TOPICS IN DIGITAL TV PART 2: 
INTRODUCTION TO 
MPEG-4 AVC TECHNOLOGY 
(AND ADVANCED AUDIO)

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<table>
<thead>
<tr>
<th>Terminology</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPEG-2</td>
<td>The ubiquitous video codec standard used in digital television today – Terrestrial Broadcasting, Cable, DBS, DVD-V</td>
</tr>
<tr>
<td>H.262</td>
<td></td>
</tr>
<tr>
<td>MPEG-4 Part 2</td>
<td></td>
</tr>
<tr>
<td>MPEG-4 SP/ASP</td>
<td>A follow-on video codec standard – not widely used for DTV (therefore not discussed further here!)</td>
</tr>
<tr>
<td>MPEG-4 AVC</td>
<td></td>
</tr>
<tr>
<td>H.264</td>
<td></td>
</tr>
<tr>
<td>MPEG-4 Part 10</td>
<td>Advanced Video Codec (AVC) – The next generation video codec standard jointly developed by ISO/IEC MPEG and ITU-T VCEG</td>
</tr>
<tr>
<td>“JVT”</td>
<td></td>
</tr>
</tbody>
</table>

*Due to ambiguity, “MPEG-4” should never be used without a qualifier, i.e. “MPEG-4 AVC”*
MPEG-2 video is close to its limit

... but MPEG-4 AVC continues on

Bit-Rate for Broadcast Quality Television (SD)

- First Broadcast MPEG-2 Encoder
- Statistical Multiplexer Enhancements
- Enhanced Motion Estimation
- Noise Reduction
- Advanced Pre-processing

Year

Bit-Rate (Mbps)


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SIMILARLY FOR HD: MPEG-2 IMPROVEMENTS HAVE SLOWED

... BUT MPEG-4 AVC CONTINUES ON

<table>
<thead>
<tr>
<th>Bit rate for Broadcast Quality HDTV</th>
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<tbody>
<tr>
<td>Bit-Rate (Mbps)</td>
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<table>
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<td>2007</td>
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<td>2009</td>
</tr>
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<td>2010</td>
</tr>
</tbody>
</table>

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ITU | ISO/IEC MPEG-RELATED VIDEO COMPRESSION FAMILY TREE

- ISO/IEC MPEG-1
- ISO/IEC MPEG-2
  - ITU-T H.262
  - ITU-T H.263
- ISO/IEC MPEG-4 Part 2
- Joint Video Team (JVT)
  - ISO/IEC MPEG-4 AVC
  - ITU-T H.264
- ITU-T H.261
- ITU-T H.263++
- ITU-T H.26L
- ITU-T H.264
## APPLICATIONS ➔ VIDEO PROFILES/LEVELS

<table>
<thead>
<tr>
<th>Application</th>
<th>MPEG-2 Video (H.262)</th>
<th>MPEG-4 AVC (H.264)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobile Devices</td>
<td>-</td>
<td>Baseline (not a subset of Main Profile)</td>
</tr>
<tr>
<td>Video Conferencing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internet Streaming</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Broadcast Quality (TV, Cinema, IPTV)</td>
<td>Main Profile</td>
<td>Main Profile</td>
</tr>
<tr>
<td></td>
<td>SD: Main Level</td>
<td>SD: Level 3</td>
</tr>
<tr>
<td></td>
<td>HD: High Level</td>
<td>HD: Level 4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High Profile</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SD: Level 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HD: Level 4</td>
</tr>
</tbody>
</table>
MPEG-4 AVC VS. MPEG-2 VIDEO BIT-RATES

› HD: 40-60% more efficient than best MPEG-2
› SD: 30-50%
› Will continue to improve further

› Examples*
  – HD: MPEG-2 Video @13-18Mbps → MPEG-4 AVC @5-10Mbps
  – SD: MPEG-2 @2.5-3.5Mbps → MPEG-4 AVC @1.2-2.5Mbps

*full resolution; varies greatly by content
OVERALL GOAL OF COMPRESSION

› Encode the smallest amount of information for a given “quality” level

› Remove spatial and temporal redundancies
  - Take advantage of deficiencies in the human visual/aural systems vs. pure mathematics

