# List of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Effect of errors in a frame of compressed video (a) Original frame (b) Affecting image locally, (c) Error affecting image globally, and (d)-(f) Effect of error propagation from first to next two frames.</td>
<td>4</td>
</tr>
<tr>
<td>2.1</td>
<td>Basic Block diagram of Video Communication</td>
<td>12</td>
</tr>
<tr>
<td>2.2</td>
<td>Basic Image and Video structure</td>
<td>12</td>
</tr>
<tr>
<td>2.3</td>
<td>YUV colour format with various chrominance sub-sampling (a) 4:4:4 format (no sub-sampling), (b) 4:2:2 format, (c) 4:1:1 format and (d) 4:2:0 format</td>
<td>14</td>
</tr>
<tr>
<td>2.4</td>
<td>Video quality assessment scale used in subjective tests</td>
<td>17</td>
</tr>
<tr>
<td>2.5</td>
<td>Different stages of video compression</td>
<td>18</td>
</tr>
<tr>
<td>2.6</td>
<td>Block diagram of a generic hybrid video coder</td>
<td>20</td>
</tr>
<tr>
<td>2.7</td>
<td>Block diagram of a 3-D wavelet video codec</td>
<td>22</td>
</tr>
<tr>
<td>2.8</td>
<td>3-D wavelet decomposition of a GOF of sixteen frames (a) input GOF and (b) the resulting spatio-temporal subbands for 4-levels of spatial and temporal decomposition</td>
<td>23</td>
</tr>
<tr>
<td>2.9</td>
<td>Principles of layered scalability</td>
<td>24</td>
</tr>
<tr>
<td>2.10</td>
<td>RS codeword structure</td>
<td>27</td>
</tr>
<tr>
<td>2.11</td>
<td>Signal space constellation diagram for $M = 4$ and $M = 16$ QAM</td>
<td>30</td>
</tr>
<tr>
<td>2.12</td>
<td>Bit error rate performance of QAM</td>
<td>31</td>
</tr>
<tr>
<td>2.13</td>
<td>The AWGN channel</td>
<td>32</td>
</tr>
<tr>
<td>2.14</td>
<td>Probability density function of Gaussian distribution for various parameter $\mu$ and $\sigma^2$</td>
<td>33</td>
</tr>
<tr>
<td>3.1</td>
<td>Constellation diagram of 4 Hierarchical PAM</td>
<td>45</td>
</tr>
<tr>
<td>3.2</td>
<td>Constellation diagram of general 16 Hierarchical QAM</td>
<td>51</td>
</tr>
<tr>
<td>3.3</td>
<td>Constellation diagram of Two Priority 16 Hierarchical QAM</td>
<td>56</td>
</tr>
<tr>
<td>3.4</td>
<td>BER performance of HP and LP bits for different values of $\alpha$</td>
<td>59</td>
</tr>
<tr>
<td>3.5</td>
<td>BER performance comparison of HP and LP bits with QPSK</td>
<td>60</td>
</tr>
<tr>
<td>3.6</td>
<td>Bit distribution of wavelet based video coded bitstream</td>
<td>61</td>
</tr>
</tbody>
</table>
3.7 Partitioning of bits in the video bitstream into HP substream and LP substream .................. 63
3.8 Proposed UEP scheme using HQAM .................. 64
3.9 Decoded video quality (PSNR) for different CNR and $\alpha$ using physical layer UEP with 16-HQAM at 1000 kbps (contd...) ........ 65
3.9 Decoded video quality (PSNR) for different CNR and $\alpha$ using physical layer UEP with 16-HQAM at 1000 kbps (contd...) ........ 66
3.9 Decoded video quality (PSNR) for different CNR and $\alpha$ using physical layer UEP with 16-HQAM at 1000 kbps ........ 67
3.10 Multilevel UEP scheme using efficiently mapped HQAM ........ 69
3.11 Decoded video quality (PSNR) for different CNR and $\alpha$ using UEP with adaptive 16-HQAM at 1000 kbps for akiyo sequence (contd...) 72
3.11 Decoded video quality (PSNR) for different CNR and $\alpha$ using UEP with adaptive 16-HQAM at 1000 kbps for akiyo sequence .......... 73
3.12 Decoded video quality (PSNR) for different CNR and $\alpha$ using UEP with adaptive 16-HQAM at 1000 kbps for football sequence (contd...) 74
3.12 Decoded video quality (PSNR) for different CNR and $\alpha$ using UEP with adaptive 16-HQAM at 1000 kbps for football sequence .......... 75
3.13 Decoded video quality (PSNR) for different CNR and $\alpha$ using UEP with adaptive 16-HQAM at 1000 kbps for foreman sequence (contd...) 76
3.13 Decoded video quality (PSNR) for different CNR and $\alpha$ using UEP with adaptive 16-HQAM at 1000 kbps for foreman sequence .......... 77
3.14 Decoded video quality (PSNR) for different CNR and $\alpha$ using UEP with adaptive 16-HQAM at 1000 kbps for flower garden sequence (contd...) .................. 78
3.14 Decoded video quality (PSNR) for different CNR and $\alpha$ using UEP with adaptive 16-HQAM at 1000 kbps for flower garden sequence .......... 79
3.15 Decoded video quality (PSNR) for different CNR and $\alpha$ using UEP with adaptive 16-HQAM at 1000 kbps for hall sequence (contd...) 80
3.15 Decoded video quality (PSNR) for different CNR and $\alpha$ using UEP with adaptive 16-HQAM at 1000 kbps for hall sequence .......... 81
3.16 Decoded video quality (PSNR) for different CNR and $\alpha$ using UEP with adaptive 16-HQAM at 1000 kbps for mobile sequence (contd...) 82
3.16 Decoded video quality (PSNR) for different CNR and $\alpha$ using UEP with adaptive 16-HQAM at 1000 kbps for mobile sequence .......... 83

4.1 Variations of bit error rates (BER) of LP and HP bits with $\alpha$ .. 89
4.2 Proposed optimized UEP scheme using HQAM .................. 89
4.3 PSNR vs $\alpha$ at different CNR at 1000 kbps (contd...) ........ 91
4.3 PSNR vs $\alpha$ at different CNR at 1000 kbps (contd...)  
4.3 PSNR vs $\alpha$ at different CNR at 1000 kbps  
4.4 Performance comparison between $\alpha$ at exact maximum PSNR, $\alpha_m$ and optimized $\alpha$ at approximated maximum PSNR obtained by the algorithm, $\alpha_{opt}$ for football sequence: (a) $\alpha$ vs CNR; (b) PSNR vs CNR for corresponding $\alpha$ plotted in (a)  
4.5 Optimum $\alpha$ vs CNR for all seven sequences and their average at 1000kbps  
4.6 Comparison of average $\alpha_{opt}$ at different bit rates  
4.7 $\Delta$PSNR (at average $\alpha$ and optimized $\alpha$) vs CNR for all sequence at 1000kbps  
4.8 Performance comparison of different HQAM based UEP schemes at 1000 kbps (contd...)  
4.8 Performance comparison of different HQAM based UEP schemes at 1000 kbps (contd...)  
4.8 Performance comparison of different HQAM based UEP schemes at 1000 kbps  
4.9 Effect of discarding LP bits in the reconstruction of video transmitted using optimized UEP with adaptive HQAM (contd...)  
4.9 Effect of discarding LP bits in the reconstruction of video transmitted using optimized UEP with adaptive HQAM (contd...)  
4.9 Effect of discarding LP bits in the reconstruction of video transmitted using optimized UEP with adaptive HQAM  
4.10 Performance of the optimized UEP schemes using adaptive HQAM for non-test sequences  
4.11 Subjective Quality Comparison of various schemes for first 5 frames of Foreman sequence coded at 1000 kbps, corrupted through AWGN channel at CNR=16 dB: (a) no error; (b) EEP; (c) HQAM at $\alpha_{opt}$; (d) HQAM at $\alpha_{opt}$ with adaptive bit reassembly at the decoder.  
5.1 A video transmission system using EEP only  
5.2 Structure of FEC coded video bitstream for EEP  
5.3 BER vs CNR for RS channel code based FEC using 16QAM over AWGN channel  
5.4 PSNR vs CNR for different value of channel coder rate, $r$, at transmission rate of 1000 kbps for (a) Akiyo sequence and (b) Foreman sequence  
5.5 A video transmission system using optimized EEP only
5.6 PSNR vs \( r \) for different value of CNR, at transmission rate of 1000 kbps for (a) Akiyo and (b) Foreman sequences 122
5.7 The optimal code rate, \( r_{opt} \), for each CNR (a) actual \( r_{opt} \) Vs CNR for each video sequence (b) according to proposed algorithm 126
5.8 Deviation of the PSNR obtained at average and individual optimized \( r \) for each test sequence 128
5.9 PSNR vs CNR for optimized EEP using FEC at 1000 kbps (contd...) 129
5.9 PSNR vs CNR for optimized EEP using FEC at 1000 kbps (contd...) 130
5.9 PSNR vs CNR for optimized EEP using FEC at 1000 kbps 131
5.10 UEP scheme of video transmission system using FEC only 132
5.11 Organization and partitioning of bits in the video bitstream into HP and LP substreams 133
5.12 Partitioning and providing FEC to HP and LP bits 134
5.13 Bit error rate performance of UEP using FEC for \( r_{avg} = 0.76 \) at different values of \( \gamma \). 136
5.14 Reconstructed video quality at different CNR at application layer UEP using FEC for Foreman sequence at transmission rate of 1000 kbps for (a) \( r_{avg} = 0.76 \) and (b) \( r_{avg} = 0.69 \) 137
5.15 UEP scheme of video transmission system using optimized FEC 138
5.16 The optimum parameters for maximizing the video quality at each CNR in FEC-based UEP for all seven test sequences (a) \( r_{opt}^{avg} \) vs CNR (b) \( \gamma_{opt} \) vs CNR 141
5.17 The optimum parameters for maximizing the video quality obtained using proposed algorithm (a) \( r_{opt}^{avg} \) vs CNR (b) \( \gamma_{opt} \) vs CNR 142
5.18 Subjective Quality Comparison between UEP scheme and other schemes for first 5 frame of Foreman sequence at 1000 kbps, corrupted through AWGN channel at CNR = 16 dB: (a) no error; (b) No channel coding; (c) Non-optimized UEP with \( r_{avg} = 0.80 \) and \( \gamma = 1.34 \); (d) Proposed UEP scheme with \( r_{opt}^{avg} \) and \( \gamma_{opt} \). 144

6.1 Cross-layer approach to achieve UEP in a video communication system 148
6.2 Video communication system using cross-layer UEP scheme 149
6.3 The objective quality of reconstructed Foreman sequence coded at 1000 kbps against different noisy conditions for cross-layer UEP (combining application layer EEP and physical layer UEP) for (a) \( r_{avg} = 0.76 \) and (b) \( r_{avg} = 0.69 \) 151
6.4 Objective quality of Foreman video sequence coded at 1000 kbps against different noisy condition for cross-layer UEP (combining application and physical layers UEP) at (a) $r_{avg} = 0.76$ and (b) $r_{avg} = 0.69$ .................................................. 152

6.5 Block diagram of a video communication system using optimized cross-layer UEP scheme .................................................. 153

6.6 PSNR vs $\alpha$ and $r_{avg}$ for different CNR at 1000 kbps for foreman sequence keeping $\gamma = 1$ (contd...) ........................................... 157

6.6 PSNR vs $\alpha$ and $r_{avg}$ for different CNR at 1000 kbps for foreman sequence keeping $\gamma = 1$ .................................................. 158

6.7 Variations of cross-layer parameters, $r_{avg}^{opt}$, $\gamma_{opt}$ and $\alpha_{opt}$ with CNR for seven test sequences (contd...) ........................................... 163

6.7 Variations of cross-layer parameters, $r_{avg}^{opt}$, $\gamma_{opt}$ and $\alpha_{opt}$ with CNR for seven test sequences ........................................... 164

6.8 Deviation of the PSNR obtained at actual optimized, and average optimized parameters, $r_{avg}^{opt}$, $\gamma_{opt}$ and $\alpha_{opt}$, for each test sequence ........................................... 164

6.9 Comparison of optimized cross-layer UEP with optimal physical and application layer UEP at 1000 kbps. (contd...) ......................... 166

6.9 Comparison of optimized cross-layer UEP with optimal physical and application layer UEP at 1000 kbps. (contd...) ......................... 167

6.9 Comparison of optimized cross-layer UEP with optimal physical and application layer UEP at 1000 kbps ......................... 168

6.10 Performance of cross-layer UEP using Adaptive reassembly with considering and discarding LP substream at 1000 kbps (contd...) ............ 170

6.10 Performance of cross-layer UEP using Adaptive reassembly with considering and discarding LP substream at 1000 kbps (contd...) ............ 171

6.10 Performance of cross-layer UEP using Adaptive reassembly with considering and discarding LP substream at 1000 kbps ......................... 172

6.11 Subjective Quality Comparison between optimized cross-layer UEP scheme with other schemes for first 5 frame of Foreman sequence at 1000 kbps, corrupted through AWGN channel at CNR = 10 dB: (a) No UEP scheme (Only QAM); (b) Optimized physical layer UEP using HQAM only; (c) Optimized application layer UEP using FEC only; (d) Optimized cross-layer UEP (combining application and physical layers UEP) considering LP substream; (e) Optimized cross-layer UEP discarding LP substream ................. 174

6.12 Non-test sequence performance for cross-layer optimized UEP using Adaptive reassembly with considering and discarding LP substream at 1000 kbps ........................................... 175
List of Figures

A.1 Akiyo ....................................................... 181
A.2 Foreman .................................................... 182
A.3 Football ..................................................... 182
A.4 Flower Garden ............................................. 183
A.5 Hall Monitor ............................................... 183
A.6 Mobile ...................................................... 184
A.7 Bus ......................................................... 184
A.8 Coastguard ............................................... 185
A.9 Container .................................................. 185