Thesis no: MSEE-2016:11

Power Consumption Models for Streaming on Mobile Terminals with On-Off Characteristics

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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 Master of Science in Electrical Engineering with Emphasis on Telecommunication Systems. The thesis is equivalent to 20 weeks of full time studies.

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ABSTRACT

The usage of smartphones has been increasing with surprising speed. These smartphones are popular for delivery of video content. The main drawbacks of these smartphones are battery life and video freezing. Despite, while streaming a video it consumes large of amount of power affecting QoE. So, in this case we considered streaming a video from server to mobile client involving ON-OFF characteristics. While streaming, there exists some transition delay while switching the power states and the effect of these transition delays might affect instantaneous power consumption of the smartphone

Henceforth, this thesis aims to determine the effect on instantaneous power consumption from distributed state durations and transitions in exponential fluid flow model, for a streamed video. Power measurements along with ON and OFF times were measured with the help of a benchmark tool, Monsoon Power Monitor tool. VLQoE tool, a video streaming tool was used to present a two state model based on the inter-picture time, for the HTTP-based video streaming. Experiments were executed in a closed enclosure setup using a black-box to avoid external obstacles that might possibly affect the power consumption metrics. Considering these measurements, the effect on instantaneous power consumption stemming from the exponentially distributed state durations and transitions in the corresponding fluid flow model can be determined and modelled.

KEYWORDS: Fluid Flow Model, On-Off Characteristics, Quality of Experience, Video Streaming.

ACKNOWLEDGMENTS

First of all, I would like to express my deep sense of gratitude to my supervisor Prof. Markus Fiedler for his endless support in every aspect to accomplish this thesis work. His encouragement, patience, interest above all his overwhelming attitude helped and benefited me to the extent that cannot be spanned by words. His timely advice and responsibility have helped me to a very great extent to accomplish this task for which I am deeply indebted to him.

I would also like to acknowledge Prof. Dr. Kurt Tutschku of Blekinge Tekniska Hogskola for his timely updates on course catalogue. His encouragement and guidance throughout my Master's education is commendable.

I would also like to extend my gratitude to my fellow mate T.N.N.P.Prithvi who rendered his constant encouragement and endless help in bringing my project work make successful. I would also like to thank V.S.B.Raviteja and my beloved ones who shared their support and stood by my side during hard times.

Above all, I would like to express my endless gratitude to my parents for giving me strength and courage to overcome hardships throughout my life. My special thanks to my father, G.Mohan Prasad for his unconditional love, encouragement and motivation throughout my education.

CONTENTS

ACRONYMS

CI	Confidence Intervals
CDF	Cumulative Distribution Function
GB	Gigabyte
GUI	Graphical Interface Unit
IP	Internet Protocol
MPMT	Monsoon Power Monitoring Tool
OS	Operating System
QoE	Quality of Experience
QoS	Quality of Service
URL	Uniform Resource Locator
WIFI	Wireless Internet for Frequent Interface
WWW	World Wide Web

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1 INTRODUCTION

This chapter provides an overview of entire thesis document. It mainly focus on problem statement, followed by research questions, hypothesis and split of work followed by outline of thesis.

1.1 PROBLEM STATEMENT

In recent times, the usage of hand held devices such as tablet PCs and smart phones has been increasing tremendously [1]. These smartphones are popular for delivery of video content. Despite that, the video streaming consumes large amount of data resulting in heavy network traffic. However, transmission of large amount of video data on smartphones face some fundamental challenges such as power and wireless bandwidth constraints. But due to flexible conditions on network and application levels, high power consumption exhibits high variance during a live streaming session due to varying conditions on network and application levels [2].

Thus, energy is highly consumed in video streaming applications due to:

- Permanent high network bandwidth demand, which internally keeps the network module of the mobile on for longer durations.
- High CPU utilization for processing the buffered data.
- Screen illumination of the smartphone.

When a smartphone streams a video, the power consumption shifts to the active, i.e., most power-consuming [3], state as the throughput increases. However, when there are no packets being transferred, the power consumption does not immediately drop back [3]. There exists also some transition delay while switching the power states, the effect of these transition delays might affect instantaneous power consumption of the smartphone.

The effect of these transitions during ON/OFF stages can be found out by conducting extensive QoE experiments and measurements on smartphones, we can assume that video stream follows a two state exponential ON/OFF model [4]. By using the VLQoE tool [3], the inter-picture time during a video stream can be measured. In parallel, the Monsoon energy measurement tool [5] can be used to measure instantaneous power consumption of a smart phone terminal. This helps us in suggesting new amendments to the existing ON/OFF model.

Therefore, the main aim of this work is to determine the effect on instantaneous power consumption stemming from the exponentially distributed state durations and transitions in the exponential fluid flow model. The main objectives of this thesis to achieve this goal are as follows:

- Carry out power measurements in a mobile scenario involving (exponential) ON/OFF channel behaviours.
- Provide the ground truth for modelling efforts, both for model building and model validation.

1.2 RESEARCH QUESTIONS

The aim of this thesis is to answer the research questions RQ1, RQ2, RQ3 listed below and the research questions are answered by carrying out power measurements in a mobile scenario involving ON/OFF channel behavior.

RQ1) How can instantaneous power consumption of a smartphone be measured with focus on mobile or wireless connections with on-off characteristics?

RQ2) How can instantaneous power consumption can be modelled (based on the fluid flow model), in particular for a mobile connection with on-off characteristics?

RQ3) How can the model parameters of the power consumption related fluid flow model be determined with sufficient confidence?

1.3 HYPOTHESIS

Video streams follow a two state ON/OFF model where Power consumption values are temporarily reduced due to high inter-picture OFF times, e.g. stemming from outages[3]. From this, we can hypothesize the following:

a) The power measurements relating to current power state of the radio module at the intermediate stages of on-off exponential model might help out in providing the ground truth and validation facilities for modelling efforts.

b) In order to improve the QoE, the number of transitions in-between the power states should be minimized, so that the data traffic is executed in less number of bursts.

c) The power consumption can be reduced by adjusting the playout buffer.

In order to investigate these hypotheses, a model that allows for calculating cumulative distribution functions of power consumption is needed.

The main objectives include:

1. Stream a video from server to mobile client involving ON-OFF characteristics.
2. Observe the effects of transition delays on power consumption while video streaming, mainly during the switching of power states, in exponential fluid flow model.
3. Calibrate the power measurements along with ON and OFF times with the help of VLQoE and Monsoon Power Monitor tools.
4. Perform experiment in a closed enclosure setup using a black-box to avoid external obstacles that might possibly affect the power consumption metrics.
5. Considering these measurements, the effect on instantaneous power consumption stemming from the exponentially distributed state durations and transitions in the corresponding fluid flow model, it can be determined and modelled.

1.4 SPLIT OF WORK

This thesis was initially split into two parts- Experimentation and power measurements & power modelling. The first part has to be carried out by my fellow partner, Vedantam Sai Bhargava Raviteja.

The first part includes:

- Carry out power measurements in a mobile scenario involving (exponential) ON/OFF channel behaviours.
- Provide the ground truth for modelling efforts, both for model building and model validation.
- Statistical analysis of the measurements.

The second part includes:

- Reviewing the mathematical description of the exponential fluid flow model.
- Extending this model to cater for power consumption.
- Use the extended model to relate outages to power consumption and Quality of Experience.

