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

MOHD NORASRI BIN ISMAIL

A thesis submitted in
fulfilment of the requirement for the award of the
Doctor of Philosophy in Information Technology

Faculty of Computer Science and Information Technology
Universiti Tun Hussein Onn Malaysia

JULY 2019

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

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

My lovely mother Hajah Norjanah binti Akhsan

and my late father Haji Ismail bin Haji Nawawi.

My caring mother in law Hajah Juminah binti Kastor

and my late father in law Bakar bin Kassim.

Thank you for your constant prayer, enduring love and encouragement to fulfil my dreams.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

ACKNOWLEDGEMENT

First and foremost, all praise be to the Allah SWT, Almighty, the Benevolent for his blessing and guidance for giving me inspiration to see this through the end.

I would like to express my sincere gratitude the Malaysia Ministry of Higher Education for granting me fund under SLAB scholarship. Special thanks to Universiti Tun Hussein Onn Malaysia (UTHM) for facilitating this research activity.

This accomplishment would not have been possible without Allah's will; also, the love and support of my family. I would like to express my deepest gratitude to my lovely wife, my adorable children, my parents, my mother in law for their continuous support and concern. Their support has given me the energy to work on my research when I was depressed.

I would like to thank my supervisors, Professor Dr. Rosziati Ibrahim and Associate Professor Dr. Hj. Mohd. Farhan Hj. Md. Fudzee, for their invaluable advice, guidance and support throughout this education journey.

Lastly, I would also like to thank my colleagues in the Faculty of Computer Science and Information Technology, UTHM and all my friends for keeping me motivated throughout my journey as a doctoral student.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

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 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

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

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

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

	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

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

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

REFERENCES **120**

APPENDIX **149**

VITAE **154**

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

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

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

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

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

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

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

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

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

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

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

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

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

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).

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

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).

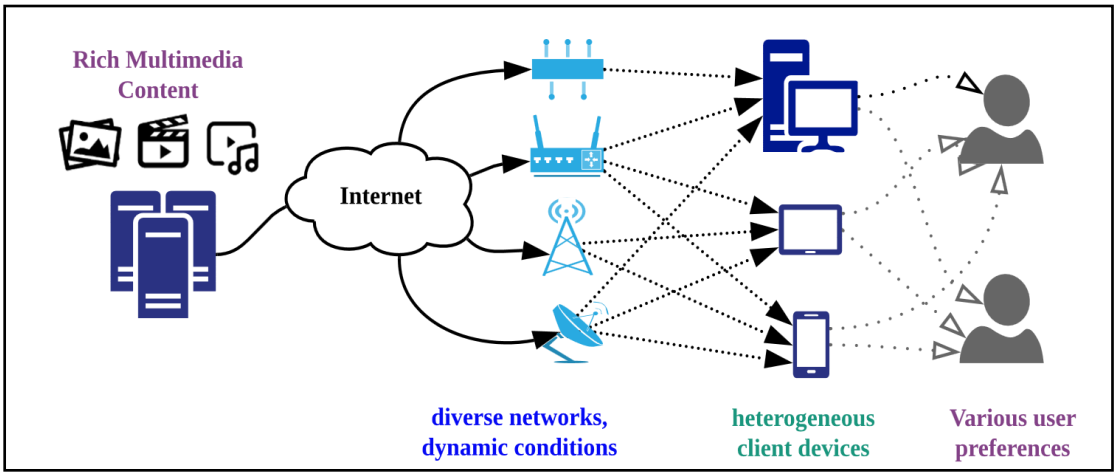

Figure 1.1: Universal Multimedia Experience (Pereira & Burnett, 2003)

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.

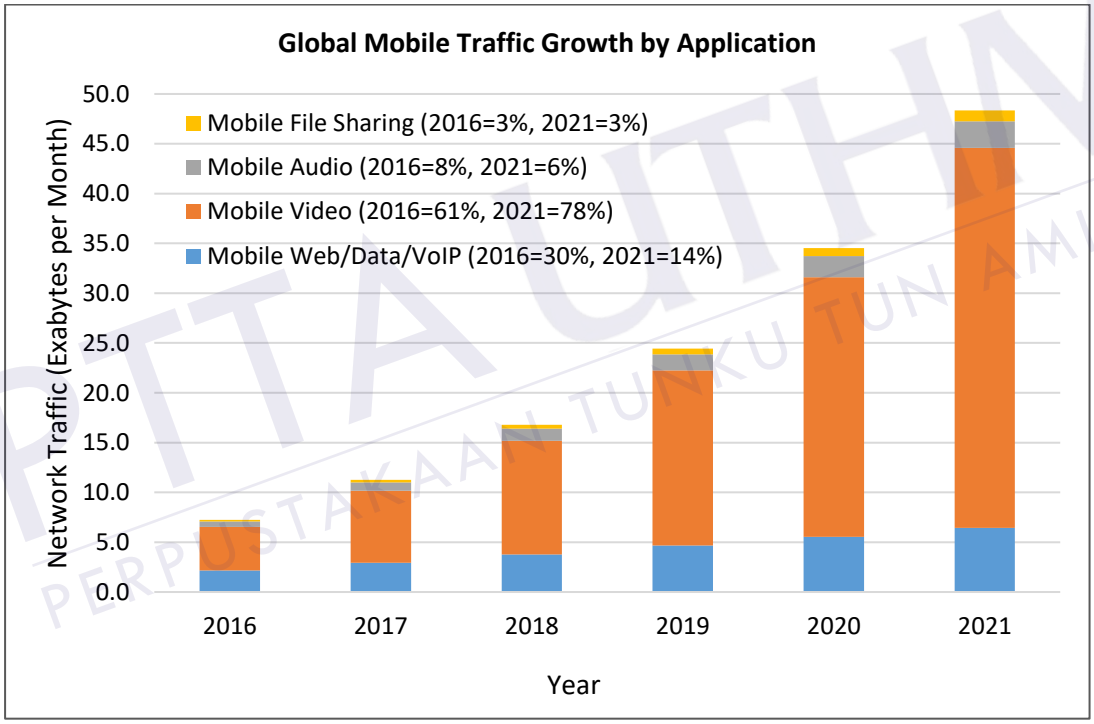

Figure 1.2: Estimated mobile data traffic by 2021

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).

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

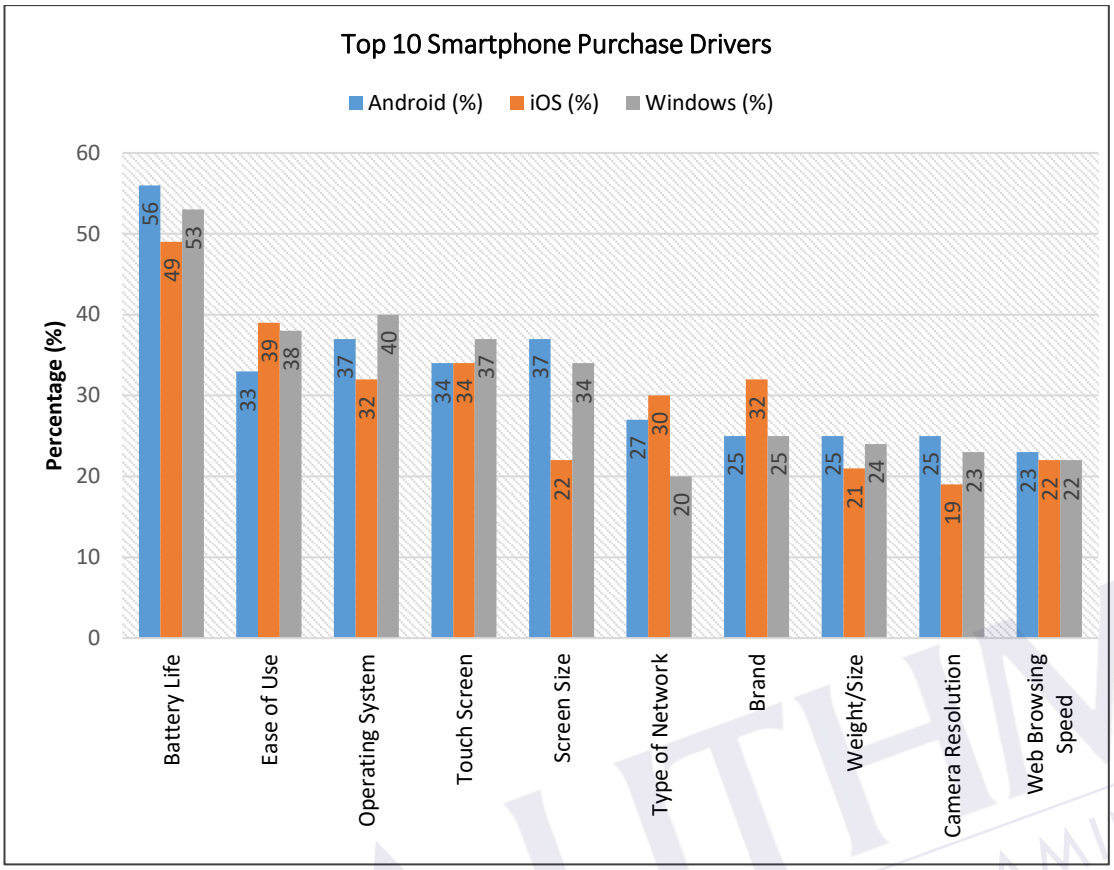

Figure 1.3: Top 10 smartphone purchase drivers (IDC, 2014)

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.

