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ERROR RESILIENCE TECHNIQUES FOR WIRELESS 3-D VIDEO TRANSMISSION

A thesis submitted by

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Abstract

Three-dimensional (3-D) video has only recently become a buzzword. It offers a high quality and immersive multimedia experience on consumer electronic platforms. The year 2009 was a seminal year for 3-D video with the first successful film *Avatar* illustrated its use to a wide audience. As a result of advances in capturing, signal processing, transmission, and display technologies, both industry and academia are now focused on delivering 3-D media to home systems and to mobile devices. Wireless transmission of 3-D video content is expected to be the next big revolution in consumer multimedia applications. It faces many challenges in the processing chain from capture to display. Because of these challenges, this thesis investigates and presents a number of novel techniques for error resilience 3-D video transmission.

Four error resilience techniques for 3-D video transmission over wireless networks were proposed. The recent H.264/AVC standard and the video-plus-depth 3-D video format were adopted to assist in implementing these techniques. The proposed methods could also be applied to other video coding standards and to different 3-D video formats.

This thesis begins by investigating the standard error resilience source coding of H.246/AVC I-frame and of JPLW for still image transmission. Standard error resilience techniques are reviewed and compared. The experimental results show that H.264/AVC is much more robust in reducing transmission errors than JPWL.

The second part of the thesis proposes a new hierarchical 16-Quadrature amplitude modulation (QAM) based unequal error protection (UEP) scheme for

3-D video with depth image based rendering (DIBR). The video-plus-depth format is partitioned into two sequences, i.e., a color sequence and a depth sequence, according to their respective importance to the overall quality of the 3-D video. In this approach, the highly important color sequence is better protected with the most significant bits (MSBs) of 16-QAM, while the less important depth sequence uses the less significant bits (LSBs).

The third part of the thesis investigates the use of cooperative diversity to enhance the performance of high data rate communication over wireless fading channels. Although cooperative diversity has received much research attention recently, it has not yet been investigated in the context of unique characteristics of 3-D video transmission. In this part, the performance of a cooperative 3-D video system, with amplify-and-forward (AF) relaying, for UEP 3-D video transmission through best relay selection is investigated. In particular, closed-form expressions for outage probability and bit error probability (BEP) were developed. The results of the BEP, outage probability, and peak signal-to-noise ratio (PSNR) were presented to demonstrate the proposed UEP scheme in terms of the received quality of 3-D video.

Finally, for more efficient 3-D video transmission, relay selection and hierarchical quadrature amplitude modulation (HQAM) were joined because they help address the problems of diversity and robustness. This part is concerned with the use of hybrid relay networks and HQAM for improved UEP transmission of color-plus-depth 3-D representation. Hybrid relay selection along with HQAM was proposed as a method to overcome the decreases in video quality of high SNR values when HQAM was used alone. It has the advantages of both techniques at different SNR regions. Analytical expressions of the BER and outage probability of the SNR were given in closed-form.

The proposed techniques offer the opportunity for significant improvements over the existing techniques for 3-D video transmission. It is expected that these methods will find wide applications in future 3-D video systems and wireless networks such as 4G networks.

Dedicated to

My very unique and deceased ***mother****,*

My dear father, and Siblings,

My wife, and daughters (Ala, Asel, and Rahaf)

Certification of Dissertation

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged. I also certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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A/ Prof. John Lies, Associate supervisor Date

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Over nearly four years of my PhD journey, it has been a short time, short enough that I clearly remember my first day in Australia. Looking back at the joys and difficulties of this period of time, I have been lucky to work with my supervisors, research colleagues, friends and family.

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Khalid Mohamed Alajel

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List of Publications

During the course of this thesis, a number of journal and conference papers were published. These publications presented some of the major results discovered during the course of this thesis. The published papers are listed as follows:

A- Publications related to the contributions of the thesis

Fully refereed journal publications

Chapter 4

[1] Khalid Mohamed Alajel, Wei Xiang, and Yafeng Wang, "Unequal Error Protection Scheme Based Hierarchical 16-QAM for 3-D Video Transmission," *IEEE Transactions on Consumer Electronics*, Vol. 58, no. 3, pp. 731-738, Aug. 2012.

Chapter 5

[2] Khalid Mohamed Alajel, Wei Xiang, and Ibrahim Salih, "Unequal Error Protection for Robust 3-D Video Transmission Through Best Relays Selection," *Journal of Annals of Telecommunications*, (under review).

Fully refereed book chapters

Chapters 2 and 4

[3] Khalid Mohamed Alajel and Wei Xiang, "A new hierarchical 16-QAM based UEP scheme for 3-D video with depth imagebased rendering," in *Advanced Video Communications over Wireless Networks*, 1^{st} ed. C. Zhu and Y. Li, Eds. Bosa Roca, US: CRC Press, Ch. 12, 2013, pp. 355-382.

Fully refereed conference publications

Chapter 3

[4] Khalid Mohamed Alajel, Wei Xiang, and John Leis, "Performance analysis of error resilient wireless image transmission using H.264/AVC I-Frame," in *Proc. Southern Region Engineering Conference (SREC'10)*, Toowoomba, Australia, Nov. 2010, pp.78-80.

[5] Khalid Mohamed Alajel, Wei Xiang, and John Leis, "Error resilience performance evaluation of H.264 I-frame and JPWL for wireless image transmission," in *Proc. 4th International Conference on Signal Processing and Communication Systems (ICSPCS'10)*, Gold Coast, Australia, Dec. 2010, pp. 1-7.