› Encode only residual or “error” signal
  - Frame “reconstruction” used to compare next frame with previous frame
  - Internal feedback loop in encoder matches decoder operation

› Better match between reconstructed frame and next frame = smaller residual = fewer bits to encode

› Encoder makes difficult decisions of how to compress efficiently (using the tool kit)
  - Decoder follows “directions” defined in received bit stream
PRINCIPLES OF COMPRESSION

› Encoders use the advantage of redundancy in moving images
  - Similarity within a frame (spatial redundancy)
  - Similarity between frames (temporal redundancy)

› Encoders create a prediction for the decoder to use
  - Then send the error signal giving the difference between the prediction and the actual

› Minimizing the error signal minimizes the data to be sent
  - Maximizes coding performance

› Generating a better prediction gives better coding performance
  - MPEG-4 AVC generates a better prediction than MPEG-2 Video

› Better coding of the error signal gives better coding performance
  - MPEG-4 AVC codes the error signal better than MPEG-2 Video
**GENERIC ENCODER BLOCK DIAGRAM**

- **Pre-Processing**
  - Removes temporal redundancy

- **Temporal Model**
  - Frame differences

- **Spatial Model**
  - Coefficients
  - Removes spatial redundancy

- **Previous/Future Frames**
  - Lossless compression

- **Entropy Encoder**
  - Vectors
  - Encoded Bit-stream

Adapted from “H.264 and MPEG-4 Video Compression”, Iain E.G. Richardson
MPEG-4 AVC VS. MPEG-2 VIDEO: WHY/HOW IS IT BETTER?

Lower bit rates from technology advances and improved tools

› Technology → Moore’s Law
  – MPEG-2 standards developed over 10 years ago
  – ~1992: IC tech >1 micron, memory >$50/MB, processors <500MHz
  – ~2006: IC tech <0.1 micron, memory <$50/GB, processors >3GHz

› Improved tools → Similar overall signal processing flows – but with more and improved algorithmic tools
  – Signal processing stage: More parallel processing and more memory look-ups/stores, with selection of most bit-efficient result
  – Bit stream syntax: More efficient use of “overhead”/structure
  – Bit stream processing stage: More computationally intensive entropy coding
MPEG-2 VS. MPEG-4 AVC OVERVIEW

› Intra Prediction Modes – fixed vs. many
› Inter Prediction Modes – some vs. many
› Motion Compensation – $\frac{1}{2}$ pel vs. $\frac{1}{4}$ pel
› Transform – 8x8 vs. adaptive block size (4x4, 8x8)
› Transform – DCT vs. simpler integer
› Deblocking Filter – none vs. in-loop
› Entropy Coder – fixed vs. context adaptive
MPEG-2 ENCODER

Frame \( i \) (current)

Frame \( i-1 \) (reconstructed references)

Motion Vector Prediction

Motion Estimation

Motion Compensation

Transform

Quantize

Zigzag Scan & Run Length Encode

Entropy Coding

Restored frame \( Fr \)

Motion vector predicted block

Intra coding

Inter coding

Fm

Er

Fm
MPEG-4 AVC REFERENCE ENCODER

Frame $n$ (current)

Frame $n-x$ (reconstructed references)

Motion Vector Prediction

Motion Estimation

Intra Prediction Mode Select

Intra Prediction

In Loop Filter

Transform

Quantize

Zig-zag Scan & Run Length Encode

Entropy Coding

Motion Compensation

Inter coding

predicted block

Intra coding

Inverse Transform

Inverse Quantize

+ -

Zig-zag Scan & Run Length Encode
MPEG-2 VS. MPEG-4 AVC: INTRA PREDICTION MODES

Block to Intra Code

MPEG-2 Modes

MPEG-4 AVC Modes

Prediction

Error Signal Encoded

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MPEG-2: INTER PREDICTION MODES

Block to Predict

16x16

16x8

Reference Picture
MPEG-4 AVC: INTER PREDICTION MODES
MOTION ESTIMATION

Motion estimation is used to identify moving image content in order to better exploit temporal redundancy.

