

Near-Capacity BICM-ID-SSD, Good for Future DTTB Systems

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Outline

Why BICM-ID?

Higher Power/Spectrum Efficiency Req.

Best-ever-known Coded Modulation

How to Design a Near-Capacity BICM-ID?

BICM-ID Design Examples

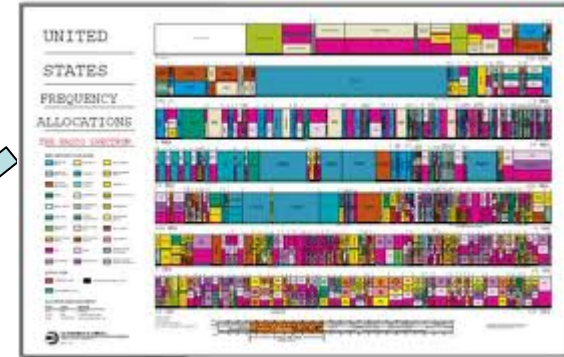
BICM-ID Implementations and Applications

Conclusions

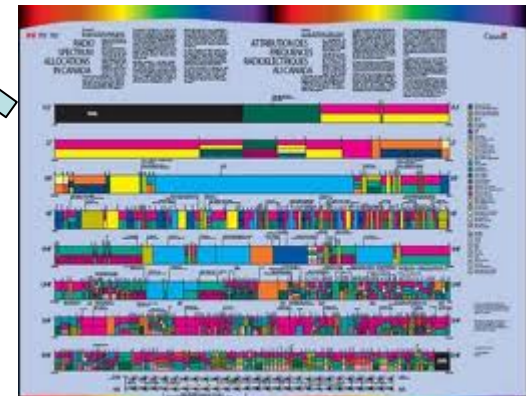
Growing Demands vs Limited Energy and Spectrum



Energy & Environment Crisis

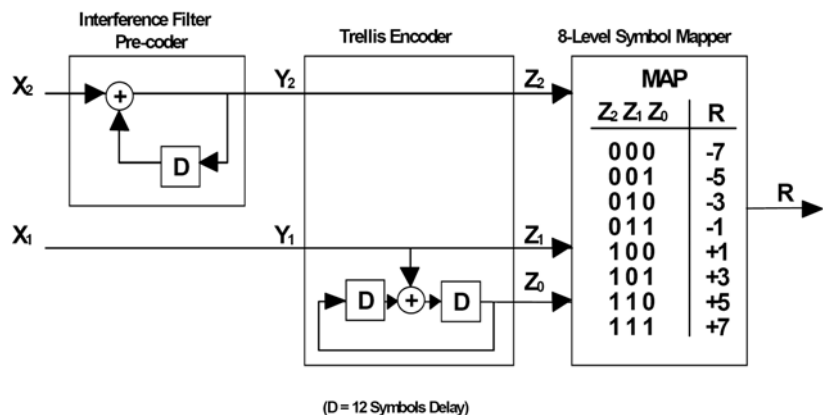


Limited Spectrum Available

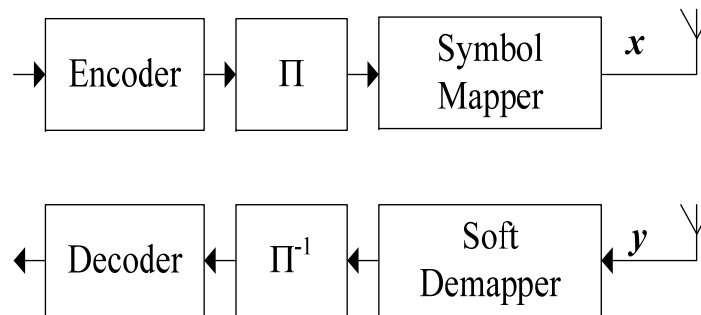


One of the most important goals of future communication and broadcasting: **Higher power/spectrum efficiency.**

