# SoftCast

## One-Size-Fits-All Wireless Video

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# Outline

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# Definition

- SoftCast is an architecture for transmitting video over wireless channels.
- The conventional wireless design separates video transmission into two sub-problems:

1. encoding the video for compression.
2. encoding the compressed data to protect it from errors during transmission over the wireless channel.

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# Components

- SoftCast design encodes the video for compression and for error protection
- It allows multicast video to be delivered to multiple mobile receivers with each receiver obtaining video quality with respect to its specific instantaneous channel quality.
- Four linear components:

1. Compression.
2. Error Protection.
3. Resilience to Packet Loss.
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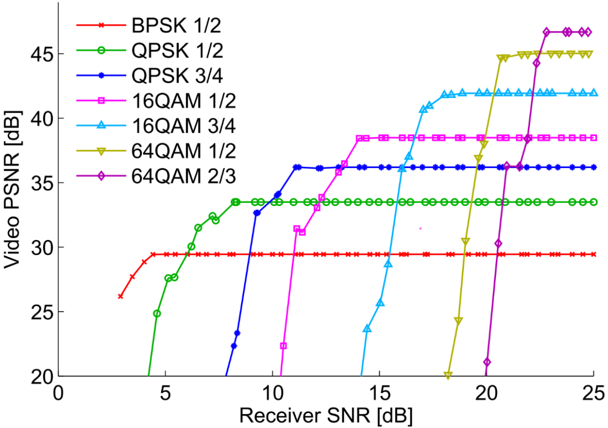
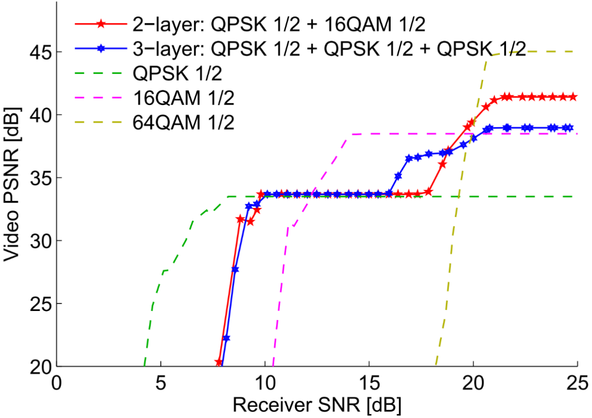
# Conventional Design



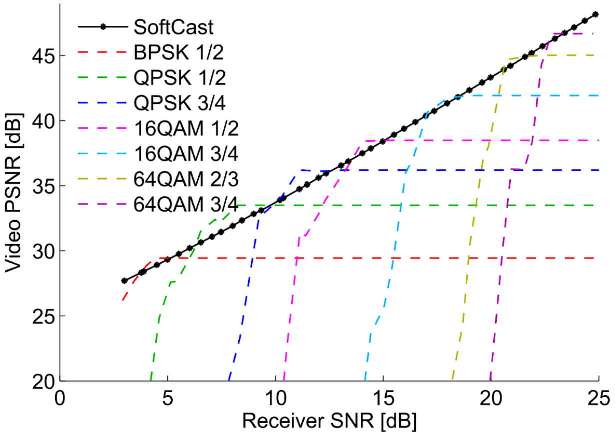

- This figure shows that for any selection of transmission bit rate the conventional design experiences a performance cliff.

# Effect of layered video




- This figure shows that layered video transforms the performance cliff of the conventional design to a few milder cliffs.

# Softcast Effect




- This figure shows that SoftCast's video quality is proportional to the channel quality and stays competitive with the envelope of all of MPEG curves

# Chunks

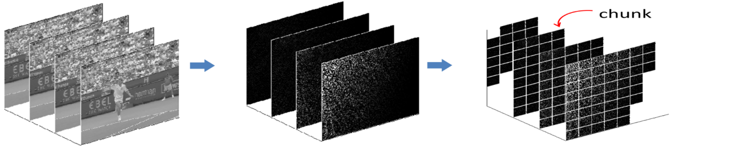
- Chunking is breaking large audio or video files into smaller, more manageable pieces called "chunks."
- The client receives these chunks and plays them in real-time, while simultaneously requesting the next chunk from the server.
- It allows the client to begin playing the audio or video immediately without waiting for the entire file to be downloaded.
- It avoids buffering and makes streaming possible over slow internet connections.
- Chunks can be processed in parallel.
- If any of the chunks is lost, it can be re-requested.

