Enhancing the Quality of Video Streaming over Unreliable Wireless Networks

A Thesis Submitted for the Degree of

Doctor of Philosophy

By

Muhammad Usman

in

Faculty of Engineering and Information Technology

UNIVERSITY OF TECHNOLOGY, SYDNEY

AUSTRALIA

October 2017

UNIVERSITY OF TECHNOLOGY, SYDNEY

Faculty of Engineering and Information Technology

The undersigned hereby certify that they have read this thesis entitled "**Enhancing the Quality of Video Streaming over Unreliable Wireless Networks**" by Muhammad Usman and that in their opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Doctor of Philosophy.

Principal Supervisor	Co-Supervisor
Prof. Xiangjian He	Dr. Min Xu

CERTIFICATE OF AUTHORSHIP

Date: **16th October 2017**

Author: Muhammad Usman
Title: Enhancing the Quality of Video Streaming over Unreliable Wireless Networks
Degree: PhD

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as part of the collaborative doctoral degree and/or fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This research is supported by UTS International Research Scholarship (IRS).

Signature of Author

Acknowledgements

Pursing a doctoral degree is a long journey that one cannot make alone. I would like to thank all those who have assisted me in one way or another along this journey.

First and foremost, I wish to thank my supervisor Prof. Xiangjian (Sean) He. He has been supportive since the days I began working as a Ph.D. researcher. I remember, he always used to say that "Yes, I know, you can do this" to encourage me to move on and focus on my work. Ever since, Prof. Sean has supported me not only by providing a research assistantship, but also academically and emotionally through the rough road to finish this thesis. And during the most difficult times when writing this thesis, he gave me the moral support and freedom I needed to move on.

Similar profound gratitude goes to Dr. Min Xu, who has been truly dedicated to her role as my secondary supervisor. I am particularly indebted to Dr. Min for her constant faith in my research work. Her valued suggestions, constant support, and encouragement has kept me moving ahead at critical times. Without her help, I would not have been able to complete this thesis.

I am very glad to have worked with wonderful researchers, such as Dr. Mian Ahmad Jan and Dr. Syed Mohsin Matloob Bokhari. I have worked with them closely and learned a lot. They are my best buddies and I have shared many happy moments with them. Without their valuable research experiences, I would not have been able to balance my research and finish this degree. I am thankful to both of them for their continuous willingness to collaborate and discuss on various ideas during my research studies.

Finally, my deep and sincere gratitude to my family for their continuous and unparalleled love, help, and support. I am grateful to both my sisters (Shaista Irum and Seema Irum) for always being there for me as my best friends. I love our funny arguments and fights and the way how we make fun of each other. Special thanks to my funny, shy, and flirty brother (Zohaib Imran) who is always ready to help me. I am forever indebted to my

brother-in-law (Zulfiqar Khan Khattak) for giving me the opportunities and experiences that have made me who I am. He selflessly encouraged me to explore new directions in life and seek my own destiny. This paragraph would be incomplete if I do not say anything about the young devils of my family, i.e., my nieces (Maryam Niazi, Zunairah Zulfiqar, and Zoha Zulfiqar) and my nephews (Shaheer Niazi, Abdul-Hadi Niazi, Zulkifal Khattak, Zain-ul-Abdin Khattak, Daud Suleman, and Muzammil Wadood). The bond I share with these girls and boys, no-one can ever have. This journey would not have been possible without all these people, and I dedicate this milestone to them.