Source: H.264 and MPEG-4 Video Compression, Iain E. G. Richardson, Wiley
MOTION ESTIMATION

Motion searching during encoding identifies the “best fit” between the current picture macroblock and the reference picture(s)

Frame N + 1

Source: H.264 and MPEG-4 Video Compression, Iain E. G. Richardson, Wiley
MOTION ESTIMATION

Only differences between pictures are encoded

Source: H.264 and MPEG-4 Video Compression, Iain E. G. Richardson, Wiley

Delta No ME
MOTION ESTIMATION

Source: H.264 and MPEG-4 Video Compression, Iain E. G. Richardson, Wiley

Delta 16x16 ME
MOTION ESTIMATION

Source: H.264 and MPEG-4 Video Compression, Iain E. G. Richardson, Wiley

Delta 8x8 ME
MOTION ESTIMATION

Delta 4x4 ME

Source: H.264 and MPEG-4 Video Compression, Iain E. G. Richardson, Wiley
MOTION ESTIMATION

MPEG-4 AVC provides more ME block sizes

Appropriate block size choices

MPEG-2
- 16x16

MPEG-4 AVC
- 16x16
- 16x8, 8x16
- 8x8
- 8x4, 4x8
- 4x4

Source: H.264 and MPEG-4 Video Compression, Iain E. G. Richardson, Wiley
MPEG-2 VS. MPEG-4 AVC: QUARTER PEL MOTION COMPENSATION

Motion Comp Options
- Integer Pixels
- Half pel (MPEG-2)
- Quarter pel (MPEG-4 AVC)
MPEG-2 VS. MPEG-4 AVC: TRANSFORM

› Smaller block size available than MPEG-2 (4x4 vs. 8x8*) and adaptive block-size selection
› Simpler transform (computationally easier but same effect)
MPEG-2 VS. MPEG-4 AVC: IN-LOOP DEBLOCKING FILTER

Without In-Loop Filter (MPEG-2 Video)  

With In-Loop Filter (MPEG-4 AVC)  

Picture taken from www.codex.com
MPEG-2 VS. MPEG-4 AVC: ENTROPY ENCODER

- Removes statistical redundancy from bit stream
- MPEG-2: Variable Length Coding
- MPEG-4 AVC: CABAC (Context-based Adaptive Binary Arithmetic Coding)
- Context-based coding -> Optimizes encoded bit string = reduces bits used
### Detailed Comparison of Tools (1 of 3)

<table>
<thead>
<tr>
<th>Tool</th>
<th>MPEG-2 Video (H.262)</th>
<th>MPEG-4 AVC (H.264)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Intra Prediction</strong></td>
<td>- None: MB encoded</td>
<td>- 4x4 Spatial Spatial</td>
</tr>
<tr>
<td></td>
<td>- DC predictors</td>
<td>- 16x16 Spatial</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- I_PCM</td>
</tr>
<tr>
<td><strong>Picture Coding Type</strong></td>
<td>- Frame</td>
<td>- Frame</td>
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<tr>
<td></td>
<td>- Field</td>
<td>- Field</td>
</tr>
<tr>
<td></td>
<td>- Picture AFF</td>
<td>- Picture AFF</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- MB AFF</td>
</tr>
<tr>
<td><strong>Motion Compensation Block Size</strong></td>
<td>- 16x16</td>
<td>- 16x16</td>
</tr>
<tr>
<td></td>
<td>- 16x8, 8x16</td>
<td>- 16x8, 8x16</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- 8x8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- 8x4, 4x8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- 4x4</td>
</tr>
</tbody>
</table>
# Detailed Comparison of Tools (2 of 3)

<table>
<thead>
<tr>
<th>Tool</th>
<th>MPEG-2 Video (H.262)</th>
<th>MPEG-4 AVC (H.264)</th>
</tr>
</thead>
</table>
| **Motion Vector Precision** | - Full Pel  
- Half Pel                                         | - Full Pel  
- Half Pel  
- Quarter Pel                                      |
| **P Frame Feature**   | - Single Reference                                       | - Single Reference  
- Multiple Reference                                    |
| **B Frame Feature**   | - 1 Reference Each Way                                   | - 1 Reference Each Way  
- Multiple Reference  
- Direct & Spatial Direct Modes  
- Weighted Prediction |
# Detailed Comparison of Tools (3 of 3)

