Joint source channel image coder for transmission over flat fading channels

WIP/CUBAN/BEATS workshop, Sidi Bau Saïd, Tunisia

Greg Håkonsen, Tor Ramstad

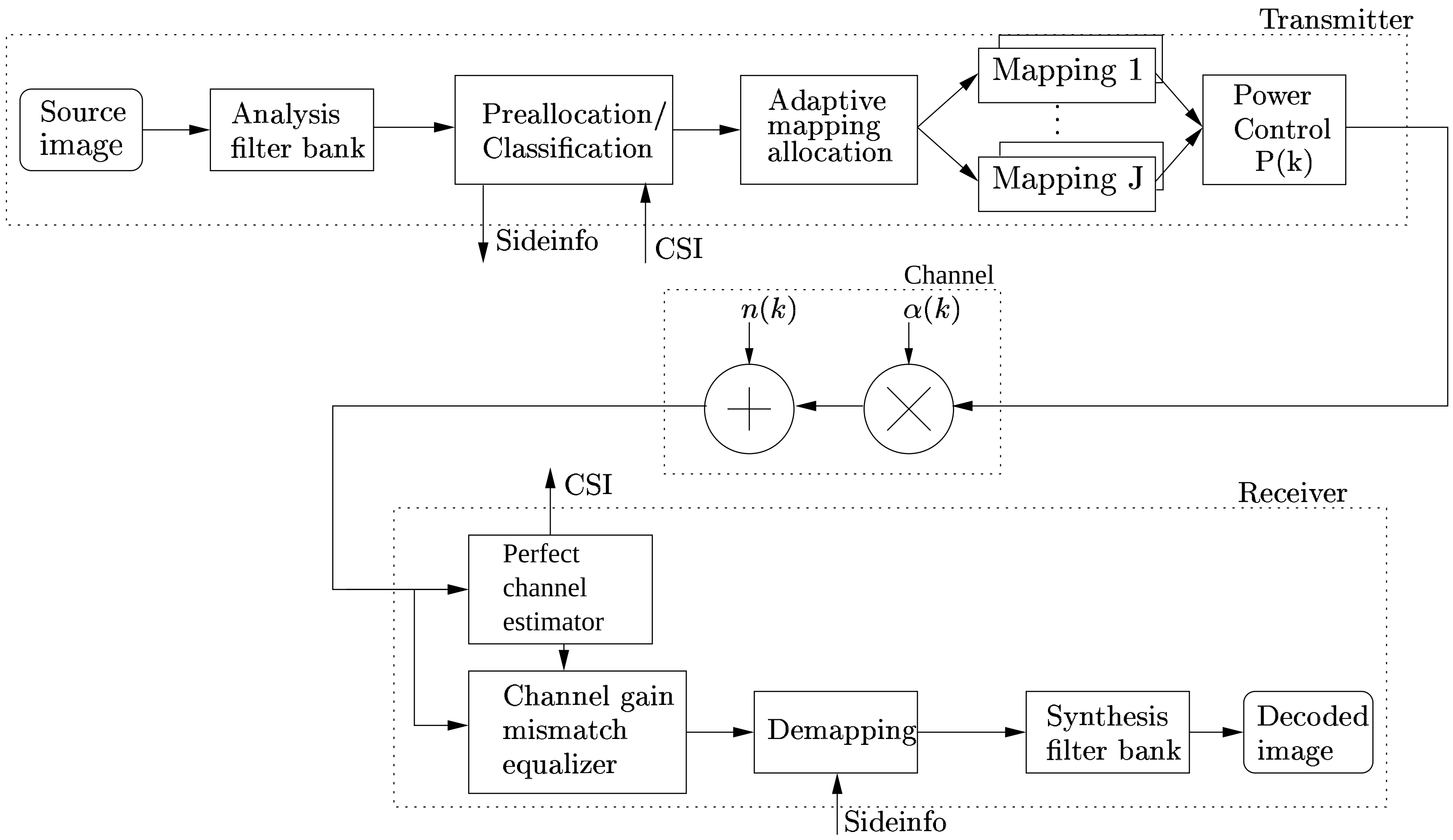
{hakonsen,ramstad}@iet.ntnu.no

Norwegian University of Science and Technology

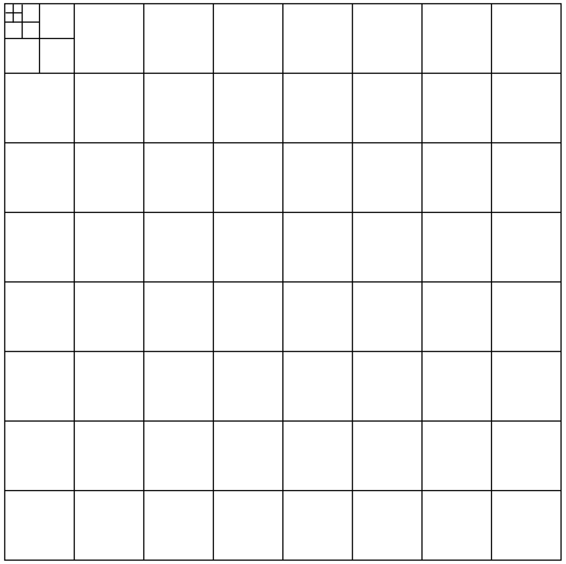
Outline

- System overview.
  - Decorrelation.
  - Selection of image quality.
  - Channel model.
  - Transmission algorithm.
  - Transmission using joint source channel coding.
- Example/results.
- Further research/discussion/conclusion/.

System overview

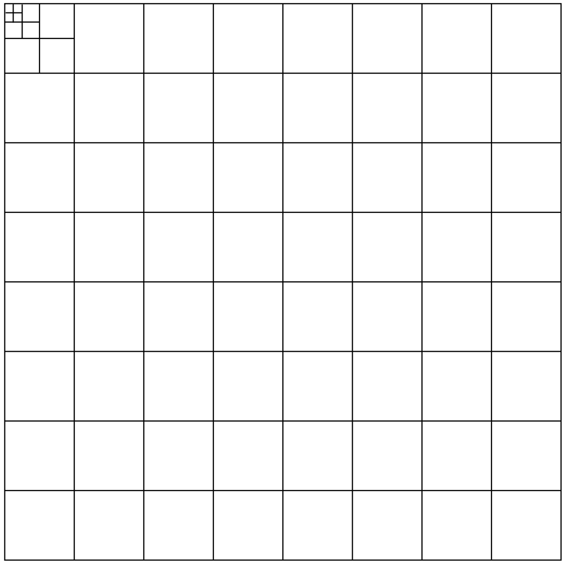


Filter bank structure



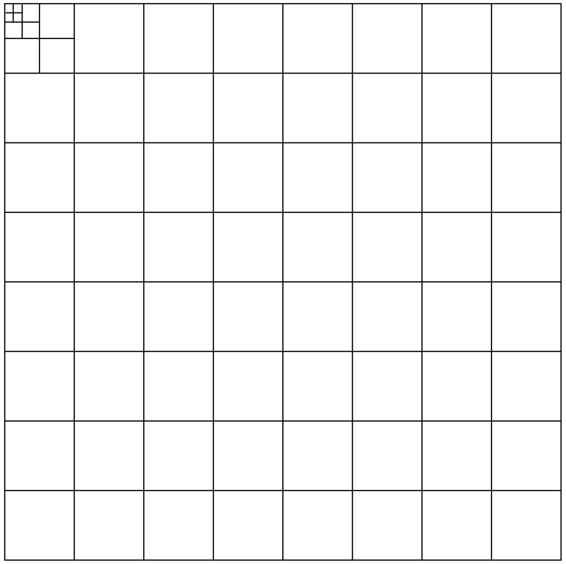
- Image is decorrelated by using a *tree structured filter bank*.
  - Eight uniform bands.
  - Lowpass band further filtered using a two band filter bank in a tree structure, *dyadic splitting*.

