Adaptive Modulation for OFDM-Based Multiple Description Progressive Image Transmission

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Overview

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Multiple Description Block

![Diagram showing multiple descriptions and lost segments.](image-url)
Introduction

- Motivation: Growing demand for high rate wireless multimedia has required an increase in data rate.

- Research on the use of adaptive modulation in progressive image transmission with multiple description coding in conjunction with an OFDM system.

- Most of the work with adaptive modulation is for a system with coding across the time. We use adaptive modulation for a system where coding across the frequency (subchannel) is used.

- In most of the literature, the same constellation size for all the descriptions is used in multiple description block. We propose using different constellation size for different descriptions.
Objective: To minimize the distortion of a progressive coded image that is transmitted over a wireless channel.

We decomposed the problem into two sub-problems:
- Decide the constellation sizes to maximize system throughput prior to RS decoding.
- Determine the code rates to minimize distortion.
System Model

- Block diagram of the image transmission system
As different subchannels may have different modulation alphabet sizes, we need a mapping from the modulated symbols to the RS code symbols:

- MQAM: 4QAM, 16QAM, 64QAM. 1 RS code symbol = 10 bits
Channel Model

- **Frequency domain:**
  - Frequency Selective OFDM Channel
  - The entire frequency band of $B_T$ Hz is assumed to be divided into $L$ i.i.d flat fading subchannels, with bandwidth approximately equal to the coherence bandwidth of the channel.

- **Time domain:**
  - Slow Rayleigh fading is assumed at each subchannel, such that the fading coefficient remains constant over a packet.
Two schemes of adaptive modulation are considered:

- **Variable Rate, Fixed Power** – responds to the channel conditions by varying constellation size.

- **Variable Rate, Variable Power** – responds to the channel conditions by varying constellation size and allocated power.

The constellation is based upon the channel state. Perfect channel estimation and an error-free feedback channel are assumed.
Variable Rate, Fixed Power Scheme

- Vary the **constellation size** at each subchannel to maximize the system throughput prior to RS decoding, with equal power allocation.
Variable Rate, Variable Power Scheme

- Both the constellation size and the allocated power for each subchannel are changed to maximize the system throughput prior to RS decoding, subject to a constraint of total transmission power.

- Problem formulation:

\[
\text{Max} : \sum_{l=1}^{L} g_{l}(p_{l}), \text{subject to} \sum_{l=1}^{L} P_{l} = P_{\text{total}}
\]

where \( L \) is the number of subchannels, \( P_{l} \) is the allocated power at the \( l^{th} \) subschannel and \( P_{\text{total}} \) is the total power constraint. \( g_{l}(p_{l}) \) is the composite throughput function of the \( l^{th} \) subchannel.
$g_i(p_i)$
A greedy algorithm was developed to allocate power and choose the constellation size for each subchannel.

Utility-cost concept was employed.

- The utility measures the benefit that the receiver is likely to achieve from receiving the packet, and the cost measures how much one has to pay to achieve a certain utility.
  - Throughput prior to RS decoding: utility value
  - Required power: cost

The algorithm assigns the power successively to maximize \( \frac{\text{throughput}}{\text{power}} \).

The constellation size of each subchannel is determined by its final power assignment.
Variable Rate, Variable Power Algorithm

- The key steps of the algorithm:
  - **Step 1**: Initialize all the subchannels with zero power
  - **Step 2**: For each subchannel, calculate the slope of throughput versus power curve when an increment $\lambda \Delta P$ of power is applied.
  - **Step 3**: Select the corresponding subchannel $\hat{i}$, with corresponding value $\hat{\lambda}$, that corresponds to the steepest slope.
  - **Step 4**: The corresponding increment, $\hat{\lambda} \Delta P$, of power is then assigned to the $i^{th}$ subchannel, and the total power budget is reduced by the allocated amount.
  - **Step 5**: Check if the total power constraint has been met.
    - Yes – go to step 6
    - No – repeat step 2
  - **Step 6**: The final step is to determine the constellation size for each subchannel based on its final allocated power.
RS Error Protection Framework

- After the adaptive modulation assignment, we then decide the rate of the RS code, to minimize the distortion.

- **FEC rate optimization problem**: Given a set of received SNRs, $\mathbf{\gamma} = [\gamma_1, \gamma_2, \ldots, \gamma_L]$, and given the operational distortion-throughput function, the FEC optimization goal is to determine the set of RS parity assignments that minimizes the conditional distortion, $D(F, \mathbf{\gamma})$

  $$D^*(\mathbf{\gamma}) = \min_{F \in F} \left\{ D(F, \mathbf{\gamma}) \right\}$$
FEC Rate Optimization

To find the FEC assignment for RS codewords, the hill climbing approach [1] is adopted:

- The algorithm starts with initializing each codeword to contain only information data.
- At each iteration, the conditional distortion is evaluated after adding or subtracting one parity symbol to each codeword. The FEC allocation with the lowest distortion is chosen.
- The iteration repeats until none of the cases examined improves the conditional distortion.

Simulation Results

- **Variable Rate Variable Power**
- **Variable Rate Fixed Power**
- **Fixed Rate Fixed Power**

**Graph:**
- Y-axis: PSNR (dB)
- X-axis: Average SNR per Symbol (dB)

- Three lines representing different power and rate combinations.
- Circles highlight specific data points for each line type.
Simulation Results (cont’d)

![Graph showing simulation results. The graph plots the average packet error rate against the average SNR per symbol (dB). The x-axis represents the average SNR per symbol (dB) ranging from 0 to 30, and the y-axis represents the average packet error rate ranging from $10^{-3}$ to $10^{0}$. Four different line types are used to represent different scenarios: Variable Rate Variable Power (green circles), Variable Rate Fixed Power (red squares), and Fixed Rate Fixed Power (blue triangles). The graph highlights the performance of these scenarios under varying SNR conditions.]
Simulation Results (cont’d)

- Variable constellation for each subchannel
- Fixed constellation for all subchannels

PSNR (dB) vs. Average SNR per Symbol (dB)
Conclusions

- We proposed an adaptive modulation technique for transmitting progressive images with multiple description coding.
- Either the constellation size or both the constellation size and the power for each description were determined based on throughput maximization.
- A greedy algorithm was proposed to decide the power and constellation at each description.
- For low SNR, changing both the power and constellation size will give us significant gain.
- For high SNR, the extra gain achieved from allocating different power to each subchannel in addition to changing constellation size is relatively small compared to the gain achieved from changing constellation size alone. This suggests that rate adaptation is the key to achieve high performance at high SNR.