<table>
<thead>
<tr>
<th>Tool</th>
<th>MPEG-2 Video (H.262)</th>
<th>MPEG-4 AVC (H.264)</th>
</tr>
</thead>
<tbody>
<tr>
<td>In-Loop Filters</td>
<td>- None</td>
<td>- De-Blocking</td>
</tr>
<tr>
<td>Entropy Coding</td>
<td>- VLC</td>
<td>- CAVLC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- CABAC</td>
</tr>
<tr>
<td>Transform</td>
<td>- 8x8 DCT</td>
<td>- 4x4 Integer “DCT”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- 8x8 Integer “DCT”</td>
</tr>
<tr>
<td>Other</td>
<td>- Quantization</td>
<td>- Quantization</td>
</tr>
<tr>
<td></td>
<td>Scaling Matrices</td>
<td>Scaling Matrices</td>
</tr>
</tbody>
</table>
# MPEG-4 AVC – MAJOR ALGORITHMIC ENHANCEMENTS

<table>
<thead>
<tr>
<th></th>
<th>MPEG-2</th>
<th>MPEG-4 AVC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Only one reference frame for P And two for B pictures</td>
<td>Multiple reference frames Bi-predictive modes for P and B pictures</td>
<td></td>
</tr>
<tr>
<td>Large square Motion Compensation blocks, 16x16</td>
<td>Various block shapes, down to 4x4</td>
<td></td>
</tr>
<tr>
<td>½ pel motion vector</td>
<td>¼ pel motion vector</td>
<td></td>
</tr>
<tr>
<td>8x8 DCT</td>
<td>4x4 integer transform</td>
<td></td>
</tr>
<tr>
<td>Single spatial prediction mode</td>
<td>Many intra prediction modes</td>
<td></td>
</tr>
<tr>
<td>Fixed quantization weighting</td>
<td>Integrated de-blocking filter</td>
<td></td>
</tr>
<tr>
<td>Variable Length Coding (Huffman)</td>
<td>Context Adaptive VLC and Context Adaptive Binary Arithmetic Coding</td>
<td></td>
</tr>
</tbody>
</table>
MPEG-4 AVC / H.264 VERSION 2
FIDELITY RANGE EXTENSIONS (“FREXT”)

› Version 1 primarily developed for direct-to-home (DTH) applications – broadcast, video discs, Internet

› Version 2 added Fidelity Range Extensions for professional applications
  – Contribution (front hauls), Distribution (back hauls)
  – Mastering, editing, archiving

› Extends color space and bit-depth (precision)

› More on this covered in “Video Compression Advances for Contribution & Distribution” (part of the IEEE BTS Distinguished Lecturer Program)
MPEG-4 AVC / H.264 EXTENSIONS: SCALABLE VIDEO CODING (SVC)

› Multi-layer encoding
  − The video bitstream contains one or more subset bitstreams that can each be decoded separately
  − Typically a Base Layer + one or more enhancement layers

› Useful for when a network or transmission medium has varying bandwidth

› Applications
  − Adaptive streaming
  − Tiered program offerings
  − Multi-device delivery (e.g., HDTV, PC, Mobile/Handheld)

› Profiles
  − Scalable Baseline (conversational, surveillance)
  − Scalable High (broadcast TV, streaming, storage)
  − Scalable High Intra (professional)

› Standard approved July 2007 (AVC Annex G)
  − Not yet widely deployed
SVC TYPES

› Temporal scalability (frame rate)
  - The video is encoded at multiple frame rates
  - The motion compensation dependencies are structured so that complete pictures can be dropped from the bitstream

› Spatial scalability (picture size)
  - The video is coded at multiple spatial resolutions
  - The data and decoded samples of lower resolutions can be used to predict data or samples of higher resolutions in order to reduce the bit-rate to code the higher resolutions

› SNR/Quality/Fidelity scalability
  - The video is coded at a single spatial resolution but at different qualities
  - The data and decoded samples of lower qualities can be used to predict data or samples of higher qualities in order to reduce the bit-rate to code the higher qualities
MPEG-4 AVC / H.264 EXTENSIONS: MULTIVIEW VIDEO CODING (MVC)

› Enables the efficient encoding of sequences captured simultaneously from multiple cameras using a single video stream

› Stereoscopic High Profile standardized in July 2009
  – First application: 3D content on Blu-ray Disc
  – Forward compatible with 2D decoders
    › Enhancement information is ignored and main layer can be decoded

› Other multiview Profiles are still work in progress

› The recent announcements regarding 3D broadcast TV do **not** use MVC
  – Most DTH providers initially will be using side-by-side interleaved pictures (1/2 horizontal resolution per eye)
WHAT ABOUT AUDIO?