Filter bank structure



- Image is decorrelated by using a *tree structured filter bank*.
  - Eight uniform bands.
  - Lowpass band further filtered using a two band filter bank in a tree structure, *dyadic splitting*.
- Filter bank is *maximally decimated*.

Filter bank structure



- Image is decorrelated by using a *tree structured filter bank*.
  - Eight uniform bands.
  - Lowpass band further filtered using a two band filter bank in a tree structure, *dyadic splitting*.
- Filter bank is *maximally decimated*.
- Different *subbands* organized as shown, low frequency bands are placed to the top left.

Description of filtered image

- Mean of lowpass-lowpass band is removed to reduce power.

Description of filtered image

- Mean of lowpass-lowpass band is removed to reduce power.
- Calculate variance from blocks of size $k \times l$ from filtered image, resulting in variances of N blocks.

Description of filtered image

- Mean of lowpass-lowpass band is removed to reduce power.
- Calculate variance from blocks of size $k \times l$ from filtered image, resulting in variances of N blocks.
- Given a target *signal to noise ratio*(SNR) value, a parameter μ can be found from

$$D = \sum_{i=0}^{N-1} \min(\mu, \sigma_{X_i}^2), \tag{2}$$

where

$$D = \frac{\sum_{i=0}^{N-1} \sigma_{X_i}^2}{\text{SNR}}. \tag{2}$$

Channel

- Consider a frequency-flat, correlated fading channel.

Channel

- Consider a frequency-flat, correlated fading channel.
- Assume that the received signal $y(k)$ can be written as

$$y(k) = \alpha(k)x(k) + n(k) \tag{3}$$

where $\alpha(k)$ is the channel gain, $x(k)$ is the sent signal and $n(k)$ is additive white gaussian noise(AWGN). Assumed $\mathcal{N}(0, 1)$.

Channel

- Consider a frequency-flat, correlated fading channel.
- Assume that the received signal $y(k)$ can be written as
$$y(k) = \alpha(k)x(k) + n(k) \quad (3)$$
where $\alpha(k)$ is the channel gain, $x(k)$ is the sent signal and $n(k)$ is additive white gaussian noise(AWGN). Assumed $\mathcal{N}(0, 1)$.
- Split *channel signal-to-noise ratio*(CSNR γ) into M regions, assign a representation value γ_j for each region. $\gamma < \gamma_0 \Rightarrow$ outage.

Channel

- Consider a frequency-flat, correlated fading channel.
- Assume that the received signal $y(k)$ can be written as
$$y(k) = \alpha(k)x(k) + n(k) \tag{3}$$
where $\alpha(k)$ is the channel gain, $x(k)$ is the sent signal and $n(k)$ is additive white gaussian noise(AWGN). Assumed $\mathcal{N}(0, 1)$.
- Split *channel signal-to-noise ratio*(CSNR γ) into M regions, assign a representation value γ_j for each region. $\gamma < \gamma_0 \Rightarrow$ outage.
- Optimize region thresholds and representation points with Lloyd-max algorithm, using MSE as distortion measure.

Preallocation

Given a channel state γ_j, and transmitted block variance $\sigma^2_{X_i}$ the needed channel samples per source sample is given by

$$r_{i,j} = \frac{\log\left(\frac{\sigma^2_{X_i}}{\mu}\right)}{\log\left(\frac{\gamma_j}{\gamma_0}\right)} \tag{4}$$

Preallocation

Given a channel state γ_j, and transmitted block variance $\sigma^2_{X_i}$ the needed channel samples per source sample is given by

$$r_{i,j} = \frac{\log\left(\frac{\sigma^2_{X_i}}{\mu}\right)}{\log\left(\frac{\gamma_j}{\gamma_0}\right)} \tag{4}$$

- Block with $\sigma^2_{X_i} < \mu$ is not transmitted.

Preallocation

Given a channel state γ_j, and transmitted block variance $\sigma^2_{X_i}$ the needed channel samples per source sample is given by

$$r_{i,j} = \frac{\log\left(\frac{\sigma^2_{X_i}}{\mu}\right)}{\log\left(\frac{\gamma_j}{\gamma_0}\right)} \qquad (4)$$

- Block with $\sigma^2_{X_i} < \mu$ is not transmitted.
- M channel states gives M possible rates per block.

Preallocation

Given a channel state γ_j, and transmitted block variance $\sigma^2_{X_i}$ the needed channel samples per source sample is given by

$$r_{i,j} = \frac{\log\left(\frac{\sigma^2_{X_i}}{\mu}\right)}{\log\left(\frac{\gamma_j}{\gamma_0}\right)} \tag{4}$$

- Block with $\sigma^2_{X_i} < \mu$ is not transmitted.
- M channel states gives M possible rates per block.
- Finite set of practical mappings.

Preallocation

Given a channel state γ_j, and transmitted block variance $\sigma^2_{X_i}$ the needed channel samples per source sample is given by

$$r_{i,j} = \frac{\log\left(\frac{\sigma^2_{X_i}}{\mu}\right)}{\log\left(\frac{\gamma_j}{\gamma_0}\right)} \tag{4}$$

- Block with $\sigma^2_{X_i} < \mu$ is not transmitted.
- M channel states gives M possible rates per block.
- Finite set of practical mappings.
- Want combination of source and channel state to give lowest possible rate.

Preallocation example

- Split channel into 4 channel states.
- $\gamma_4 > \gamma_3 > \gamma_2 > \gamma_1$.

γ_4	$\sigma^2_{X_1}$			
γ_3	$\sigma^2_{X_2}$	$\sigma^2_{X_3}$	$\sigma^2_{X_4}$	
γ_2	$\sigma^2_{X_5}$	$\sigma^2_{X_6}$	$\sigma^2_{X_7}$	$\sigma^2_{X_8}$
γ_1	$\sigma^2_{X_9}$	$\sigma^2_{X_{10}}$	$\sigma^2_{X_{11}}$	$\sigma^2_{X_{12}}$

Preallocation example

γ_4	$\sigma^2_{X_1}$			
γ_3	$\sigma^2_{X_2}$	$\sigma^2_{X_3}$	$\sigma^2_{X_4}$	
γ_2	$\sigma^2_{X_5}$	$\sigma^2_{X_6}$	$\sigma^2_{X_7}$	$\sigma^2_{X_8}$
γ_1	$\sigma^2_{X_9}$	$\sigma^2_{X_{10}}$	$\sigma^2_{X_{11}}$	$\sigma^2_{X_{12}}$

- Split channel into 4 channel states.
- $\gamma_4 > \gamma_3 > \gamma_2 > \gamma_1$.
- $\sigma^2_{X_1} > \cdots > \sigma^2_{X_{12}}$

Preallocation example

γ_4	$\sigma^2_{X_1}$			
γ_3	$\sigma^2_{X_2}$	$\sigma^2_{X_3}$	$\sigma^2_{X_4}$	
γ_2	$\sigma^2_{X_5}$	$\sigma^2_{X_6}$	$\sigma^2_{X_7}$	$\sigma^2_{X_8}$
γ_1	$\sigma^2_{X_9}$	$\sigma^2_{X_{10}}$	$\sigma^2_{X_{11}}$	$\sigma^2_{X_{12}}$

- Split channel into 4 channel states.
- $\gamma_4 > \gamma_3 > \gamma_2 > \gamma_1$.
- $\sigma^2_{X_1} > \cdots > \sigma^2_{X_{12}}$
- Number of blocks per state depends on probability of state.