Dedicated to my family

Table of Contents

List of Tables

List of Figures

Abbreviations

Abbreviations	Descriptions
HEVC	High Efficiency Video Coding
QoS	Quality of Service
EC	Error Concealment
HD	High Definition
UHD	Ultra High Definition
ME	Motion estimation
WMSN	Wireless Multimedia Sensor Network
PLR	Packet Loss Ratio
QoE	Quality of Experience
VSP	Video Service Provider
ITU-T	International Telecommunication Union-Telecommunication
VCEG	Video Coding Experts Group
MPEG	Moving Picture Experts Group
VCL	Video Coding Layer
NAL	Network Abstraction Layer
MIMO	Multiple-Input-Multiple-Output
ER	Error Resilience
VoD	Video on Demand
FEC	Forward Error Correction

ARQ	Automatic Repeat Request
QP	Quantisation Parameter
SHVC	Scalable High Efficiency Video Coding
MANETs	Mobile Ad-hoc Networks
BL	Base Layer
EL	Enhancement Layer
JCT-VC	Joint Collaborative Team on Video Coding
CTU	Coding Tree Unit
MB	MacroBlock
CTB	Coding Tree Block
CB	Coding Block
CU	Coding Unit
SCB	Smallest Coding Block
LCB	Largest Coding Block
PB	Prediction Block
PU	Prediction Unit
MV	Motion Vector
TB	Transform Block
DCT	Discrete Cosine Transform
DST	Discrete Sine Transform
FS	Full Search
TSS	Three Step Search
FSS	Four Step Search

DS	Diamond Search
HS	Hexagonal Search
MC	Motion Compensation
URQ	Uniform Reconstruction Quantisation
SAO	Sample Adaptive Offset
CABAC	Context Adaptive Binary Arithmetic
HM	HEVC test Model
AI	All-Intra
LDP	Low-Delay P
LDB	Low-Delay B
RA	Random Access
GoP	Group of Pictures
RDO	Rate Distortion Optimisation
RD	Rate Distortion
SAD	Sum of Absolute Difference
TSAD	Hadamard Transformed SAD
SSE	Sum of Square Error
SVC	Scalable Video Coding
PSNR	Peak-Signal-to-Noise-Ratio
fps	frames per second
FIR	Finite Impulse Response
SHM	SHVC test model
LUT3D	3D Look-Up-Table

SEC	Spatial Error Concealment
TEC	Temporal Error Concealment
HEC	Hybrid Error Concealment
PDF	Probability Density Function
KDE	Kernel Density Estimation
MESE	Mean Error Square Estimator
DP	Dynamic Programming
MFI	Motion Field Interpolation
FBM	Flexible Block Matching
TLRA	Tensor Low Rank Approximation
MVE	Motion Vector Extrapolation
MDC	Multiple Description Coding
EII	Examplar-based Image Inpainting
SI	Spatial Interpolation
PDIP	Primal-Dual Interior Point
SO	Spare Optimisation
RoI	Region of Interest
PIR	Passive Infra Red
BS	Base Station
WSN	Wireless Sensor Network
UWB	Ultra Wide Band
MSE	Mean Square Error
CSP	Cloud Service Provider

SaaS	Software as a Service
PaaS	Platform as a Service
IaaS	Infrastructure as a Service
CD	compact Disc
DVD	Digital Video Disc
BMA	Block Matching Algorithm
FC	Frame Copy
FI	Frame Interpolation
IV	Input Video
OV	Output Video
IB	Input Block
RB	Reference Block
SW	Search Window
TDLS	Two Dimensional Logarithmic Search
SES	Simple and Efficient Search
ARPS	Adaptive Rood Pattern Search
SSD	Sum of Square Difference
SHD	Sum of Hamming Distance
MAD	Minimum Absolute Difference
LSAD	Locally scaled SAD
LSSD	Locally scaled SSD
ZSAD	Zero-mean SAD
ZSSD	Zero-mean SAD

NCC	Normalised Cross Correlation
ZNCC	Zero-mean NCC
IFC	Intelligent Frame Creation
CF	Concealed Frame
AFO	Adaptive Filter Output
AMF	Adaptive Mean Filter
RAM	Random Access Memory
SNR	Signal-to-Noise-Ratio
SFI	Scalable Frame Interpolation
TZS	Test Zone Search
RS	Raster Search
FME	Forward Motion Estimation
FMV	Forward Motion Vector
BME	Backward Motion Estimation
BMV	Backward Motion Vector
MSN	Multimedia Sensor Node
IPS	Indirect Path from Sender
ACK	Acknowledgement
NACK	Negative ACK
IoT	Internet of Things
SDN	Software Defined Network