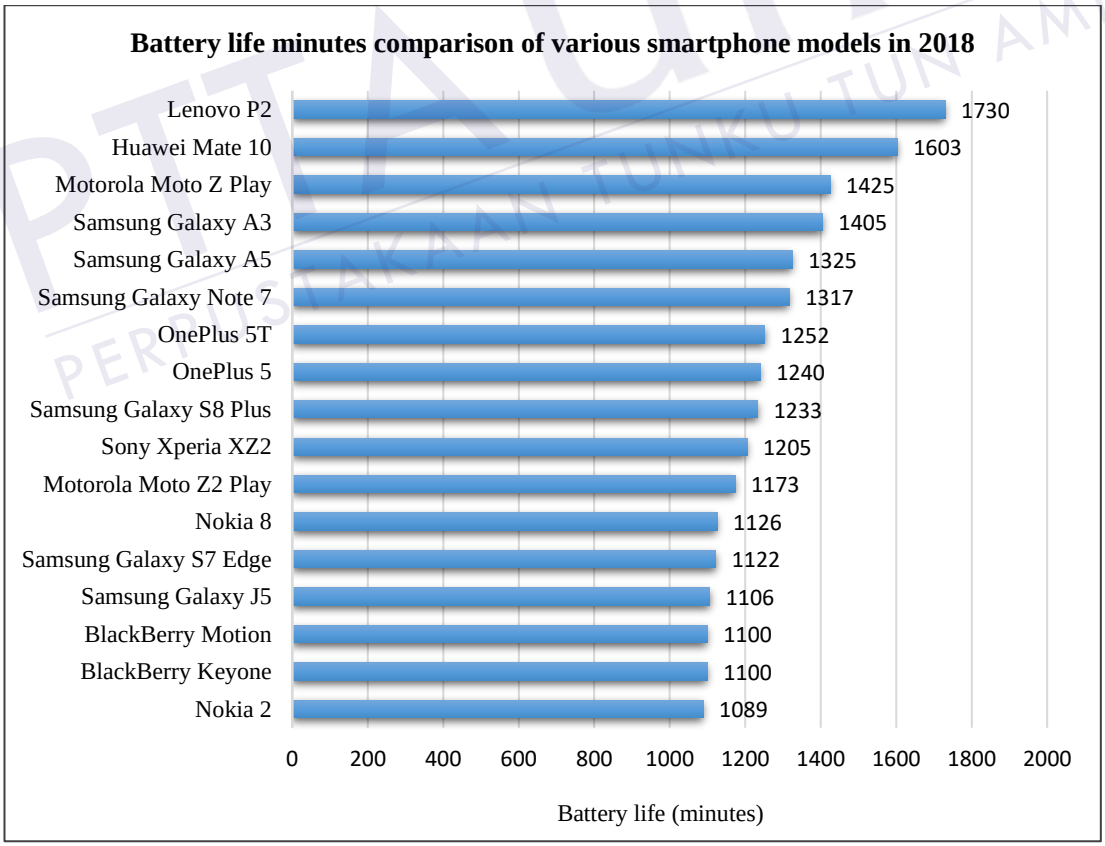

Figure 1.4: Battery life of various smartphones models in 2018 (Statista, 2019)

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,

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

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

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

REFERENCES

Adams, J., & Muntean, G. M. (2007). Adaptive-buffer power save mechanism for mobile multimedia streaming. *IEEE International Conference on Communications*. https://doi.org/10.1109/ICC.2007.751

Adobe. (2018). Adobe HTTP Dynamic Streaming. https://doi.org/10.18637/jss.v068.c02

Adzic, V., Kalva, H., & Furht, B. (2011). *A survey of multimedia content adaptation for mobile devices*. 379–396. https://doi.org/10.1007/s11042-010-0669-x

Akhtar, Z., & Falk, T. H. (2017). Audio-Visual Multimedia Quality Assessment: A Comprehensive Survey. *IEEE Access*, *5*, 21090–21117. https://doi.org/10.1109/ACCESS.2017.2750918

Alt, A., & Simon, D. (2010). Control strategies for H . 264 video decoding under resources constraints. *SIGOPS Oper. Syst. Rev.*, *44*(3).

Amiri, M. M., & Olfat, A. (2014). Low complexity adaptive transmission scheme for cooperative networks with decode-and-forward relay. *2014 7th International Symposium on Telecommunications, IST 2014*, 1128–1132. https://doi.org/10.1109/ISTEL.2014.7000873

Android-Developers. (2018). Battery Manager. Retrieved October 22, 2018, from https://developer.android.com/reference/android/os/BatteryManager

Android-Developers. (2019). Platform Architecture. https://doi.org/10.1016/b978-0-12-408066-9.00005-9

Ansari, M. A., & Khan, I. U. (2015). Performance analysis and evaluation of proposed algorithm for advance options of H.263 and H.264 video codec. *2015 International Conference on Recent Developments in Control, Automation and Power Engineering, RDCAPE 2015*, 371–376. https://doi.org/10.1109/RDCAPE.2015.7281427

Apple. (2018). HTTP Live Streaming (HLS) - Apple Developer. Retrieved December 20, 2018, from https://developer.apple.com/streaming/

Apple. (2019). Apple Lithium-ion Batteries. Retrieved July 7, 2019, from https://www.apple.com/my/batteries/

Ardito, L. (2013). Energy Aware Self-Adaptation in Mobile Systems. *2013 35th International Conference on Software Engineering (ICSE)*, 1435–1437.

Ardito, L., Procaccianti, G., Torchiano, M., Migliore, G., & Torino, P. (2013). *Profiling Power Consumption on Mobile Devices*. (c), 101–106.

Arnaiz, L., Menendez, J. M., & Jimenez, D. (2011). Efficient Personalized Scalable Video Adaptation Decision-taking Engine based on MPEG-21. *IEEE International Conference on Consumer Electronics (ICCE)*, 763–770.

Arshad, Q. K. U. D., Kashif, A. U., & Qureshi, I. manzoor. (2019). A Review on the Evolution of the Cellular Technologies. *Academic Perspective Procedia*, *1*(1), 1146–1156. https://doi.org/10.33793/acperpro.01.01.184

Aubry, W., Negru, D., Le Gal, B., Desfarges, S., & Dallet, D. (2012). A Generic Video Adaptation Framework Towards Content- and Context-Awareness in Future Networks. *20th European Signal Processing Conference (EUSIPCO 2012)*, 2218–2222.

Azwar, H., & Hendrawan. (2015). H.265 video delivery using dynamic adaptive streaming over HTTP (DASH) on LAN network. *Proceedings of 2014 8th International Conference on Telecommunication Systems Services and Applications, TSSA 2014*, 1–6. https://doi.org/10.1109/TSSA.2014.7065962

Bailey, J. M. (2011). *Live Video Streaming from Android-Enabled Devices to Web Browsers*.

Bakhtiar, B. (2007). *Video Content Adaptation Based on User Preferences and Network Bandwidth*.

Bankoski, J., Wilkins, P., & Xu, Y. (2011). Technical overview of VP8, an open source video codec for the web. *Proceedings - IEEE International Conference on Multimedia and Expo*, 1–6. https://doi.org/10.1109/ICME.2011.6012227

Bedregal, J. V. (2013). Optimizing energy consumption per application in mobile devices. *International Conference on Information Society (i-Society 2013)*, 106–110. Infonomics Society.

Belda, R., De Fez, I., Arce, P., & Guerri, J. C. (2018). Look Ahead: A DASH Adaptation Algorithm. *IEEE International Symposium on Broadband Multimedia Systems and Broadcasting, BMSB*, *2018-June*, 0–5. https://doi.org/10.1109/BMSB.2018.8436718

Berhe, G., Brunie, L., & Pierson, J.-M. (2005). Distributed content adaptation for pervasive systems. *Information Technology: Coding and Computing, 2005. ITCC 2005. International Conference On*, *2*, 234-241 Vol. 2. https://doi.org/10.1109/ITCC.2005.133

Bienik, J., Uhrina, M., Kuba, M., & Vaculik, M. (2016). Performance of H.264, H.265, VP8 and VP9 Compression Standards for High Resolutions. *NBiS 2016 - 19th International Conference on Network-Based Information Systems*, 246–252. https://doi.org/10.1109/NBiS.2016.70

Blender. (2019). Big Buck Bunny. Retrieved July 8, 2019, from https://peach.blender.org/

Bokani, A., Hoseini, S. A., Hassan, M., Kanhere, S. S., & Csiro, D. (2016). *Implementation and Evaluation of Adaptive Video Streaming based on Markov Decision Process*.