Preallocation example

γ_4	$\sigma^2_{X_1}$			
γ_3	$\sigma^2_{X_2}$	$\sigma^2_{X_3}$	$\sigma^2_{X_4}$	
γ_2	$\sigma^2_{X_5}$	$\sigma^2_{X_6}$	$\sigma^2_{X_7}$	$\sigma^2_{X_8}$
γ_1	$\sigma^2_{X_9}$	$\sigma^2_{X_{10}}$	$\sigma^2_{X_{11}}$	$\sigma^2_{X_{12}}$

- Split channel into 4 channel states.
- $\gamma_4 > \gamma_3 > \gamma_2 > \gamma_1$.
- $\sigma^2_{X_1} > \cdots > \sigma^2_{X_{12}}$
- Number of blocks per state depends on probability of state.
- Transmit blocks with highest variance within each channel state first.

Preallocation example

γ_4	$\sigma^2_{X_1}$			
γ_3	$\sigma^2_{X_2}$	$\sigma^2_{X_3}$	$\sigma^2_{X_4}$	
γ_2	$\sigma^2_{X_5}$	$\sigma^2_{X_6}$	$\sigma^2_{X_7}$	$\sigma^2_{X_8}$
γ_1	$\sigma^2_{X_9}$	$\sigma^2_{X_{10}}$	$\sigma^2_{X_{11}}$	$\sigma^2_{X_{12}}$

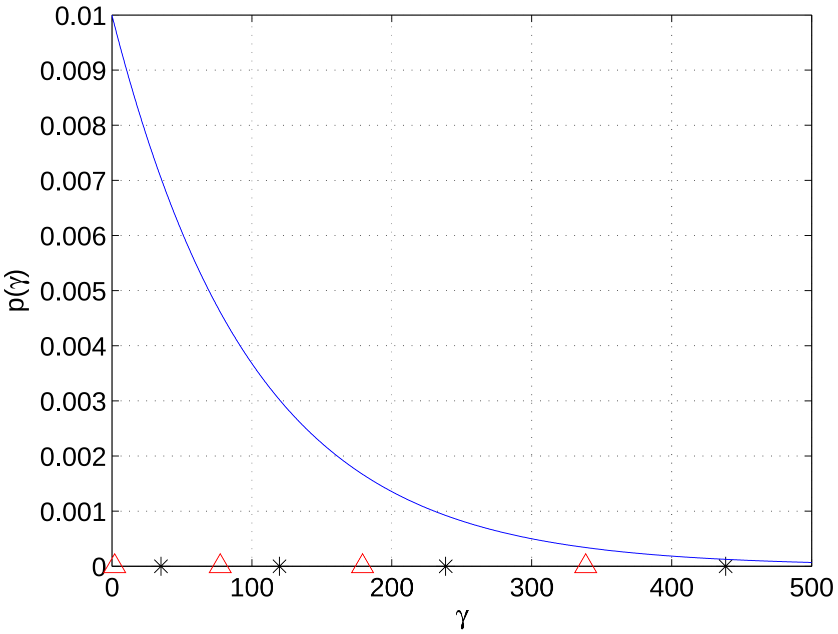
- Split channel into 4 channel states.
- $\gamma_4 > \gamma_3 > \gamma_2 > \gamma_1$.
- $\sigma^2_{X_1} > \cdots > \sigma^2_{X_{12}}$
- Number of blocks per state depends on probability of state.
- Transmit blocks with highest variance within each channel state first.
- If channel state set is empty, choose blocks from set for better channel states.

Side information

To be able to decode the transmitted information some side information is needed.

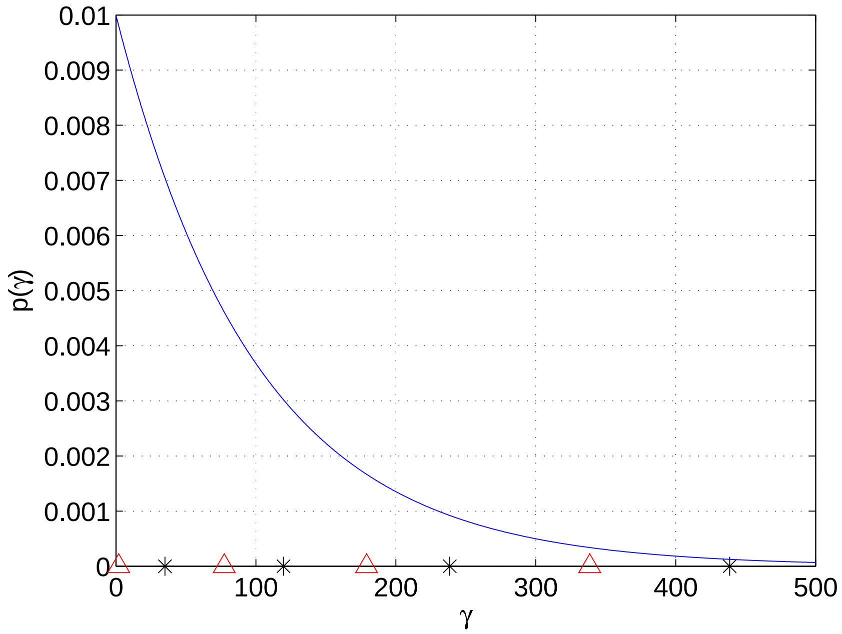
- The variance of blocks.
- The mean value of the lowpass lowpass band.