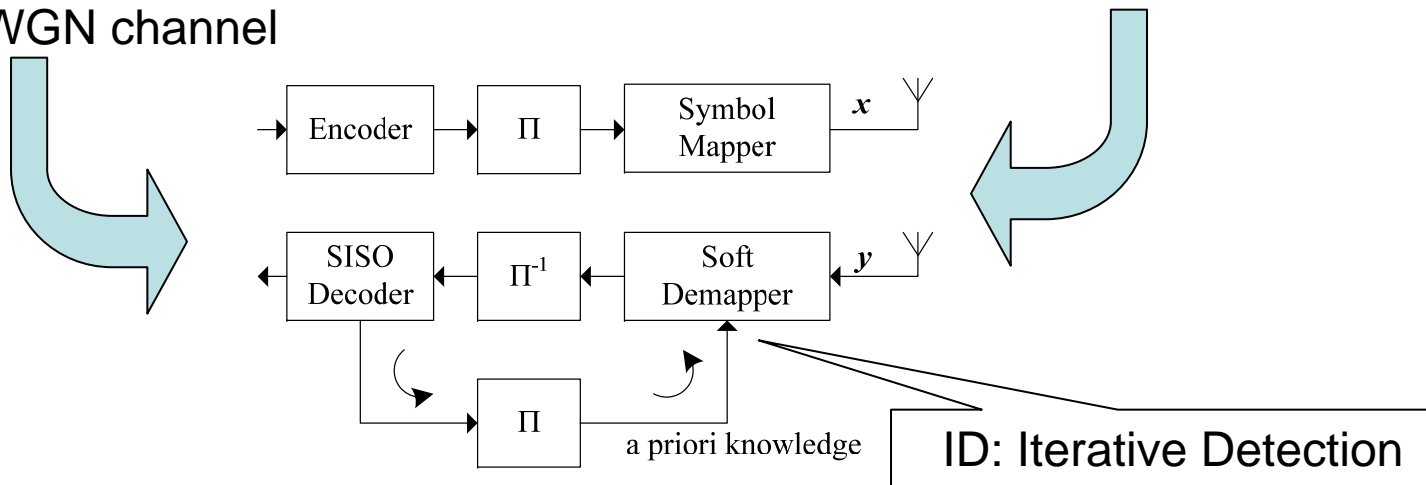
Coded Modulation for Higher Power/Spectrum Efficiency



Trellis Coded Modulation for ATSC:
good for AWGN channel



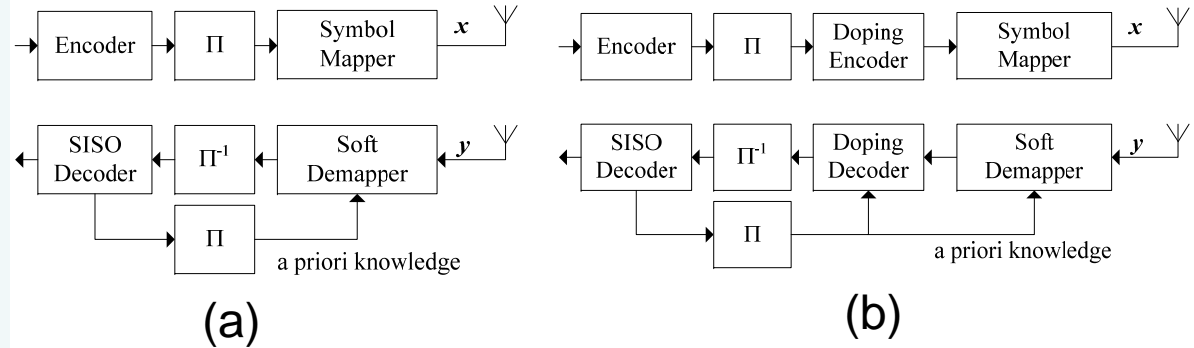
Bit-Interleaved Coded Modulation:
excellent for fading channels.