Bokhari, M., & Wagner, M. (2016). Optimising energy consumption heuristically on android mobile phones. *2016 Genetic and Evolutionary Computation Conference, Denver, USA*, 1139–1140. https://doi.org/10.1145/2908961.2931691

Brewer, E. A., Katz, R. H., Chawathe, Y., Gribble, S. D., Hodes, T., Nguyen, G., … Seshan, S. (1998). A network architecture for heterogeneous mobile computing. *Personal Communications, IEEE*, *5*(5), 8–24. https://doi.org/10.1109/98.729719

Brocanelli, M., & Wang, X. (2017). Making Smartphone Smart on Demand for Longer Battery Life. *2017 IEEE 37th International Conference on Distributed Computing Systems*, 2288–2293. https://doi.org/10.1109/ICDCS.2017.263

Butko, A., Bruguier, F., Gamatié, A., Sassatelli, G., Novo, D., Torres, L., & Robert, M. (2016). Full-System Simulation of big.LITTLE Multicore Architecture for Performance and Energy Exploration. *Proceedings - IEEE 10th International Symposium on Embedded Multicore/Many-Core Systems-on-Chip, MCSoC 2016*, (5422), 201–208. https://doi.org/10.1109/MCSoC.2016.20

Buyukkokten, O., Kaljuvee, O., Garcia-Molina, H., Paepcke, A., & Winograd, T. (2002). Efficient Web Browsing on Handheld Devices Using Page and Form Summarization. *ACM TRANSACTIONS ON INFORMATION SYSTEMS (TOIS*.

Cao, Y., Nejati, J., Wajahat, M., Balasubramanian, A., & Gandhi, A. (2017). Deconstructing the Energy Consumption of the Mobile Page Load. *Proceedings of the ACM on Measurement and Analysis of Computing Systems*, *1*(1), 1–25. https://doi.org/10.1145/3084443

Castellano, B. (2018). Intelligent scene cut detection and video splitting tool. Retrieved October 22, 2018, from https://pyscenedetect.readthedocs.io/en/latest/

Chandra, S., & Vahdat, A. (2002). Application-specific Network Management for Energy-Aware Streaming of Popular Multimedia Formats. *Proceedings of the General Track of the Annual Conference on USENIX Annual Technical Conference*, 329–342. Retrieved from http://dl.acm.org/citation.cfm?id=647057.713865

Chang, S., & Vetro, A. (2005). Video Adaptation : Concepts , Technologies , and Open Issues. *Proceedings of the IEEE*, *93*(1), 148–158.

Chen, C., Choi, L. K., De Veciana, G., Caramanis, C., Heath, R. W., & Bovik, A. C. (2014). Modeling the time-Varying subjective quality of HTTP video streams with rate adaptations. *IEEE Transactions on Image Processing*, *23*(5), 2206–2221. https://doi.org/10.1109/TIP.2014.2312613

Chen, H., Luo, B., & Shi, W. (2012). Anole: A Case for Energy-Aware Mobile Application Design. *2012 41st International Conference on Parallel Processing Workshops*, 232–238. https://doi.org/10.1109/ICPPW.2012.34

Chen, L.-Q., Xie, X., Ma, W.-Y., Zhang, H.-J., Xie, X., Zhou, H., & Feng, H. (2002). DRESS : A Slicing Tree Based Web Representation for Various Display Sizes. In *Microsoft Research Technical Report MSR-TR-2002-126*.

Chen, X., Ding, N., Jindal, A., Hu, Y. C., Gupta, M., & Vannithamby, R. (2015). Smartphone Energy Drain in the Wild. *ACM SIGMETRICS Performance Evaluation Review*, *43*(1), 151–164. https://doi.org/10.1145/2796314.2745875

Chowdhury, S. R., Kar, P., Chattopadhyay, M., Bhattacharya, M., & Chattopadhyay, S. (2018). Mobile enabled content adaptation system for PDF documents. *International Conference on Software, Knowledge Information, Industrial Management and Applications, SKIMA, 2017-Decem*. https://doi.org/10.1109/SKIMA.2017.8294100

Chua, H. N., Scott, S. D., Choi, Y. W., & Blanchfield, P. (2005). Web-Page Adaptation Framework for PC & Mobile Device Collaboration. *19th International Conference on Advanced Information Networking and Applications (AINA'05) Volume 1 (AINA Papers)*, *2*, 727–732. https://doi.org/10.1109/AINA.2005.348

Chuah, S. P., Chen, Z., & Tan, Y. P. (2012). Energy-efficient resource allocation and scheduling for multicast of scalable video over wireless networks. *IEEE Transactions on Multimedia*, *14*(4 PART 2), 1324–1336. https://doi.org/10.1109/TMM.2012.2193560

Cika, P., & Starha, D. (2018). Video Quality Assessment on Mobile Devices. *2018 25th International Conference on Systems, Signals and Image Processing (IWSSIP)*, 1–4. https://doi.org/10.1109/IWSSIP.2018.8439684

Cisco. (2017). *Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2016-2021*. Retrieved from http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/mobile-white-paper-c11-520862.pdf

Clark, M., Kodi, A., Bunescu, R., & Louri, A. (2018). LEAD: Learning-enabled Energy-aware Dynamic Voltage/Frequency Scaling in NoCs. *Proceedings of the 55th Annual Design Automation Conference*, 82:1--82:6. https://doi.org/10.1145/3195970.3196068

Corral, L., Georgiev, A. B., Sillitti, A., & Succi, G. (2013). A method for characterizing energy consumption in Android smartphones. *2013 2nd International Workshop on Green and Sustainable Software, GREENS 2013 - Proceedings*, 38–45. https://doi.org/10.1109/GREENS.2013.6606420

Couto, M., Cunha, J., Fernandes, J. P., Pereira, R., & Saraiva, J. (2016). GreenDroid: A tool for analysing power consumption in the android ecosystem. *2015 IEEE 13th International Scientific Conference on Informatics, INFORMATICS 2015 - Proceedings*, 73–78. https://doi.org/10.1109/Informatics.2015.7377811

Curum, B., Gumbheer, C. P., Khedo, K. K., & Cunairun, R. (2017). A content-adaptation system for personalized m-learning. *2017 1st International Conference on Next Generation Computing Applications, NextComp 2017*, 121–128. https://doi.org/10.1109/NEXTCOMP.2017.8016186

Dan, C. (2014). Review of Generations and Physics of Cellphone Technology. *International Journal of Information Science*, *4*(1), 1–7. https://doi.org/10.5923/j.ijis.20140401.01

Datt, M., & Mukhopadhyay, J. (2018). Content Based Video Summarization: Finding Interesting Temporal Sequences of Frames. *Proceedings - International Conference on Image Processing, ICIP*, 1268–1272. https://doi.org/10.1109/ICIP.2018.8451282

Dayananda, U. S. M., & Swaminathan, V. (2015). Investigating Scalable High Efficiency Video Coding for HTTP streaming. *2015 IEEE International Conference on Multimedia and Expo Workshops, ICMEW 2015*, 2–7. https://doi.org/10.1109/ICMEW.2015.7169809

Deloitte. (2011). *Squeezing the electrons in : batteries don't follow Moore's Law*. Retrieved from http://www.deloitte.com/assets/Dcom-Global/Local Assets/Documents/TMT/Predictions 2011 PDFs/8855A TMT Squeezing LB1.pdf

Di Nucci, D., Palomba, F., Prota, A., Panichella, A., Zaidman, A., & De Lucia, A. (2017). Software-based energy profiling of Android apps: Simple, efficient and reliable? *2017 IEEE 24th International Conference on Software Analysis, Evolution and Reengineering (SANER)*, 103–114. https://doi.org/10.1109/SANER.2017.7884613

Dong, M., Choi, Y.-S. K., & Zhong, L. (2009). Power modeling of graphical user interfaces on OLED displays. *Proceedings of the 46th Annual Design Automation Conference on ZZZ - DAC '09*, 652. https://doi.org/10.1145/1629911.1630084

Dong, M., & Zhong, L. (2011). *Chameleon : A Color-Adaptive Web Browser for Mobile OLED Displays*.

Dragi, L., Hofman, D., Kova, M., Žagar, M., & Knezovi, J. (2014). *Power Consumption and Bandwidth Savings with Video Transcoding to Mobile Device-specific Spatial Resolution*. 348–352.

Duanmu, Z., Rehman, A., Zeng, K., & Wang, Z. (2016). Quality-of-experience prediction for streaming video. *Proceedings - IEEE International Conference on Multimedia and Expo, 2016-Augus*, 1–6. https://doi.org/10.1109/ICME.2016.7552859

Dubey, A., De, P., Dey, K., Mittal, S., Agarwal, V., Cheltur, M., & Mukherjea, S. (2014). ScoDA: Cooperative content adaptation framework for mobile browsing. *2014 IEEE International Conference on Mobile Data Management*, 305–312. https://doi.org/10.1109/MDM.2014.43

El-Khoury, V., Coquil, D., Bennani, N., & Brunie, L. (2014). Personalized Video Adaptation Framework (PIAF): High-level Semantic Adaptation. *Multimedia Tools and Applications*, *70*(2), 1099–1140. https://doi.org/10.1007/s11042-012-1225-7

Elert, G. (2019). The Physics Hypertextbook. https://doi.org/10.2307/1790441

Elliott, J., Kor, A., & Omotosho, O. (2017). Energy Consumption in Smartphones: An Investigation of Battery and Energy Consumption of Media Related Applications on Android Smartphones. *International SEEDS Conference*. Retrieved from http://eprints.leedsbeckett.ac.uk/4703/

Emigh, J. (2006). New flash player rises in the web-video market. *Computer*, *39*(2), 14–16. https://doi.org/10.1109/MC.2006.66

Fan, D., Chan, Y. S., Yu, X., & Modestino, J. W. (2008). Network-adaptive transport of motion-compensated fine granularity scalability video using multiple asymmetric paths. *Proceedings - International Conference on Image Processing, ICIP*, 2320–2323. https://doi.org/10.1109/ICIP.2008.4712256

Fawaz, Y., Bognanni, C., Scuturici, V., & Brunie, L. (2008). Fault Tolerant Content Adaptation for a Dynamic Pervasive Computing Environment. *3rd International Conference on Information and Communication Technologies: From Theory to Applications, 2008. ICTTA 2008.*, 1–6.