› For the last few years digital broadcast channels have handled audio in the following formats
  - MPEG-1 Layer II
  - Linear PCM
  - Dolby E
  - Dolby Digital (2/0 and 5.1)
  - Digital Theater Sound (DTS)

› New audio formats have arisen
  - Advanced Audio Coding (AAC-LC and HE-AAC v1/v2)
  - Dolby Digital plus
  - Dolby Pulse
## NAME TRANSLATIONS (“WHAT’S IN A NAME”)

<table>
<thead>
<tr>
<th>Technology Name (standard)</th>
<th>Vendor Brand Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>AAC-LC</td>
<td>AAC</td>
</tr>
<tr>
<td>HE-AAC v1</td>
<td>aacPlus v1</td>
</tr>
<tr>
<td>HE-AAC v2</td>
<td>aacPlus v2</td>
</tr>
<tr>
<td>AC-3</td>
<td>Dolby® Digital</td>
</tr>
<tr>
<td>E-AC-3</td>
<td>Dolby® Digital Plus+</td>
</tr>
<tr>
<td>HE-AAC + metadata</td>
<td>Dolby Pulse</td>
</tr>
</tbody>
</table>

### Dictionary

- AAC: Advanced Audio Compression
- HE: High Efficiency
- LC: Low Complexity
- AC: Audio Coding
- E-AC: Enhanced Audio Coding
### DON'T FORGET AUDIO BIT-RATE PLANNING!

<table>
<thead>
<tr>
<th># of Audio Channels</th>
<th>MPEG Layer II</th>
<th>Dolby Digital (AC-3)</th>
<th>Dolby Digital Plus+</th>
<th>MPEG AAC-LC</th>
<th>MPEG HE-AAC</th>
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</thead>
<tbody>
<tr>
<td>Stereo</td>
<td>192kbps</td>
<td>192kbps</td>
<td>96kbps</td>
<td>96kbps</td>
<td>64kbps (v1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>48kbps (v2)</td>
</tr>
<tr>
<td>5.1</td>
<td>Not Supported</td>
<td>384kbps - 448kbps</td>
<td>&lt;320kbps</td>
<td>256kbps</td>
<td>160kbps</td>
</tr>
</tbody>
</table>

*Claimed rates for CD quality for average-complexity content*

- Audio bit-rates primary planning factor as video rates decrease
- Multiple languages per video service
- CBR – can’t be stat muxed

*For AVC SD, audio bit-rate allocation could be higher than video!*
When talking about advanced audio compression there are two things to consider:

› Compression algorithm
› Method of encapsulation
THE AAC COMPRESSION ALGORITHM FAMILY

› AAC
  - Core audio compression algorithms common to MPEG-2 and MPEG-4 standards

› HE-AAC v1
  = AAC + SBR tool

› HE-AAC v2
  = AAC + SBR + PS tools
  - Decoded as mono by HE-AAC v1 decoder

Dictionary

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>AAC</td>
<td>Advanced Audio Compression</td>
</tr>
<tr>
<td>HE</td>
<td>High Efficiency</td>
</tr>
<tr>
<td>LC</td>
<td>Low Complexity</td>
</tr>
<tr>
<td>SBR</td>
<td>Spectral Band Replication</td>
</tr>
<tr>
<td>PS</td>
<td>Parametric Stereo</td>
</tr>
</tbody>
</table>
MPEG-4 HIGH EFFICIENCY AUDIO PROFILE

› HE-AAC combines AAC-LC with 2 other audio coding techniques

› Spectral Band Replication
  – A bandwidth extension technique and audio coding enhancement tool
  – A method of high efficiency coding of high audio frequencies to supplement the performance of the main coder handling the lower part of the spectrum
  – HE-AAC (v1) = AAC-LC + SBR