But due to some personal issues, the fellow partner discontinued the course. So, I took up the whole project. In this regard, my major thesis includes measurements & experimentation and couldn't concentrate much on modelling.

1.5 METHODOLOGY

This thesis mainly includes Modelling and Experimentation of video streaming. VLQoE tool and Monsoon Power Monitoring Tool were used for carrying out the experiment. Initially, a video has been streamed from server to the mobile client and using power monitoring hardware and software power measurements are carried out involving ON-OFF behaviors. These power measurements help in suggesting new amendments to the existing ON-OFF model.

1.6 OUTLINE OF THESIS

This thesis is structured as follows:

Chapter 2 gives the description about the background and literature work on the concepts QoE, Power Measurements and Exponential ON-OFF model.

Chapter 3 gives a detailed description of methodologies used in this thesis. It involves modelling and experimentation.

Chapter 4 provides a tabular representation of results obtained from experimentation, together with a set of relevant summary statistics.

Chapter 5 includes results and statistical analysis.

Chapter 6 includes explanation of results and answers to research questions.

2 BACKGROUND WORK

This chapter provides the description or background knowledge on the concepts of Quality of Experience, Monsoon power Monitor tool, VLQoE tool and Fluid flow model.

2.1 QUALITY OF EXPERIENCE

Quality of Experience (QoE) is the degree of delight or annoyance of the user of an application or service. It results from the fulfillment of his or her expectations with respect to the utility and / or enjoyment of the application or service in the light of the user's personality and current state. In the context of communication services, QoE is influenced by service, content, network, device, application, and context of use[17].

The main factors influencing QoE while streaming a video are battery life and temporal impairments [6]. Battery life can be defined as the amount of time a user can operate on a single charge and the operating time or battery lifetime is based on the energy consumed by the mobile. The second factor is temporal impairments. The best example for temporal impairments during a video streaming is video freezing. Video freezing can affect the QoE by increasing energy consumption. So, a tool called VLQoE [7] has been developed to record and measure timestamps.

2.2 POWER MEASUREMENT

Power consumption measurements can be obtained using a software tool without influencing the actual usage behavior of a mobile device, however it might not obtain accurate measurements. Whereas, hardware measurement tools are poor with regards to portability, and force experiments to be carried out in lab environments.

For example, we use Monsoon Power Monitoring device which contains the power monitor hardware and the power tool software. It runs on WindowsXP and Windows7 and can provide robust measurements on any device that uses a single Lithium (Li) battery. The obtained measurements can be saved with a sampling rate of 5 kHz. The Monsoon external power-monitoring device is typically used for taking ground-truth measurements [5].

2.3 FLUID FLOW ON-OFF MODEL

A fluid flow model of a queuing system is an abstraction in which the queue with its discrete waiting facilities is replaced by a bucket or funnel, offering a certain volume $K = X_{max}$. The behavior of inlet and outlet of a fluid queue over time are described by the rate processes $R^{in}(t)$ and $R^{out}(t)$, respectively [8].

This fluid flow model is appropriate to stream a video to produce a certain amount of traffic to be transmitted in certain amount of time. Here, the drift can be given by

$$D(t) = R^{in}(t) - R^{out}(t)$$

The drift varies from ON state to OFF state as follows:

1. During the OFF state, the inlet rate over time is smaller than the outlet rate resulting a negative drift until the buffer becomes empty.
2. During the ON state, the inlet rate over time exceeds the outlet rate resulting a positive drift until the buffer gets full, which is an overload situation.

As ON and OFF states are governed by random process (typically good or bad network behaviors), the buffer content X(t) is a random variable. In the stationary case (i.e. no dependency on t), the buffer content is described by the cdf $F(x)= Pr\{X<x\}$ [9].

In this work, the concept of the buffer content is translated into power values. The drift reflects the transitions from OFF to ON (power "up") and from ON to OFF (power "down") with the help of fluid flow analysis.

3 RELATED WORK

In study [4], the authors addressed by determining them through comprehensive user study and later proceeded through qualitative and quantitative methods. He also suggested on how Quality of Experience can be enhanced and maintained from network level and application levels. The author mainly concentrated on video streaming with the focus on temporal impairments and also recommended some energy saving factors for video streaming on smartphone.

In study [1], the author explained about the exponential on-off models for QoE. In this thesis, the author states that mobile connectivity exhibits an on-off behavior and the duration of this behavior can be represented by exponential distributions. This thesis provided a bridge between traffic measurements and analysis has been done based on Markov-modulated fluid flow model. In addition, the author has also explained the usefulness of exponential on-off traffic models for modelling QoE for video streaming on smartphones.

In study [2], the author discussed on the fluctuations of the instantaneous power consumption of the smartphones. This paper mainly focused on the stalling events and their influence on instantaneous total power consumption. An experiment has been carried out using MPMT and SVT to observe live instantaneous power consumption values. Both hardware and software measurements were taken. They observed that the variation in power consumption values during steady state is due to the existence of stalling events or reasons related to the application.

In study [8], the author assessed the impact of buffering on Quality of Experience through the freeze probability of the video. In this paper, the author researches about the potential of improving the QoE of a video delivery by buffering. It mainly aims to describe the importance of delivering a video to the end user without any freezes. A fluid flow model has been developed for freeze probability considering the on and off state to exponential distributions.

In study [15], the author has implemented a methodology to design user ware streaming strategies for energy efficient smartphone video playback applications. A Gaussian Mixture Model (GMM) has been implemented to capture the distribution of play back length by analyzing various users video-watching activities. This theory is employed to find out the optimal buffering points to minimize energy waste on the cellular interface. This paper summarizes that about 10% energy can be saved by using this method rather than the best static buffering method.

4 METHODOLOGY

4.1 MODELLING

From [8], mobile data traffic exhibits an on-/off characteristic due to disturbances and countermeasures on the wireless channel. Indeed the disturbance process can be modelled by a two-state Markov process with exponential state durations.

A fluid flow model [10] is used to describe the accumulation of data in a buffer in case of mismatches between the data rates at inlet and outlet. Due to its focus on flows and their intensities, it fits well to the modeling of streaming services. From such a model, performance measures such as loss ratio and delay distributions can be derived.

Two states can be distinguished:

- OVERLOAD STATE: When the inlet rate R^{in} exceeds the outlet rate R^{out}, the buffer fills up with the positive drift until it gets full.

$$D = R^{in} - R^{out} > 0.$$

- UNDERLOAD STATE: When the inlet rate R^{in} is lower than the outlet rate R^{out}, the buffer content sinks with the negative drift until it gets empty.