Feng, W. chi, & Sechrest, S. (1995). Critical bandwidth allocation for the delivery of compressed video. *Computer Communications*, *18*(10), 709–717. https://doi.org/10.1016/0140-3664(95)98484-M

Fettes, Q., Clark, M., Bunescu, R., Karanth, A., & Louri, A. (2018). Dynamic Voltage and Frequency Scaling in NoCs with Supervised and Reinforcement Learning Techniques. *IEEE Transactions on Computers*, *PP*(X), 1–1. https://doi.org/10.1109/TC.2018.2875476

FFmpeg. (2017). FFmpeg Documentation. Retrieved July 23, 2017, from https://ffmpeg.org/documentation.html

Fimic, N., Tanackovic, S., Kovacevic, J., & Temerinac, M. (2016). Implementation of multi-format adaptive streaming server. *5th IEEE International Conference on Consumer Electronics - Berlin, ICCE-Berlin 2015*, 218–220. https://doi.org/10.1109/ICCE-Berlin.2015.7391239

Gao, G., Zhang, H., Hu, H., Wen, Y., Cai, J., Luo, C., & Zeng, W. (2018). Optimizing Quality of Experience for Adaptive Bitrate Streaming via Viewer Interest Inference. *IEEE Transactions on Multimedia*, *20*(12), 3399–3413. https://doi.org/10.1109/TMM.2018.2838330

Gartner. (2019). *Forecast: PCs, Ultramobiles and Mobile Phones, Worldwide, 2017-2023, 1Q19 Update*. Retrieved from https://www.gartner.com/document/3905864?ref=solrAll&refval=219602921&qid=ea9debeb4f8397e81b9

Goode, L. (2018). Batteries Still Suck, But Researchers Are Working on It. *Wired.Com*. Retrieved from https://www.wired.com/story/building-a-better-battery/

Google. (2019). ExoPlayer. Retrieved July 8, 2019, from https://exoplayer.dev/

Grafl, M., Timmerer, C., Waltl, M., Xilouris, G., Zotos, N., Renzi, D., … Chernilov, A. (2012). Distributed adaptation decision-taking framework and Scalable Video Coding tunneling for edge and in-network media adaptation. *2012 International Conference on Telecommunications and Multimedia (TEMU)*, 163–168. https://doi.org/10.1109/TEMU.2012.6294710

GSMArena. (2019). GSMArena Phone Finder. Retrieved July 8, 2019, from GSMArena.com

Guo, Y., Wang, C., & Chen, X. (2017). Understanding Application-Battery Interactions on Smartphones : A Large-Scale Empirical Study. *IEEE Access*, *5*, 13387–13400.

Han, H., Yu, J., Zhu, H., Chen, Y., & Li, M. (2013). E 3 : Energy-Efficient Engine for Frame Rate Adaptation on Smartphones. *11th ACM Conference on Embedded Networked Sensor Systems - SenSys 2013*, 1–14.

He, J., Gao, T., Hao, W., Yen, I., & Bastani, F. (2007). A Flexible Content Adaptation System Using a Rule-Based Approach. *IEEE Transactions on Knowledge and Data Engineering*, *19*(1), 127–140.

Hemalatha, K., Yadav, P. K., & Ramasubramanian, N. (2015). Adaptive bitrate transcoding for power efficient video streaming in mobile devices. *2015 3rd International Conference on Signal Processing, Communication and Networking, ICSCN 2015*, 1–5. https://doi.org/10.1109/ICSCN.2015.7219825

Hill, M., & Janapa Reddi, V. (2019). Gables: A roofline model for mobile SoCs. *Proceedings - 25th IEEE International Symposium on High Performance Computer Architecture, HPCA 2019*, 317–330. https://doi.org/10.1109/HPCA.2019.00047

Hiwarekar, S., Tayal, A. R., & Kale, R. (2014). A Survey on Energy Consumption in Smartphones over Wi-Fi. *International Journal of Scientific and Research Publications*, *4*(2), 4–6.

Hoque, Mohammad A, Siekkinen, M., & Nurminen, J. K. (2011). On the Energy Efficiency of Proxy-Based Traffic Shaping for Mobile Audio Streaming. *8th Annual IEEE Consumer Communications and Networking Conference - Multimedia & Entertainment Networking and Services*, 891–895.

Hoque, Mohammad Ashraful, Siekkinen, M., Khan, K. N., Xiao, Y., & Tarkoma, S. (2015). Modeling , Profiling , and Debugging the Energy Consumption of Mobile Devices. *ACM Computing Surveys*, *48*(3), 1–40.

Hoque, Mohammad Ashraful, Siekkinen, M., & Nurminen, J. K. (2012). Energy Efficient Multimedia Streaming to Mobile Devices – A Survey. *IEEE Communications Surveys & Tutorial*, *14*(4), 1–19.

Hoque, Mohammad Ashraful, Siekkinen, M., Nurminen, J. K., Aalto, M., & Tarkoma, S. (2014). Mobile Multimedia Streaming Techniques: QoE and Energy Consumption Perspective. *Pervasive and Mobile Computing*.

Hosseinabadi, M. T., & Ansari, N. (2014). Multi-Power-Level Energy Saving Management for Passive Optical Networks. *Journal of Optical Communications and Networking*, *6*(11), 965. https://doi.org/10.1364/JOCN.6.000965

Hsiao, J.-L., Hung, H.-P., & Chen, M.-S. (2008). Versatile Transcoding Proxy for Internet Content Adaptation. *Multimedia, IEEE Transactions On*, *10*(4), 646–658. https://doi.org/10.1109/TMM.2008.921852

Hu, S., Sun, L., Xiao, C., & Gui, C. (2017). Semantic-aware adaptation scheme for soccer video over MPEG-DASH. *Proceedings - IEEE International Conference on Multimedia and Expo*, 493–498. https://doi.org/10.1109/ICME.2017.8019541

IDC. (2014). *ConsumerScape 360*.

IDC. (2019). Smartphone Market Share. Retrieved from https://www.idc.com/promo/smartphone-market-share/os

Ilias, I. S. H. C., Munisamy, S. B., & Rahman, N. A. A. (2013). A study of video performance analysis between Flash video and HTML 5 video. *Proceedings of the 7th International Conference on Ubiquitous Information Management and Communication*, 1–4. https://doi.org/10.1145/2448556.2448586

ISO. *ISO 14496-2: Information technology - Coding of audio-visual objects - Part 2: Visual*. , (2001).

ITU-T. (2008a). Audiovisual Quality in Multimedia Services: Subjective Video Quality Assessment Methods for Multimedia Applications. In *SERIES P: TELEPHONE TRANSMISSION QUALITY, TELEPHONE INSTALLATIONS, LOCAL LINE NETWORKS* (No. P.910). Geneva.

ITU-T. (2008b). *Multimedia quality of service and performance – Generic and user-related aspects: Quality of experience requirements for IPTV services* (No. G.1080). Retrieved from https://www.itu.int/rec/T-REC-G.1080-200812-I

ITU-T. (2016). *Methods for Objective and Subjective Assessment of Speech and Video Quality: Mean Opinion Score (MOS) Terminology* (No. P.800.1). https://doi.org/10.1109/DSD.2009.139

ITU. (2016). *ICT Facts and Figures 2016*. Retrieved from https://www.itu.int/en/ITU-D/Statistics/Documents/facts/ICTFactsFigures2016.pdf

ITU. (2017). *ICT Facts and Figures*. Retrieved from https://www.itu.int/en/ITU-D/Statistics/Documents/facts/ICTFactsFigures2017.pdf

JD-Power and Associates. (2012). *2012 US Wireless Smartphone and Traditional Mobile Phone Customer Satisfaction Study*. Retrieved from www.jdpower.com/content/press-release/py6kvam/2012-u-s-wireless-smartphone-and-traditional-mobile-phone-satisfaction-studies-volume

Jha, J. T., & Nanda, J. K. (2017). Factors Affecting Consumer Buying Decisions of Smartphones. *IMPACT: International Journal of Research in Business Management*, *5*(9), 179–200. Retrieved from www.impactjournals.us

Kamiyama, T., Hiroshi, I., & Ohta, K. (2014). A Model-based Energy Profiler using Online Logging for Android Applications. *Seventh International Conference on Mobile Computing and Ubiquitous Networking (ICMU)*, 7–13.