BICM-ID: for both AWGN and fading channels

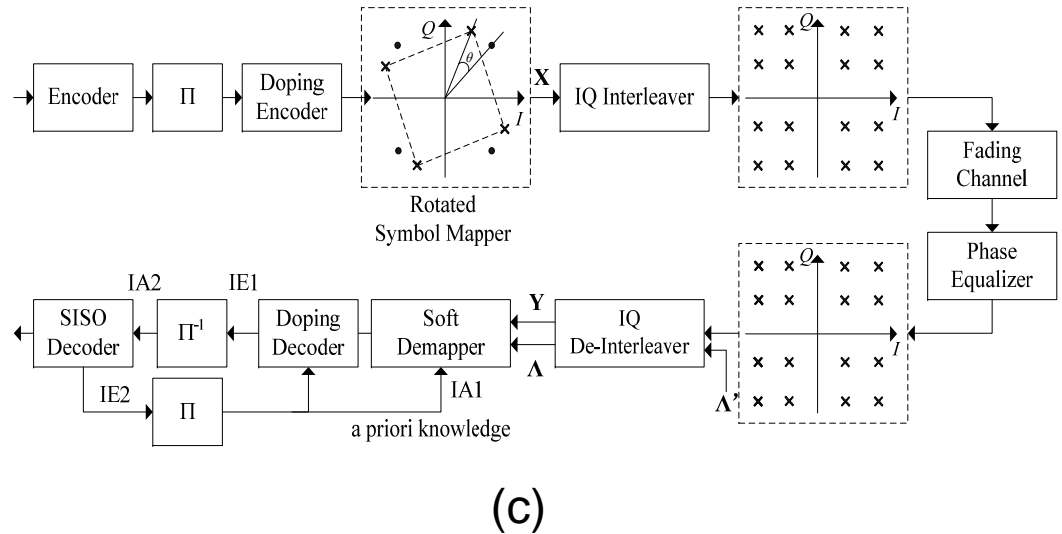
History of Bit-Interleaved Coded Modulation with Iterative Demapping/Decoding

(a) Original BICM-ID, by X. Li and ten Brink [1-2].



(b) BICM-ID with doping, by Pfletschinger *et.al* for **error-floor removal** [3].

(c) We proposed a BICM-ID scheme with doping and signal space diversity (SSD): **near-capacity performance for both AWGN and fading channels** [4-5].



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Why BICM-ID?

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Information Theory

EXIT Charts

BICM-ID Design Examples

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Challenges for Near-Capacity BICM-ID?

Key challenges for near-capacity BICM-ID

How to solve these problems? [4] [5] [7]



• Lower constellation-constraint capacity limits.



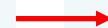
• Information theory.

• Bit-to-symbol Mapping.
• SSD for near-capacity performance for both AWGN and fading channels.



• Extrinsic information transfer (EXIT) charts.

• Interleaver design.

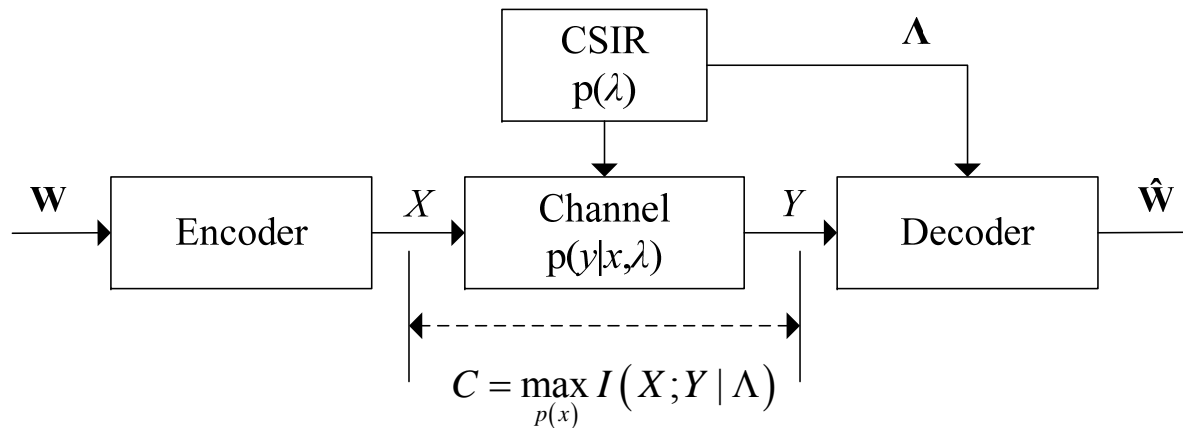


• Left open.