$$D = R^{in} - R^{out} < 0.$$

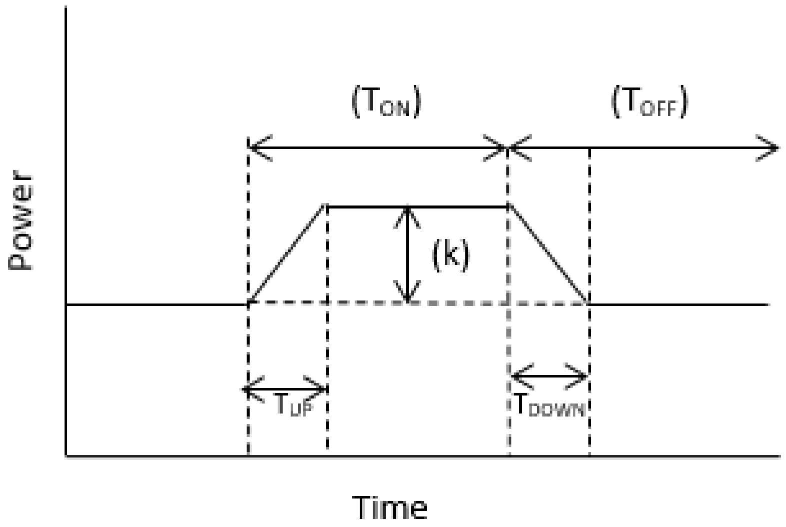

Figure 1: Extended Fluid Flow ON-OFF Model

Now, we associate a buffer content X (non-negative and upper-bounded by the buffer size K) with the power level beyond a certain baseline P_0 over time, including a corresponding adaption of units. The resulting power will be

$$P(t) = X(t) + P_0. \qquad (1)$$

The drift of the both states changes according to the change rate of the power levels, all of which is illustrated in Figure 1. Both staates can be distinguished as:

OVERLOAD STATE: The overload state occurs when the network interface is active, i.e. when the video playout gets active. Here, when the network interface becomes active, the power raises from P_0 to $P_0 + K$. The change of rate or drift can be derived by

$$D = R^{in} - R^{out} = K / T_{up}$$

UNDERLOAD STATE: The overload state occurs when the network interface is active (i.e.) when the video playout gets inactive.The change of rate or drift can be derived by

$$D = R^{in} - R^{out} = -K / T_{down}$$

The strength of the fluid flow modelling is that it is able to take into account random (exponential) on/off behavior into the calculation of distributions of the buffer content *X*, which can be translated into distributions of power according to Equation (1).

For this, the following values need to be estimated from power measurements:

1. K – The difference between video-on and video-off power levels.
2. T_{up} – The time taken for the graph to reach the upper threshold when it changes from OFF-state to ON-state.
3. T_{down} – The time taken for the graph to reach the lower threshold when it changes from ON-state to OFF-state

4.2 EXPERIMENTATION

The experimentation mainly deals with streaming a video from a server to a mobile device. The purpose of conducting this experiment to carry out power measurements involving ON-OFF behaviours. We use different tools to measure time and power consumption.

4.2.1 EXPERIMENTATION TOOLS

This chapter provides a detailed description of different tools that have been used to carry out power measurements in a mobile scenario. Brief overviews of vlqoe tool and power monitor tool are presented in the following subsections respectively.

VLQoE tool

VLQoE tool [3] is a further developed version of VLC player by providing some additional functionalities. The original version of VLC player consists of video pane that displays the video and a set of video control buttons such as play, pause, forward and rewind. Various functions has been implemented and developed for VLQoE TOOL. Some additional functionalities are timestamps of the displayed picture that can be recorded during a video stream [11]. Furthermore, user rating buttons are provided, i.e. the user can rate the video by pressing the buttons displayed on top of the screen. Other features like freeze button, play/pause, rewind, forward button etc are available as well.

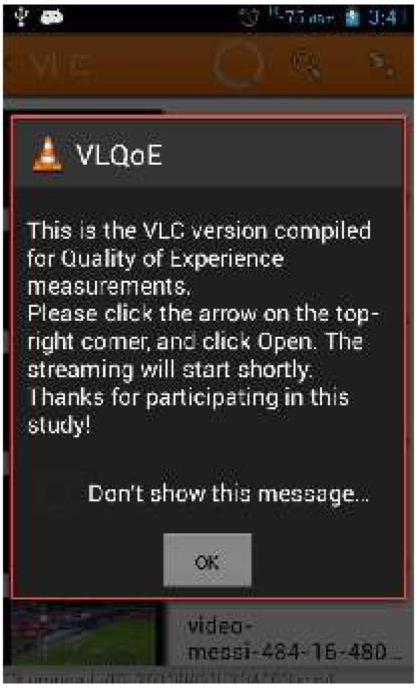

Figure 2

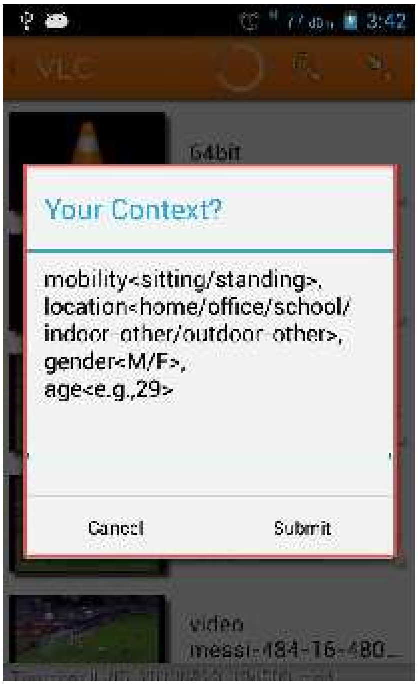

Figure 3

Figure 2 & Figure 3: Screenshots of VLQoE Tool

In this thesis, VLQoE tool is used to stream a video from server to a mobile client. To stream a video, initially the VLQoE tool has to be installed. Then, a welcome message will be displayed as shown in Figure 2. Then we have to provide it with the IP address of the server. Wherein the video would be streamed in the mobile for which timestamps are calculated.

Monsoon Power Monitor Tool

Monson Power Monitoring Tool is used to measure instantaneous power consumption. This device consists of both a hardware device and a software tool. This tool runs on Windows OS and provides measurements for devices using a single lithium battery. The main use of the hardware tool is it powers up the mobile and is thus able to measure current and power. This tool is mainly used for ground truth measurements. Monsoon Power Monitor software and Monsoon Power Hardware are shown in figures 4 and 5 below.