› Parametric Stereo
  – A parametric representation of the stereo image of an audio signal is extracted and sent along with an encoded mono channel
  – In the decoder the full stereo audio signal is reproduced.
  – HE-AAC v2 = AAC-LC + SBR + PS
MPEG-4 HIGH EFFICIENCY AUDIO PROFILE

HE-ACC

AAC-LC + SBR + PS

HE-AAC v1

HE-AAC v2
**SBR AND PS**

- Spectral Band Replication processes the audio HF more efficiently and separately

- Parametric Stereo sends a mono signal with metadata
TYPICAL BIT-RATES (STEREO)

Source: ETSI TS 101.154
Compression algorithm vs. encapsulation

› **MPEG-2 AAC**
  - MPEG-2 AAC-LC (low complexity) profile is sometimes used for broadcast
    - This is common “AAC” format in Japan
  - Uses ADTS (Audio Data Transport Stream) encapsulation into MP2 Transport Stream
    - Theoretically, ADTS could be used for HE-AAC, but this is not recommended

› **MPEG-4 HE-AAC / MPEG-4 HE-AAC v2**
  - DVB recommends MPEG-4 HE-AAC profile for broadcast
  - Uses LATM/LOAS dual layer encapsulation into MP2 Transport Stream
    - LATM = Low-overhead Audio Transport Multiplex
    - LOAS = Low-Overhead Audio Stream
  - MPEG-4 HE-AAC v2 encoding often used for very low bit-rate apps
    - Picture-in-picture, mobile DTV
TRANSPORT STREAM DESCRIPTORS

MPEG-2 AAC (ADTS)
- PMT
  Stream Type – 15 (0xF)  
  Descriptor
    - Tag 121  
    - Length 2  
    - Data 51 00  
- PES
  Stream ID 0xC0

MPEG-4 HE-AAC (LATM/LOAS)
- PMT
  Stream type – 17 (0x11)  
  Descriptor
    - Tag 121  
    - Length 2  
    - Data 58 00  
- PES
  Stream ID 0xC0
## Quick Reference Guide to Audio Codecs

<table>
<thead>
<tr>
<th>Audio Codec</th>
<th>Application</th>
<th>Bit-rate</th>
<th>Market acceptance</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPEG Layer II (stereo)</td>
<td>SD</td>
<td>32-384 kbps</td>
<td>High</td>
<td>192 kbps* Outperforms mp3 &gt;256 kbps</td>
</tr>
<tr>
<td></td>
<td>music</td>
<td>32-320 kbps</td>
<td>High</td>
<td>128 kbps* Outperforms Layer II &lt;192kbps</td>
</tr>
<tr>
<td>MPEG Layer III (mp3, stereo)</td>
<td>SD or music</td>
<td>8-529 kbps</td>
<td>High</td>
<td>96 kbps* Outperforms others at any bit-rate, but requires more processing</td>
</tr>
<tr>
<td>MPEG AAC-LC (stereo)</td>
<td>SD or HD</td>
<td>8-529 kbps</td>
<td>High</td>
<td>256 kbps* Outperforms others at any bit-rate, but requires more processing</td>
</tr>
<tr>
<td>MPEG AAC-LC (5.1)</td>
<td>SD or HD</td>
<td>8-529 kbps</td>
<td>High</td>
<td></td>
</tr>
<tr>
<td>MPEG HE-AAC (stereo) (5.1)</td>
<td>PiP/handheld</td>
<td>8-256 kbps</td>
<td>Medium</td>
<td>v1: 48 kbps* v2: 32 kbps, 48 kbps* 160 kbps*</td>
</tr>
<tr>
<td>DOLBY DIGITAL (AC-3, stereo)</td>
<td>SD or HD</td>
<td>32-640 kbps (448 kbps limit in many apps)</td>
<td>High</td>
<td>192 kbps* best for special effects</td>
</tr>
<tr>
<td>DOLBY DIGITAL (AC-3, 5.1)</td>
<td>SD or HD</td>
<td>32-640 kbps (448 kbps limit)</td>
<td>High</td>
<td>384-448 kbps* best for special effects</td>
</tr>
</tbody>
</table>

*claimed rate for CD quality for average-complexity content*