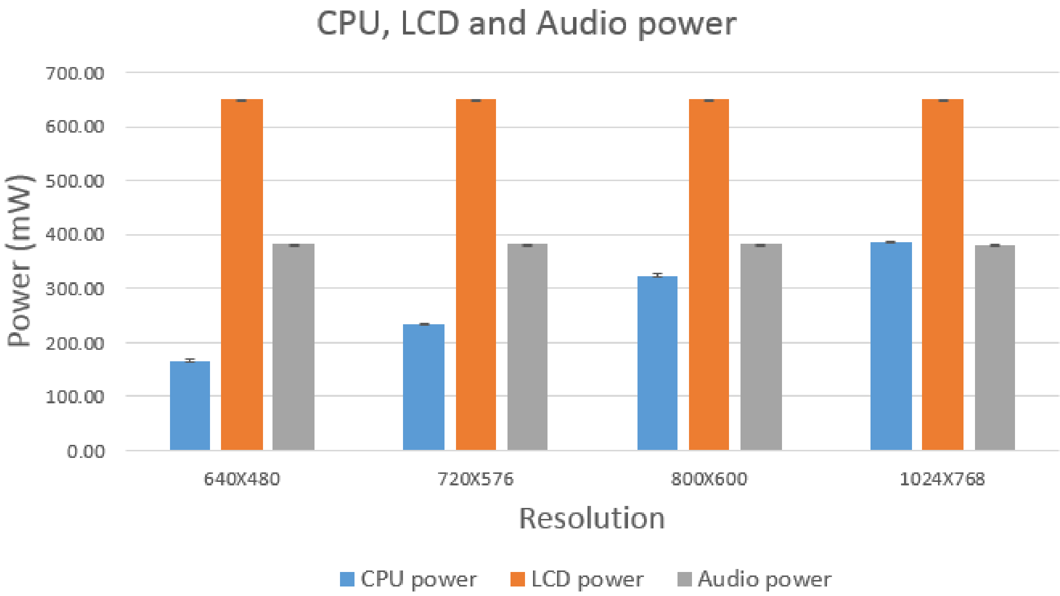

Figure 5.3: Analysis of CPU, LCD and Audio power

Chapter 6

Conclusions and Future Work

The experimental results depict that how the power consumption of the mobile device on client side varies when there is a change in resolution from low to high. Initially, the game is streamed from GamingAnywhere server to GamingAnywhere client and the total power is calculated by using the hardware monsoon power monitoring tool and CPU, LCD and Audio power were calculated by using the software PowerTutor and memory usage by Trepn Profiler.

In the analysis, when the resolution is varying from low to high, the power consumption of the mobile device is also increasing slightly. The comparison between monsoon power tool results and the PowerTutor results depicts that there is a small difference between the results of hardware and software from which we can estimate that the software PowerTutor can be used instead of Hardware Monsoon tool as the software is capable of measuring the power consumption of even individual components of mobile device. In this thesis, memory usage of the mobile device is calculated and analyzed. When the resolution is varying from low to high, there is a slight increase in memory usage of the mobile device.

The following ways can be done as future work:

- GPU is also a major component that consume power of the mobile device when streaming the game to the GA client. So, Measuring GPU power can be done as a future work.

- In this research, to measure the power consumption, the hardware tool monsoon power monitor is used which can calculate the total power of the mobile device but not the power of the individual components of the mobile device. So, building a hardware tool that calculates the power of the individual components of the mobile device can be done.

- The highest resolution which have been used in this thesis is 1024 x 768 but now a days even more high resolution gaming came into existence so the GamingAnywhere server can be designed in such a way that high resolutions also been possible to stream the game from GA server to GA client can also be done as a future work.

ANSWERS TO THE RESEARCH QUESTIONS

1. **What is the impact on energy consumption of mobile clients when using GamingAnywhere for different resolutions?**
   Ans. when using GamingAnywhere and streaming the game from server to the client, the impact of energy consumption is measured by calculating the total power of the mobile device for four resolutions by using the hardware Monsoon power monitoring tool and also with the software PowerTutor along with the standard deviation and 95% confidence intervals and tabulated them in Table 5.1.1 and 5.2.1 respectively.

2. **What is the power consumed by each component of the mobile device using GamingAnywhere for different resolutions ?**
   Ans. To calculate the power consumed by each component of the mobile device, the software PowerTutor is used where the CPU, LCD and Audio power were calculated and logged to a text file which is then taken into an excel sheet and have been analyzed that there is a slight increase in CPU power when there is a variation in resolution from low to high but the LCD and Audio power stand constant as the calculations are done considering the ideal case. (In ideal case, game is streamed from the server to client but no user inputs were given)

3. **How does, the results generated by monsoon power monitoring tool map with the results generated by an android application?**
   Ans. The results generated by the hardware monsoon power monitoring tool and the software PowerTutor were taken into an excel sheet and have been mapped by plotted the graph. From the graphical analysis, Fig 5.1 depicted that the results taken from monsoon power monitoring tool are slightly higher than the results taken from the software PowerTutor.

4. **What is the memory usage of the mobile device using GamingAnywhere for different resolutions ?**
   Ans. When the game is streamed from the server to the client, the memory usage of the mobile device is found for four resolutions by using an android application Trepn Profiler. The collected data is logged to a text file which is then taken into an excel sheet and have been plotted graph. From the graphical analysis, it explains that there is an increase in memory usage when the resolution is varying from low to high.

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