# Outline

# SoftCast Encoder: Video Compression.

- Treats pixel values in a GoP as a 3-dimensional matrix.
- It takes a 3-dimensional DCT transform of this matrix, transforming the data to its frequency representation.

# SoftCast Encoder: Video Compression.




(a) 4-frame GoP (b) 3D DCT of GoP (c) Discarding Zero-Valued Chunks

# SoftCast Encoder: Video Compression.

- Sends Non Zero values but sends metadata to the decoder about the locations of the discarded DCT components.
- SoftCast encoder informs the decoder of the locations of the nonzero chunks (which includes many DCT components).
- SoftCast sorts the chunks in decreasing order of their energy and picks chunks to fill the bandwidth with reconstruction error minimization.

$$Err = \sum_i \left( \sum_j (x_i[j] - \hat{x}_i[j])^2 \right)$$

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# SoftCast Encoder: Error Protection

- Tradition Error Protection: transform real value video data into bit sequence.
- SoftCast's: scaling the magnitude of the DCT components in a frame and finds a single optimal scaling factor for all the DCT components in each chunk.

# SoftCast Encoder: Error Protection

1. Model the values within each chunk as random variables from some distribution Di.
2. Remove the mean from each chunk to get zero-mean distributions and send the means as metadata.
3. Given the mean, the amount of information in each chunk is captured by its variance λi.
4. Compute the variance of each chunk, and define an optimization problem that finds the per-chunk scaling factors such that GoP reconstruction error is minimized.

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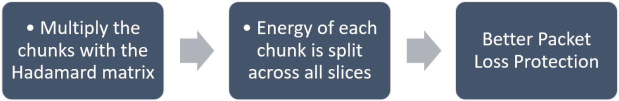
# SoftCast Encoder: Error Protection

$$u_i[j] = g_i x_i[j]$$

$$g_i = \lambda_i^{-1/4}\left(\sqrt{\frac{P}{\sum_i \sqrt{\lambda_i}}}\right)$$

# SoftCast Encoder: Resilient to Packet Loss

- SoftCast's approach ensures that all packets equally important.
- SoftCast transorms the chunks into equal-energy slices (each slice is a linear combination of all chunks).
- Transformation is done using Hadamard which is used in communications technology to redistribute energy.
- Packetization: Assigning slices to packets.



# SoftCast Encoder: Metadata

- Encoder sends video data and a small amount of metadata to assist the decoder in inverting the received signal.
- Encoder sends the mean and the variance of each chunk, and a bitmap that indicates the discarded chunks.
- Metadata compressed using Huffman coding.
- Protection of metadata from channel error: sent using BPSK modulation and half rate convolutional code (BPSK 1/2 : modulation scheme and FEC code corresponding to the lowest 802.11 bit rate).
- Each Softcast packet starts with a standard 802.11 header followed by the metadata then the coded video data
- Finally, the equation of encoding of a GoP: $Y = HGX = CX$

# Outline

# SoftCast Decoder: Linear Least Square Estimator (LLSE).

- Received GoP Values: $\hat{Y} = CX + N$
- Linear least square estimator is the solution to estimating original DCT components.
- It estimates the DCT components by leveraging knowledge of the statistics of the DCT components.
- $X_{LLSE} = \Delta_x C^T (C \Delta_x C^T + \sum)^{-1} \hat{Y}$
- At high SNR $\sum$ tends to 0 and hence we trust the measurement not the statistics.
- Thus LLSE becomes: $X_{LLSE} = C^{-1} \hat{Y}$
- Finally, applies 3D IDCT.