Karagkioules, T., Tsilimantos, D., Concolato, C., & Valentin, S. (2017). A Comparative Case Study of HTTP Adaptive Streaming Algorithms in Mobile Networks. *Proceedings of the 27th Workshop on Network and Operating Systems Support for Digital Audio and Video (NOSSDAV'17)*, 1–6. https://doi.org/10.1145/3083165.3083170

Kennedy, M., Venkataraman, H., & Muntean, G.-M. (2010). Battery and Stream-Aware Adaptive Multimedia Delivery for wireless devices. *IEEE Local Computer Network Conference*, 843–846. https://doi.org/10.1109/LCN.2010.5735821

Kennedy, M., Venkataraman, H., & Muntean, G. (2011). Energy Consumption Analysis and Adaptive Energy Saving Solutions for Mobile Device Applications. In J. H. Kim & M. J. Lee (Eds.), *Green IT: Technologies and Applications* (1st editio, pp. 173–189). https://doi.org/10.1007/978-3-642-22179-8_9

Khakurel, S., Musavian, L., Vu, H. V., & Le-Ngoc, T. (2018). QoS-Aware Utility-Based Resource Allocation in Mixed-Traffic Multi-User OFDM Systems. *IEEE Access*, *6*, 21646–21657. https://doi.org/10.1109/ACCESS.2018.2823004

Khalil, M. I., Hossain, M. A., Haque, M. J., & Hasan, M. N. (2017). EERC-MAC: Energy efficient Receiver Centric MAC protocol for Wireless Sensor network. *2017 IEEE International Conference on Imaging, Vision and Pattern Recognition, IcIVPR 2017*, 1–5. https://doi.org/10.1109/ICIVPR.2017.7890861

Kim, E., Jeong, H., Yang, J., & Song, M. (2014). Balancing energy use against video quality in mobile devices. *IEEE Transactions on Consumer Electronics*, *60*(3), 517–524. https://doi.org/10.1109/TCE.2014.6937338

Ko, S., Park, S., & Han, H. (2013). Design analysis for real-time video transcoding on cloud systems. *Proceedings of the 28th Annual ACM Symposium on Applied Computing*, 1610–1615. https://doi.org/10.1145/2480362.2480663

Kofler, I., Timmerer, C., Hellwagner, H., Hutter, A., & Sanahuja, F. (2007). Efficient MPEG-21-based Adaptation Decision-Taking for Scalable Multimedia Content. *Proc. SPIE 6504, Multimedia Computing and Networking 2007*, *43*(463).

Korbel, F. (2012). *FFmpeg Basics*. CreateSpace Independent Publishing Platform.

Köster, F., Mittag, G., & Möller, S. (2017). Modeling the overall quality of experience on the basis of underlying quality dimensions. *2017 9th International Conference on Quality of Multimedia Experience, QoMEX 2017*. https://doi.org/10.1109/QoMEX.2017.7965647

Krejcar, O. (2011). Testing the Battery Life of Mobile Phones and PDAs. *2011 International Conference on Software and Computer Applications IPCSIT*, *9*, 132–136.

Kreuzberger, C., Posch, D., & Hellwagner, H. (2015). A scalable video coding dataset and toolchain for dynamic adaptive streaming over HTTP. *Proceedings of the 6th ACM Multimedia Systems Conference on - MMSys '15*, 213–218. https://doi.org/10.1145/2713168.2713193

Kume, H. (2010). Panasonic's New Li-Ion Batteries Use Si Anode for 30 % Higher Capacity. Retrieved from http://techon.nikkeibp.co.jp/article/HONSHI/20100223/180545/

Laako, T., & Hiltunen, T. (2005). Adapting Web Content to Mobile User Agents. *IEEE Magazine on Internet Computing*, *9*(April), 46–53.

Lee, J. Y., Kim, H., Lee, W., & Kim, H. (2016). Adaptive Transmission Scheme for TCP in Wireless Multi-Hop Network. *Proceedings - Conference on Local Computer Networks, LCN*, 503–506. https://doi.org/10.1109/LCN.2016.78

Lee, Joohyung, Yeo, B. C., Kim, J. S., Jang, M. S., & Choi, J. K. (2013). Energy efficient scalable video coding based cooperative multicast scheme with selective layer forwarding. *IEEE Communications Letters*, *17*(6), 1116–1119. https://doi.org/10.1109/LCOMM.2013.050313.130062

Lee, Jungwoo, Han, H., & Song, M. (2017). Balancing Transcoding Against Quality-of-Experience to Limit Energy Consumption in Video-on-Demand Systems. *Proceedings - 2017 IEEE International Symposium on Multimedia, ISM 2017*, *2017-Janua*, 334–337. https://doi.org/10.1109/ISM.2017.61

Lee, P.-J., Bui, T.-A., & Yao, S.-R. (2019). Improve The HEVC Algorithm Complexity Based On The Visual Perception. *2019 IEEE International Conference on Consumer Electronics, ICCE 2019*, 1–4. https://doi.org/10.1109/ICCE.2019.8662038

Lee, S., Rho, S., & Park, J. H. (2014). Multimedia contents adaptation by modality conversion with user preference in wireless network. *Journal of Network and Computer Applications*, *37*, 25–32. https://doi.org/10.1016/j.jnca.2011.03.034

Leu, J. S., Yu, M. C., Liu, C. Y., Budiarsa, A. P. B., & Utomo, V. (2016). Energy efficient streaming for smartphone by video adaptation and backlight control. *Computer Networks*, *113*, 111–123. https://doi.org/10.1016/j.comnet.2016.12.007

Li, Qiang, Cui, H., & Tang, K. (2002). Fine granularity scalability video coding algorithm. *2002 International Conference on Communications, Circuits and Systems and West Sino Exposition, ICCCAS 2002 - Proceedings*, (69972020), 5–9. https://doi.org/10.1109/ICCCAS.2002.1180559

Li, Qilin, & Zhou, M. (2011). The Survey and Future Evolution of Green Computing. *2011 IEEE/ACM International Conference on Green Computing and Communications*, 230–233. https://doi.org/10.1109/GreenCom.2011.47

Li, W. (2001). Overview of fine granularity scalability in MPEG-4 video standard. *IEEE Transactions on Circuits and Systems for Video Technology*, *11*(3), 301–317. https://doi.org/10.1109/76.911157

Li, X., & Gallagher, J. P. (2016). A Source-Level Energy Optimization Framework for Mobile Applications. *2016 IEEE 16th International Working Conference on Source Code Analysis and Manipulation*, 31–40. https://doi.org/10.1109/SCAM.2016.12

Li, Zhi, Zhu, X., Gahm, J., Pan, R., Hu, H., Begen, A. C., & Oran, D. (2014). *Probe and Adapt : Rate Adaptation for HTTP Video Streaming At Scale*.

Li, Zhichao, Grosu, R., Muppalla, K., Smolka, S. A., Stoller, S. D., & Zadok, E. (2011). Model discovery for energy-aware computing systems: An experimental evaluation. *2011 International Green Computing Conference and Workshops*, 1–6. https://doi.org/10.1109/IGCC.2011.6008572

Lin, C., Liu, J., & Liao, C. (2007). Energy Analysis of Multimedia Video Decoding on Mobile Handheld Devices. *International Conference on Multimedia and Ubiquitous Engineering (MUE'07)*.

Linden, D., & Reddy, T. B. (2011). *Handbook of Batteries* (4th ed.). https://doi.org/10.1016/0378-7753(86)80059-3

Liu, Y., Ci, S., Tang, H., Ye, Y., & Liu, J. (2012). QoE-oriented 3D video transcoding for mobile streaming. *ACM Transactions on Multimedia Computing, Communications, and Applications*, *8*(3s), 1–20. https://doi.org/10.1145/2348816.2348821

Lum, W. Y., & Lau, F. C. M. (2002). A Context-Aware Decision Engine for Content Adaptation. *IEEE Pervasive Computing*, *1*(3), 41–49.

Lum, W. Y., & Lau, F. C. M. (2003). User-Centric Content Negotiation for Effective Adaptation Service in Mobile Computing. *IEEE TRANSACTIONS ON SOFTWARE ENGINEERING*, *29*(12), 1100–1111.

Mach, P., Member, I., Becvar, Z., & Member, I. (2017). *Mobile Edge Computing : A Survey on Architecture and Computation Offloading*. *XX*(XX). https://doi.org/10.1109/COMST.2017.2682318

Mademlis, I., Tefas, A., & Pitas, I. (2018). Summarization of human activity videos using a salient dictionary. *Proceedings - International Conference on Image Processing, ICIP*, *2017-Septe*, 625–629. https://doi.org/10.1109/ICIP.2017.8296356

Majid, M., & Abhayaratne, C. (2010). Scalable multiple description video coding using successive refinement of side quantizers. *28th Picture Coding Symposium, PCS 2010*, 602–605. https://doi.org/10.1109/PCS.2010.5702576

Mayo, R. N., & Ranganathan, P. (2003). Energy consumption in mobile devices: Why future systems need requirements-aware energy scale-down. *Proceedings of the Workshop on Power-Aware Computing Systems*, 26–40. https://doi.org/10.1007/978-3-540-28641-7_3

Mcmullin, D., Trestian, R., & Muntean, G. (2009). Power Save-based Adaptive Multimedia Delivery Mechanism. *The 9th Information Technology and Telecomunication Conference (IT&T)*. Dublin, Ireland.

Md-Fudzee, M. F., & Abawajy, J. (2008). A Classification for Content Adaptation System. *Proceeding of IiWAS 2008*, 426–429.

Md Fudzee, M. F. (2011). *Broker-based Service-oriented Content Adaptation Framework*.

Md Fudzee, M. F., & Abawajy, J. (2010). Request-Driven Cross-Media Content Adaptation Technique. In K. Ragab, T. Helmy, & A. E. Hassanien (Eds.), *Developing Advanced Web Services through P2P Computing and Autonomous Agents: Trends and Innovations* (pp. 91–113). Retrieved from http://www.igi-global.com/chapter/request-driven-cross-media-content/43649/

Md Fudzee, M. F., & Abawajy, J. (2011). Developing Advanced Web Services through P2P Computing and Autonomous Agents : Trends and Innovations. In K. Ragab, K. Klinger, L. Johnston, & J. Snavely (Eds.), *Developing Advanced Web Services through P2P Computing and Autonomous Agents : Trends and Innovations* (pp. 91–113). IGI Global: USA.