Used mappings



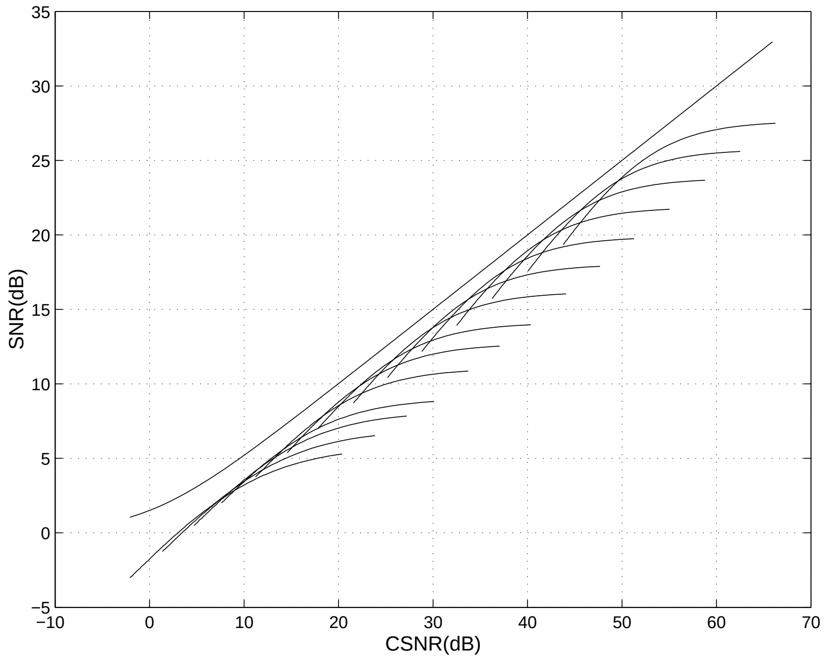
- $\hat{r}_{i,j} \in \{0, \frac{1}{4}, \frac{1}{2}, \frac{2}{3}, 1, 2\}$.
- Each mapping is optimized for a given γ_j(CSNR). Comparable to BER in adaptive coded modulation.

Used mappings



- $\hat{r}_{i,j} \in \{0, \frac{1}{4}, \frac{1}{2}, \frac{2}{3}, 1, 2\}$.
- Each mapping is optimized for a given γ_j(CSNR). Comparable to BER in adaptive coded modulation.
- Transmitter and receiver use same configuration.

Used mappings



- $\hat{r}_{i,j} \in \{0, \frac{1}{4}, \frac{1}{2}, \frac{2}{3}, 1, 2\}$.
- Each mapping is optimized for a given γ_j(CSNR). Comparable to BER in adaptive coded modulation.
- Transmitter and receiver use same configuration.
- Optimization/robustnes for $\hat{r}_{i,j} = \frac{1}{2}$ shown.

Mapping design

- Given avarage transmission power $\bar{P}$.

Mapping design

- Given avarage transmission power $\bar{P}$.
- Given representation points γ_j, $j = 1, \ldots, M$.

Mapping design

- Given avarage transmission power $\bar{P}$.
- Given representation points γ_j, $j = 1, \ldots, M$.
- Transmission power P_j set according to water filling which results in received/design CSNR

$$\gamma_{j_{\text{des}}} = \frac{P_j}{\bar{P}} \gamma_j . \tag{6}$$

Mapping design

- Given avarage transmission power $\bar{P}$.
- Given representation points γ_j, $j = 1, \ldots, M$.
- Transmission power P_j set according to water filling which results in received/design CSNR

$$\gamma_{j_{\text{des}}} = \frac{P_j}{\bar{P}} \gamma_j . \qquad (6)$$

- Assumed channel gain found by $|\alpha_j|^2 = \gamma_j / \bar{P}$.

Mapping design

- Given avarage transmission power $\bar{P}$.
- Given representation points γ_j, $j = 1, \ldots, M$.
- Transmission power P_j set according to water filling which results in received/design CSNR

$$\gamma_{j_{\text{des}}} = \frac{P_j}{\bar{P}} \gamma_j . \qquad (6)$$

- Assumed channel gain found by $|\alpha_j|^2 = \gamma_j / \bar{P}$.
- Compensate for channel gain mismatch in receiver

$$\gamma_{j_{\text{des}}} \approx \gamma_{j_{\text{rec}}}(k) = \underbrace{P_j}_{\text{transmitter}} \underbrace{|\alpha(k)|^2}_{\text{channel}} \underbrace{\frac{|\alpha_j|^2}{|\alpha(k)|^2}}_{\text{receiver}} \qquad (6)$$

where $\alpha(k)$ is actual channel gain.

Image Example

- Rayleigh fading channel.
- CSNR $= 15$ dB.
- Total rate $r_{\text{avg}} \approx 0.05$.
  ($\sum$channel samples/$\sum$source samples).
- Targeted SNR is 16 dB.
- Blocksize 8×8

Channel regions/probabilities

$\gamma_{j_{\text{des}}}$ (dB)	p_{calc}	p_{actual}	region (dB)
Outage	0.08	0	$-\infty$ - 3.0
10.8	0.49	0.63	3.0 - 14.1
16.0	0.28	0.11	14.1 - 17.6
19.0	0.12	0.26	17.6 - 20.4
21.6	0.03	0	20.4 - ∞
Assumed rate	0.05		
Actual rate	0.057		