# SoftCast Decoder: Decoding in the Presence of Packet Loss.

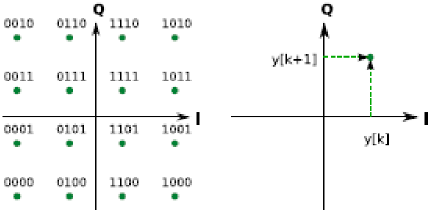
- When a packet is lost, SoftCast can match it to a slice, hence the absence of a row in $Y$.
- We define $Y_{*i}$ that represents $Y$ after removing i-th row. Likewise for $C$ & $N$.
- $X_{LLSE} = \Delta_x C_{*i}^T (C_{*i} \Delta_x C_{*i}^T + \sum_{(*i,*i)})^{-1} \hat{Y}_{*i}$
- SoftCast's approximation degrades gradually along with the loss of packets.
- No special packets in SoftCast whose loss causes the prevention of decoding process.

# SoftCast Decoder: Softcast's PHY Layer

- The PHY layer -in general- is responsible for error protection.
- Takes a stream of bits, codes them for error protection, then modulates them to produce real-value digital samples that are transmitted on the channel.
- Example: 16-QAM modulation takes sequences of 4 bits and maps each sequence to complex I/Q number.
- SoftCast's codec outputs real values that are already coded for error protection.
- We can then directly map the coded values to I & Q digital signal components.

# SoftCast Decoder: Softcast's PHY Layer

- A direct map of I/Q digital signal components of SoftCast can be represented easily.



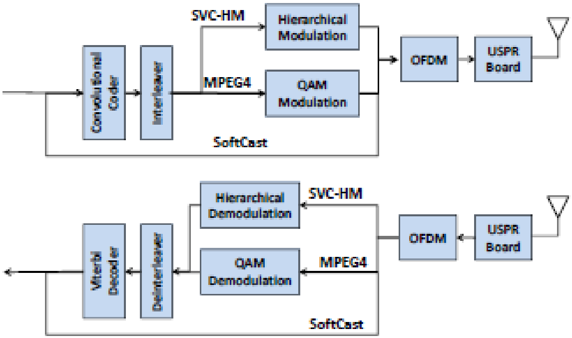
# Outline

# Implementation.

- We use the GNURadio to build a prototype of SoftCast and an evaluation infrastructure to compare it against two baselines: MPEG4 over an 802.11 PHY.
- Layered video where the video is coded using the scalable video extension (SVC) of H.264 and is transmitted over hierarchical modulation.

# Implementation: The Physical Layer

- It is built to allow the execution to branch depending on the evaluated video scheme.
- The PHY implementation is a slight upgrade over OFDM implementation in GNU Radio (in terms of incorporate pilot subcarriers & phase tracking).



# Implementation: The Physical Layer

- Universal Single Platform Radio: technology used in conjunction with OFDM in some wireless communication systems to provide robust and efficient wireless communication.
- OFDM performs carrier frequency offset (CFO) estimation and correction, channel estimation and correction, and phase tracking.

# Implementation: Video Coding

- SoftCast implementation is done in Python.
- We generate MPEG-4 streams using the H.264/AVC codec.
- We also generate the SVC stream using the JSVM implementation, which allows us to control the number of layers.
- All the schemes: MPEG4, SVC-HM, and SoftCast use a GoP of 16 frames.

# Outline

# Evaluation Environment: Test Bed

- We run our experiments in the 20-node GNURadio testbed.

# Evaluation Environment: Modulation

- We use the standard modulation and FEC, i.e., BPSK, QPSK, 16QAM, 64QAM and 1/2, 2/3, and 3/4 FEC code rates.
- The hierarchical modulation scheme uses QPSK for the base layer and 16QAM for the enhancement layer.

# Evaluation Environment: The Wireless Environment

- The carrier frequency is 2.4 GHz which is the same as that of 802.11.
- The channel bandwidth after decimation is 1.25 MHz.
- There is also an unavoidable interference between USRP radios and 802.11 WLANs (operate in same frequency band).
- In order to be able to avoid them, we run the experiments at night.

# Evaluation Environment: Metric

- We compare the schemes using the Peak Signal-to-Noise Ratio (PSNR). It is a standard metric for video quality.
- $PSNR = 20Log_{10}\frac{2^L-1}{\sqrt{MSE}}dB$
- L is the number of bits used to encode pixel luminance, typically 8.