Metri, G., Agrawal, A., Peri, R., & Shi, W. (2012). What is eating up battery life on my SmartPhone: A case study. *2012 International Conference on Energy Aware Computing, ICEAC 2012*. https://doi.org/10.1109/ICEAC.2012.6471003

Microsoft. (2018a). Experience IIS Smooth Streaming. Retrieved December 20, 2018, from http://www.iis.net/media/experiencesmoothstreaming

Microsoft. (2018b). Microsoft Media Server Protocol.

Mihaylov, G. Y., Iliev, T. B., Ivanova, E. P., Stoyanov, I. S., & Radev, D. I. (2017). Universal multimedia access and network coding - Working together for best user multimedia experience. *2017 25th Telecommunications Forum, TELFOR 2017 - Proceedings*, 1–4. https://doi.org/10.1109/TELFOR.2017.8249290

Min-yi, G. (2010). Green Computing : Connotation and Tendency. *Computer Engineering*, *36*(10), 1–7.

Misra, R., Gupta, A., & Pratap, A. (2016). Fairness while improving smartphone battery life using D2D cooperative relays underlaying LTE networks. *2016 International Conference on Computational Techniques in Information and Communication Technologies, ICCTICT 2016 - Proceedings*, (0), 459–462. https://doi.org/10.1109/ICCTICT.2016.7514624

Mittal, S. (2016). A Survey of Techniques for Architecting and Managing Asymmetric Multicore Processors. *ACM Computing Surveys*, *48*(3), 1–38. https://doi.org/10.1145/2856125

Mohan, R., Smith, J. R., & Li, C. (1999). Adapting Multimedia Content for Universal Access. *IEEE Transactions on Multimedia*, *1*(1), 104–114.

Mohapatra, S., Cornea, R., Oh, H., Lee, K., Kim, M., Dutt, N., … Venkatasubramanian, N. (2005). A cross-layer approach for power-performance optimization in distributed mobile systems. *Parallel and Distributed Processing Symposium, 2005. Proceedings. 19th IEEE International*, 8 pp. https://doi.org/10.1109/IPDPS.2005.13

Moldovan, A.-N., & Muntean, C. H. (2012). Subjective Assessment of BitDetect: A Mechanism for Energy-Aware Multimedia Content Adaptation. *IEEE Transactions on Broadcasting*, *58*(3), 480–492. https://doi.org/10.1109/TBC.2012.2191688

Moon, S. E., & Lee, J. S. (2017). Implicit Analysis of Perceptual Multimedia Experience Based on Physiological Response: A Review. *IEEE Transactions on Multimedia*, *19*(2), 340–353. https://doi.org/10.1109/TMM.2016.2614880

Morales, R., Saborido, R., Khomh, F., Chicano, F., & Antoniol, G. (2018). EARMO: An Energy-Aware Refactoring Approach for Mobile Apps. *IEEE Transactions on Software Engineering*, *44*(12), 1176–1206. https://doi.org/10.1109/TSE.2017.2757486

MPEG. (2016). MPEG--21. Retrieved from http://mpeg.chiariglione.org/standards/mpeg-21

Muntean, C. H., & McManis, J. (2004). A QoS-aware adaptive Web-based system. *Communications, 2004 IEEE International Conference On*, *4*, 2204-2208 Vol.4. https://doi.org/10.1109/ICC.2004.1312909

Muntean, G. (2007). *Adaptive Multimedia Content Delivery over Wired and Wireless Networks PEL - Overview*.

Naghshineh, M., & Willebeek-LeMair, M. (1997). End-to-End QoS Provisioning in Multimedia Wireless/Mobile Networks Using an Adaptive Framework. *IEEE Communications Letters*, (November), 72–81.

Nam, J., Ro, Y. M., Huh, Y., & Kim, M. (2005). Visual content adaptation according to user perception characteristics. *IEEE Transactions on Multimedia*, *7*(3), 435–445. https://doi.org/10.1109/TMM.2005.846801

Nguyen-Vuong, Q. T., Ghamri-Doudane, Y., & Agoulmine, N. (2008). On utility models for access network selection in wireless heterogeneous networks. *NOMS 2008 - IEEE/IFIP Network Operations and Management Symposium: Pervasive Management for Ubiquitous Networks and Services*, 144–151. https://doi.org/10.1109/NOMS.2008.4575128

Nightingale, J., Wang, Q., Alcaraz Calero, J. M., Chirivella-Perez, E., Ulbricht, M., Alonso-López, J. A., … Reinsch, C. (2016). QoE-Driven, Energy-Aware Video Adaptation in 5G Networks: The SELFNET Self-Optimisation Use Case. *International Journal of Distributed Sensor Networks*, *2016*, 1–15. https://doi.org/10.1155/2016/7829305

Noble, B. D., Satyanarayanan, M., Narayanan, D., Tilton, J. E., Flinn, J., & Walker, K. R. (1997). Agile application-aware adaptation for mobility. *SIGOPS Oper. Syst. Rev.*, *31*(5), 276–287. https://doi.org/10.1145/269005.266708

Nunez-Yanez, J. L. (2018). Energy Proportional Neural Network Inference with Adaptive Voltage and Frequency Scaling. *IEEE Transactions on Computers*, *PP*, 1. https://doi.org/10.1109/TC.2018.2879333

Nur, G., Arachchi, H. K., Dogan, S., & Kondoz, A. M. (2014). Seamless video access for mobile devices by content-aware utility-based adaptation. *Multimedia Tools and Applications*, *70*(2), 689–719. https://doi.org/10.1007/s11042-012-1120-2

Nur, Gokce, Arachchi, H. K., Dogan, S., & Kondoz, A. M. (2012). Advanced Adaptation Techniques for Improved Video Perception. *IEEE Transactions on Circuits and Systems for Video Technology*, *22*(2), 225–240. https://doi.org/10.1109/TCSVT.2011.2160600

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

Oyman, O., & Singh, S. (2012). Quality of experience for HTTP adaptive streaming services. *IEEE Communications Magazine*, *50*(4), 20–27. https://doi.org/10.1109/MCOM.2012.6178830

Park, K., & Kim, M. (2019). EVSO : Environment-aware Video Streaming Optimization of Power Consumption. *IEEE INFOCOM 2019 - IEEE Conference on Computer Communications*, 973–981. IEEE.

Park, S, Lee, Y., Lee, J., & Shin, H. (2005). Quality-adaptive requantization for low-energy MPEG-4 video decoding in mobile devices. *Consumer Electronics, IEEE Transactions On*, *51*(3), 999–1005. https://doi.org/10.1109/TCE.2005.1510514

Park, Seongho, Oh, H., & Kim, W. (2006). Wavelet-based Scalable Video Coding with Low Complex Spatial Transform. *8th International Conference Advanced Communication Technology,IEEE*, 1333–1335.

Parmar, H., & Thornburgh, M. (2012). Adobe's Real Time Messaging Protocol Specification.

Pathak, A., Hu, Y. C., & Zhang, M. (2012). Where is the energy spent inside my app? Fine Grained Energy Accounting on Smartphones with Eprof. *Proceedings of the 7th ACM European Conference on Computer Systems*, 29–42. Bern, Switzerland: ACM.

Patnaik, Y., & Patra, D. (2014). Wavelet based scalable video coding: A comparative study. *2014 Students Conference on Engineering and Systems*, 1–6. https://doi.org/10.1109/SCES.2014.6880062

Pereira, F., & Burnett, I. (2003). Universal multimedia experiences for tomorrow. *IEEE Signal Processing Magazine*, *20*(March), 63–73.

Pham Van, L., De Praeter, J., Van Wallendael, G., Van Leuven, S., De Cock, J., & Van De Walle, R. (2016). Efficient Bit Rate Transcoding for High Efficiency Video Coding. *IEEE Transactions on Multimedia*, *18*(3), 364–378. https://doi.org/10.1109/TMM.2015.2512231

Qualcomm Technologies. (2015). *Trepn Profiler Starter Edition User Guide* (pp. 1–49). pp. 1–49.

Raha, A., Mitra, S., Raghunathan, V., & Rao, S. (2015). VIDalizer : An Energy Efficient Video Streamer. *2015 IEEE Wireless Communications and Networking Conference (WCNC)*, 2251–2256.