1 CSNR region, AWGN channel

AWGN
PSNR = 30.13 dB

Gain compensation
PSNR = 29.46 dB

1 CSNR region

No gain compensation

PSNR = 23.97 dB

Gain compensation

PSNR = 29.46 dB

4 CSNR regions

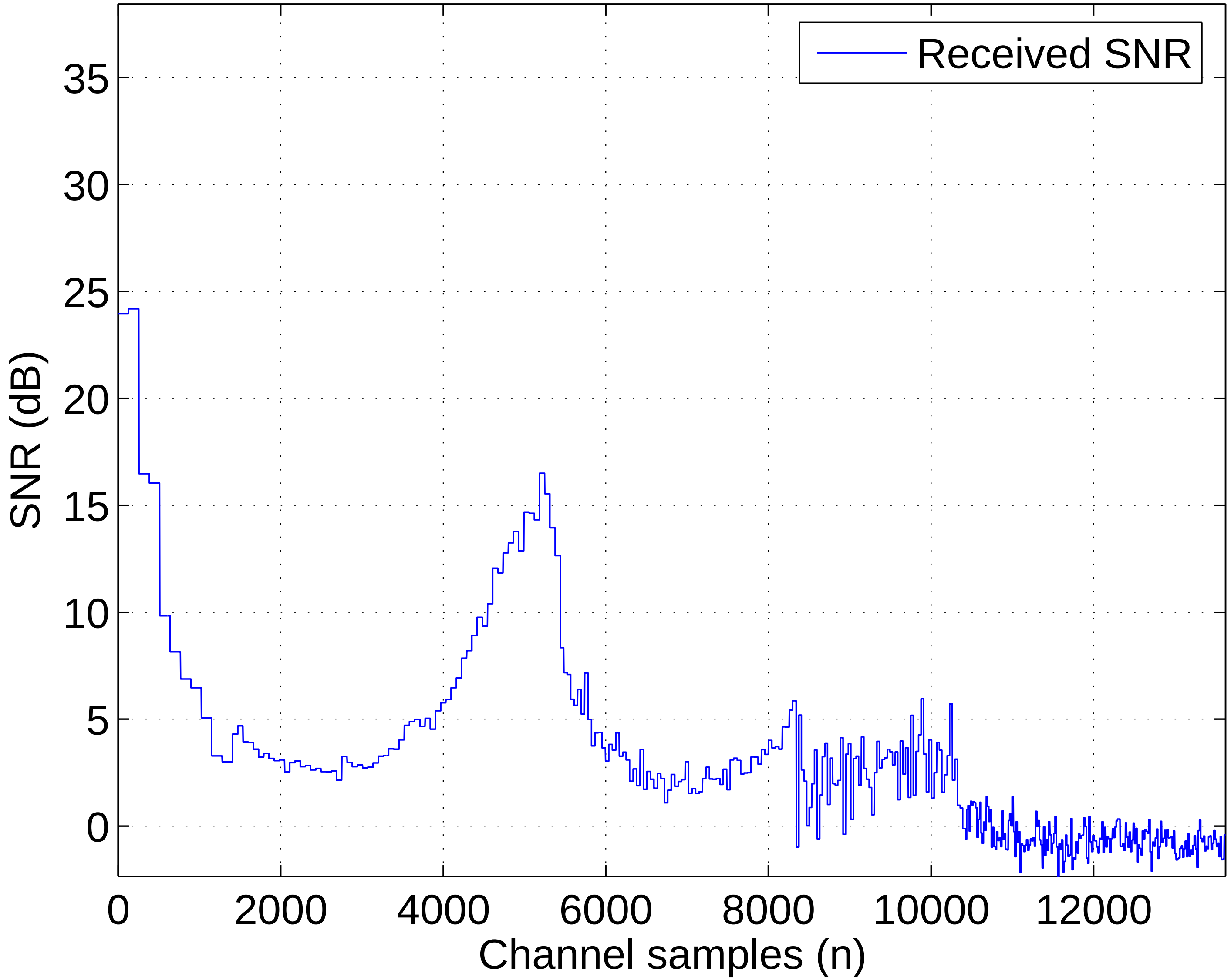
No gain compensation

PSNR = 28.8 dB

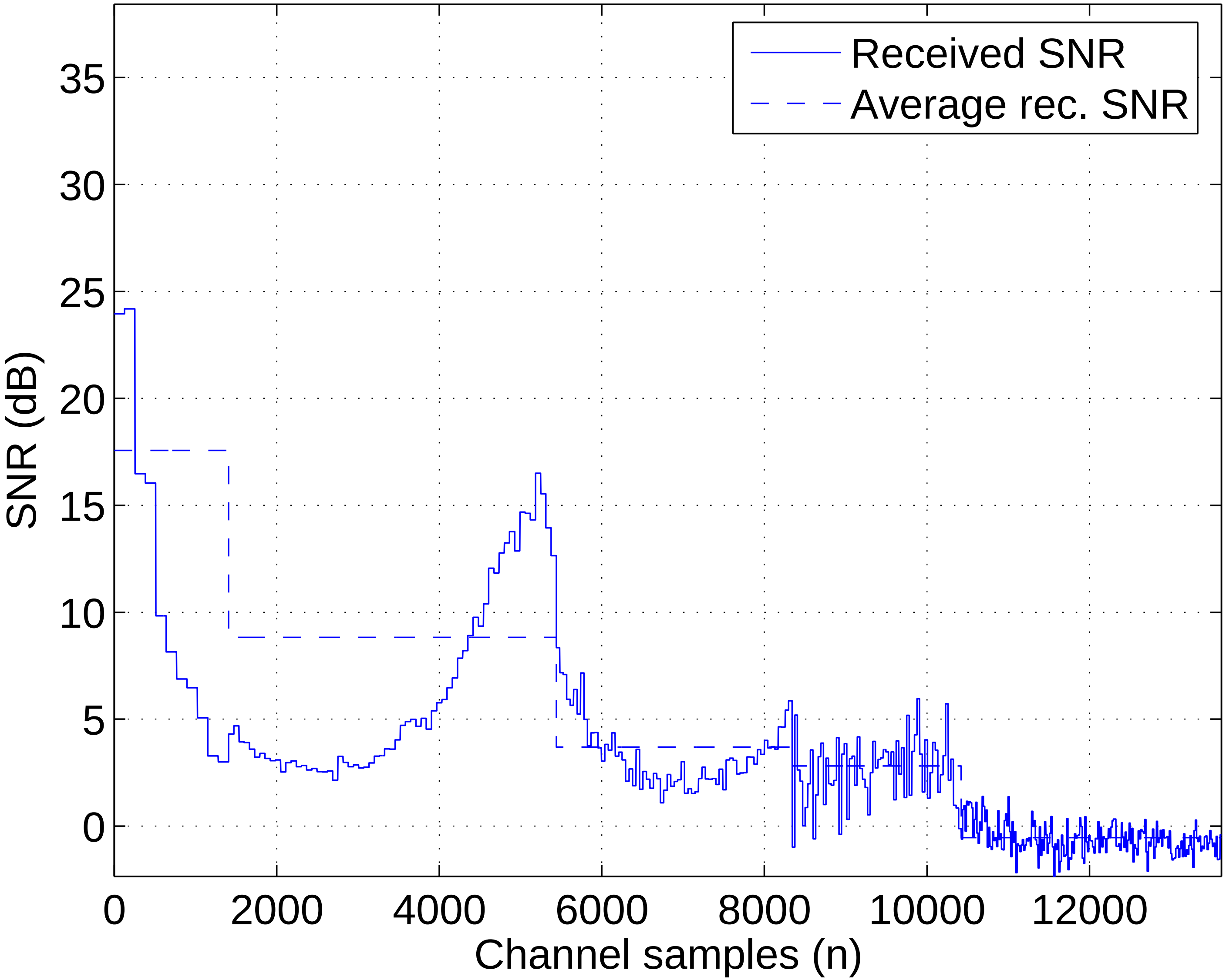
Gain compensation

PSNR = 30.2 dB

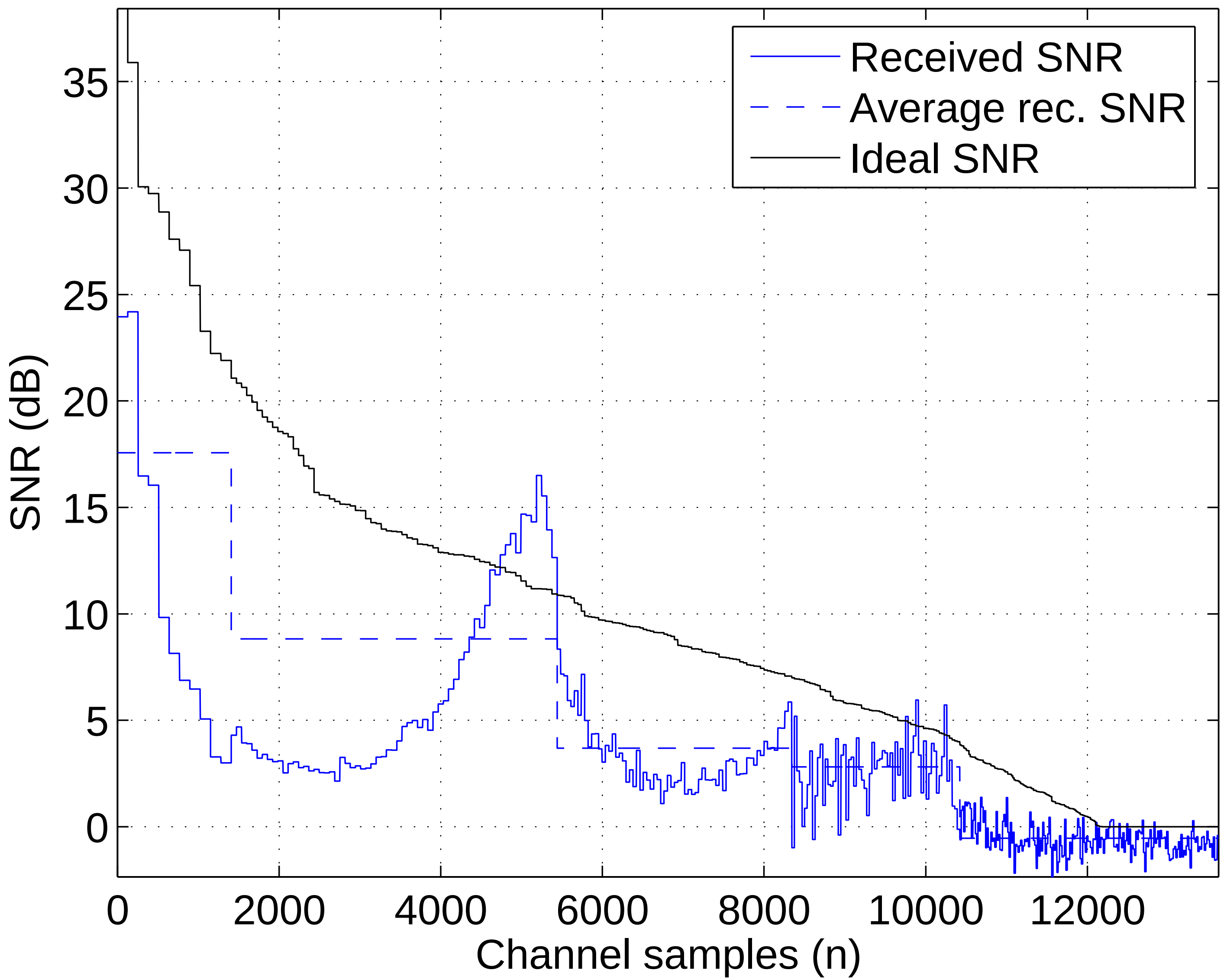
No compensation



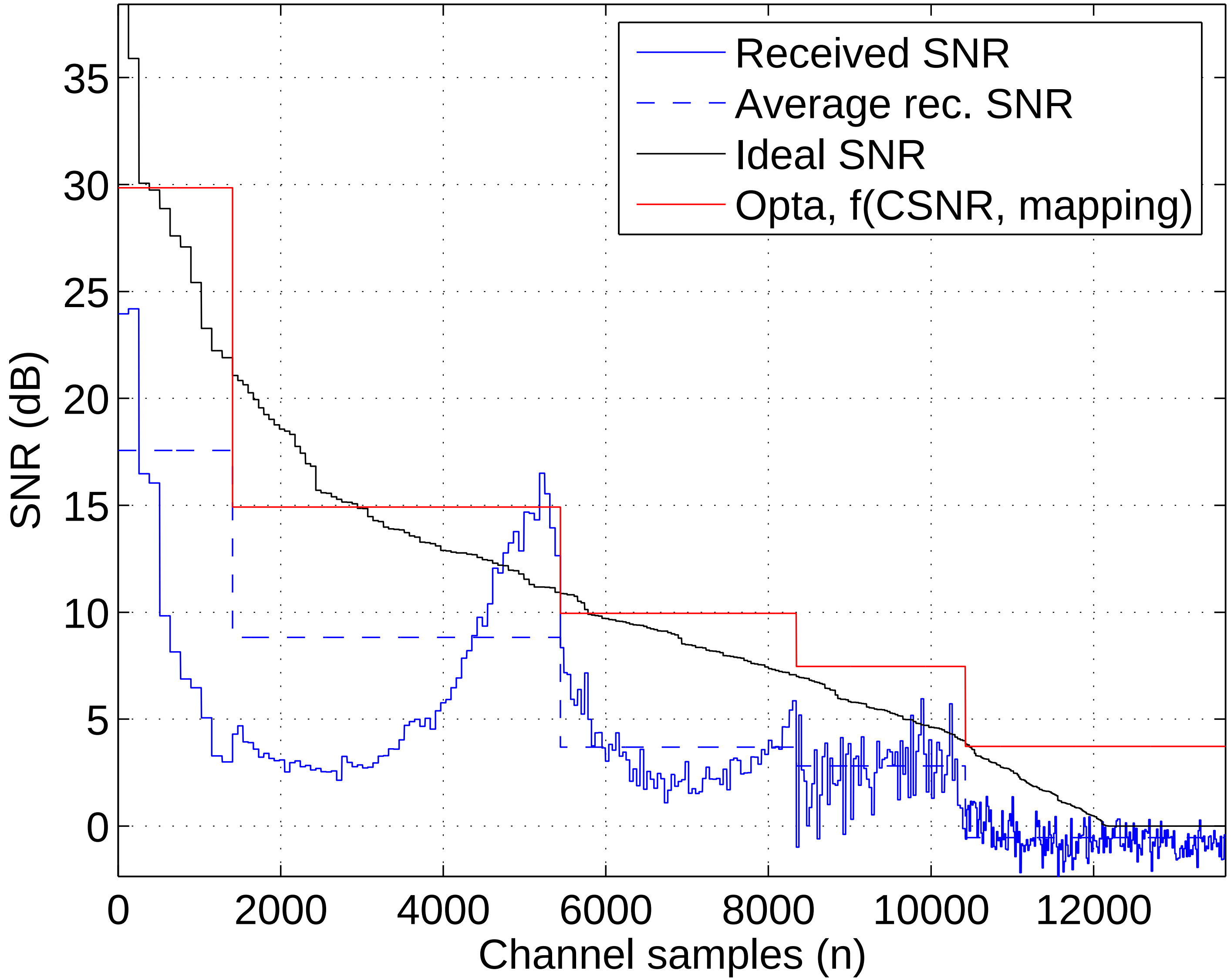
No compensation



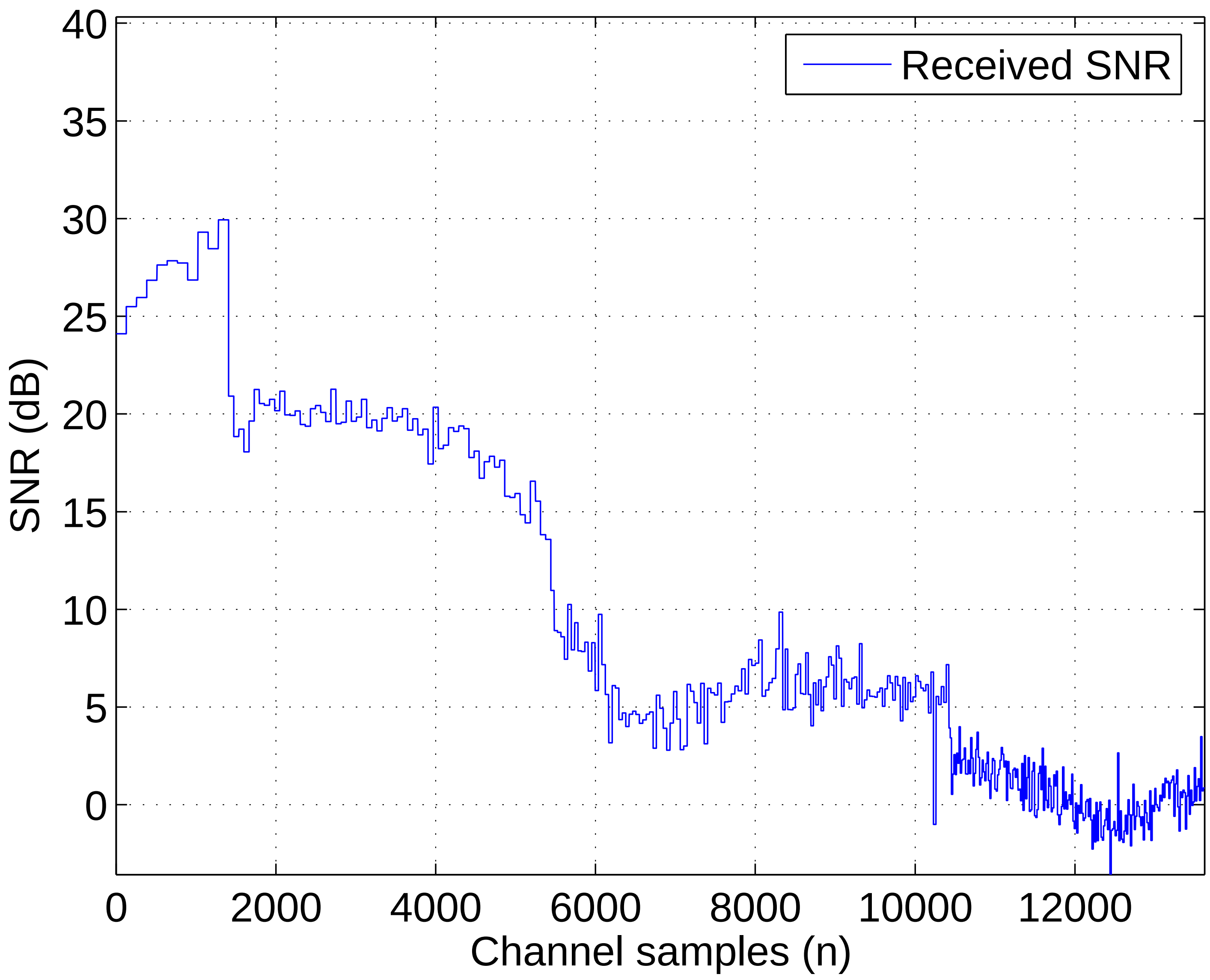
No compensation



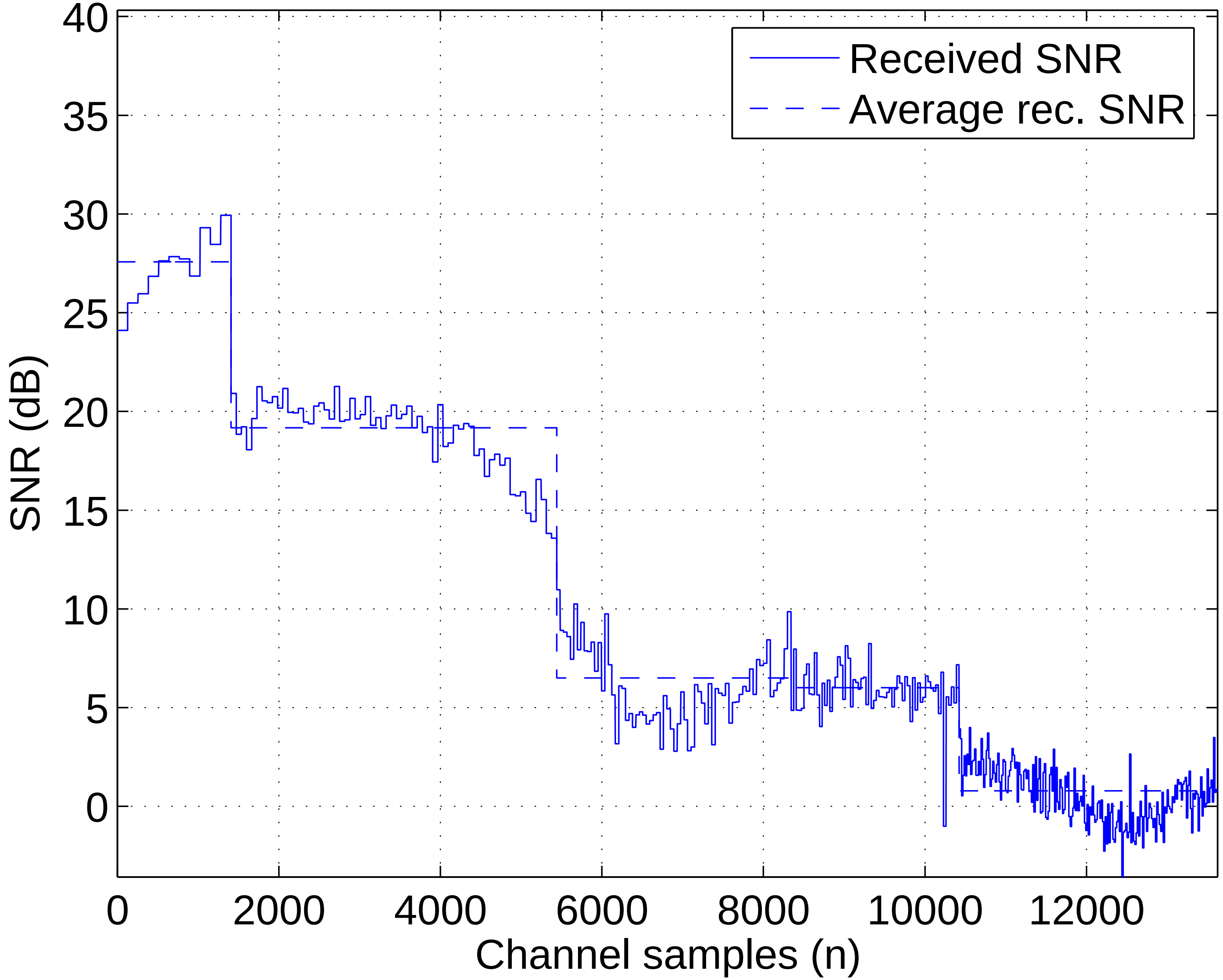
No compensation



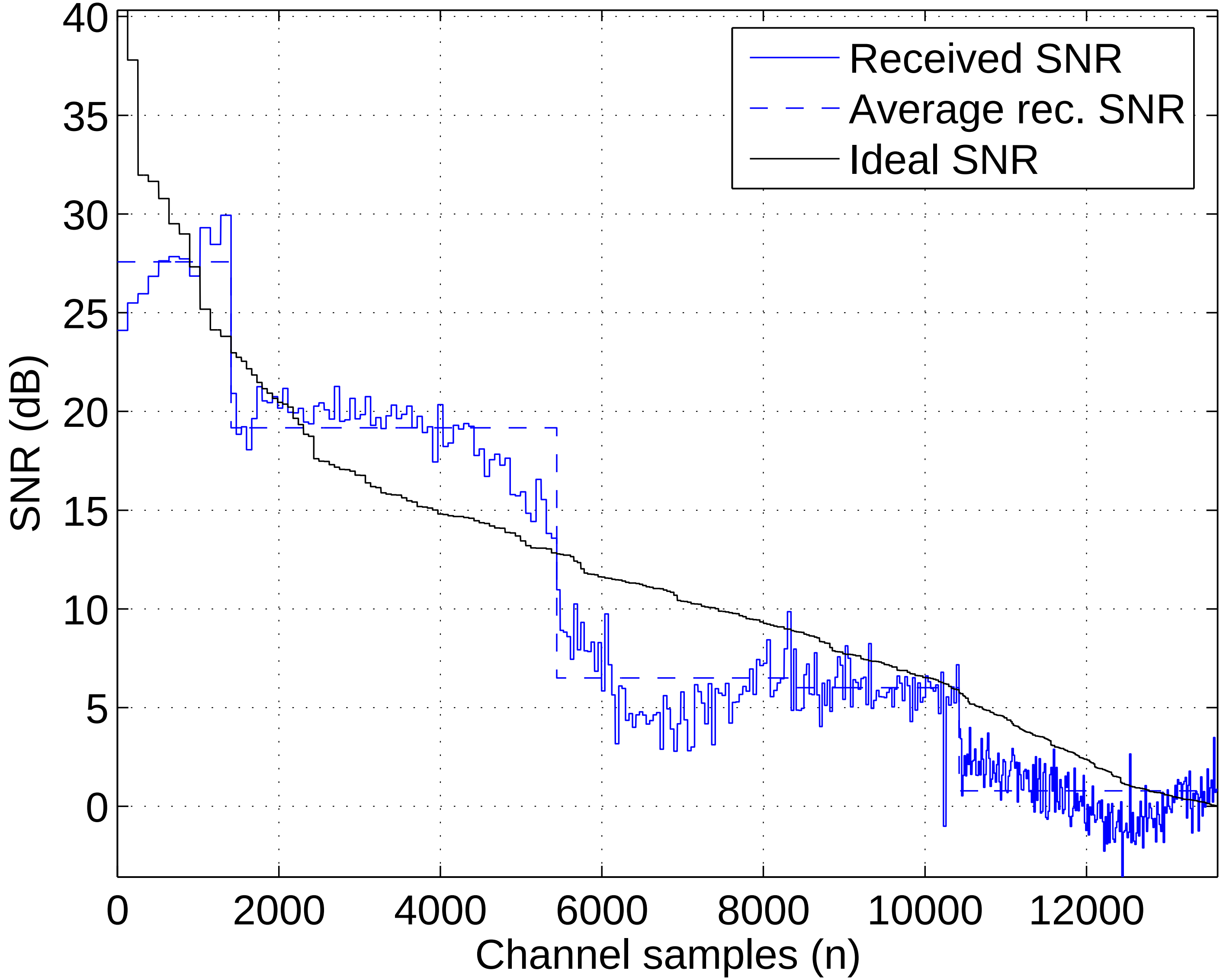
Gain compensation



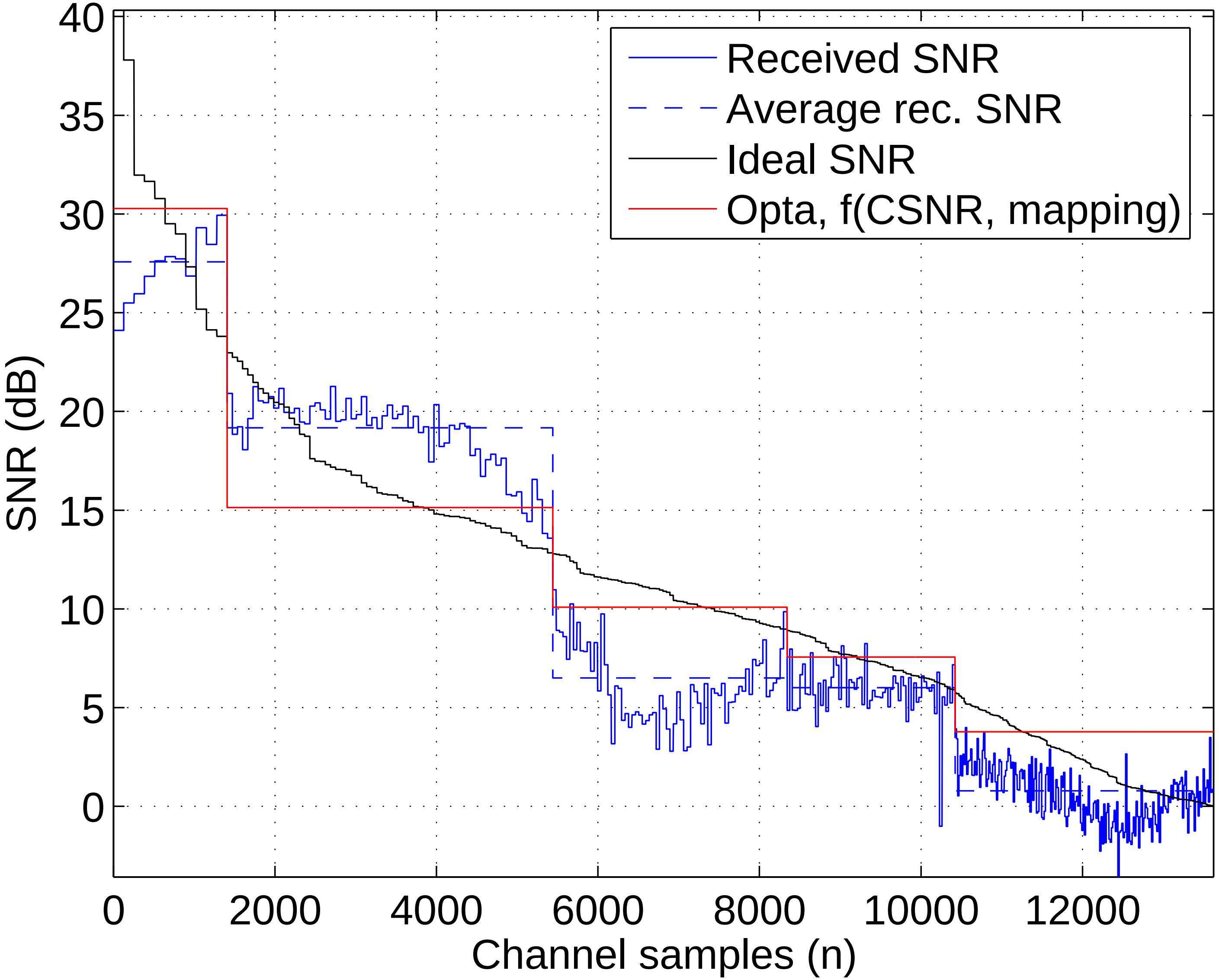
Gain compensation



Gain compensation



Gain compensation



Artifacts

Due to low dimensionality of mappings, certain artifacts may appear for poor channels.

Further research

- Look at side information, effects of quantizing block variances.
- Insert pilots, pilot spacing?
- Predictor, estimator.
- Find CSNR regions and representation points more optimal.
- Compensate for the nonoptimality of the different mappings.
- Varying robustness of mappings?
- Scalability, how early should important info be sent?
- Better gain mismatch compensation?