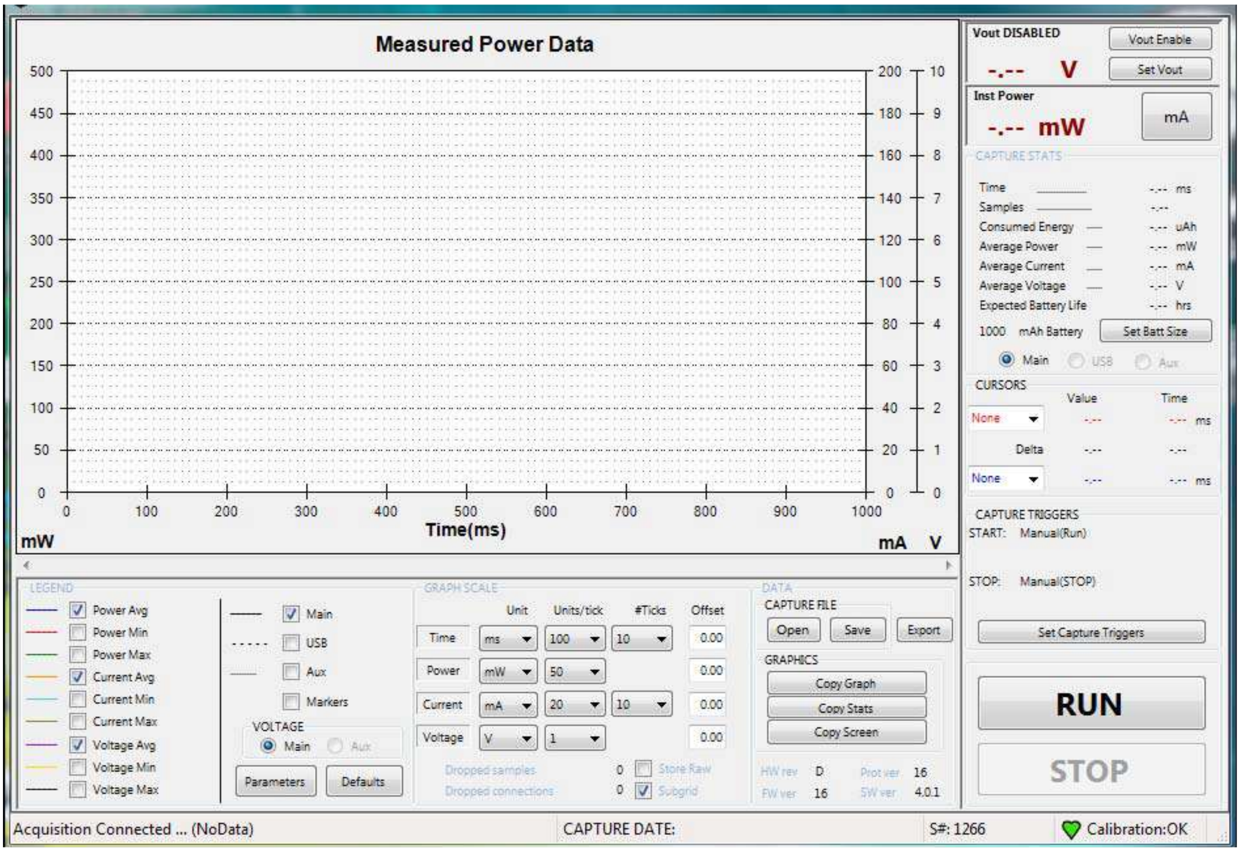

Figure 4 Monitor Tool Software

Figure 5 Power Monitor Hardware

4.2.2 EXPERIMENTAL SETUP

This section includes the experimental setup for carrying out the experiment.

Power monitoring tool connections:

Figure 6 below portrays the power monitor tool connections.

a. Install VLC media player in the mobile phone.
b. Now, insulate the battery of the mobile phone with insulation tape to avoid contact with the mobile charging terminals.
c. Take two copper wires and connect one end of the copper wires to the charging terminals and the other end to connecting probes.
d. Now, the other end of the connecting probes are fastened to the power monitoring tool such that the positive terminal is connected to the positive channel of MPMT and the negative terminal is connected to the negative channel of the MPMT.

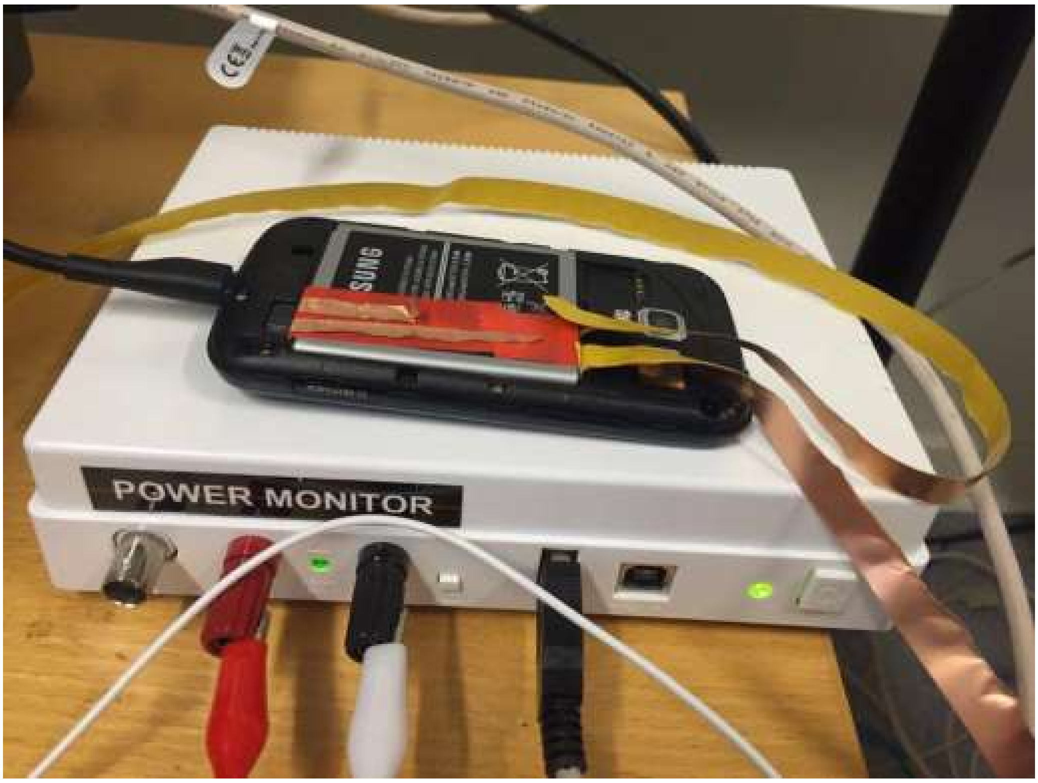

Figure 6 Power Monitor Connections

The requirements to run a power monitor software:

• Microsoft Windows XP SP2, Windows Vista and Windows 7 is supported

• 1 GHz 32-bit (x86) or 64-bit (x64) processor

• 1 GB of system memory

• 40 GB hard drive with at least 15 GB of available space

• Full Speed USB 1.1/USB 2.0 – integrated chipset or PCI/PCI Express add in card. USB Hubs should not be used with the Mobile Device Power Monitor [5].

Black box connections:

A black box is a device which can be viewed in terms of its inputs and outputs, without any knowledge of its internal workings. It ensures that the results are based solely on observable elements, by cutting off varying effects of uncertain surroundings [9]. Black box testing in this scenario is used to block external factors that affect voltage variations and to ensure entire internet connection is available only to the equipment used. Figures 7 and 8 depict the exterior and interior views of black box.