# Evaluation Environment: Test Videos

- We use standard reference videos in the SIF format. (352x240 pixels, 30 fps)
- We also create one monochrome 480-frame test video due to variation of codec performance from video to another.
- We do that by splicing 32 frames (1 second) from each of 16 popular reference videos: akiyo, bus, coastguard, crew, flower, football, foreman, harbour, husky, ice, news, soccer, stefan, tempete, tennis, waterfall.

# Evaluation Environment: Other Parameters

- The packet length is 14 OFDM symbols.
- The channel bandwidth is 1.25Mhz.
- The transmission power is 100mW.

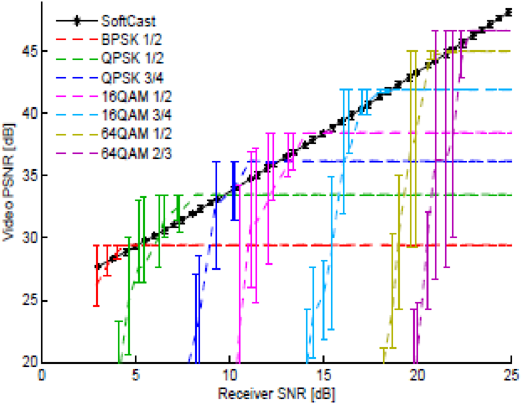
# Outline

# Results: Benchmark Results

- We pick a node randomly in our testbed
- Make it broadcast the video using the conventional design, SoftCast, and SVC-HM.
- We run MPEG4 over 802.11 for all 802.11 choices of modulation and FEC code rates.
- We also run SVC-HM for the case of 2-layer and 3-layer video.
- During the video broadcast, all nodes other than the sender act as receivers.
- We compute the average SNR of its channel and the PSNR of its received video.

# Results: Benchmark Results

- We plot the video PSNR as a function of channel SNR, by dividing the SNR range into bins of 0.5 dB each, and take the average PSNR across all receivers whose channel SNR falls in the same bin.

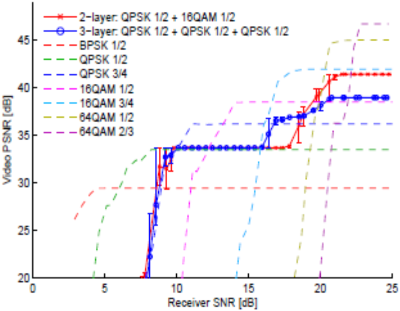



**(a) SoftCast vs. Conventional Design**

# Results: Benchmark Results

- For any choice of 802.11 modulation and FEC code rate, there exists a critical SNR below which the conventional design degrades sharply, and above it the video quality does not improve with channel quality.
- In contrast, SoftCast's PSNR scales smoothly with the channel SNR.
- Softcast hence can significantly improve video performance for mobile and multicast receivers while maintaining the efficiency of the existing design for the case of a single static receiver.

# Results: Benchmark Results

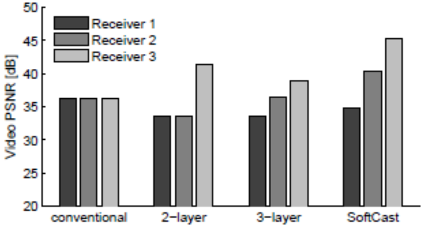



(b) SVC-HM vs. Conventional Design

- The second figure shows that a layered approach based on SVC-HM exhibits milder cliffs than the conventional design and can provide quality differentiation.
- Layering reduces the overall performance in comparison with conventional single layer MPEG4. (requires higher SNR)

# Results: Multicast

- We pick a single sender and three multicast receivers from the set of nodes in our testbed. The receivers' SNRs are 11 dB, 17 dB, and 22 dB..




- The figure shows that, in the conventional design, the video PSNR for all receivers is limited by the receiver with the worse channel.
- In contrast, 2-layer and 3-layer SVC-HM provide different performance to the receivers.