Rainer, B., Posch, D., & Hellwagner, H. (2016). Investigating the performance of pull-based dynamic adaptive streaming in NDN. *IEEE Journal on Selected Areas in Communications*, *34*(8), 2130–2140. https://doi.org/10.1109/JSAC.2016.2577365

Rajaraman, S. V., Siekkinen, M., & Hoque, M. A. (2014). Energy consumption anatomy of live video streaming from a smartphone. *IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, PIMRC*, *2014-June*, 2013–2017. https://doi.org/10.1109/PIMRC.2014.7136502

Ramaswamy, L., lyengar, A., Liu, L., & Douglis, F. (2005). Automatic fragment detection in dynamic Web pages and its impact on caching. *Knowledge and Data Engineering, IEEE Transactions On*, *17*(6), 859–874. https://doi.org/10.1109/TKDE.2005.89

Reiterer, B., Concolato, C., Lachner, J., Le Feuvre, J., Moissinac, J.-C., Lenzi, S., … Hellwagner, H. (2008). User-centric universal multimedia access in home networks. *The Visual Computer*, *24*(7–9), 837–845. https://doi.org/10.1007/s00371-008-0265-5

Ren, J., Jiang, J., & Feng, Y. (2010). Activity-driven content adaptation for effective video summarization. *Journal of Visual Communication and Image Representation*, *21*(8), 930–938. https://doi.org/10.1016/j.jvcir.2010.09.002

Ren, R., Juarez, E., Sanz, C., Raulet, M., & Pescador, F. (2015). Energy estimation models for video decoders: reconfigurable video coding-CAL case-study. *IET Computers & Digital Techniques*, *9*(1), 3–15. https://doi.org/10.1049/iet-cdt.2014.0087

Rice, A., & Hay, S. (2010). Decomposing power measurements for mobile devices. *2010 IEEE International Conference on Pervasive Computing and Communications (PerCom)*, *42*(2), 70–78. https://doi.org/10.1109/PERCOM.2010.5466991

Rodríguez-Sánchez, R., Igual, F. D., Martínez, J. L., Mayo, R., & Quintana-Ortí, E. S. (2014). Parallel performance and energy efficiency of modern video encoders on multithreaded architectures. *2014 22nd European Signal Processing Conference (EUSIPCO)*, 191–195.

Satyanarayanan, M. (1996). Fundamental challenges in mobile computing. *Proceedings of the Fifteenth Annual ACM Symposium on Principles of Distributed Computing - PODC '96*, 1–7. https://doi.org/10.1145/248052.248053

Schirmer, M., & Hagen, H. (2012). Software-based Energy Requirement Measurement for Smartphones. *42. Annual Conference of the German Computer Society*.

Schulzrinne, H., Casner, S., Frederick, R., & Jacobson, V. (2003). RTP: A Transport Protocol for Real-Time Applications. *IETF RFC 3550*, 1–89. https://doi.org/10.17487/rfc3550

Schwarz, H., Marpe, D., & Wiegand, T. (2007). Overview of the Scalable Video Coding Extension of the H.264/AVC Standard. *Circuits and Systems for Video Technology, IEEE Transactions On*, *17*(9), 1103–1120. https://doi.org/10.1109/TCSVT.2007.905532

Seufert, M., Egger, S., Slanina, M., Zinner, T., Hossfeld, T., & Tran-gia, P. (2015). A Survey on Quality of Experience of HTTP Adaptive Streaming. *Ieee Communication Surveys & Tutorials*, *17*(1), 469–492. https://doi.org/10.1109/COMST.2014.2360940

Shahidi, M., & Aghvami, H. (2008). Content Adaptation : Requirements and Architecture. *Scenario*, (c), 626–629. https://doi.org/10.1145/1497308.1497427

Shin, D., Kim, Y., Chang, N., & Pedram, M. (2011). Dynamic voltage scaling of OLED displays. *Proceedings of the 48th Design Automation Conference*, 53–58. https://doi.org/10.1145/2024724.2024737

Shukla, N. K., Pila, R., & Rawat, S. (2016). Utilization-based Power Consumption Profiling in Smartphones. *2nd International Conference on Contemporary Computing and Informatics (IC3I)*, 881–886.

Snowdon, D. C., Le Sueur, E., Petters, S. M., & Heiser, G. (2009). Koala: A Platform for OS-Level Power Management. *Proceedings of the 4th ACM European Conference on Computer Systems, EuroSys '09, New York, NY, USA, 2009.*, 289–302.

Statista. (2019). *Battery life minutes comparison of various smartphone models in 2018 (in minutes).* Retrieved from https://www.statista.com/statistics/697053/smartphone-battery-life/

Streijl, R. C., Winkler, S., & Hands, D. S. (2016). Mean Opinion Score (MOS) revisited : Methods and applications , limitations and alternatives. *Multimedia Systems*, *22*(2), 213–227.

Sugita, K., & Yokota, M. (2013). Implementation of sightseeing information contents for universal multimedia access. *2013 8th International Conference on P2P, Parallel, Grid, Cloud and Internet Computing*, 569–573. https://doi.org/10.1109/3PGCIC.2013.98

Ta, T., Baras, J. S., & Zhu, C. (2014). *Improving Smartphone Battery Life Utilizing Device-to-device Cooperative Relays Underlaying LTE Networks*. 5263–5268.

Taha, M., Jimenez, J. M., Canovas, A., & Lloret, J. (2017). Intelligent Algorithm for Enhancing MPEG-DASH QoE in eMBMS. *Network Protocols and Algorithms*, *9*(3–4), 94–114. https://doi.org/10.5296/npa.v9i3-4.12573

Taha, M., Lloret, J., Canovas, A., & Garcia, L. (2017). Survey of Transportation of Adaptive Multimedia Streaming service in Internet. *Network Protocols and Algorithms*, *9*(1–2), 85–125. https://doi.org/10.5296/npa.v9i1-2.12412

Tamai, M., Sun, T., Yasumoto, K., Shibata, N., & Ito, M. (2004). Energy-aware video streaming with QoS control for portable computing devices. *Proceedings of the 14th International Workshop on Network and Operating Systems Support for Digital Audio and Video*, 68–73. https://doi.org/10.1145/1005847.1005863

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

Thiagarajan, N., Aggarwal, G., Nicoara, A., Boneh, D., & Singh, J. P. (2012). Who Killed My Battery : Analyzing Mobile Browser Energy Consumption. *21st International Conference on World Wide Web, Lyon, France*, 41–50.

Thomas, S. S., Gupta, S., & Subramanian, V. K. (2017). Smart surveillance based on video summarization. *TENSYMP 2017 - IEEE International Symposium on Technologies for Smart Cities*. https://doi.org/10.1109/TENCONSpring.2017.8070003

Thomas, S. S., Gupta, S., & Venkatesh, K. S. (2014). An Energy Minimization Approach for Automatic Video Shot and Scene Boundary Detection. *2014 Tenth International Conference on Intelligent Information Hiding and Multimedia Signal Processing*, 297–300. https://doi.org/10.1109/IIH-MSP.2014.80

Timmerer, C., Ortega, V. H., Gonzalez, J. M., & Leon, A. (2008). Measuring Quality of Experience for MPEG-21-based Cross-Layer. *IEEE/ACS International Conference on Computer Systems and Applications, 2008. AICCSA 2008*, 969–974.

Tong, M.-W., Yang, Z.-K., & Liu, Q.-T. (2010). A novel model of adaptation decision-taking engine in multimedia adaptation. *Journal of Network and Computer Applications*, *33*(1), 43–49. https://doi.org/10.1016/j.jnca.2009.06.004

Trestian, R., Ormond, O., & Muntean, G.-M. (2010). Power-friendly access network selection strategy for heterogeneous wireless multimedia networks. *2010 IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB)*, 1–5. https://doi.org/10.1109/ISBMSB.2010.5463147

Trollmann, F., Fähndrich, J., & Albayrak, S. (2018). Hybrid Adaptation Policies – Towards a Framework for Classification and Modelling of Different Combinations of Adaptation Policies. *2018 ACM/IEEE 13th International Symposium on Software Engineering for Adaptive and Self-Managing Systems Hybrid*, 76–86. https://doi.org/10.1145/3194133.3194137

Uhrina, M., Bienik, J., & Vaculik, M. (2016). Coding Efficiency of VP8 and VP9 Compression Standards for High Resolutions. *2016 ELEKTRO*, 100–103. https://doi.org/10.1109/NBiS.2016.70

Vallina-Rodriguez, N., Hui, P., Crowcroft, J., & Rice, A. (2010). Exhausting Battery Statistics Understanding the energy demands on mobile handsets. *Proceedings of the Second ACM SIGCOMM Workshop on Networking, Systems, and Applications on Mobile Handhelds - MobiHeld '10*, (February), 9. https://doi.org/10.1145/1851322.1851327

Van Berkel, C. H. (2009). Multi-Core for Mobile Phones. *2009 Design, Automation & Test in Europe Conference & Exhibition*, 1260–1265.

velárquez-García, F. J., Halvorsen, P., Stensland, H. K., & Eliassen, F. (2018). Dynamic Adaptation of Multimedia Presentations for Videoconferencing in Application Mobility. *2018 IEEE International Conference on Multimedia and Expo (ICME)*, 1–6. https://doi.org/10.1109/ICME.2018.8486565

Vetro, A., & Sun, H. (2001). Media conversions to support mobile users. *Electrical and Computer Engineering, 2001. Canadian Conference On*, *1*, 607–612 vol.1. https://doi.org/10.1109/CCECE.2001.933753

Wang, L., & Wang, T. (2011). Green Computing Wanted: Electricity Consumptions in the IT Industry and by Household Computers in Five Major Chinese Cities. *2011 IEEE/ACM International Conference on Green Computing and Communications*, 226–229. https://doi.org/10.1109/GreenCom.2011.46

Wang, X., Vasilakos, A. V., Chen, M., Liu, Y., & Kwon, T. T. (2012). A Survey of Green Mobile Networks: Opportunities and Challenges. *Mobile Networks and Applications*, *17*(1), 4–20. https://doi.org/10.1007/s11036-011-0316-4

Wang, Y., Kim, J., Chang, S., & Kim, H. (2007). Utility-Based Video Adaptation for Universal Multimedia Access (UMA) and Content-Based Utility Function Prediction for Real-Time Video Transcoding. *IEEE Transactions on Multimedia*, *9*(2), 213–220.