Theoretical Characterization

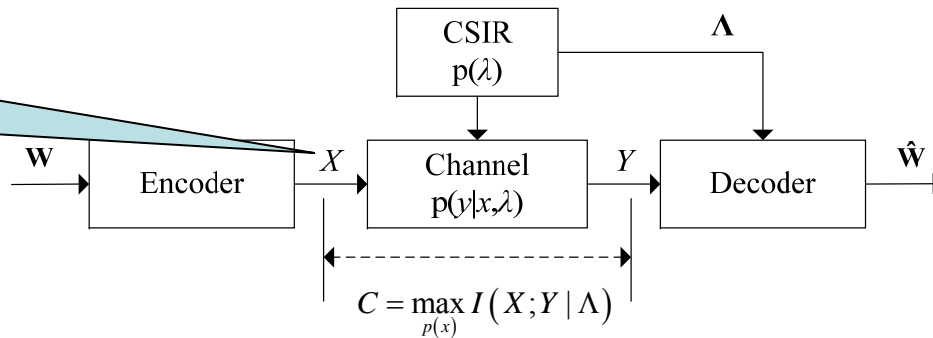
- **Channel capacity** is the maximum average mutual information (AMI) between the channel inputs and outputs by adjusting the inputs' distribution.
- The channel input X has **no or few constraints**, e.g., only the **power constraint for AWGN channels**.
- Channel capacity provides a fundamental **tight upper bound** of information that can be reliably transmitted over arbitrary channel.



The abstract model in pure information theory

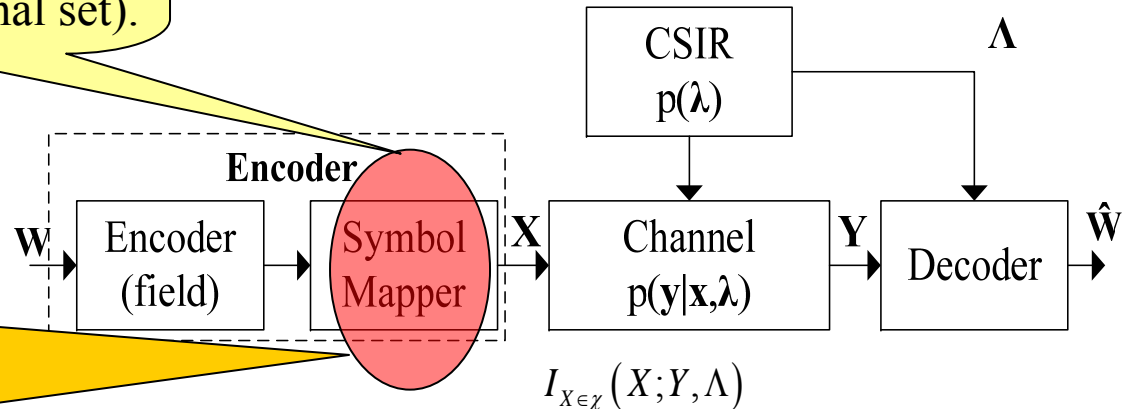
Constellation Constraint Channel Capacity

X can be arbitrary distributed.



Shannon channel capacity.

X can only take the limited elements from an alphabet (the constellation signal set).



Designing a constellation to have a larger DCMC capacity is important.

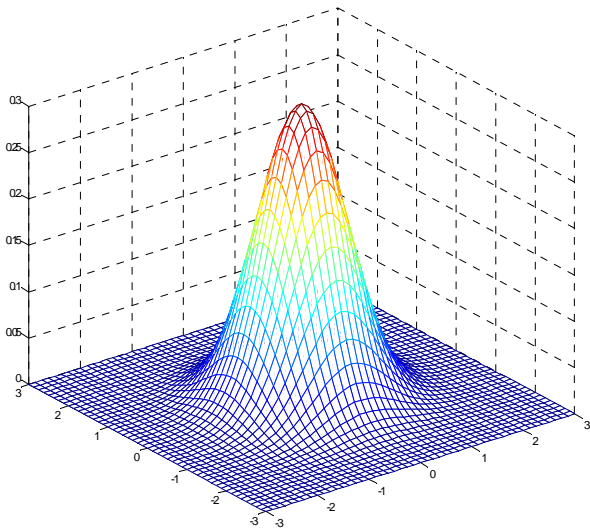
Constellation constraint channel capacity, also referred to discrete-input continuous-output memoryless channel (DCMC) capacity.



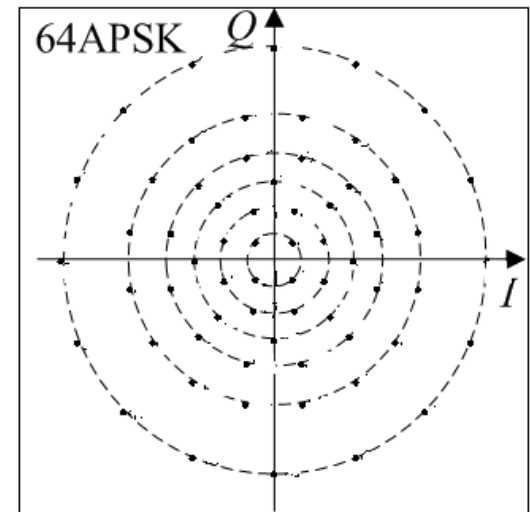
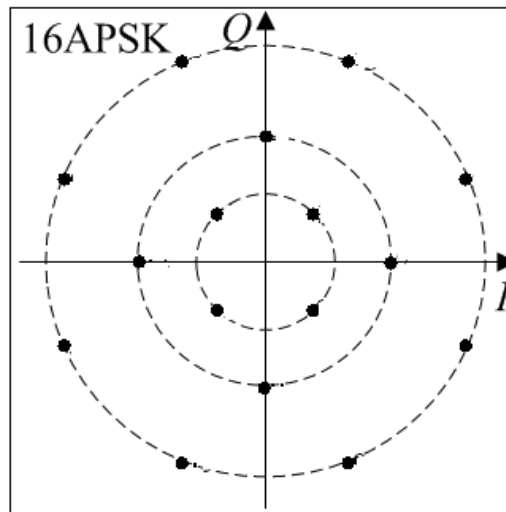
DCMC Capacity: Why APSK Constellations?

Information theory: only Gaussian inputs can achieve the AWGN channel capacity.

For complex AWGN channels, circular APSK constellations rather than square QAM constellations seem closer to Gaussian inputs [5].



Complex Gaussian distribution



The APSK Constellation Construction Process

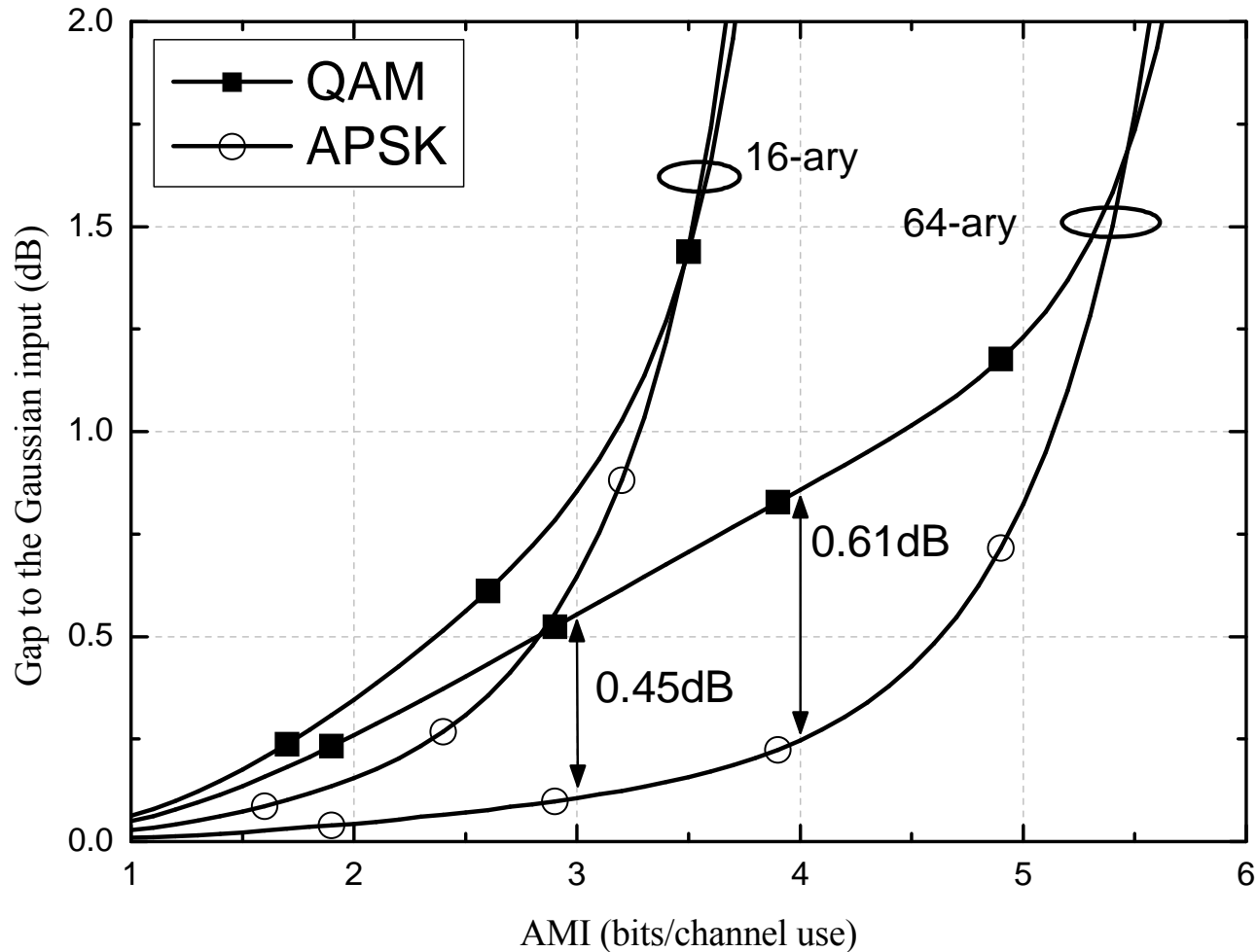
The APSK constellation set can be given by

$$\chi = \begin{cases} r_1 \exp \left(j \left(\frac{2\pi}{n_1} i + \theta_1 \right) \right) & i = 0, \dots, n_1 - 1 \\ r_2 \exp \left(j \left(\frac{2\pi}{n_2} i + \theta_2 \right) \right) & i = 0, \dots, n_2 - 1 \\ \dots & \\ r_R \exp \left(j \left(\frac{2\pi}{n_R} i + \theta_R \right) \right) & i = 0, \dots, n_R - 1 \end{cases}$$

The general M-APSK constellation construction process is listed below.