Figure 7 Black box Exterior View

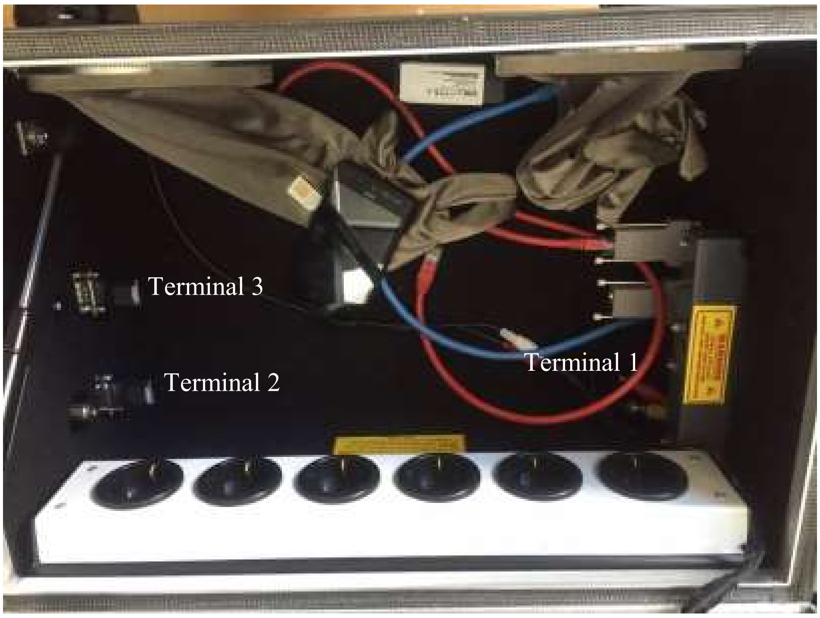

Figure 8 Black Box Interior View

From Figure 8 depicting the connections of black box, for Internet connection, one side of "Terminal 1" is connected to the Ethernet cable and the other side is connected to the Wi-Fi modem. The Wi-Fi modem has to be powered on. One end of "Terminal 2" is connected to the dongle (receives internet from the Wi-Fi modem) and the other end to the PC. One end of "Terminal 3" is connected to the charging port of mobile device and the other end to the Power Monitor. The MPMT and black box have to be powered on. Connect the power monitoring tool to the system.

ANDROID PHONE:

A wireless device has been used in carrying out the experiment for streaming a video from the system. The mobile phone used is "Samsung ACE 2".

The specifications of the mobile phone can be described as:
• OS: Android.
• Display Size: 3.8 inches.
• Resolution: 480 x 800 pixels.
• Battery capacity: 1500 mAh.

4.2.3 EXPERIMENTAL PROCEDURE

This section provides a step-wise experimental procedure that has been followed in this thesis.

1. Install Power Monitor Software on PC, commence the tool and enable V_{out}.

2. Adjust voltage according to the specifications or capacity of mobile phone and set the voltage to 4V.

3. Power on the mobile phone after connecting it to the power monitoring tool (i.e.) the mobile phone receives from the power monitor.

4. Adjust the voltage accordingly.

5. Now, download a video in the system and open the selected video in VLC media player.

6. Stream the video from the system to the mobile phone. Enter IP address of system in the mobile in order to receive the streamed video and RUN the power tool software.

7. Pause the video in the mobile phone to observe ON-OFF transitions. Repeat the experiment to analyze power measurements.

8. The observed power measurements are determined graphically. The graphs are noted in pairs, each graph having two sets of ON-OFF transitions.

9. A total of 40 such transitions have been observed to validate the results, i.e., 20 graphs have been captured.

The following figures denotes graphical representation for the power measurements represented in the tabular column (Table 1) from the previous section.

Fig.9 & fig.10 depicts graph1-1,1-2 & graph 2-1,2-2 respectively.