Wilk, S., Stohr, D., & Effelsberg, W. (2015). VAS: A Video Adaptation Service to Support Mobile Video. *25th Workshop on Network and Operating Systems Support for Digital Audio and Video (NOSSDAV), USA*, 37–42. https://doi.org/10.1145/2736084.2736092

Wu, W., Arefin, A., Rivas, R., Nahrstedt, K., & Sheppard, R. M. (2009). Quality of Experience in Distributed Interactive Multimedia Environments: Toward a Theoretical Framework. *Proceedings of the 17th ACM International Conference on Multimedia*, 481–490.

Wu, Z., Yu, H., Tang, B., & Chen, C. W. (2012). Adaptive initial quantization parameter determination for H.264/AVC video transcoding. *IEEE Transactions on Broadcasting*, *58*(2), 277–284. https://doi.org/10.1109/TBC.2011.2182430

Xiao, Y., Cui, Y., Savolainen, P., Siekkinen, M., Wang, A., Yang, L., & Ylä-jääski, A. (2014). Modeling Energy Consumption of Data Transmission Over Wi-Fi. *IEEE TRANSACTIONS ON MOBILE COMPUTING*, *13*(8), 1760–1773.

Xie, L., Zhou, C., Zhang, X., & Guo, Z. (2017). Dynamic Threshold Based Rate Adaptation for HTTP Live Streaming. *2017 IEEE International Symposium on Circuits and Systems (ISCAS)*, 1–4.

Xu, J., Xu, M., Wei, Y., Wang, Z., & Guan, Z. (2018). Fast H.264 to HEVC Transcoding: A Deep Learning Method. *IEEE Transactions on Multimedia*, *21*(7), 1633–1645. https://doi.org/10.1109/TMM.2018.2885921

Xu, M., He, X., Peng, Y., Jin, J. S., Luo, S., Chia, L.-T., & Hu, Y. (2012). Content on demand video adaptation based on MPEG - 21 digital item adaptation. *EURASIP Journal on Wireless Communications and Networking 2012*, *2012*(104), 1–19. https://doi.org/10.1186/1687

Xu, M., Jin, J. S., & Luo, S. (2008). Personalized video adaptation based on video content analysis. *Proceedings of the 9th International Workshop on Multimedia Data Mining Held in Conjunction with the ACM SIGKDD 2008 - MDM '08*, 26–35. https://doi.org/10.1145/1509212.1509216

Yan, M., Chan, C. A., Gygax, A. F., Yan, J., Campbell, L., Nirmalathas, A., & Leckie, C. (2019). Modeling the Total Energy Consumption of Mobile Network Services and Applications. *Energies*, *12*(1), 184. https://doi.org/10.3390/en12010184

Yang, F., Wan, S., & Izquierdo, E. (2007). Lagrange Multiplier Selection for 3-D Wavelet Based Scalable Video Coding. *2007 IEEE International Conference on Image Processing*, 309–312.

Yang, J., & Song, M. (2015). *Threshold-Based Frame-Rate Adjustment for Energy-Saving in Portable Media Players*. (2), 50–51.

Yang, S. J. H., & Shao, N. W. Y. (2007). Enhancing pervasive Web accessibility with rule-based adaptation strategy. *Expert Syst. Appl.*, *32*(4), 1154–1167. https://doi.org/10.1016/j.eswa.2006.02.008

Yang, S. J. H., Zhang, J., Chen, R. C. S., & Shao, N. W. Y. (2007). A Unit of Information-Based Content Adaptation Method for Improving Web Content Accessibility in the Mobile Internet. *ETRI Journal*, *29*(6), 794–807. https://doi.org/10.4218/etrij.07.0107.0086

Yoon, Y., Kim, M., Lee, S., Lee, B., Hyun, S. J., & Lee, K. (2012). Performance Analysis of H . 264 / AVC , H . 264 / SVC , and VP8 over IEEE 802 . 11 Wireless Networks. *2012 IEEE Symposium on Computers and Communications (ISCC)*, 151–156.

Yuan, Z., Ghinea, G., & Muntean, G. M. (2015). Beyond multimedia adaptation: Quality of experience-aware multi-sensorial media delivery. *IEEE Transactions on Multimedia*, *17*(1), 104–117. https://doi.org/10.1109/TMM.2014.2371240

Zaman, N., & Almusalli, F. A. (2017). Review: Smartphones power consumption & energy saving techniques. *ICIEECT 2017 - International Conference on Innovations in Electrical Engineering and Computational Technologies 2017, Proceedings*, (0), 0–2. https://doi.org/10.1109/ICIEECT.2017.7916593

Zeng, F., & Zhong, J. (2018). Utility-based cooperative spectrum leasing scheme for CR networks with hybrid energy supplies. *IET Communications*, *12*(5), 509–517. https://doi.org/10.1049/iet-com.2017.0210

Zeng, J., Au, O. C., Dai, W., Kong, Y., Jia, L., & Zhu, W. (2013). A Tutorial on Image / Video Coding Standards. *2013 Asia-Pacific Signal and Information Processing Association Annual Summit and Conference, Kaohsiung*, 1–7. Kaohsiung.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

Zhang, D. (2007). Web content adaptation for mobile handheld devices. *Commun. ACM*, *50*(2), 75–79. https://doi.org/10.1145/1216016.1216024

Zhang, Heli, Ji, H., Li, X., Wang, K., & Wang, W. (2016). Energy efficient resource allocation over cloud-RAN based heterogeneous network. *Proceedings - IEEE 7th International Conference on Cloud Computing Technology and Science, CloudCom 2015*, 483–486. https://doi.org/10.1109/CloudCom.2015.97

Zhang, Hongjiang. (2000). Adaptive Content Delivery: A New Application Area for Media Computing Research. *International Workshop on Multimedia Data Storage, Retrieval, Integration and Applications*, (5). Hong Kong.

Zhang, J., Wu, D., Ci, S., Wang, H., & Katsaggelos, A. (2009). Power-Aware Mobile Multimedia : a Survey (Invited Paper). *Journal of Communications*, *4*(9), 600–613. https://doi.org/10.4304/jcm.4.9.600-613

Zhang, X., Yu, R., Zhang, Y., Gao, Y., Im, M., Cuthbert, L., & Wang, W. (2014). Energy-efficient multimedia transmissions through base station cooperation over heterogeneous cellular networks exploiting user behavior. *IEEE Wireless Communications*, *21*(4), 54–61. https://doi.org/10.1109/MWC.2014.6882296

Zhang, Y., Long, H., Liu, F., Wang, W., & Lei, L. (2012). *A QoE-Aware Method for Energy Efficient Network Selection*. 850–854.

Zhao, M., Jia, B., Wang, J., Wu, M., & Yu, H. (2018). Performance Optimization on Dynamic Adaptive Streaming over HTTP in Multi-User MIMO LTE Networks. *IEEE Transactions on Mobile Computing*, *17*(12), 2853–2867. https://doi.org/10.1109/TMC.2018.2817220

Zhao, S., Muppala, G., Li, Z., & Medhi, D. (2018). Smooth Streaming with MPEG-DASH Using SDN-Based Application-Aware Networking. *2018 International Conference on Computing, Networking and Communications, ICNC 2018*, 77–81. https://doi.org/10.1109/ICCNC.2018.8390315

Zhao, Z., Ostermann, J., & Chen, H. (2009). Low complexity multiple description coding for the scalable extension of H.264/AVC. *2009 Picture Coding Symposium*, 1–4. https://doi.org/10.1109/PCS.2009.5167458

Zheng, M., Liang, W., & Yu, H. (2018). Utility-Based Resource Allocation in Wireless-Powered Communication Networks. *IEEE Systems Journal*, *12*(4), 3881–3884. https://doi.org/10.1109/JSYST.2018.2805887

Zou, L., Trestian, R., & Muntean, G. M. (2018). E 3 DOAS: Balancing QoE and Energy-Saving for Multi-Device Adaptation in Future Mobile Wireless Video Delivery. *IEEE Transactions on Broadcasting*, *64*(1), 26–40. https://doi.org/10.1109/TBC.2017.2722221

Zsak, N., & Wolff, C. (2014). *Impact of video quality and wireless network interface on power consumption of mobile devices*. Retrieved from http://arxiv.org/abs/1407.7667

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

VITAE

The author was born in July 23, 1976 in Kampung Tampok Laut, Pontian, Johor. He went to Sekolah Rendah Kebangsaan Sri Benut, Pontian for his primary education and Sekolah Menengah Benut for his secondary school. He then pursued his Diploma and Bachelor of Computer Science at Universiti Teknologi Malaysia. Upon graduation in 1999, he works as Research Officer at Universiti Teknologi Malaysia for 6 months. Then he works as IT Officer at Elektrisola Sdn Bhd for 3 years. In 2003 he worked as Internal Audit Executive at Perodua. Afterward, in 2004, he worked as Tutor at Universiti Tun Hussein Onn Malaysia. He received his Master of Science degree in Information Technology in 2007 from Universiti Teknologi MARA. In 2007, he worked as lecturer at Universiti Tun Hussein Onn Malaysia till now. During his PhD, he manages to publish several research articles at reputable platform and appointed as reviewer for some national and international conference paper.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH