Source-Channel Diversity Approaches for Multimedia Communication

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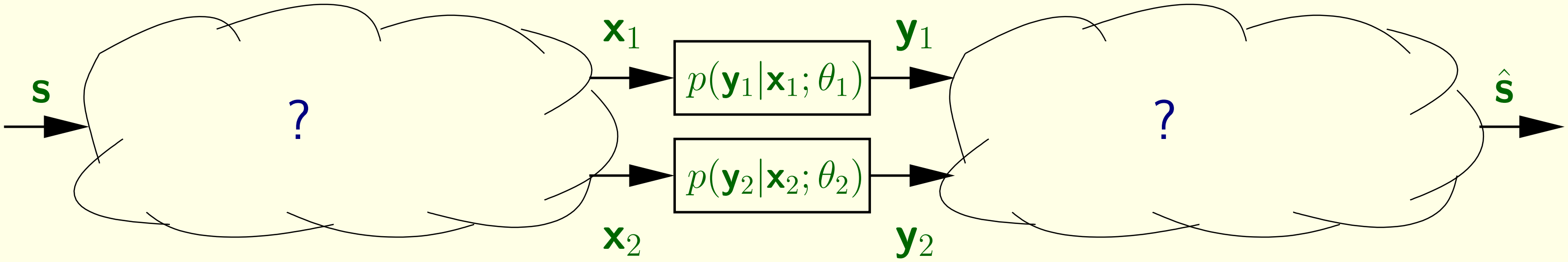
Problem:

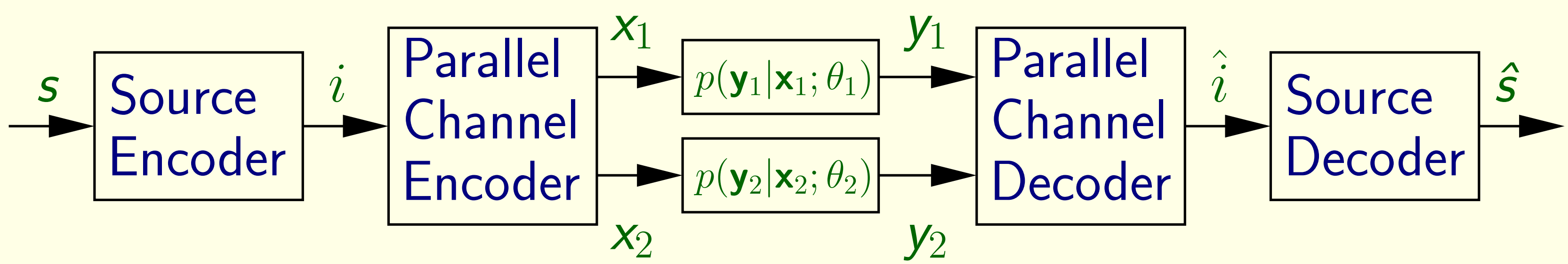
- Transmit over channel with unknown state, e.g. path loss/interference/slow fading/congestion/etc.



Goal:

- Minimize average distortion: $E_\theta[D]$.

The Physical Layer Approach:



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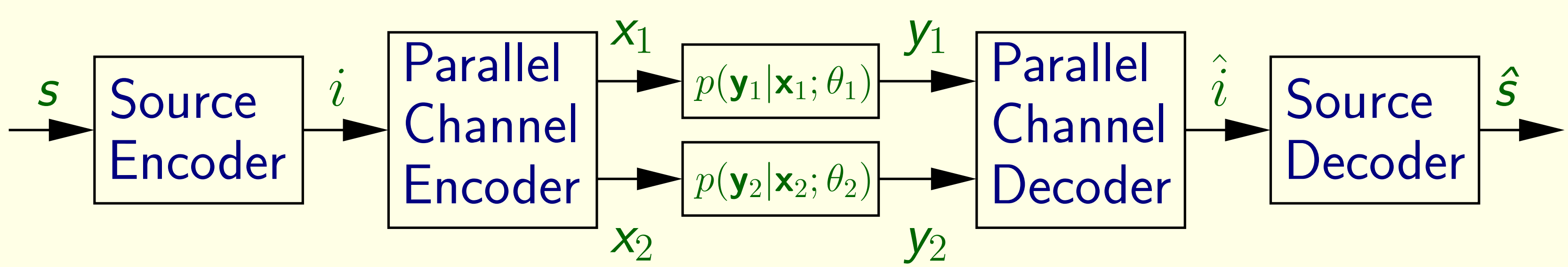
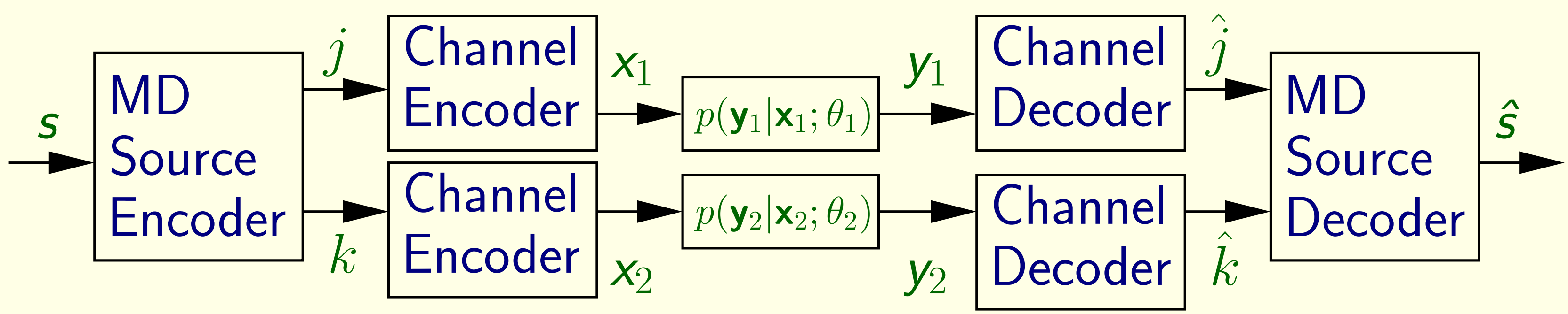
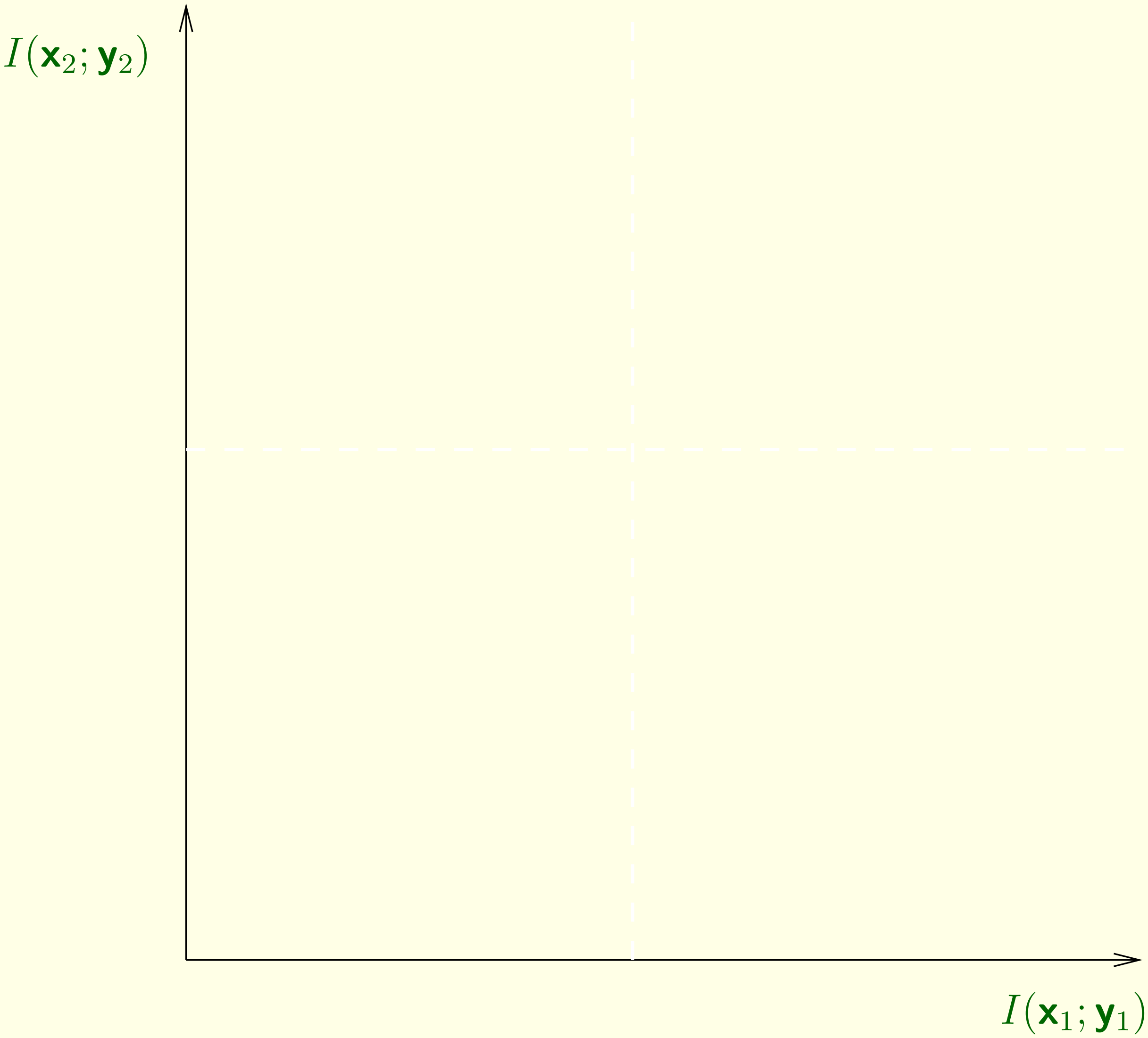


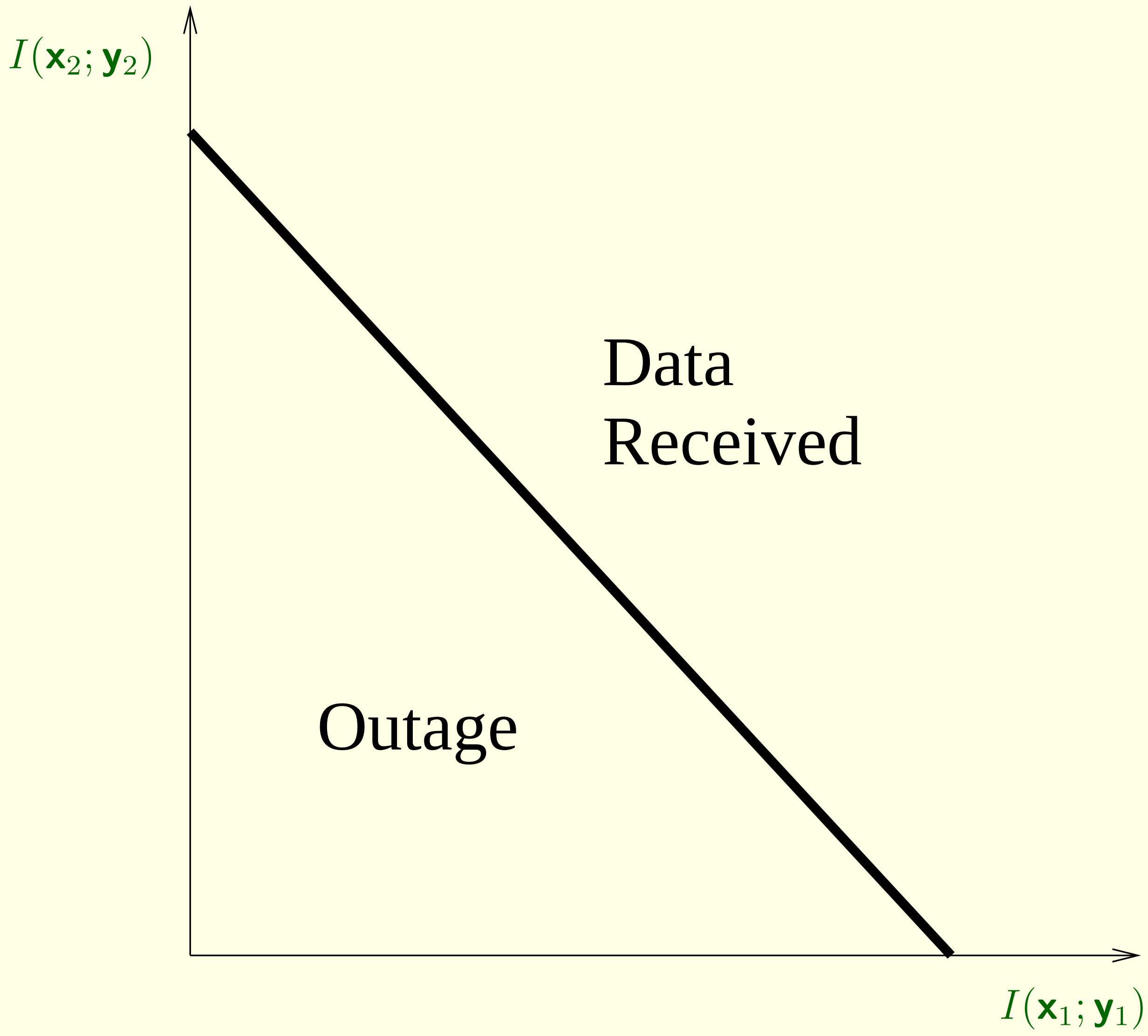
The Application Layer Approach:



Physical Layer Approach:

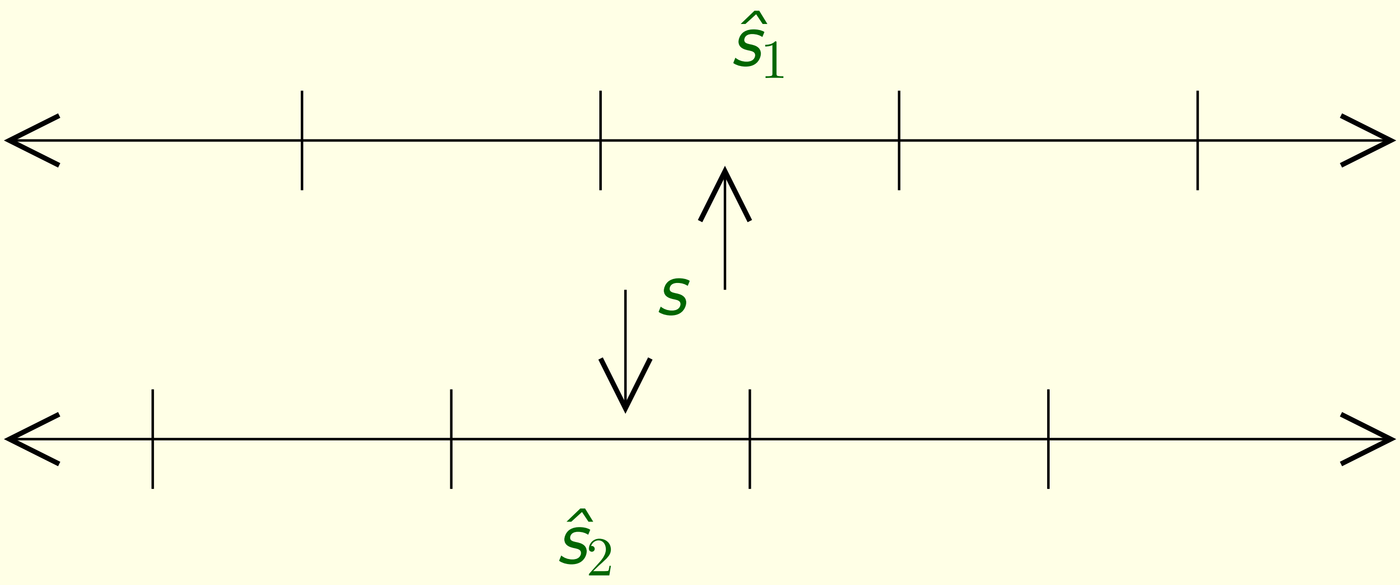


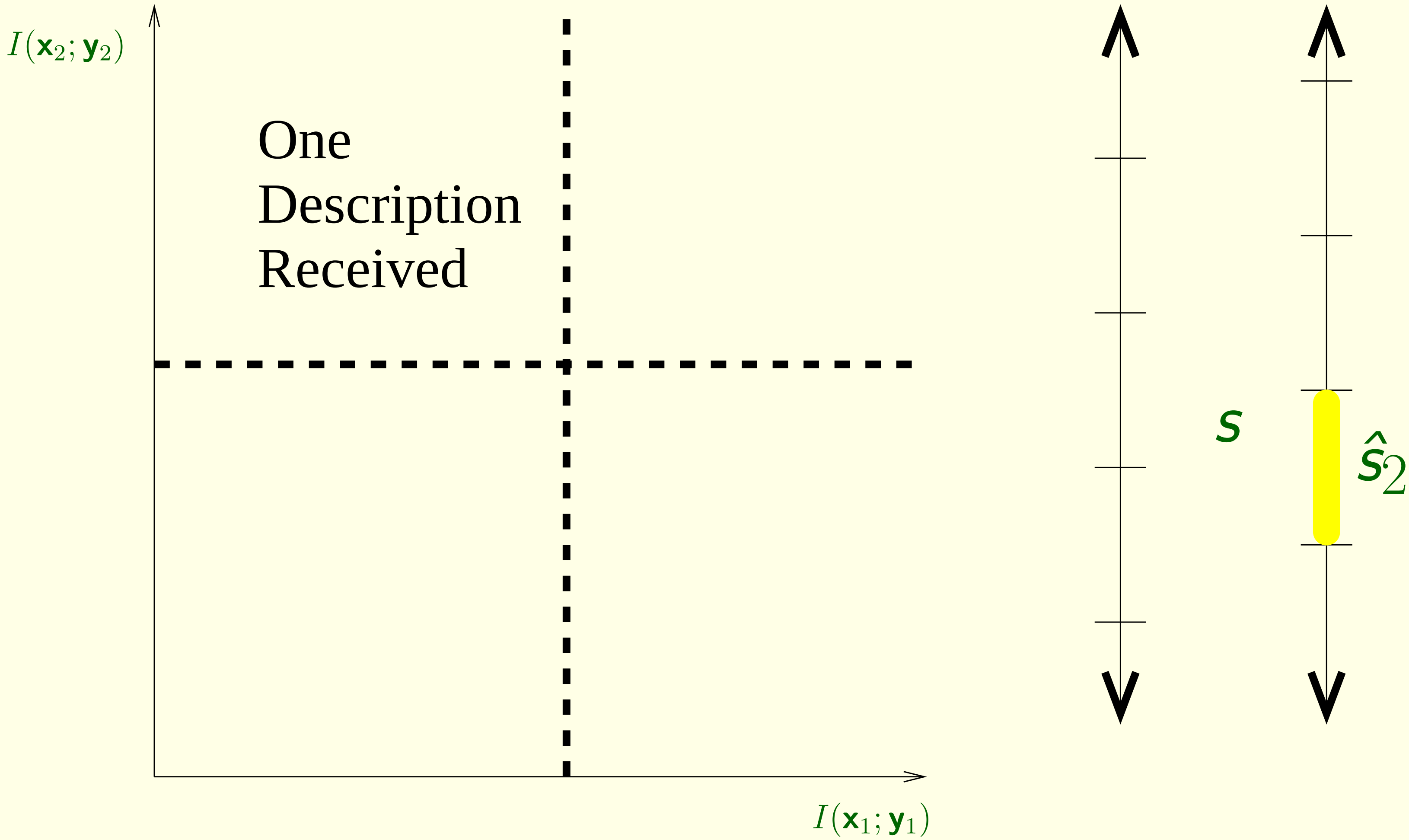
Physical Layer Approach:



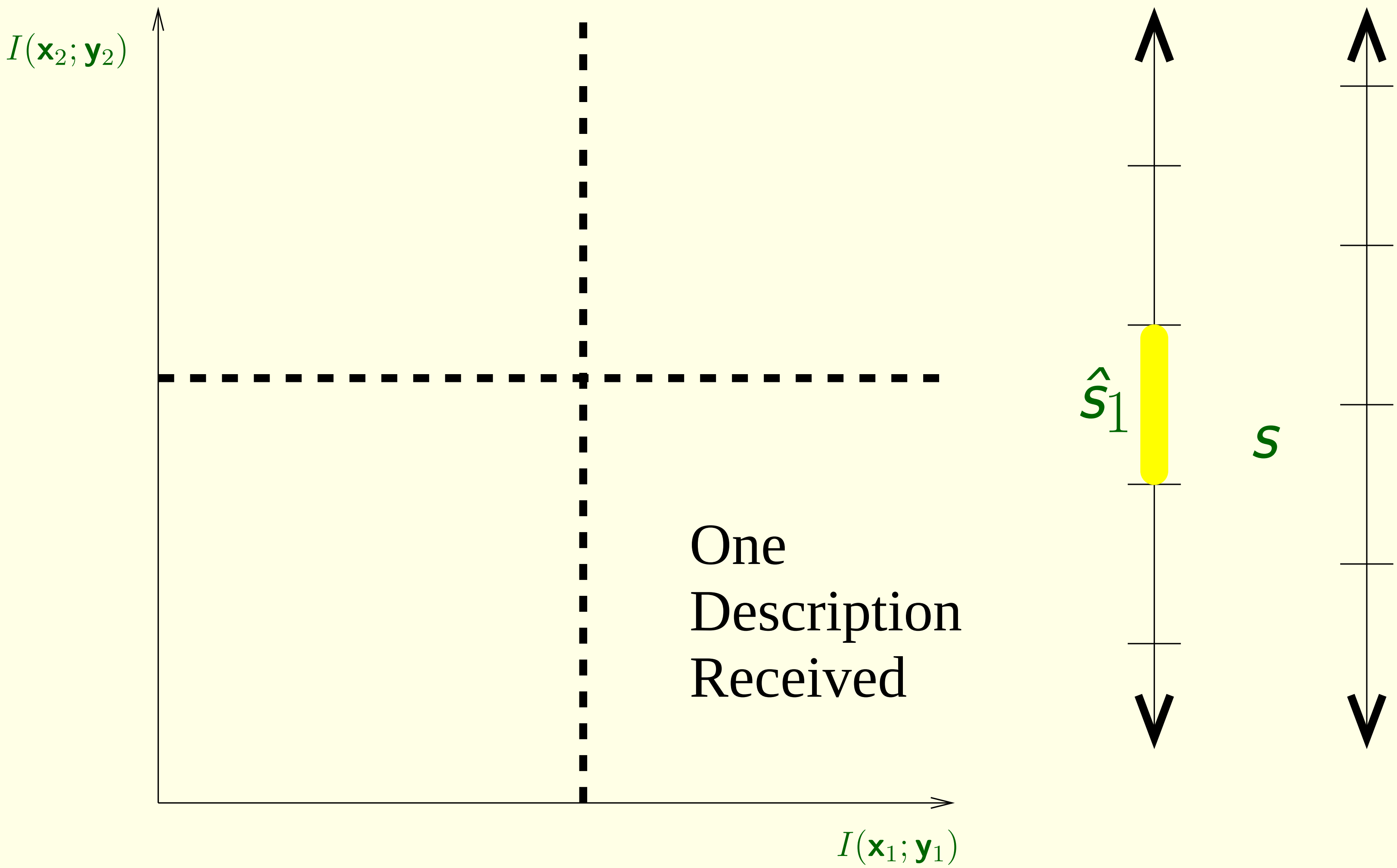
Diversity Via MD Coding:

- Quantize source, s, to two descriptions, $\hat{s}_1$, $\hat{s}_2$.

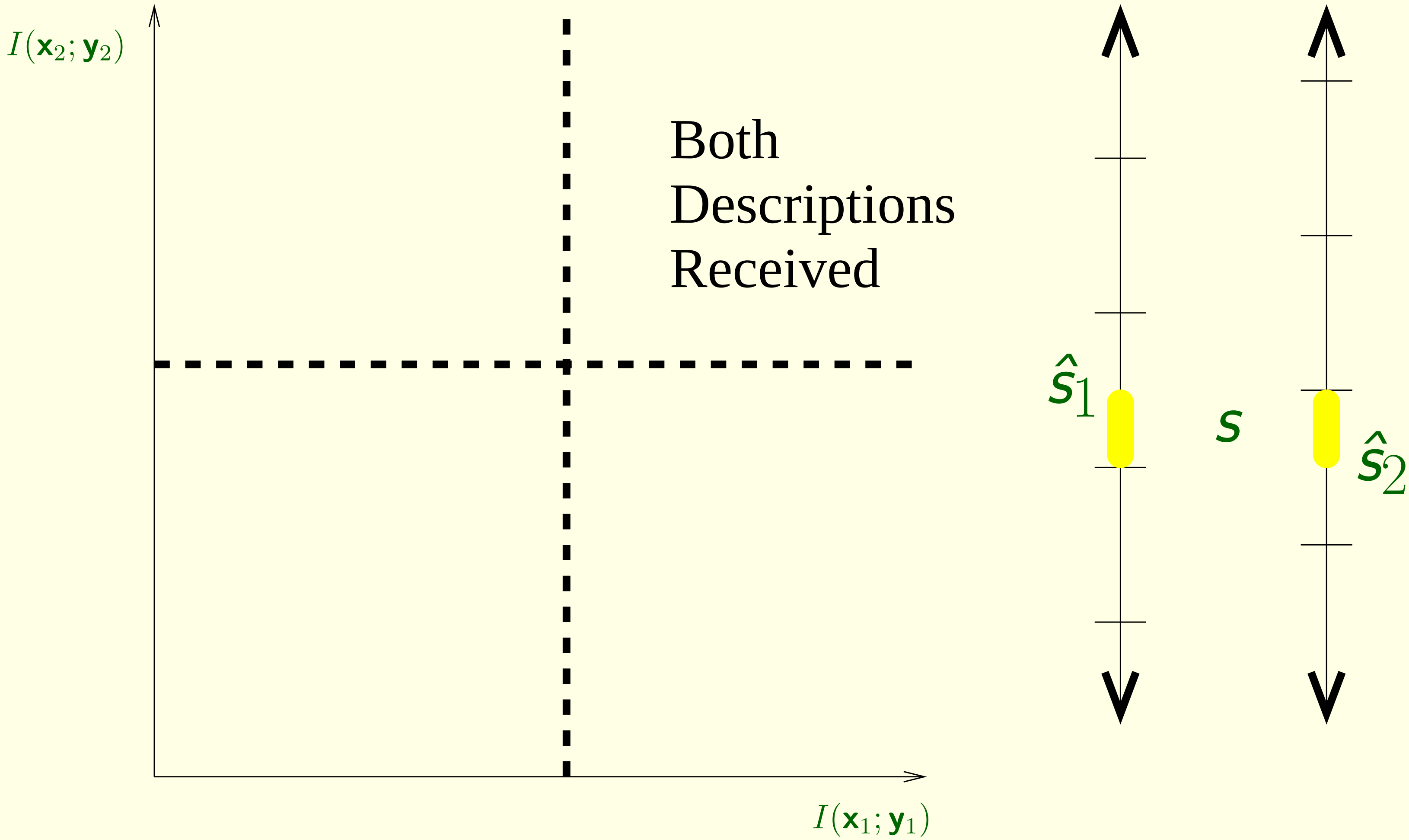




$I(\mathbf{x}_2; \mathbf{y}_2)$
One
Description
Received
$I(\mathbf{x}_1; \mathbf{y}_1)$
s
$\hat{s}_2$

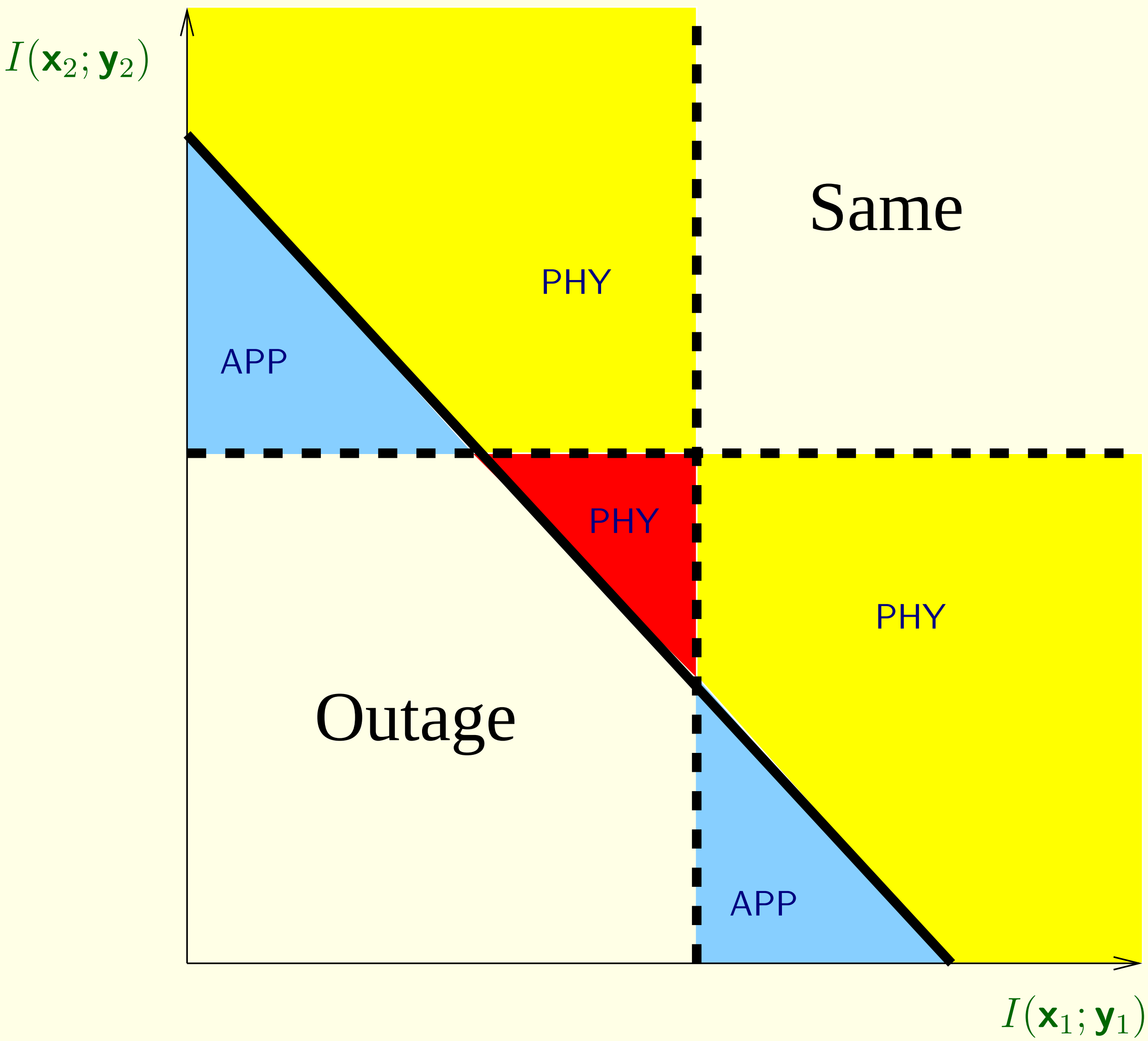


$I(\mathbf{x}_2;\mathbf{y}_2)$
$I(\mathbf{x}_1;\mathbf{y}_1)$
One Description Received
$\hat{s}_1$
s

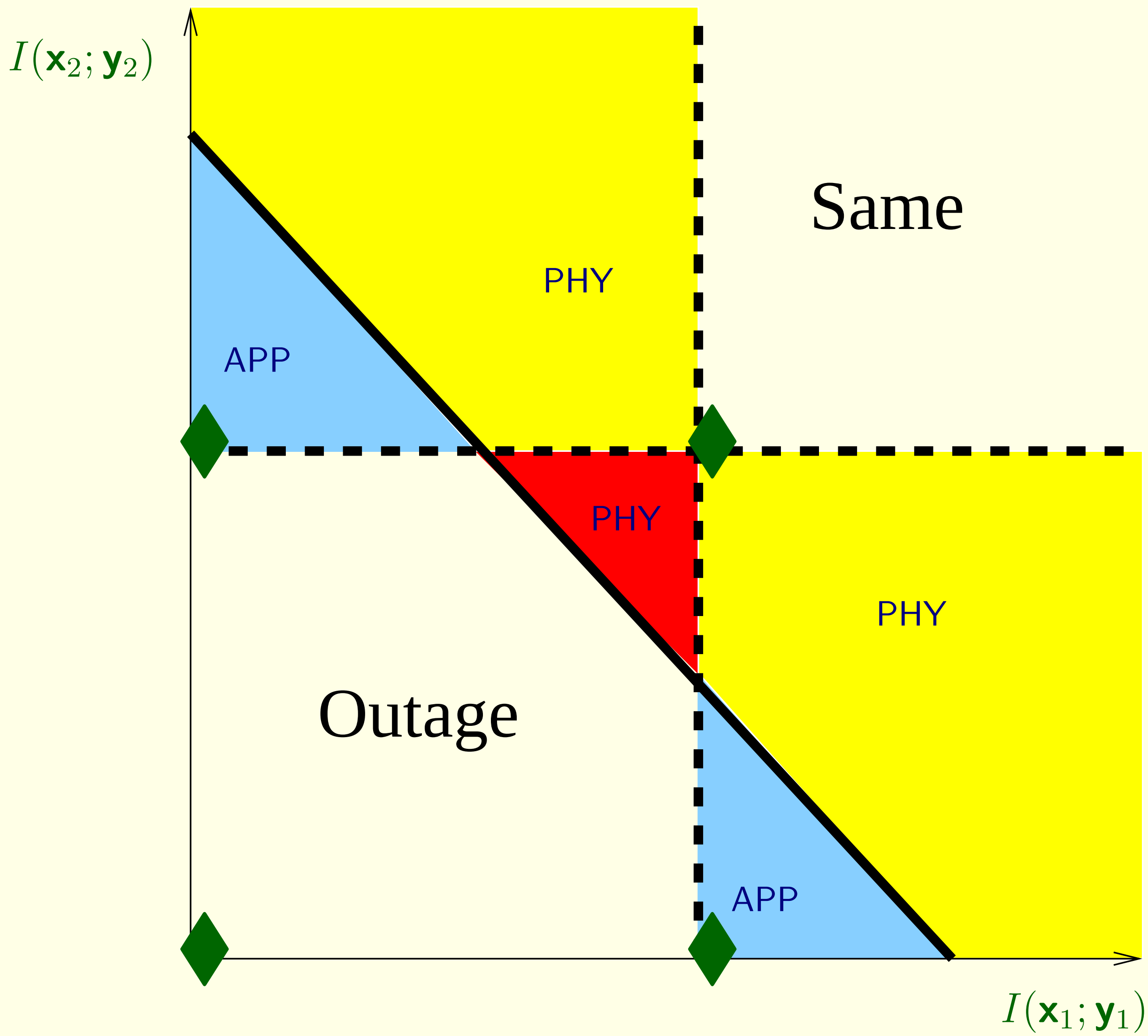


$I(\mathbf{x}_2;\mathbf{y}_2)$
Both
Descriptions
Received
$\hat{s}_1$
s
$\hat{s}_2$
$I(\mathbf{x}_1;\mathbf{y}_1)$

MD vs. SD Performance:



MD vs. SD Performance:



Performance For Gaussian Model:

- Unit variance Gaussian source, MSE distortion
- Rayleigh Fading AWGN Channel

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Optimal physical layer diversity performance:

$$E[D] \approx \min_{\mathrm{R}} p_{\mathrm{pc}}^{\mathrm{out}}(\mathrm{R}) + D(\mathrm{R})$$

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- Rayleigh Fading AWGN Channel

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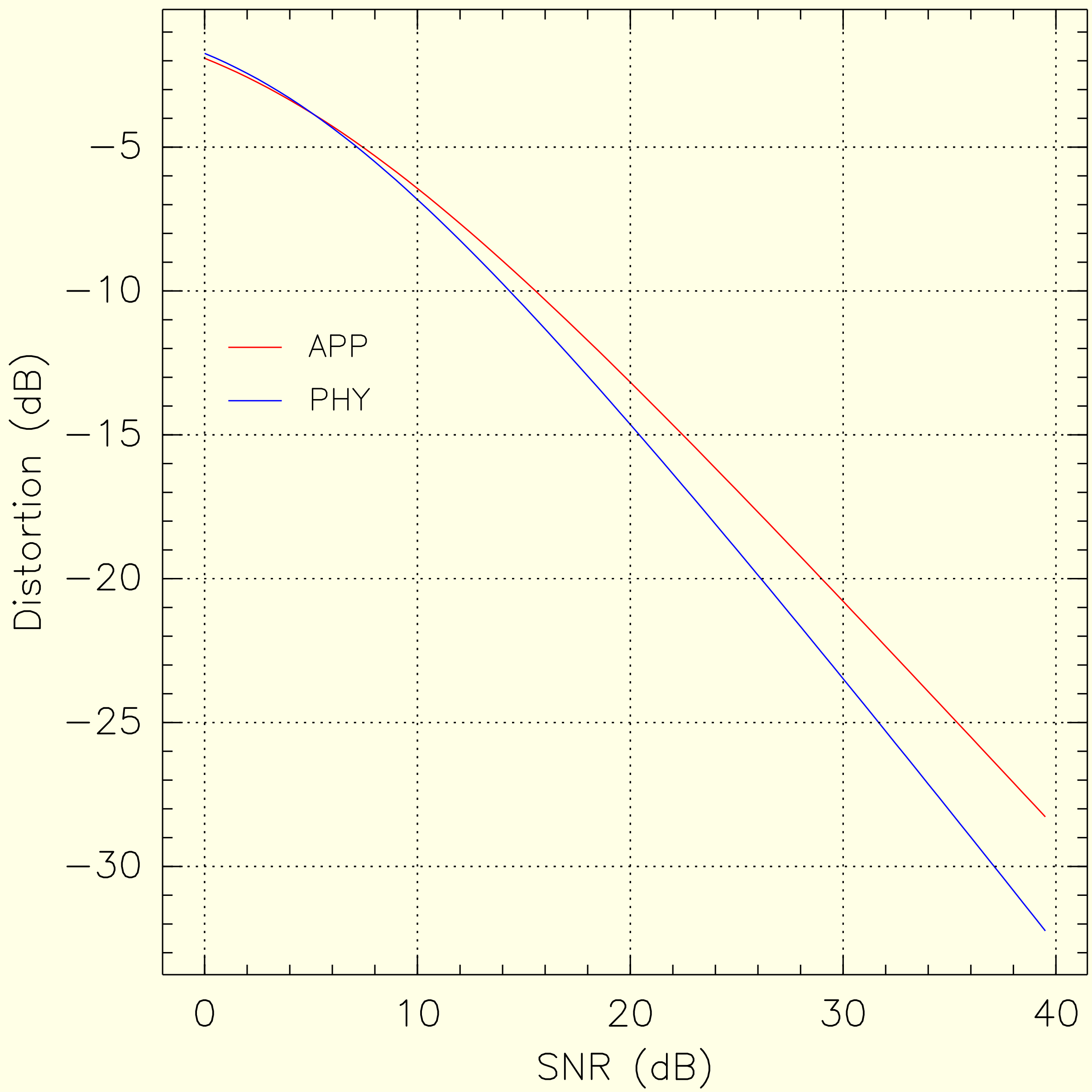
Optimal application layer diversity performance:

$$E[D] \approx \min_{\mathrm{R}} p_{\mathrm{ic}}^{\mathrm{out}}(\mathrm{R})^2 + 2 \cdot D_{\mathrm{single}} \cdot p_{\mathrm{ic}}^{\mathrm{out}}(\mathrm{R}) + D_{\mathrm{both}}$$



Distortion (dB)
−5
−10
−15
−20
−25
−30
0
10
20
30
40
SNR (dB)
APP
PHY

More general source/channel models

- "Smooth" sources with finite $h(s)$ and $E[s^2]$
- Channels with $\Pr[\exp I(x_i; y_i) < t] \approx c \cdot \left(\frac{t}{\mathrm{SNR}}\right)^p$
- Processing gain (source samples per channel samples) $\stackrel{\triangle}{=} \omega$
- For high SNR, $E[D] \approx \mathrm{SNR}^{-\Delta(\omega,p)}$:

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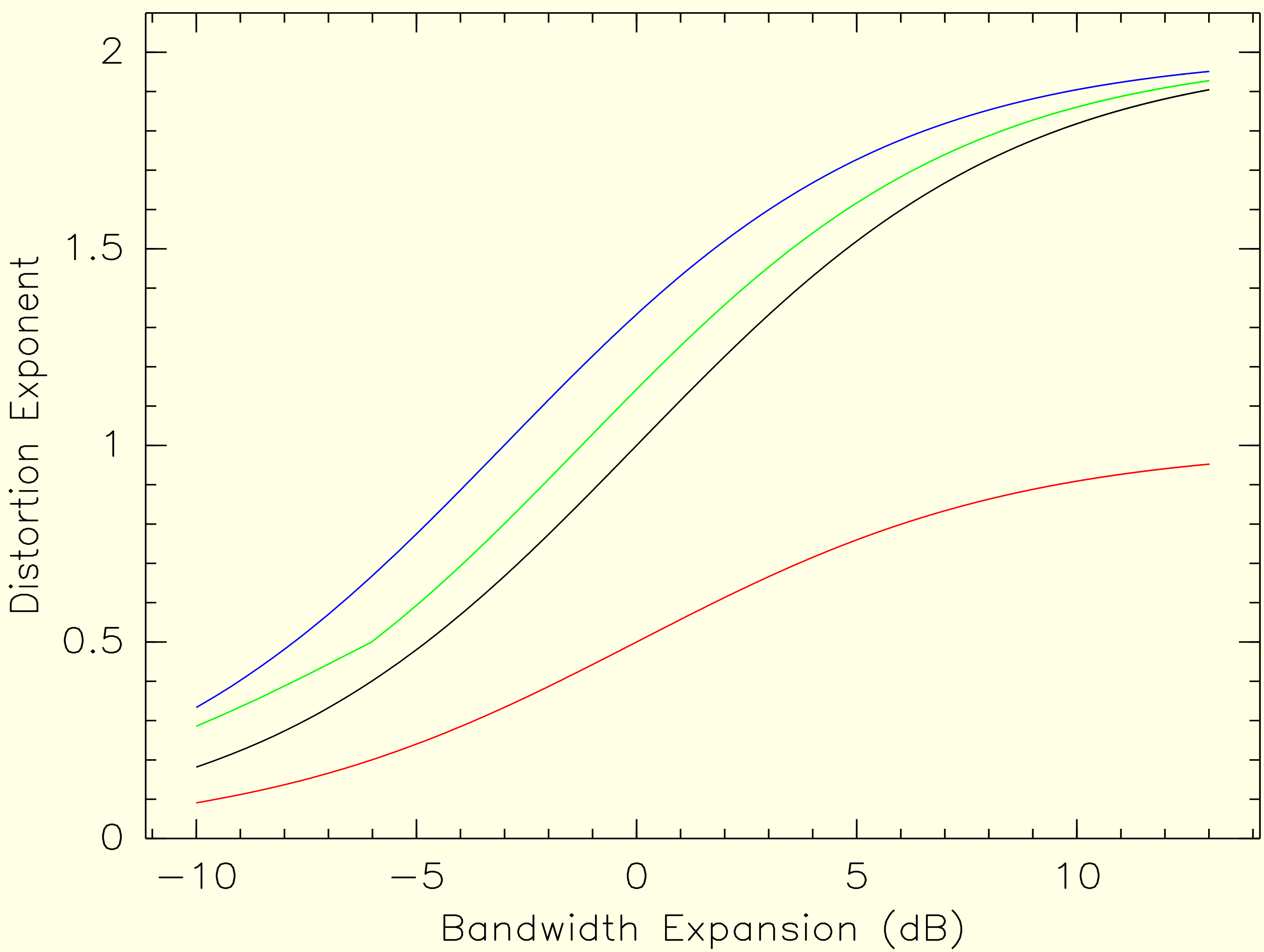
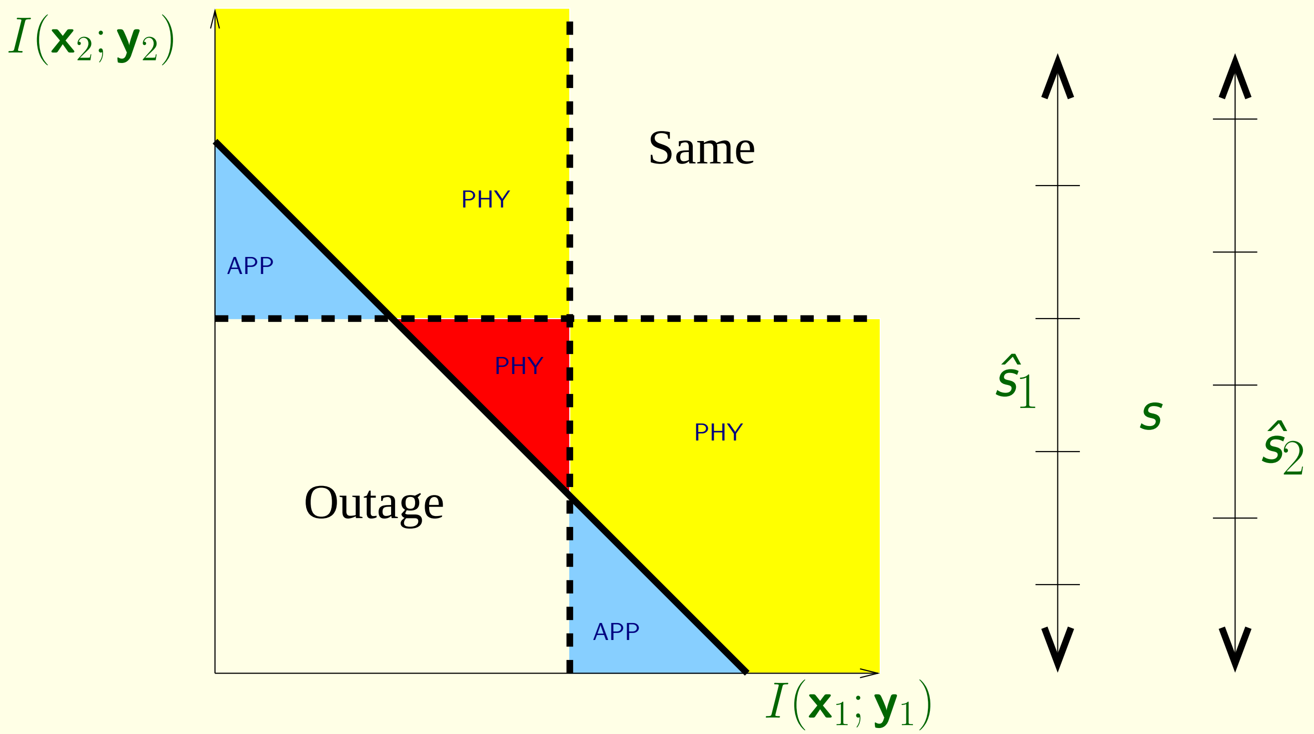
- Processing gain (source samples per channel samples) $\stackrel{\triangle}{=} \omega$
- For high SNR, $E[D] \approx \mathrm{SNR}^{-\Delta(\omega,p)}$:

System	Δ
No Diversity	$\frac{\omega p}{\omega + p}$
Repetition Diversity	$\frac{2\omega p}{\omega + p}$
Source Diversity	$\max\left[\frac{8\omega p}{4\omega + 3p}, \frac{4\omega p}{4\omega + p}\right]$
Optimal Channel Diversity	$\frac{4\omega p}{2\omega + p}$

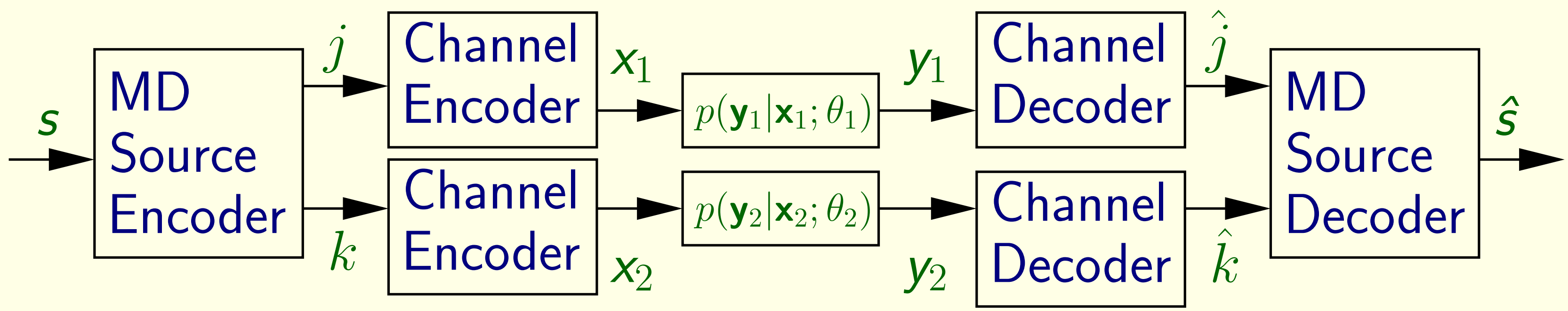


2
1.5
1
0.5
0
−10
−5
0
5
10
Distortion Exponent
Bandwidth Expansion (dB)

Joint Source-Channel Decoding



The Application Layer Approach:



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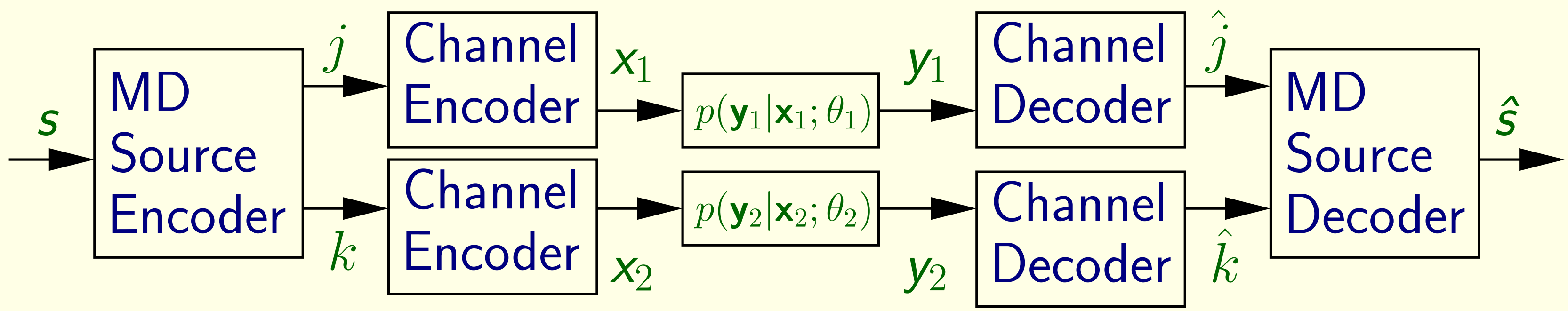

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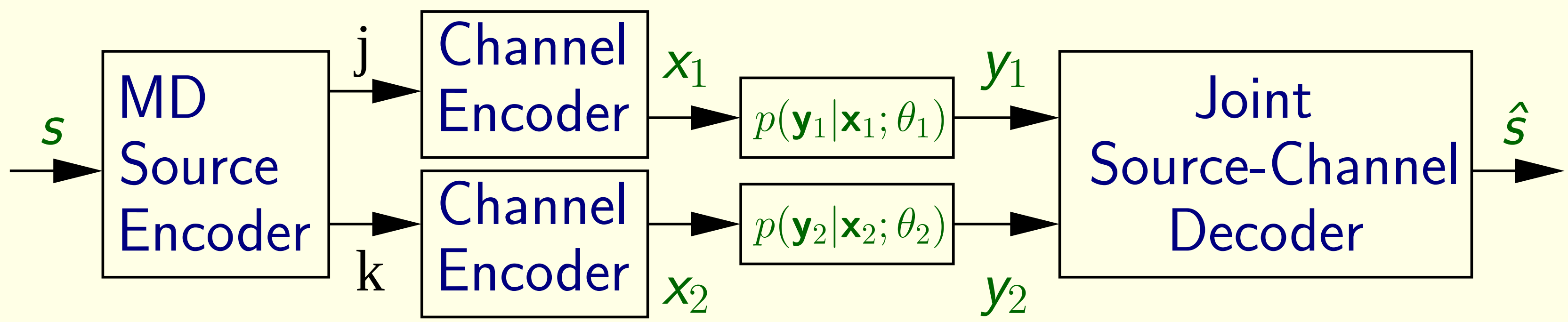


Find Codewords

Typical with $\mathbf{y}_1$

$\mathbf{x}_1 = -2\ 0\ 4\ 2$
$\mathbf{x}_1 = 0\ 0\ 4\ 2$
$\mathbf{x}_1 = 2\ 0\ 0\ 2$

Find Codewords

Typical with $\mathbf{y}_2$

$\mathbf{x}_2 = -4\ 0\ 4\ 6$
$\mathbf{x}_2 = -2\ 2\ 4\ 2$
$\mathbf{x}_2 = 0\ \ -2\ 0\ 4$

Find Codewords

Typical with $\mathbf{y}_1$

$\mathbf{x}_1 = -2\ 0\ 4\ 2$

$\mathbf{x}_1 = 0\ 0\ 4\ 2$

$\mathbf{x}_1 = 2\ 0\ 0\ 2$

Find Corresponding

Source Codewords

$\hat{\mathbf{s}}_1 = -.4\ .5\ .3\ .2$

$\hat{\mathbf{s}}_1 = .2\ .8\ 0\ 0$

$\hat{\mathbf{s}}_1 = 0\ -.3\ .5\ .7$

Find Codewords

Typical with $\mathbf{y}_2$

$\mathbf{x}_2 = -4\ 0\ 4\ 6$

$\mathbf{x}_2 = -2\ 2\ 4\ 2$

$\mathbf{x}_2 = 0\ -2\ 0\ 4$

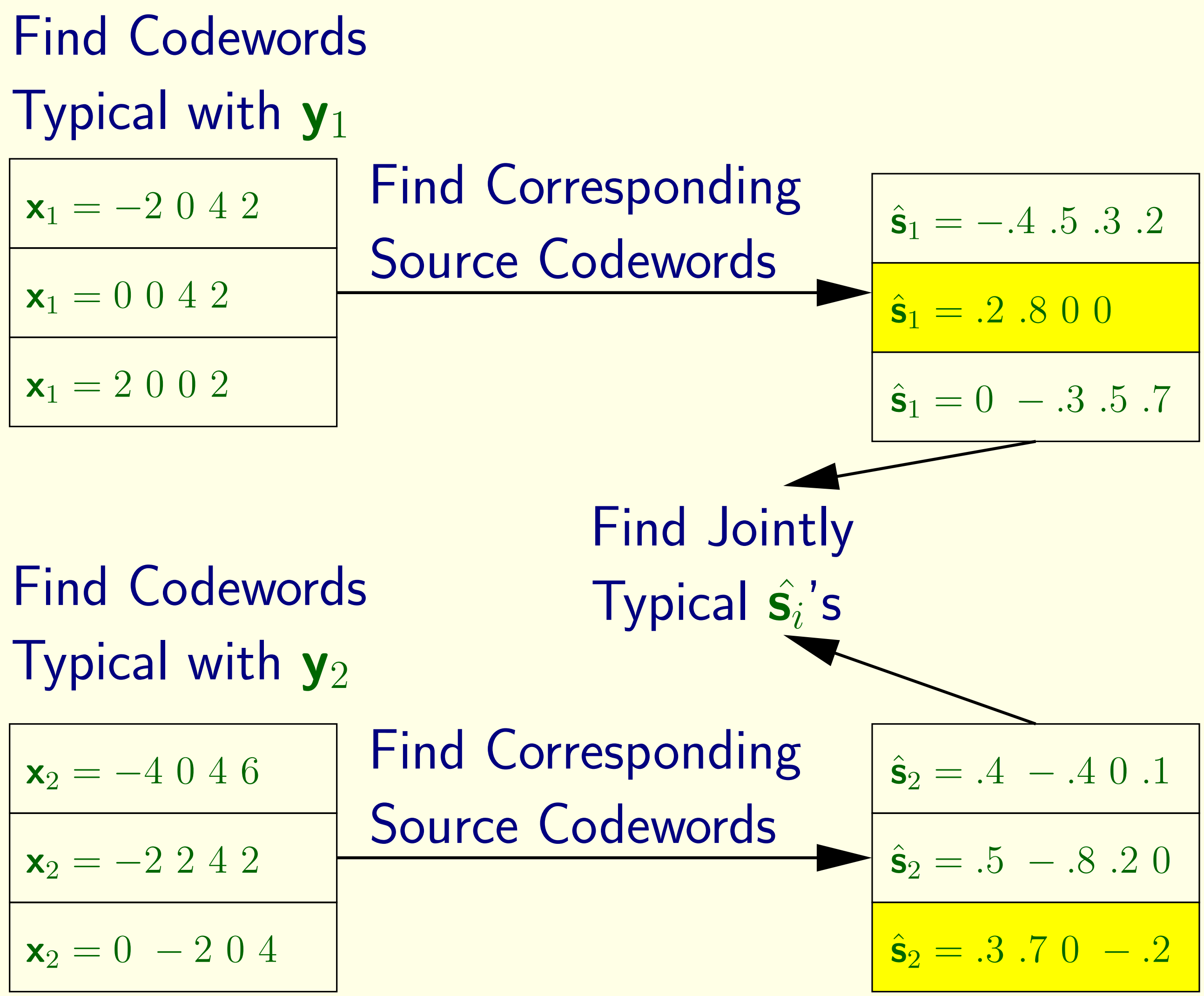
Find Corresponding

Source Codewords

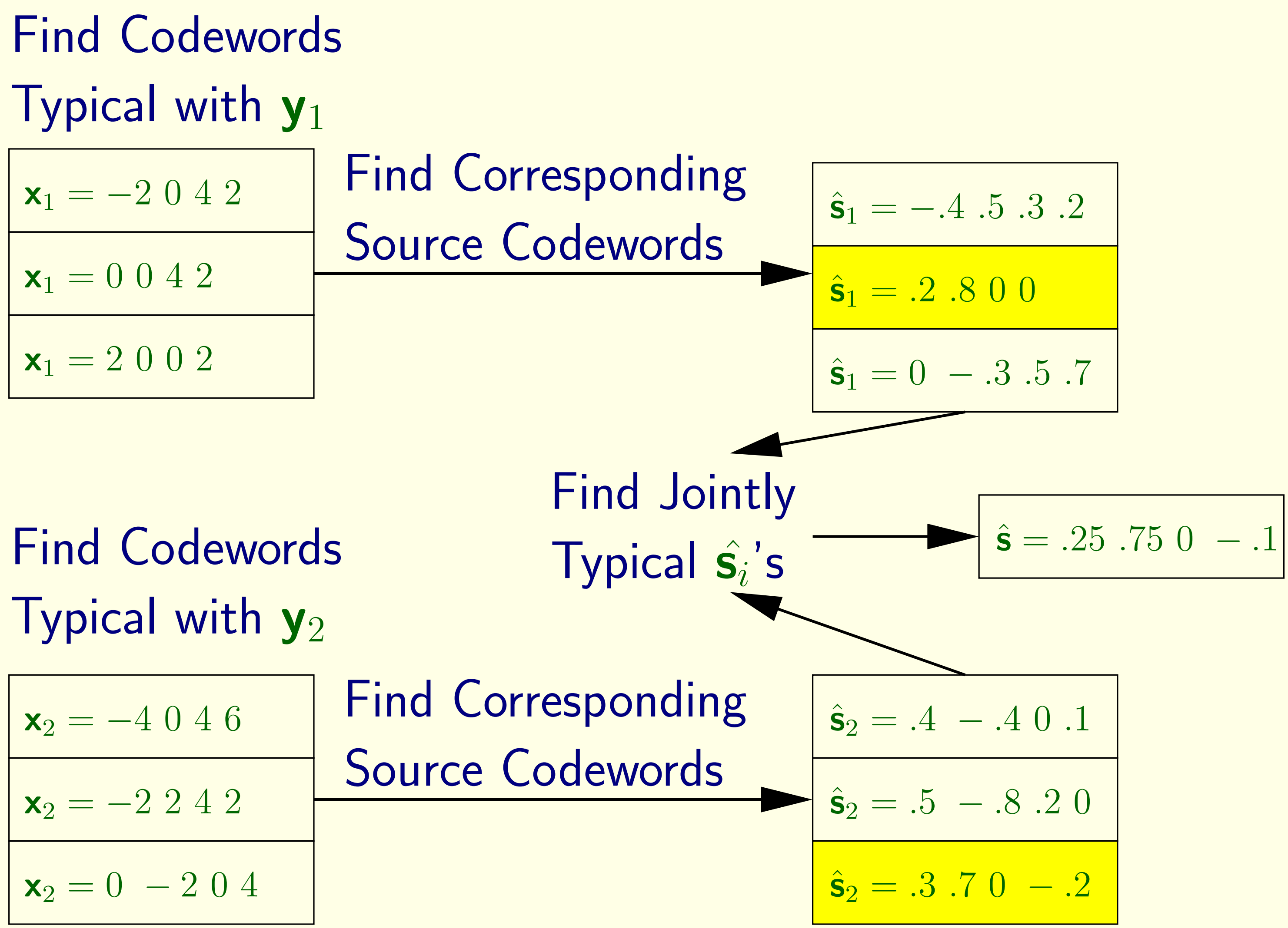
$\hat{\mathbf{s}}_2 = .4\ -.4\ 0\ .1$

$\hat{\mathbf{s}}_2 = .5\ -.8\ .2\ 0$

$\hat{\mathbf{s}}_2 = .3\ .7\ 0\ -.2$



Find Codewords Typical with $\mathbf{y}_1$
$\mathbf{x}_1 = -2\ 0\ 4\ 2$
$\mathbf{x}_1 = 0\ 0\ 4\ 2$
$\mathbf{x}_1 = 2\ 0\ 0\ 2$
Find Corresponding Source Codewords
$\hat{\mathbf{s}}_1 = -.4\ .5\ .3\ .2$
$\hat{\mathbf{s}}_1 = .2\ .8\ 0\ 0$
$\hat{\mathbf{s}}_1 = 0\ -.3\ .5\ .7$
Find Jointly Typical $\hat{\mathbf{s}}_i$'s
Find Codewords Typical with $\mathbf{y}_2$
$\mathbf{x}_2 = -4\ 0\ 4\ 6$
$\mathbf{x}_2 = -2\ 2\ 4\ 2$
$\mathbf{x}_2 = 0\ -2\ 0\ 4$
Find Corresponding Source Codewords
$\hat{\mathbf{s}}_2 = .4\ -.4\ 0\ .1$
$\hat{\mathbf{s}}_2 = .5\ -.8\ .2\ 0$
$\hat{\mathbf{s}}_2 = .3\ .7\ 0\ -.2$


Find Codewords
Typical with $\mathbf{y}_1$
$\mathbf{x}_1 = -2\ 0\ 4\ 2$
$\mathbf{x}_1 = 0\ 0\ 4\ 2$
$\mathbf{x}_1 = 2\ 0\ 0\ 2$
Find Corresponding
Source Codewords
$\hat{\mathbf{s}}_1 = -.4\ .5\ .3\ .2$
$\hat{\mathbf{s}}_1 = .2\ .8\ 0\ 0$
$\hat{\mathbf{s}}_1 = 0\ -.3\ .5\ .7$
Find Jointly
Typical $\hat{\mathbf{s}}_i$'s
$\hat{\mathbf{s}} = .25\ .75\ 0\ -.1$
Find Codewords
Typical with $\mathbf{y}_2$
$\mathbf{x}_2 = -4\ 0\ 4\ 6$
$\mathbf{x}_2 = -2\ 2\ 4\ 2$
$\mathbf{x}_2 = 0\ -2\ 0\ 4$
Find Corresponding
Source Codewords
$\hat{\mathbf{s}}_2 = .4\ -.4\ 0\ .1$
$\hat{\mathbf{s}}_2 = .5\ -.8\ .2\ 0$
$\hat{\mathbf{s}}_2 = .3\ .7\ 0\ -.2$

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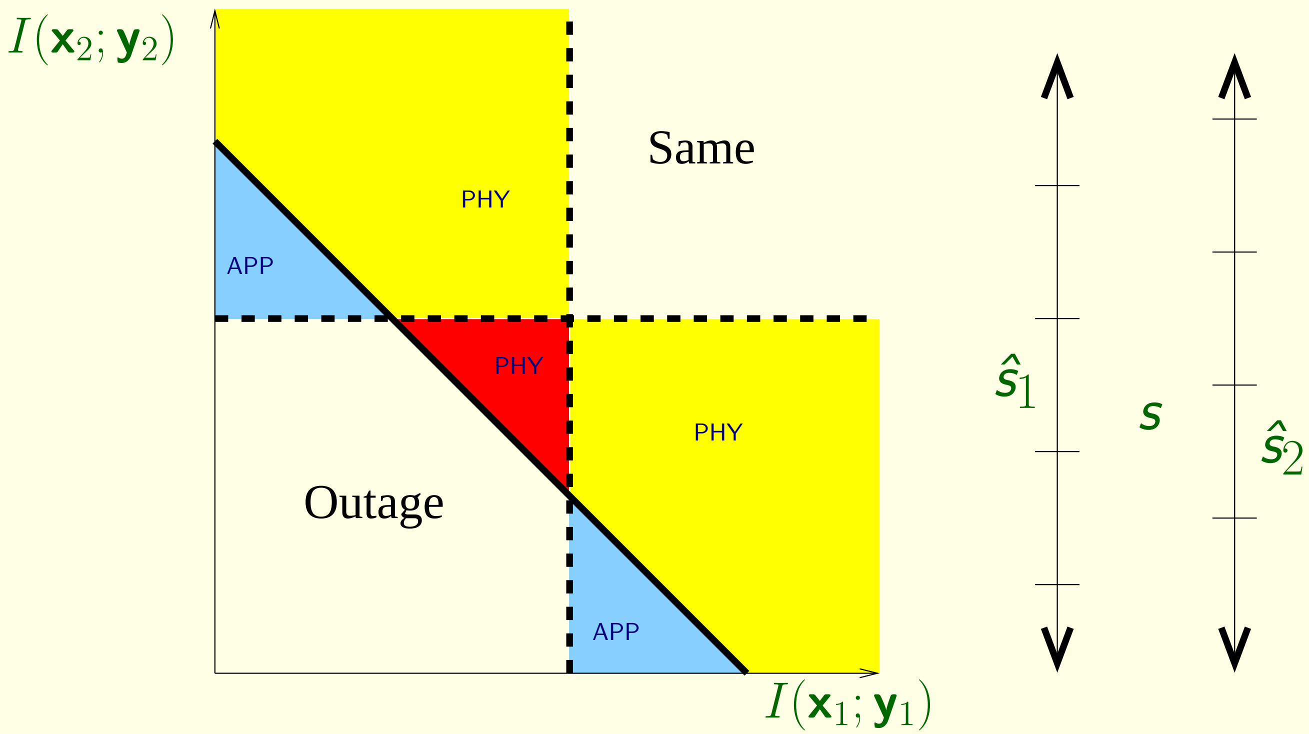

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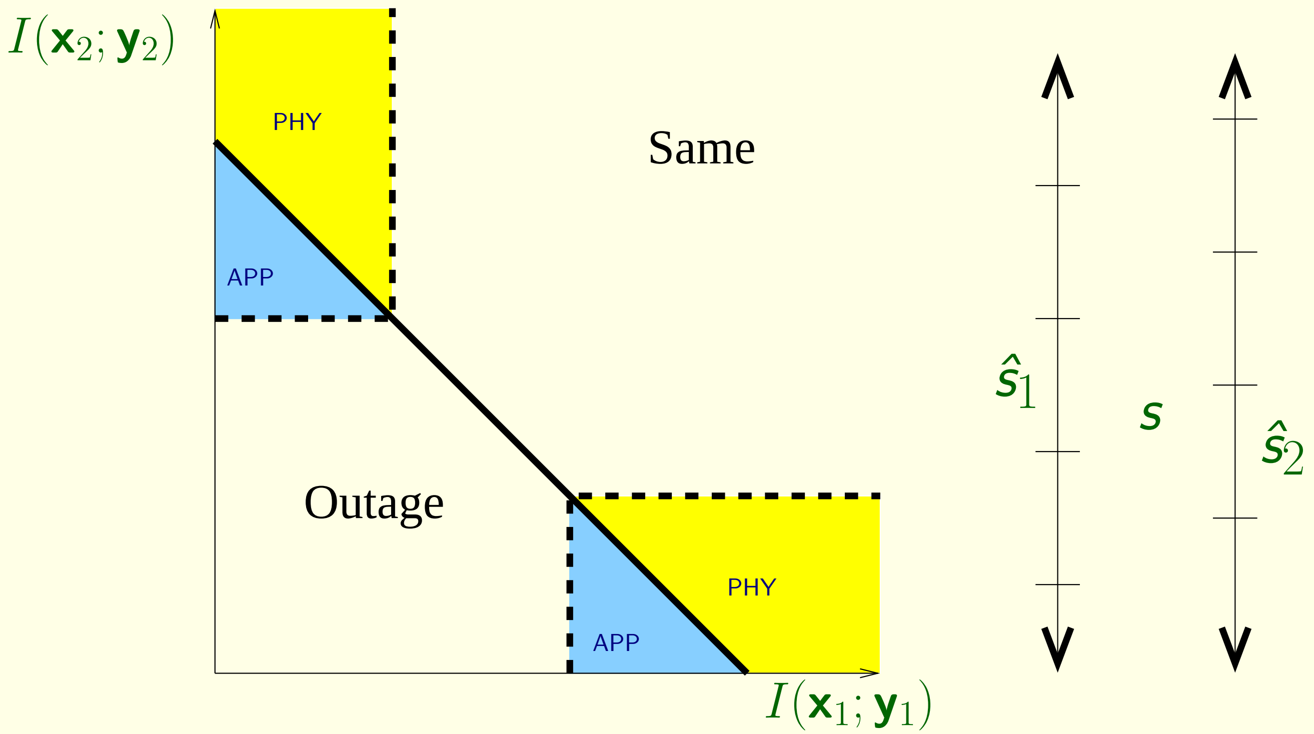

Concluding Remarks

- APP layer diversity better for On-Off channels.
- PHY layer diversity better for continuous channels.
- Joint design achieves best of both.