Chapter 4

[6] Khalid Mohamed Alajel and Wei Xiang, "Color Plus Depth 3-D Video Transmission with Hierarchical 16-QAM," in *Proc. 3DTV-Conference 2012, The True Vision: Capture, Transmission and Display of 3D Video*, Zurich, Switzerland, Oct. 2012, pp. 1-4.

Chapter 5

[7] Khalid Mohamed Alajel, Wei Xiang, and Ibrahim Salih, "Best Relays Selection Method for Error-Resilient 3-D Video Transmission," in *Proc. IEEE 12th International Symposium on Communications and Information Technologies (ISCIT'12)*, Gold Coast, Queensland, Australia, Oct. 2012, pp. 1-5.

Chapter 6

[8] Ibrahim Salih, Khalid Mohamed Alajel, and Wei Xiang, "Cooperative relay selection based UEP scheme for 3-D video transmission over Rayleigh fading channel," in *Proc. IEEE International Conference on Digital Image Computing: Techniques and Applications (DICTA'11)*, Noosa, Queensland, Australia, Dec. 2011, pp. 689-693.

B- Other fully refereed conference publications

[9] Khalid Mohamed Alajel, Wei Xiang, and John Leis, "Face detection based

on skin color modeling and modified Hausdorff distance," in *Proc. 2011 IEEE Consumer Communications and Networking Conference (CCNC'11)*, Las Vegas, USA, June. 2011, pp. 78-80.

[10] Ibrahim Salih, Wei Xiang, and Khalid Mohamed Alajel, "Outage Probability of Unequal Block-Based OFDM Amplify-and-Forward Relay Protocol Over Wideband Channels," in *Proc. IEEE 12th International Symposium on Communications and Information Technologies (ISCIT'12)*, Gold Coast, Queensland, Australia, Oct. 2012, pp. 599-603.

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List of Acronyms

2-D	Two-dimensional
3-D	Three-dimensional
3DTV	Three dimensional television
3DTV-CON	Three dimensional television-conference
3G	Third generation
4G	Fourth generation
AF	Amplify-and-forward
AVC	Advanced video coding
AWGN	Additive white Gaussian noise
B	Bidirectional
BEP	Bit error probability
BER	Bit error rate
BMP	Bitmap
BPSK	Binary phase shift keying
CABAC	Context-adaptive binary arithmetic coding
CAVLC	Context-adaptive variable-length coding
CDF	Cumulative density function
CIF	Common intermediate format
CRC	Cyclic redundancy check
CSI	Channel state information
CSV	Conventional stereo video
DCP	Disparity compensation prediction
DCPM	Differential plus code modulation
DCT	Discrete cosine transform

DF	Decode-and-forward
DIBR	Depth image-based rendering
DP	Data partitioning
DSPLap	Digital signal processing lab
DT	Direct transmission
DTV	Digital television
DVB-H	Digital video broadcasting Handheld
DVB-T	Digital video broadcasting-terrestrial
DWT	Discrete wavelet transform
EBCOT	Embedded bitplane coding with optimal truncation
EEP	Equal error protection
EPB	Error protection block
EPC	Error protection capability
ESD	Error sensitivity descriptor
EZW	Embedded zerotree wavelet
FEC	Forward error correction
FMO	Flexible macroblock ordering
FVV	Free viewpoint video
GOP	Group of pictures
GSM	Global system for mobile communications
HDTV	High definition television
HEVC	High efficiency video coding
HM	Hierarchical modulation
HP	High priority
HQAM	Hierarchical quadrature amplitude modulation
HRSP	Hybrid relay selection protocol
HVS	Human visual system
IDR	Instantaneous decoder refresh
IEEE	Institute of electrical and electronics engineers
I-frame	Intra-frame
I.I.D	Independent and identically distributed
IP	Internet protocol

ISO	International organization for standardization
ITU-T	International telecommunication union-telecommunication
JMVC	Joint multiview video coding
JPWL	Wireless JPEG2000
JSCC	Joint source channel coding
JVT	Joint video team
LDPC	Low density parity check
LDV	Layered depth video
LP	Low priority
LSBs	Less significant bits
MBAmap	Macroblock allocation map
MBs	Macroblocks
MCP	Motion compensation prediction
MDC	Multiple description coding
MGF	Moment generation function
MDC	Multiple description coding
MIMO	Multiple-input-multiple-output
MP	Main-profile
MPEG	Moving picture expert group
MRC	Maximum ratio combining
MRS	Mixed resolution stereoscopic
MSBs	Most significant bits
MSE	Mean squared error
MVC	Multiview coding
MVD	Multiview video-plus-depth
MVE	Motion vector extrapolation
MVV	Multiview video
NAL	Network abstraction layer
NALU	Network abstraction layer unit
OFDM	Orthogonal frequency division multiplexing
P	Predictive
PAM	Pulse amplitude modulation

PDF	Probability density function
PS	Picture segmentation
PSK	phase-shift keying
PSNR	peak signal-to-noise ratio
QAM	Quadrature amplitude modulation
QoE	Quality of experience
QoS	Quality of services
QP	Quantization parameters
QPSK	Quadrature phase shift keying
RCPC	Rate compatible punctured codes
R-D	Rate-distortion
RED	Residual error descriptor
R-S	Reed-Solomon
RS	Redundant slice
SEI	Supplement enhancement information
SEP	Symbol error probability
SER	Symbol error rate
SG	Slice groups
SNR	Signal-to-noise-ratio
SPIHT	Set partitioning in hierarchical trees
STC	Space-time code
SVC	Scalable video coding
TC	Turbo code
TV	Television
UEP	Unequal error protection
VCEG	Video coding expert group
VCL	Video coding layer
VLC	Variable-length code
V+D	Video-plus-depth
YUV	A color space
ZPS	Zero parallax setting