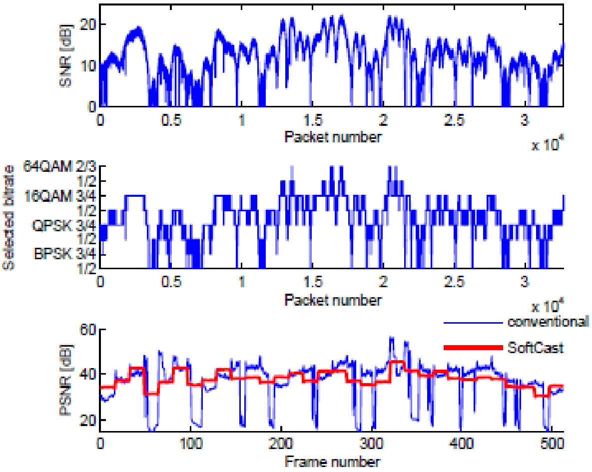
# Results: Multicast

- Layering must make a tradeoff between performance differentiation and video PSNR. (more layers implies higher overhead)
- SoftCast does not incur a layering overhead and hence can provide each receiver with a video quality that scales with its channel quality, while maintaining a higher overall PSNR.

# Results: Mobility of a Single Receiver

- We perform the mobility experiment with non-video packets from which we can extract the errors in the I/Q values to create a noise pattern.
- We then apply the same noise pattern to each of the three video transmission schemes to emulate its transmission on the channel.
- The goal is to allow us to compare the performance of the 3 schemes under the same conditions.

# Results: Mobility of a Single Receiver

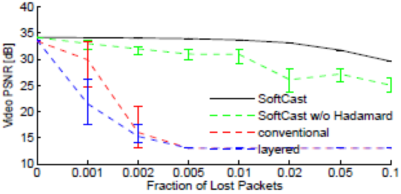


# Results: Mobility of a Single Receiver

- The figure above compares the video quality of the conventional design and SoftCast under mobility.
- The conventional design is allowed to adapt its bitrate and video code rate.
- Even with rate adaptation, a mobile receiver still suffers significant glitches with the conventional design. In contrast, SoftCast can eliminate these glitches.
- SVC-HM are not plotted because SVC-HM failed to decode almost all frames.
- Because during hierarchical modulation, the enhancement layers are effectively noise during the decoding of the base layer, making the base layer highly fragile to SNR dips.

# Results: Resilience to Packet Loss

- We pick a random pair of nodes from the testbed and transmit video between them.
- We generate packet loss by making an interferer transmit at constant intervals.
- We compare four schemes: the conventional design based on MPEG4, 2-layer SVC-HM, full-fledged SoftCast, and SoftCast after disabling the Hadamard multiplication.



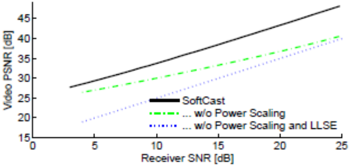
# Results: Resilience to Packet Loss

- The figure above shows that both SVC-HM and the conventional MPEG-based design suffer dramatically at a packet loss rate as low as 0.5%.
- In contrast, SoftCast's design is only mildly affected even when the loss rate is as high as 10%.
- The figure also shows the performance of SoftCast if it did not use the Hadamard matrix to ensure that all packets are equally important.

# Results: Microbenchmark of SoftCast Components

- We pick a sender receiver pair at random and vary the SNR by varying the transmission power at the sender.
- For each SNR we make the sender transmit the video with SoftCast, SoftCast with linear scaling disabled, and SoftCast with both linear scaling and LLSE disabled.
- Finally, we repeat and record the average performance at different SNRs.

# Results: Microbenchmark of SoftCast Components




- The figure above plots the contributions of SoftCast's components to its video quality.
- The figure shows that the use of LLSE is particularly important at low SNRs where as error protection via power scaling is important at high SNRs.

# Outline

# Concluding Remarks

- SoftCast is a clean-slate design for wireless video.
- SoftCast enables a video source to broadcast a single stream that each receiver decodes with a video quality commensurate with its current channel quality.
- It requires no receiver feedback, bitrate adaptation, or video code rate adaptation.