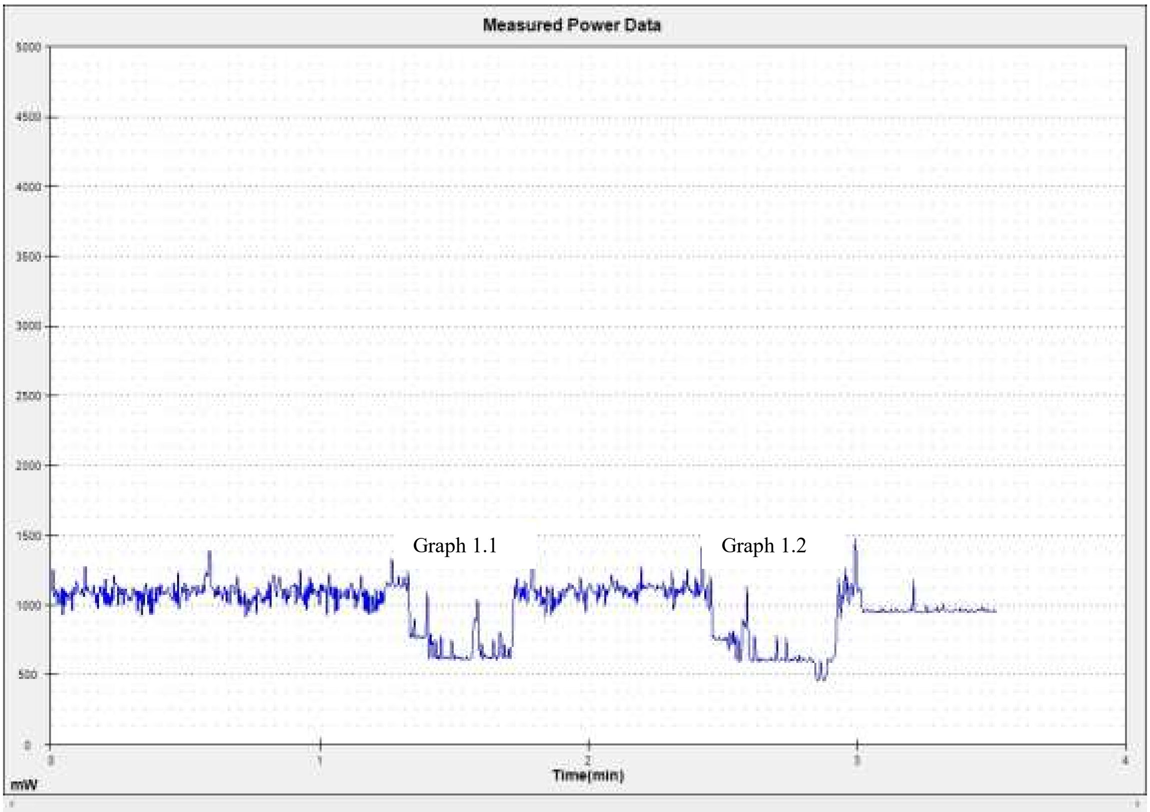

Figure 9 Graphical Representation of power measurement of Graph1.1 & Graph1.2

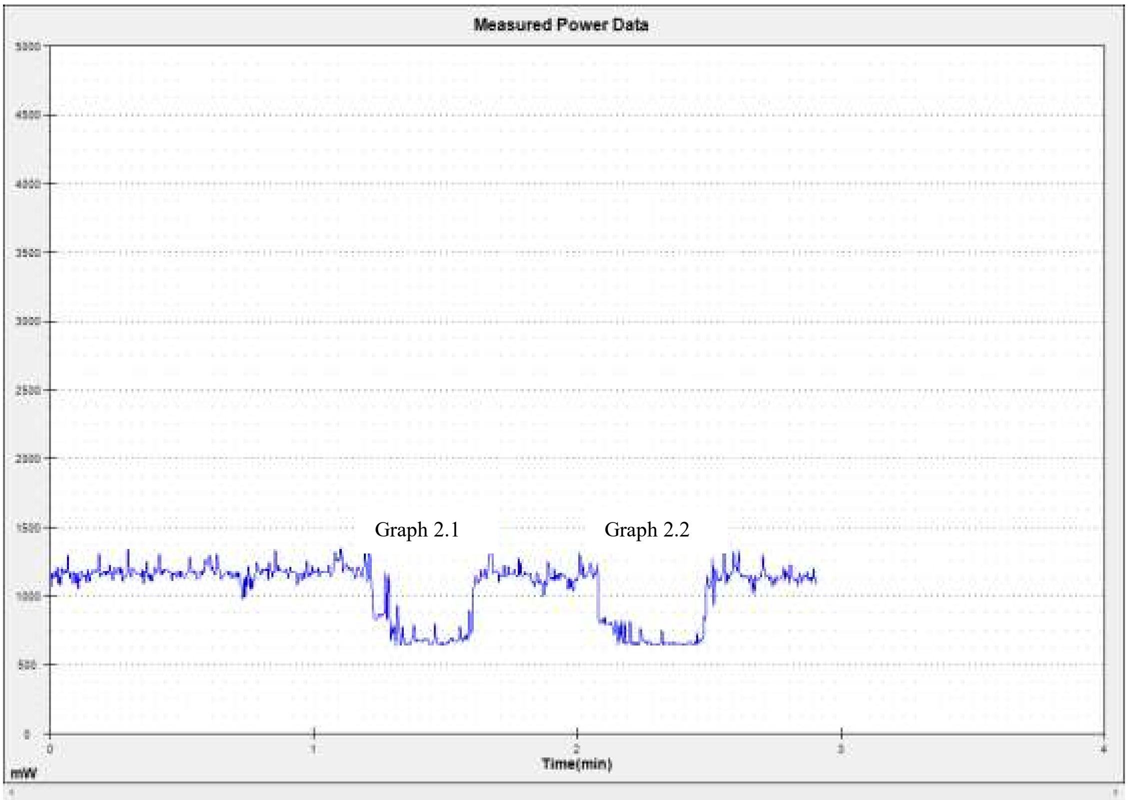

Figure 10 Graphical Representation of power measurements of Graph2.1 & Graph2.2

These figures are the outcomes of power monitoring tool for every video streamed on an android device. As discussed earlier, these are the automated graphs from monitoring tool software displayed on PC. It constitutes the power measurements on y-axis and Time in minutes on x-axis. The sampling interval was kept constant, 0.2 seconds for all the consolidated tabulated figures in previous section. The power measurements of these automated graphs could be exported to an excel sheet, which are further analysed for calculation of 'K' value. To cut short the exported table, average power of every 1000th sample was exported.

For better understanding, consider fig.9,

Here, we have taken two transitions .consider them to be graph1-1 & graph1-2

Graph1-1:

A simple 7mins 3gp video was streamed on an android phone, for which power measurements at different instances are represented graphically. Here, we have paused the video at 79.8s (t_1). It could be observed that the power reaches the OFF state at 85.6s (t_2).

Similarly, power can also be calculated at on and off states (i.e) average power during on state is 1383mW (P_1) and average power during off state is 604mw (P_2).

Now, we have resumed the video at 97.8s (t_3).It could be observed that the power reaches its original state at 101.8s (t_4).

By considering these values, we can calculate K, T_{up},$T_{down.}$

$$K = P_1\text{-}P_2 = 1283\text{-}604 = 679 \text{ mW.}$$

$$T_{up} = T_2\text{-}T_1 = 85.6\text{-}79.8 \text{ s} = 5.8 \text{ s.}$$

$$T_{down} = T_4\text{-}T_3 = 101.8\text{-}97.8 = 4 \text{ s.}$$

Graph1-2:

A simple 7mins 3gp video was streamed on an android phone, for which power measurements at different instances are represented graphically. Here, we have paused the video at 147.4s (t_5). It could be observed that the power reaches the OFF state at 156.4s (t_6).

Similarly, power can also be calculated at on and off states (i.e.) average power during on state is 1188mW (P_5) and average power during off state is 449 mW (P_6).

Now, we have resumed the video at 172.8s (t_7).It could be observed that the power reaches its original state at 176.8 (t_8).

By considering these values, we can calculate K, T_{up}, $T_{down.}$

$$K = P_5\text{-}P_6 = 1188\text{-}449 = 739 \text{ mW.}$$

$$T_{up} = T_6\text{-}T_5 = 156.4\text{-}147.4\text{s} = 9 \text{ s.}$$

$$T_{down} = T_8\text{-}T_7 = 176.8\text{-}172.8\text{s} = 4 \text{ s.}$$

For better understanding, Additional graphs portraying the values of power measurements have been included in the appendix. `

5 RESULTS

The power measurements have been depicted in the following Table 1 along with T_{up} and T_{down} calculations

S.No.	K [mW]	T_{down} [s]	T_{up} [s]	Name of the graph
1	679	5.8	4.0	grph1-1
2	739	9	4	grph1-2
3	738	6	4.6	grph2-1
4	628	7.8	4.2	grph2-2
5	728	6.8	3.6	grph3-1
6	785	6.8	3.1	grph3-2
7	659	9.2	3.8	grph4-1
8	847	7.6	2.8	grph4-2
9	638	9.6	3.8	grph5-1
10	736	7.4	5	grph5-2
11	664	8.4	3.4	grph6-1
12	617	7	4.2	grph6-2
13	639	7.6	3.2	grph7-1
14	688	8.8	3.6	grph7-2
15	700	6.6	3.6	grph8-1
16	790	9	3.2	grph8-2
17	566	9	4.6	grph9-1
18	811	6.4	3.8	grph9-2
19	700	8.2	2.8	grph10-1
20	629	7.3	4.2	grph10-2
21	624	9.6	3.6	grph10-3
22	592	8.4	3.6	grph11-1
23	546	7.6	3.4	grph11-2
24	531	6.8	3.8	grph11-3
25	566	5.8	3	grph12-1
26	536	7.2	3.6	grph12-2
27	509	5	2.8	grph13-1
28	545	7.7	4.2	grph13-2
29	703	6.6	4.6	grph14-1
30	586	5.7	3.6	grph14-2
31	588	6.2	4.6	grph14-3
32	520	6.5	3.8	grph15-1
33	527	7.1	2.8	grph15-2
34	548	5.2	3.4	grph16-1
35	654	7.1	3.6	grph16-2
36	632	6.9	4.2	grph16-3

37	598	7.6	3.2	grph17-1
38	621	7.4	3.6	grph17-2
39	570	8.2	2.8	grph18-1
40	586	7.9	3.8	grph18-2

Table 1: Results of Power Measurements

The above table represents the power measurements determined with respect to WiFi. Due to time limitations, only WiFi measurements have been performed.

Statistical Analysis:

Statistical analysis including the calculations of mean, standard deviation, standard error, 95% confidence Intervals and Lag-1 autocorrelation has been performed, with the results reported in Table 2.

	K	T_{up}	T_{down}
Mean	639.075	7.385	3.687
Standard deviation	86.434	1.180	0.559
Standard error	13.666	0.187	0.088
95% CI	26.787	0.366	0.173
Autocorrelation	+0.400	+0.012	-0.080

Table 2: Results of Statistical Analysis

6 ANALYSIS AND DISCUSSION

Statistical analysis:

The statistical analysis that includes the calculations of mean, standard deviation, standard error and lag-1 auto correlation were calculated, which were depicted in table 2. It can be observed that all the individual values of K, T_{up} and T_{down} are quite not too far from their mean values.
As 95% confidence Intervals (CI), we obtained

K: 612.289- 665.861mW
T_{up} : 7.019-7.751 s.
T_{down}: 3.514-3.8 s.

In case of K, the lag-1 autocorrelation is rather large, which means that the confidence intervals for K are probably bigger in reality due to the positive autocorrelation.. However, in the case of the estimated transition times, T_{up} and T_{down} the reasonably small autocorrelation values indicate reasonable and reliable confidence intervals. Indeed, it could be observed that there is a significant difference amongst the intervals of T_{up} and T_{down}.

The averages for K, T_{up} and T_{down} can now be used for modelling the power distribution with the help of the fluid flow model in case of exponential ON-OFF times as described in Section 4.1.

Answers to Research Questions:

RQ1) How can instantaneous power consumption of a smartphone be measured with focus on mobile or wireless connections with on-off characteristics?

In this thesis, we have measured instantaneous power consumption in a mobile scenario by streaming a video from server to a wireless device (Android phone). Initially, the client (wireless device) has to be connected to a monsoon power monitor tool (MPMT). The MPMT tool provides power to the mobile device. A standard 3gp video has been streamed from server to android phone. MPMT tool software records the power consumption while streaming the video. By pausing and resuming the video, it can experience ON-OFF characteristics. The monsoon power monitor software exports the average power and displays the graph directly with ON-OFF characteristics.

RQ2) How can instantaneous power consumption can be modelled (based on the fluid flow model), in particular for a mobile connection with on-off characteristics?

A fluid flow model is used to describe the accumulation of data in a buffer in case of mismatches between the data rates at inlet and outlet. From these, performance measures such as loss ratio and delay distributions can be derived. We associate a buffer content X (non-negative and upper-bounded by the buffer size K) with the power level beyond a certain power baseline over time. The resulting power will be calculated. The drift of the both states changes according to the change rate of the power levels in both ON-state and OFF-state and can be derived from transition time measurements.

RQ3) How can the model parameters of the power consumption related fluid flow model be determined with sufficient confidence?

The statistical analysis that includes the calculations of mean, standard deviation, standard error and lag-1 auto correlation were calculated. The calculations were shown in section-4. The values of k T_{up} and T_{down} are close by to their mean values. The 95% confidence Intervals (CI) are obtained as follows: K: 612.289- 665.861mW; for T_{up} : 7.0-7.8 s; and for T_{down}: 3.5-3.8 s. It could be observed that there is a significant difference amongst the intervals of k, T_{up} and T_{down}. And that the rather small values of lag-1 autocorrelation contribute to the credibility of those CI.

7 CONCLUSION AND FUTURE WORK

7.1 CONCLUSION

The video streaming consumes large amount of data resulting in heavy network traffic due to buffering or freezing of a video. To outshine, the experiment was carried out in a mobile scenario with ON-OFF state characteristics. Time delay and power consumption were measured using benchmark tools, VLQoE and MPMT. The experiment was accomplished to estimate the values of power consumption and time delay involving ON-OFF state transitions. These estimated values could be used to extend the exponential fluid flow model in order to calculate the distribution of power values. Due to time constraint and paucity of the thesis partner, the modelling part could not be executed. Henceforth, this could be recommended for future work.

7.2 FUTURE WORK:

These power measurements and analytics would have been done similarly for any other wireless/mobile technologies like 3G or 4G. Considering the empirical study and performance analytical results of power consumption during ON-OFF state characteristics, it could be applied to extend already existing exponential ON-OFF fluid flow model to cater for power consumption. The hypotheses that could not be addressed in this work will have to be left for future studies.

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APPENDIX

This section presents Installation steps of Power Monitor Software and Additional graphs of power measurements for better understanding.

Installation of Power Monitor Tool:

1. Go to http://www.msoon.com/powermonitor/powermonitor.html, then click Power Monitor Software and download PowerTool.zip.

2. Create a new folder on the development workstation called Power Tool under the root Directory (C:\).

3. Copy PowerTool.zip to the development workstation.

4. Extract the contents of PowerTool.zip to the C:\PowerTool folder.

5. Run PMSetup.msi

6. Follow the on screen prompts to install the Power Tool Software.

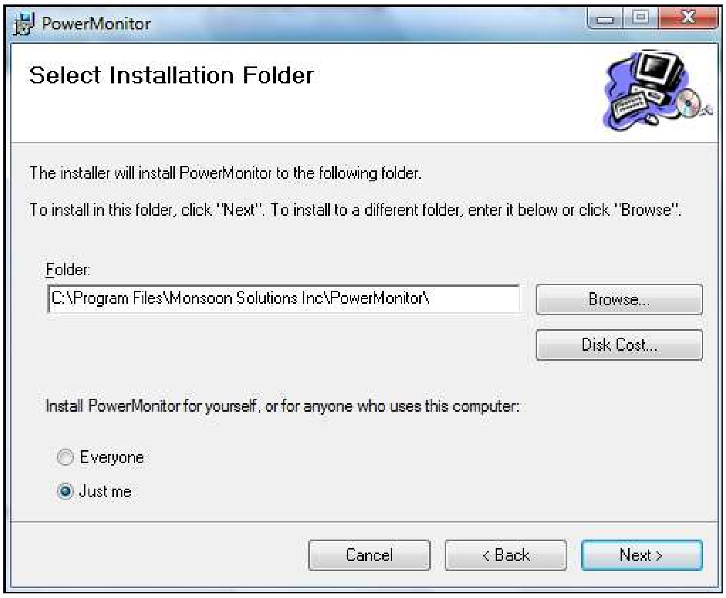

Fig. A.1

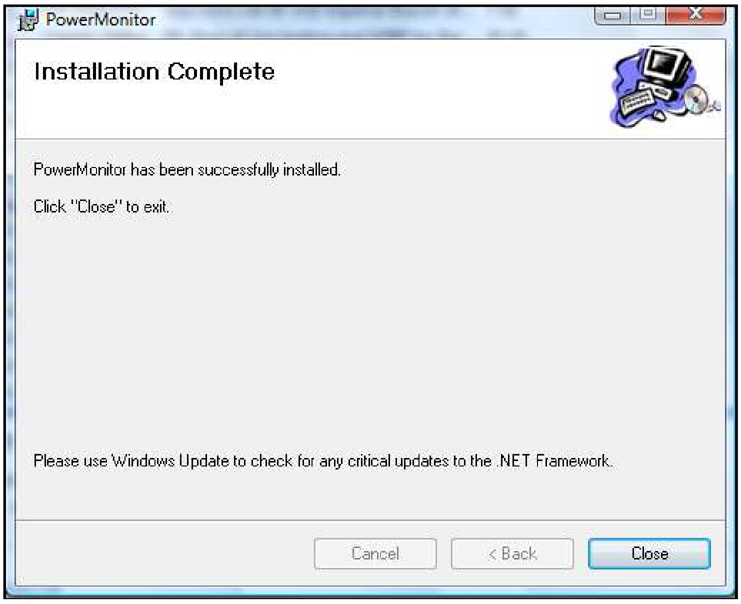

Fig. A.2

Power Measurement Graphs:

These figures are the outcomes of power monitoring tool for every video streamed on an android device. As discussed earlier, these are the automated graphs from monitoring tool software displayed on PC. It constitutes the power measurements on y-axis and Time in minutes on x-axis. The sampling interval was kept constant, 0.2 seconds for all the consolidated tabulated figures in previous section. The power measurements of these automated graphs could be exported to an excel sheet, which are further analysed for calculation of 'K' value. To cut short the exported table, average power of every 1000th sample was exported.

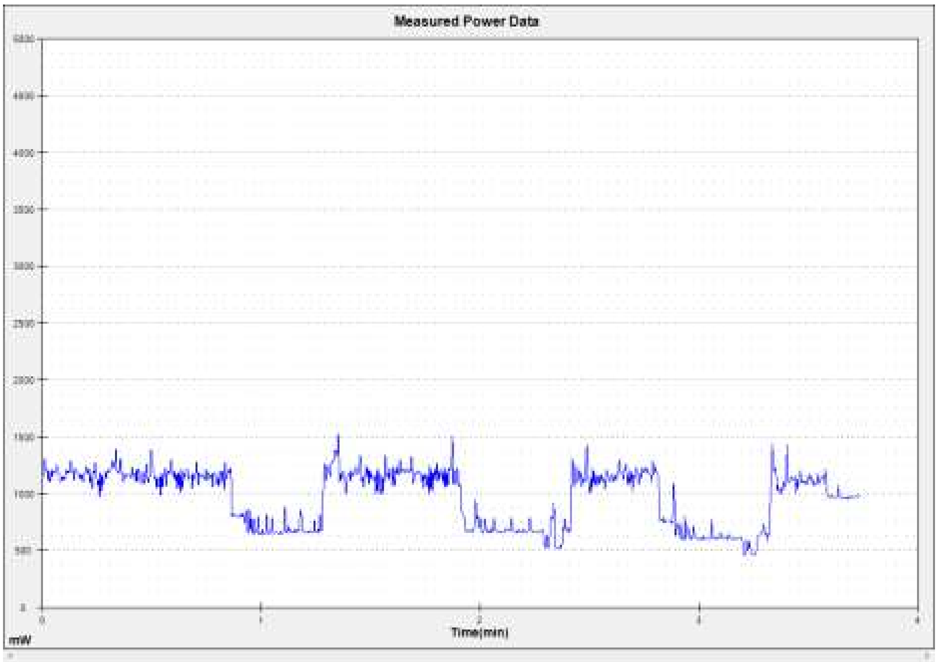

Fig. A.3 Graphical representation of Graph6.1 & Graph 6.2

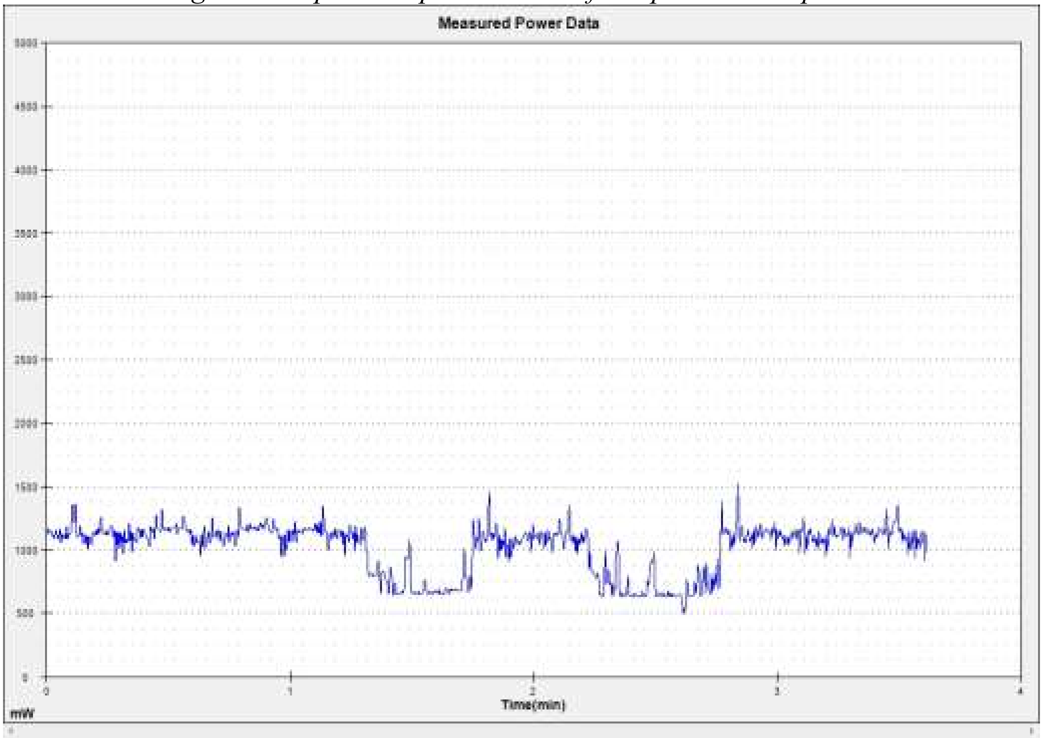

Fig.A.4 Graphical representation of Graph5.1 & Graph 5.2

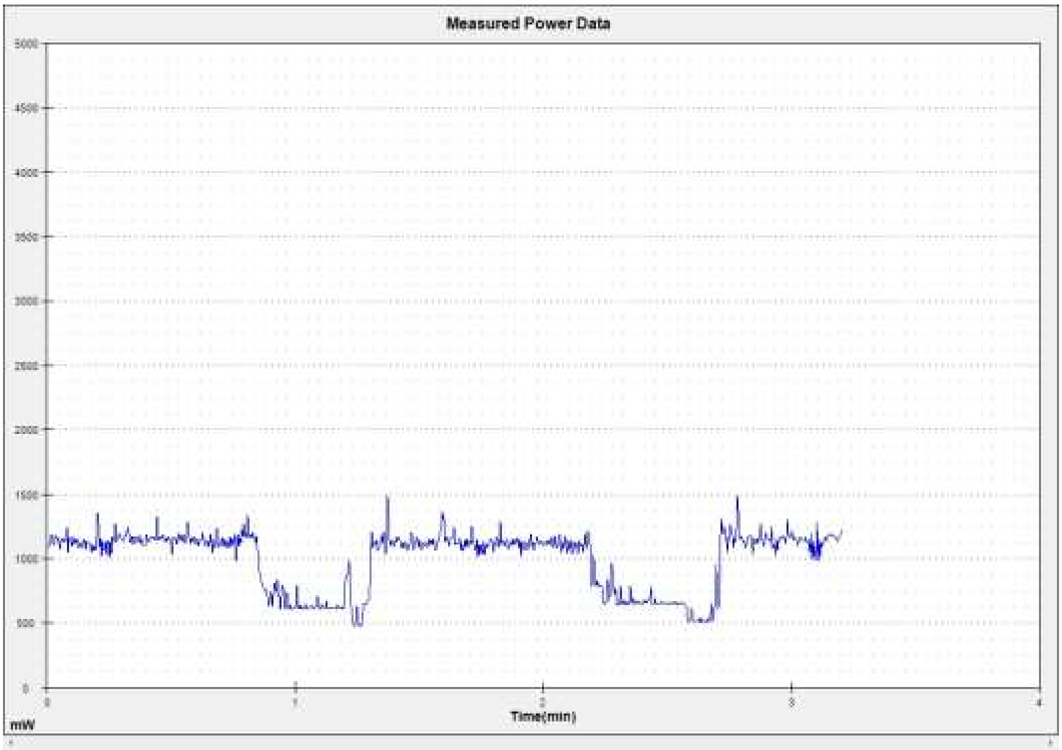

Fig.A.5 Graphical representation of Graph4.1 & Graph 4.2