Abstract

Real-time video transmission over unreliable wireless networks remains a serious challenge due to bandwidth limitation and sensitive nature of video bitstreams generated by today's complex video encoders, e.g., High Efficiency Video Coding (HEVC/H.265). These compressed video bitsreams face packet-drop problem when transmitted over unreliable wireless networks. The effect of packet-drop on the received video quality can be minimised in two ways 1) increasing Quality of Service (QoS) by adopting efficient routing schemes between source and destination, and 2) maintaining video quality at receiver's side by applying smart and real-time-based Error Concealment (EC) techniques. The QoS refers to the capability of a transmission network to provide better service to selected network traffic. It is a generic term and can be applied to any data transmission network. The term video quality refers to perceived video degradation and is compared to the original video. In this dissertation, we explore the above mentioned two ways and propose a comprehensive solution for real-time video transmission over unreliable networks with the contributions as follows.

1. An efficient, lightweight and real-time EC algorithm is proposed to conceal the missing/lost video frames in H.265 encoded HD videos. The EC algorithm is based on threshold-based distributed Motion Estimation (ME) scheme and utilises only two video frames to estimate the missing one, thus eliminating the need for a large buffer and processing of a bundle of video frames to estimate the missing one.

2. Scalable video coding produces multiple interrelated bitstreams of a single video with different bitrates. For scalable bitstreams, we propose a lightweight and real-time EC algorithm to cover up the effects of missing/lost video frames. Due to complicated nature of scalable video bitstreams, our proposed EC algorithm utilises three previously processed video frames along with their master video frames to perform threshold-based distributed ME to estimate the missing video frames in

enhancement layer.

3. We propose a feed-back-based on-demand multipath routing scheme over a multi-hop Wireless Multimedia Sensor Network (WMSN) to ensure the QoS. The feed-back helps in deciding the optimum path between sources and destinations and reduces the Packets Loss Ratio (PLR) during the transmissions. On-demand connection assists in saving the available network resources while multipath routing aids in maintaining the connection between sources and destinations.

The proposed research makes notable contributions to designing a QoS-supported HD video streaming paradigm to deliver HD videos over unreliable networks and to maintain the received video quality on resource-constrained mobile terminals.

List of Publications

Journal Papers

1. Muhammad Usman, Xiangjian He, Kin-Man Lam, Min Xu, Syed Mohsin Matloob Bokhari, and Jinjun Chen, Frame Interpolation for Cloud-Based Mobile Video Streaming, IEEE Transactions on Multimedia, vol. 18, No. 05, pp.831-839, 2016.
2. Muhammad Usman, Xiangjian He, Kin-Man Lam, Min Xu, Syed Mohsin Matloob Bokhari, and Jinjun Chen, Cloud-Hosted and Assisted Scalable Video Coding and Concealment for High Definition Videos, IEEE Transactions on Cloud Computing, (Accepted for Publication on 22 July 2017).
3. Muhammad Usman, Mian Ahmad Jan, Xiangjian He, Min Xu, and Kin-Man Lam, A Joint Framework for QoS and QoE for Video Transmission over Wireless Multimedia Sensor Networks, IEEE Transactions on Mobile Computing, (Accepted for Publication on 03 August 2017).

Conference Papers

1. Muhammad Usman, Xiangjian He, Min Xu, and Kin-Man Lam, Survey of Error Concealment Techniques, Research Directions and Open Issues, 21st International Packet Video Workshop in Conjunction with 31st Picture Coding Symposium PCS, pp.233-238, 2015, IEEE).
2. Muhammad Usman, Mian Ahmad Jan, Xiangjian He, and Priyadarsi Nanda, Data Sharing in Secure Multimedia Wireless Sensor Networks, 15th International Conference on Trust, Security and Privacy in Computing and Communications (TrustCom), 2016, IEEE.