A SELECTIVE APPROACH FOR ENERGY-AWARE VIDEO CONTENT ADAPTATION DECISION-TAKING ENGINE IN ANDROID BASED SMARTPHONE

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I humbly thank Allah Almighty, the Merciful and the Beneficent, who gave me health, thoughts and co-operative people to enable me achieve this goal.

For my beloved wife, Masliana binti Bakar

And wonderful kids, Muhammad Akmal, Muhammad Luqman, Muhammad Faiz, Muhammad Imran and Maryam Safiya

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ABSTRACT

Rapid advancement of technology and their increasing affordability have transformed mobile devices from a means of communication to tools for socialization, entertainment, work and learning. However, advancement of battery technology and capacity is slow compared to energy need. Viewing content with high quality of experience will consume high power. In limited available energy, normal content adaptation system will decrease the content quality, hence reducing quality of experience. However, there is a need for optimizing content quality of experience (QoE) in a limited available energy. With modification and improvement, content adaptation may solve this issue. The key objective of this research is to propose a framework for energy-aware video content adaptation system to enable video delivery over the Internet. To optimise the QoE while viewing streaming video on a limited available smartphone energy, an algorithm for energy-aware video content adaptation decision-taking engine named EnVADE is proposed. The EnVADE algorithm uses selective mechanism. Selective mechanism means the video segmented into scenes and adaptation process is done based on the selected scenes. Thus, QoE can be improved. To evaluate EnVADE algorithm in term of energy efficiency, an experimental evaluation has been done. Subjective evaluation by selected respondents are also has been made using Absolute Category Rating method as recommended by ITU to evaluate EnVADE algorithm in term of QoE. In both evaluation, comparison with other methods has been made. The results show that the proposed solution is able to increase the viewing time of about 14% compared to MPEG-DASH which is an official international standard and widely used streaming method. In term of QoE subjective test, EnVADE algorithm score surpasses the score of other video streaming method. Therefore, EnVADE framework and algorithm has proven its capability as an alternative technique to stream video content with higher QoE and lower energy consumption.

ABSTRAK

Perkembangan pesat teknologi mudah alih serta kos pemilikan yang rendah telah merubah fungsi telefon mudah alih dari hanya alat komunikasi kepada alat untuk bersosial, berhibur, melaksanakan kerja dan pembelajaran. Namun, perkembangan teknologi dan kapasiti bateri peranti adalah perlahan berbanding keperluan tenaga. Penggunaan tenaga adalah tinggi ketika menonton kandungan berkualiti tinggi. Dalam situasi tenaga terhad, kaedah adaptasi kandungan biasa akan mengurangkan kualiti kandungan, justeru mengurangkan kualiti pengalaman (QoE). Namun, masih terdapat keperluan untuk mengoptimumkan QoE. Dengan penambahbaikan, kaedah adaptasi kandungan berpotensi menangani masalah ini. Objektif utama kajian ini adalah membangunkan satu rangka kerja sistem adaptasi kandungan video peka tenaga bagi membolehkan video dihantar melalui Internet. Kajian ini juga mencadangkan algoritma enjin pembuatan keputusan adaptasi kandungan video peka tenaga yang diberi nama EnVADE bagi mengoptimumkan QoE video strim dalam situasi tenaga terhad. Algoritma EnVADE menggunakan mekanisme selektif. Mekanisme selektif bermaksud video dipecahkan kepada babak-babak dan proses adaptasi dilakukan berdasarkan babak-babak terpilih. Dengan itu, pengalaman kualiti dapat dipertingkatkan. Penilaian eksperimental dilaksanakan bagi menilai algoritma EnVADE dari sudut kecekapan tenaga. Manakala penilaian subjektif dijalankan menggunakan *Absolute Category Rating* yang disarankan oleh *ITU* bagi menilai algoritma EnVADE dari sudut QoE. Perbandingan dengan kaedah adaptasi kandungan sedia ada telah dilakukan dalam kedua-dua pengujian tersebut. Hasil pengujian menunjukkan algoritma EnVADE berjaya meningkatkan masa menonton sehingga hampir 14% berbanding MPEG-DASH iaitu kaedah standard antarabangsa rasmi yang digunakan meluas. Bagi pengujian subjektif QoE, algoritma EnVADE memperolehi skor melepasi skor kaedah yang lain. Oleh itu, rangka kerja dan algoritma EnVADE membuktikan keupayaan sebagai alternatif penstriman kandungan video dengan QoE yang tinggi dan penggunaan tenaga yang rendah.

TABLE OF CONTENTS

	ACKNOWLEDGEMENT		**iv**
	ABSTRACT		**v**
	ABSTRAK		**vi**
	TABLE OF CONTENTS		**vii**
	LIST OF TABLES		**xi**
	LIST OF FIGURES		**xii**
	LIST OF SYMBOLS AND ABBREVIATIONS		**xiv**
	LIST OF PUBLICATIONS		**xvii**
CHAPTER 1	**INTRODUCTION**		**1**
	1.1	Research background	1
	1.2	Research motivation	4
	1.3	Problem statement	6
	1.4	Research objectives	8
	1.5	Contributions	8
	1.6	Research scope	9
	1.7	Thesis organization	10
CHAPTER 2	**LITERATURE REVIEW**		**11**
	2.1	Introduction	11
	2.2	General smartphone architecture	13
		2.2.1 Smartphone battery	15
	2.3	Energy awareness in smartphone technology	17

	2.3.1	Energy profiling method	17
2.4	Video content adaptation		21
	2.4.1	Video Codecs	21
	2.4.2	Video granularity level	23
	2.4.3	Content adaptation framework characteristics	24
2.5	Taxonomy in energy-aware content adaptation		25
	2.5.1	Strategies	28
	2.5.2	Localities	29
	2.5.3	Purpose	30
	2.5.4	Mechanism	31
	2.5.5	Methods	32
	2.5.6	Context	38
2.6	Existing video streaming and adaptation framework		39
	2.6.1	Traditional video streaming and adaptation	39
	2.6.2	HTTP Adaptive Streaming	40
	2.6.3	Non-HTTP Adaptive Streaming	46
2.7	Quality of experience in video adaptation		47
	2.7.1	Semantic quality	49
	2.7.2	Perceptual quality	51
2.8	Gap analysis		51
2.9	Chapter summary		53

CHAPTER 3 RESEARCH METHODOLOGY **54**

3.1	Introduction		54
3.2	Energy-aware video adaptation system framework		54
	3.2.1	Content server	55
	3.2.2	Client	56
	3.2.3	Proxy	57
	3.2.4	Adaptation module	57
3.3	The proposed EnVADE model		60
3.4	Experiment design		72
	3.4.1	Hardware setup	72
	3.4.2	Energy measurement method	73
	3.4.3	Network connection test scenario	73

3.4.4 Energy-aware experiment testing 76
3.4.5 Subjective QoE evaluation setting 77
3.5 Analysis of framework 79
3.6 Chapter summary 80

CHAPTER 4 RESULTS AND DISCUSSION 81
4.1 Introduction 81
4.2 Effect of display brightness 81
4.3 Effect of network type and condition 82
4.4 Effect of video quality properties 83
4.4.1 Resolution 83
4.4.2 Frame rate 85
4.4.3 Bitrate 86
4.5 Proposed EnVADE result 87
4.5.1 Scenario 1: full depletion test 88
4.5.2 Scenario 2: 10 percent energy left 89
4.5.3 Scenario 3: 8 percent energy left 91
4.5.4 Scenario 4: 6 percent energy left 92
4.5.5 Scenario 5: 4 percent energy left 93
4.5.6 Scenario 6: 2 percent energy left 94
4.6 Energy awareness and video QoE 95
4.6.1 Smartphone platform and age 96
4.6.2 Energy awareness among smartphone users 97
4.6.3 Video QoE 101
4.7 Subjective QoE result 106
4.7.1 Scenario 1: 10 percent energy left 107
4.7.2 Scenario 2: 5 percent energy left 107
4.7.3 Scenario 3: 2 percent energy left 108
4.8 Discussion 109
4.9 Chapter Summary 111

CHAPTER 5 CONCLUSION AND FUTURE WORKS 113
5.1 Introduction 113
5.2 Objective Achievement 114

5.3 Contribution of Research 116
5.4 Future Works 117
5.5 Concluding Remarks 118

REFERENCES **120**

APPENDIX **149**

VITAE **154**

LIST OF TABLES

2.1	Evolution of smartphone and their characteristics	14
2.2	Strategies of content adaptation	29
2.3	Localities of content adaptation	30
2.4	Purpose of content adaptation	31
2.5	Mechanism of content adaptation	32
2.6	Techniques of energy-aware content adaptation	33
2.7	Context of content adaptation	39
3.1	Hardware specification for LGE Nexus 5	72
3.2	TP-Link Archer C1200 Wi-Fi router specification	73
3.3	Test video encoding setting	74
3.4	EnVADE energy consumption test scenarios	77
3.5	EnVADE test video quality level	77
3.6	Eleven-grade quality scale (ITU-T, 2008a)	78
4.1	Scene detected from Big Buck Bunny video clip	87
4.2	EnVADE result for 10 percent battery left	90
4.3	EnVADE result for 8 percent battery left	91
4.4	EnVADE result for 6 percent battery left	92
4.5	EnVADE result for 4 percent battery left	93
4.6	EnVADE result for 2 percent battery left	94
4.7	Subjective QoE test scenarios	106

LIST OF FIGURES

1.1	Universal Multimedia Experience	2
1.2	Estimated mobile data traffic by 2021	3
1.3	Top 10 smartphone purchase drivers (IDC, 2014)	5
1.4	Battery life of various smartphones models in 2018	6
2.1	Taxonomy of energy-aware content adaptation system	13
2.2	Smartphone battery capacities from 2016 to 2019	16
2.3	Hardware-based and software-based energy profiling schemes	18
2.4	Trepn profiler interface	20
2.5	PowerTutor interface	20
2.6	General video structure	24
2.7	Typical content adaptation framework	25
2.8	HTTP adaptive streaming principle	45
3.1	Energy-aware video content adaptation system framework	59
3.2	Energy-aware video content adaption decision-taking engine flowchart	62
3.3	Energy-aware video content adaption decision-taking engine algorithm	63
3.4	Video scene quality level initialization algorithm	68
3.5	Video scene energy requirement estimation algorithm	70
3.6	Video scene sorting algorithm	70
3.7	Wi-Fi test-bed setup	75
3.8	Cellular data test-bed setup	76
4.1	Energy consumption over display brightness level	82
4.2	Energy consumption over network type and condition	83
4.3	Video resolution average energy consumption	84

4.4	Energy savings of different video resolution	84
4.5	Video frame rate average energy consumption	85
4.6	Energy savings of different video frame rate	85
4.7	Video bit rate average energy consumption	86
4.8	Energy savings of different video bit rate	86
4.9	Comparison of video streaming energy consumption rate between EnVADE, MPEG-DASH, no adaptation and full adaptation	89
4.10	Age of respondents	95
4.11	Gender of respondents	95
4.12	Smartphone platform	96
4.13	Smartphone age	96
4.14	Attitude towards saving energy	97
4.15	Awareness of energy use impact to the environment	98
4.16	Daily charging frequency	98
4.17	Smartphone power backup	99
4.18	Battery life influence in buying decision	100
4.19	Smartphone dependency	100
4.20	Low battery anxiety	101
4.21	Online videos viewing using smartphone	102
4.22	Online videos average viewing time using smartphone	102
4.23	Internet connection type for watching online video	103
4.24	Online video quality satisfaction	104
4.25	Battery drainage	104
4.26	Frustration for drained battery while watching online video	105
4.27	Willingness to watch video in low quality to save energy	106
4.28	QoE comparative result for 10 percent energy left	107
4.29	QoE comparative result for 5 percent energy left	108
4.30	QoE comparative result for 2 percent energy left	108

LIST OF SYMBOLS AND ABBREVIATIONS

ICT	-	Information and Communications Technology
MOOC	-	Massive Open Online Courses
ADTE	-	Adaptation Decision-Taking Engine
AE	-	Adaptation Engine
AEE	-	Adaptation Execution Engine
UMA	-	Universal Multimedia Access
UME	-	Universal Multimedia Experience
QoE	-	Quality of Experience
QoS	-	Quality of Services
JPEG	-	Joint Picture Expert Group
M-JPEG	-	Motion JPEG
MPEG	-	Moving Pictures Expert Group
FLV	-	Flash Video
MKV	-	Matroska Video
3G	-	Third Generation Network
3GPP	-	3rd Generation Partnership Project
Wh	-	Watt per Hour
Wi-Fi	-	Wireless Fidelity
MOS	-	Mean Opinion Score
SLA	-	Service Level Agreement
PSNR	-	Peak-Signal-to-Noise Ratio
SoC	-	System on a Chip
RF	-	Radio Frequency
DRAM	-	Dynamic Random-Access Memory
CPU	-	Central Processing Unit
DSP	-	Digital Signal Processor
GPS	-	Global Positioning System

Li-ION	-	Lithium Ion
Li-PO	-	Lithium Polymer
NiMH	-	Nickel-metal Hydride
NiCd	-	nickel-cadmium
HEP	-	Hardware-based Energy Profiling
SEP	-	Software-based Energy Profiling
DUT	-	Device Under Test
HEVC	-	High Efficiency Video Coding
ISO	-	International Organization for Standardization
IEC	-	International Electrotechnical Commission
W3C	-	World Wide Web Consortium
ITU	-	International Telecommunication Union
VQEG	-	Video Quality Expert Group
DVFS	-	Dynamic Voltage and Frequency Scaling
FLOPS	-	Floating-point Operations per Second
UoI	-	Unit of Information
SVC	-	Scalable Video Coding
LCD	-	Liquid Crystal Display
OLED	-	Organic Light-Emitting Diode
TFT	-	Thin-Film Transistor
EDLS	-	Extended Dynamic Luminance Scaling
FGS	-	Fine Granularity Scalability
MDC	-	Multiple Description Coding
HAS	-	HTTP Adaptive Streaming
HLS	-	HTTP Live Streaming
MSS	-	Microsoft IIS Smooth Streaming
HDS	-	Adobe HTTP Dynamic Streaming
DASH	-	Dynamic Adaptive Streaming over HTTP
MPD	-	Media Presentation Description
RTP	-	Real-Time Protocol
RTMP	-	Real-Time Messaging Protocol
RTCP	-	Real-Time Control Protocol
RTT	-	Round-Trip Time
MMS	-	Microsoft Media Server

UDP	-	User Datagram Protocol
AAC	-	Advanced Audio Coding
MOS	-	Mean Opinion Score
ACR	-	Absolute Category Rating
RV	-	Reference Video
VQM	-	Video Quality Metric
MPEG-21 DIA	-	MPEG-21 Digital Item Adaptation
UF	-	Utility Function
ROI	-	Region of Interest
AP	-	Access Point
RSSI	-	Received Signal Strength Indication
EnVADE	-	Energy-Aware Video Content Adaptation Decision-Taking Engine
SCTE	-	Society of Cable and Telecommunications Engineers

LIST OF PUBLICATIONS

Journals:

(i) Ismail, M.N., Ibrahim, R., Fudzee, M.F.M. (2013). A survey on content adaptation systems towards energy consumption awareness. *Advances in Multimedia*, Volume 2013, ISSN 1687-5699, pp.1-8 (Indexed by SCOPUS).

(ii) Ismail, M.N., Ibrahim, R., Fudzee, M.F.M., Jofri, M.H. (2015). SLA-based content adaptation framework for optimizing QoE and energy consumption. *ARPN Journal of Engineering and Applied Science*. Vol.10, No.2, ISSN 1819-6608, pp. 1-8 (Indexed by SCOPUS).

(iii) Ismail, M.N., Ibrahim, R., Fudzee, M.F.M., Jofri, M.H. (2017). Video streaming energy consumption analysis for content adaptation decision-taking. *Journal of Telecommunication, Electronic and Computer Engineering*. Vol. 9, No.2-4, E-ISSN 2289-8131/ ISSN 2180-1843, pp. 143-147 (Indexed by SCOPUS).

Proceedings:

(i) Ismail, M.N., Ibrahim, R., Fudzee, M.F.M. (2013). Classifying content adaptation systems based on energy-aware requirements. 2013 8th International Conference on Information Technology in Asia - Smart Devices Trend: Technologizing Future Lifestyle, Proceedings of CITA 2013, IEEE Computer Society, pp. 1-8 (Indexed by SCOPUS).

CHAPTER 1

INTRODUCTION

1.1 Research background

Widespread usage of mobile technologies to almost everyone is one of the significant progresses of the twenty first century. Recent advancement of mobile technologies lead to smartphones with a larger and crisper screens, improved graphics, faster processors, higher memory, high-speed connectivity and competitive price. Moreover, new Internet services introduction such as video streaming, online games, Internet television, Internet phone and Internet video call have increased the popularity of mobile technologies. The introduction of these services has changed the way web content is consumed. Access to these multimedia rich web contents is widely available through smartphones. Recent statistic shows that total sales of smartphone to end users worldwide in year 2018 reach 1.81 billion of units compared to only 0.29 billion of units of traditional personal computers (Gartner, 2019). Another statistic reveals that mobile broadband is the single most dynamic Information and Communications Technology (ICT) service in year 2017 with penetration rate almost reaching 60 percent globally (ITU, 2017).

However, increased popularity of mobile technologies lead to the increased heterogeneity of their features (e.g., processing capabilities, resolution size, and network connection) (Mihaylov, Iliev, Ivanova, Stoyanov, & Radev, 2017). Also, different devices and applications are used to perform different roles and tasks in daily life. In normal situation, the development of content targeted for a specific platform and also comprises of several types of media objects with complex layout and structure (Fawaz, Bognanni, Scuturici, & Brunie, 2008; Lee, Rho, & Park, 2014). Traditional direct delivery approach of the content to smartphones without any customization is often ineffective and leads to information disorganization (Mohan, Smith, & Li, 1999; Lee et al., 2014). Thus, the main challenge for content providers from this heterogeneity is to align and customize exchange of data representation to different users.

Growing mismatch occurs when user request for rich multimedia content over the Internet using heterogeneous client devices through diverse network and dynamic condition. A concept named Universal Multimedia Access (UMA) was coined to handle this growing mismatch situation (Mohan et al., 1999). UMA is a concept concerning the ability to access any multimedia content regardless of location, time, device differences, and networks (Curum, Gumbheer, Khedo, & Cunairun, 2017; Chowdhury, Kar, Chattopadhyay, Bhattacharya, & Chattopadhyay, 2018). UMA also can be achieved using content adaptation approach. UMA is a mechanism to bridge the gap of content format incompatibilities with ultimate goal of the (Sugita & Yokota, 2013; Mihaylov et al., 2017). Early UMA approaches concentrate to meet technical requirements without any regards to user satisfaction. Then, UMA was enhanced to Universal Multimedia Experience (UME) as presented in Figure 1.1 in order to give focus back to user preferences (Pereira & Burnett, 2003; Nur, Arachchi, Dogan, & Kondoz, 2012; Yuan, Ghinea, & Muntean, 2015; Mihaylov et al., 2017; Moon & Lee, 2017). Challenge faced by multimedia content providers is to keep their clients by maximizing quality of experience (QoE) by enabling multimedia content to be created, stored and presented in different variants. UME can be achieved by adapting content to handle technical and semantic constraints so the content can be accessible anytime and anywhere as well as improving user experience and satisfaction (El-Khoury, Coquil, Bennani, & Brunie, 2014; Mihaylov et al., 2017; Moon & Lee, 2017).

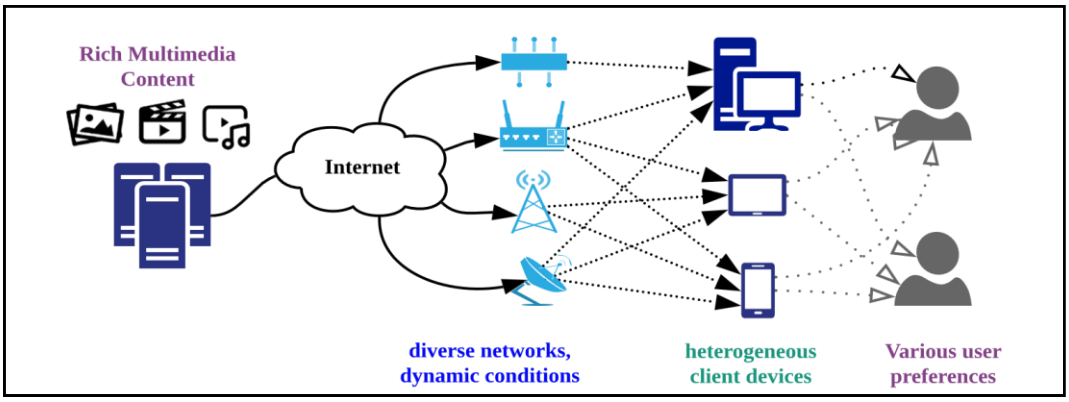

Figure 1.1: Universal Multimedia Experience (Pereira & Burnett, 2003)

The forecast by Cisco Systems (Cisco, 2017) in Figure 1.2 shows that a huge increment of monthly global mobile video traffic from end of 2016 to 2021. The expected increment is from 4.4 exabytes to a staggering 38.1 exabytes. It is the highest growth rate among mobile application from 2016 to 2021. The percentage of Internet video traffic in 2016 is 61 percent and expected to increase to 78 percent in 2021. This indicate that the impact on traffic today is immediate. Multimedia content production and consumption through smartphone are expected to increase in coming years. This situation has been seen since 2016, which is more than half of global traffic for mobile data occupied by Internet video.

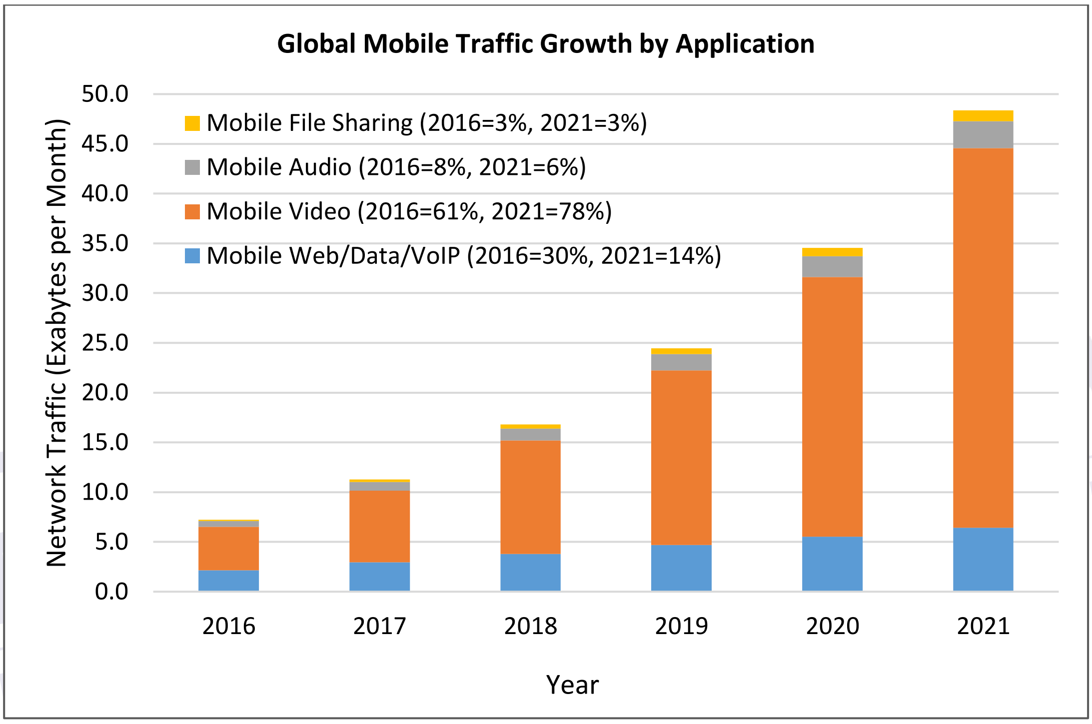

Figure 1.2: Estimated mobile data traffic by 2021

The improvement of hardware capabilities as well as software application development, and the function of a smartphone is diverging. Smartphones are not only be used to make phone calls, but are also used in many functionalities such as playing games, watching videos, browsing web pages and so on. There is no doubt that smartphones are the most versatile devices of the 21st century. However, these diverse usages come with a drawback due to limited battery capability in smartphones. This is a significant and current problem especially when consuming online as well as offline multimedia contents (Bokhari & Wagner, 2016; Li & Gallagher, 2016; Guo, Wang, & Chen, 2017; Zaman & Almusalli, 2017; Goode, 2018). Although a lot of previous research and developments have been made by researchers around the world, the energy awareness is still insufficient. The need is growing especially for supporting vast multimedia contents and applications.

The increasing demand of multimedia traffic and applications especially Internet video further worsen energy issue. Also, rather than normally linked with entertainment, Internet video is increasingly giving impact in other field such as education, surveillance, healthcare and agriculture. For example, Internet video are increasingly used as a means for delivery and teaching and learning, such as through blended learning programs in educational institutions such as schools, colleges and universities. Internet video also widely used in recent online educational method known as Massive Open Online Courses (MOOCs) providers such as Coursera, edX, FutureLearn, Cognitive Class, iversity and Udacity. Online courses offered by these providers are reaching ten thousand. Therefore, Internet video impact beyond just entertainment and leisure is inevitable.

1.2 Research motivation

One of the most desired features among smartphone users is longer battery life (IDC, 2014; Jha & Nanda, 2017). However, the limitation of space and the design of smartphone battery has made energy issues difficult and challenging to be solved in term of battery hardware. The following Figure 1.3 present the top 10 smartphone purchase drivers in 2014 (IDC, 2014).

Previous results show that there are potential to optimize energy consumption through applications (Thiagarajan, Aggarwal, Nicoara, Boneh, & Singh, 2012; Thomas, Gupta, & Venkatesh, 2014; Raha, Mitra, Raghunathan, & Rao, 2015; Brocanelli & Wang, 2017; Yan et al., 2019). The way application worked may significantly influence energy consumption and comparable to hardware energy consumption trade-offs. Content adaptation mechanism might be needed for viewing multimedia content. This mechanism also have potential to optimize energy consumption in term of software and application perspectives (Ardito, Procaccianti, Torchiano, Migliore, & Torino, 2013; Nightingale et al., 2016).

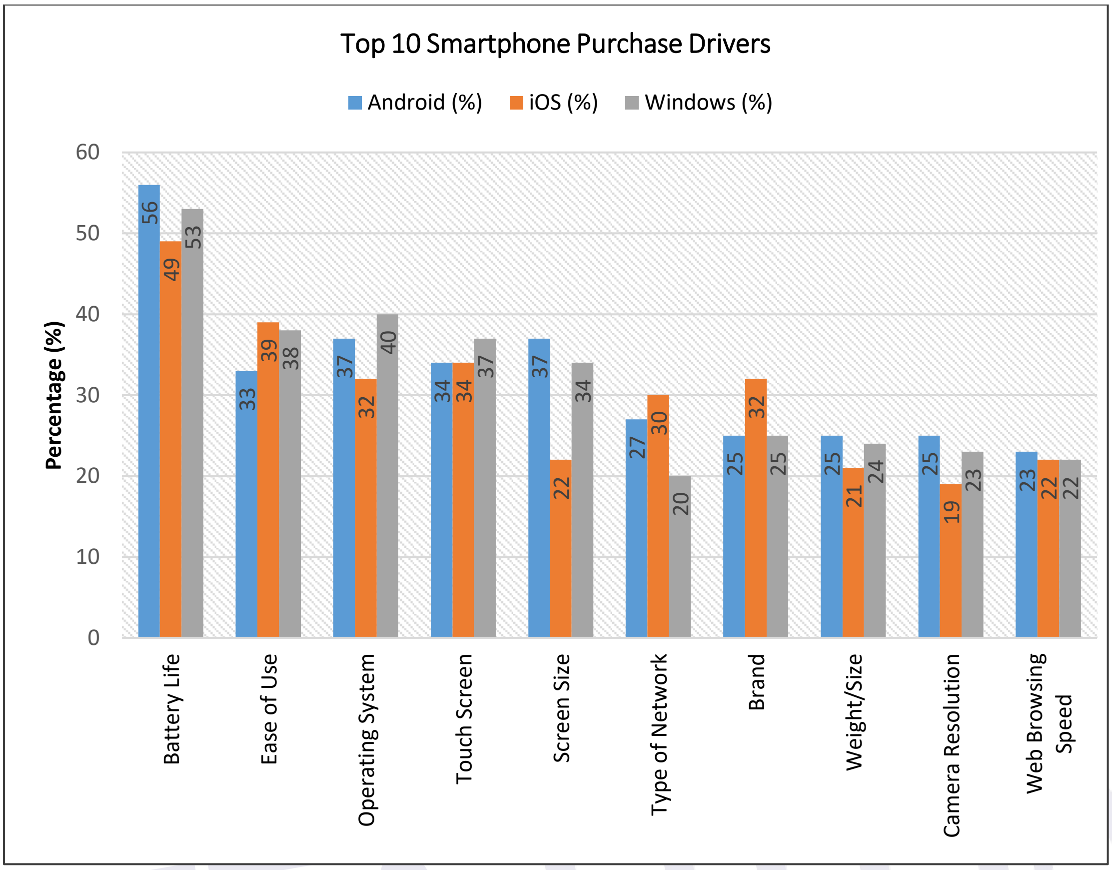

Figure 1.3: Top 10 smartphone purchase drivers (IDC, 2014)

The growth of smartphone technology and usage as well as the need to consume content correctly on heterogeneous devices drives the emergent of content adaptation methods (Dubey et al., 2014; El-Khoury et al., 2014; Wilk, Stohr, & Effelsberg, 2015). Content adaptation methods are needed to modify media content to be suit to user devices and simultaneously reducing energy consumption. This means, content adaptation could be used to trade quality of streaming video for energy savings. However, focus is given to adapting content to available format, with less consideration on energy efficiency. Some adapted content consumes more energy than other, for example uncompressed bitmap image consume more energy than compressed JPEG image (Thiagarajan et al., 2012). Therefore, content adaptation mechanisms are proven can be used to ensure longer lasting smartphone battery life while playing or viewing multimedia content (Moldovan & Muntean, 2012; Zou, Trestian, & Muntean, 2018). It can be considered as the most significant application layer method in energy-efficient computing techniques.

1.3 Problem statement

Although there has been significant improvement on smartphones technology where it become more powerful in term of processing power, graphics and display, and higher memory; the battery life has not improved much (Raha et al., 2015; Misra, Gupta, & Pratap, 2016; Goode, 2018). It may cause by the battery dimension which is needed to be small and thin to be put inside smartphone. Thus, the battery capacity is limited. Furthermore, many features and services included in the smartphone are requiring more energy and making the smartphone energy inefficient (Guo et al., 2017; Goode, 2018). This becomes a limiting factor for such powerful tool.

Ordinary smartphones nowadays only able to last not more than 24 hours with full charge (Guo et al., 2017). Figure 1.4 shows battery life of various smartphones models in 2018. This shows energy consumption is crucial for battery operated smartphones.

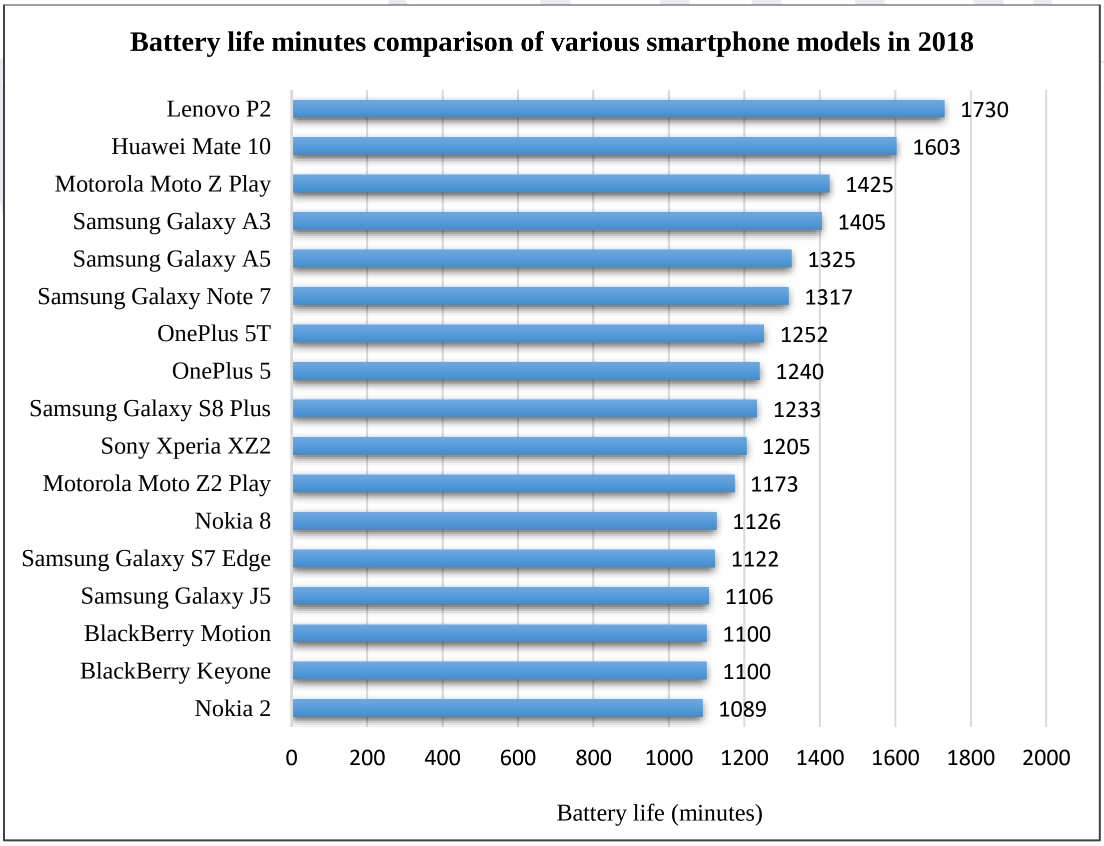

Figure 1.4: Battery life of various smartphones models in 2018 (Statista, 2019)

Moreover, mobile application as well as multimedia content is increasingly complex and power-hungry (Rajaraman, Siekkinen, & Hoque, 2014). For example, decoding video content while having the display on can together consume high amount of energy (Ren, Juarez, Sanz, Raulet, & Pescador, 2015). Codec computational complexity and the compression technique used for video encoding determine the required energy. Meanwhile, wireless communication can also consume equal or more amount of energy while streaming video in smartphones (Kennedy, Venkataraman, & Muntean, 2011; Nightingale et al., 2016). The amount of energy consumption is also depending on the type of wireless interface. Generally, energy needed to stream video by Wi-Fi is around three times of the needed energy to decode streaming video. Whereas to stream video using 3G cellular network needs around five times energy compared to the energy needed to decode video content (Hoque et al., 2011). That high consumption of energy is due to the need to power these wireless interfaces most of the time to handle continuous traffic flow during streaming.

Simultaneous running applications can easily drain smartphone battery within 12 hours (Guo et al., 2017). Furthermore, the smartphone batteries need a long time to charge and lacking in capacity. Though there are backup battery (i.e. power bank) available, users normally don't want to bring it around with them. Users also could be frustrated and some in-progress data could be loss when battery is depleted while using the smartphone (JD-Power and Associates, 2012; Hiwarekar et al., 2014; Li & Gallagher, 2016). The rapidly increased popularity of applications that requires Internet connectivity also worsen the scenario (Li & Gallagher, 2016).

Furthermore, smartphone systems are needed to be as light and thin as possible to keep the mobility feature. However, normal batteries feature requires a significant portion of smartphone in term of size and weight. Therefore, increasing battery capacity would also increase smartphone size and weight. Moreover, the technological advancement of smartphone battery is slower compared to the other components of smartphone (Goode, 2018). Hence, battery capacity and mobile multimedia content consumption gap is widening. The energy demand of mobile multimedia hardware and application could not always be fulfilled. Therefore, energy awareness of mobile computing emerged to be one of the significant issues in recent study.

Despite many recent approaches in content adaptation that have been proposed, only few focussing on energy efficiency as well as quality of experience to support UMA/UME efficiently (Zhang, Wu, Ci, Wang, & Katsaggelos, 2009; Kennedy, Venkataraman, & Muntean, 2010; Moldovan & Muntean, 2012; Hoque, Siekkinen, & Nurminen, 2012; Han, Yu, Zhu, Chen, & Li, 2013; Hoque, Siekkinen, Nurminen, Aalto, & Tarkoma, 2014; X. Zhang et al., 2014). Thus, the in-depth exploration of energy-efficient content adaptation techniques is needed while waiting for breakthrough in battery technology.

The most challenging task is to seek the right proportion of the energy consumption and Quality of Experience (Moldovan & Muntean, 2012; Zou et al., 2018). While optimizing the energy consumption by targeting different energy consuming operations, the user QoE should also be considered to achieve UME. Specifically, during the content adaptation decision-taking process, the available battery energy level as well as the optimum QoE shall be considered to present the multimedia content. This led to decision making problem on a content adaptation system. Therefore, research on QoE modelling for energy-aware online video streaming is recent (Duanmu, Rehman, Zeng, & Wang, 2016; Akhtar & Falk, 2017). To address these shortcomings, a mechanism for energy efficient and optimum QoE video adaptation is proposed.

1.4 Research objectives

The main objectives of this thesis are:

(i) To identify energy consumption rate in relation to various video properties.

(ii) To propose a framework that includes adaptation decision-taking engine algorithm for supporting energy-aware video content adaptation system to determine optimum solutions for improving quality of experience.

(iii) To analyse the proposed approach in term of energy efficiency and adapted content quality of experience.

1.5 Contributions

The challenge of content adaptation system is to enable wide variety of client devices accessing original contents properly and at the same time optimize user satisfaction. Another challenge is to view multimedia content in a very limited device energy. Battery life in smartphone is an important issue where mobile users tend to run many background applications along with browsing the content. User may find it frustrating

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