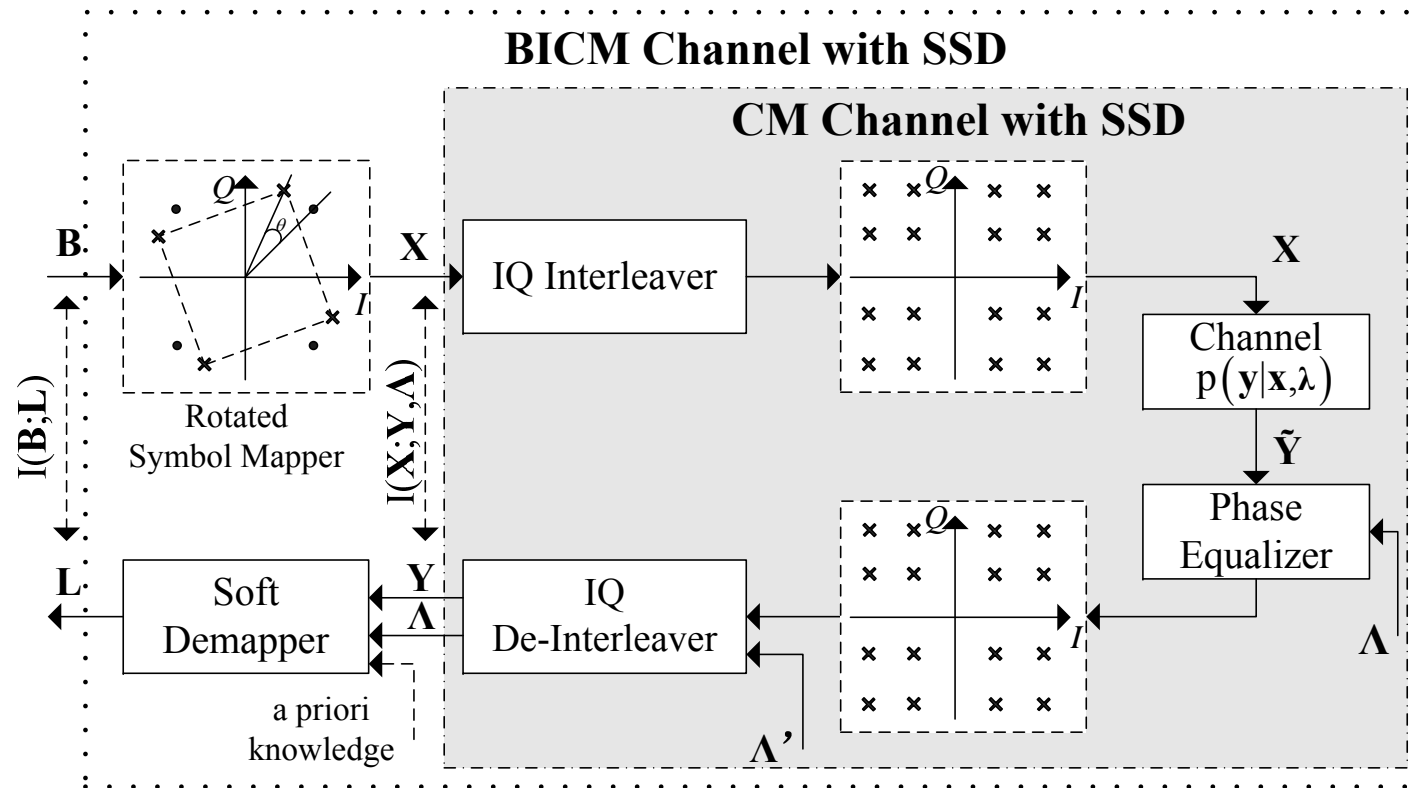
1. Select the number of rings R and the number of constellation points on each ring $n_l (l = 1, \dots, R)$, so that $\sum_{l=1}^R n_l = M$ is satisfied.
2. Determine the radius r_l so that the cumulative probability of the standard complex Gaussian distribution within ring l obeys $P_l = \left(\sum_{i=1}^{l-1} n_i + n_l/2 \right) / M$
3. Choose $\theta_l (l = 1, \dots, R)$ to maximize the $I(X;Y)$.

Numerical Results of DCMC Capacity with APSK



Gaps between the DCMC capacity and the AWGN channel capacity [4-5].

DCMC Capacity: Optimal Rotation Angle of Signal Space Diversity for Square QAM. (1/3)



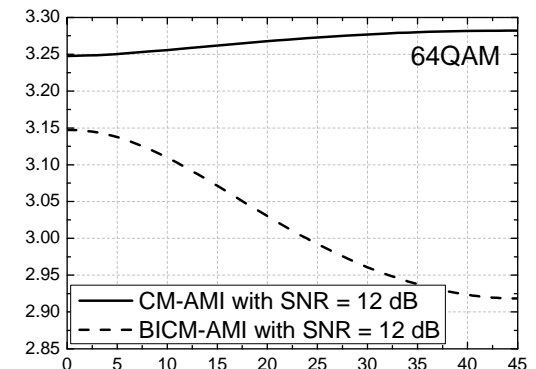
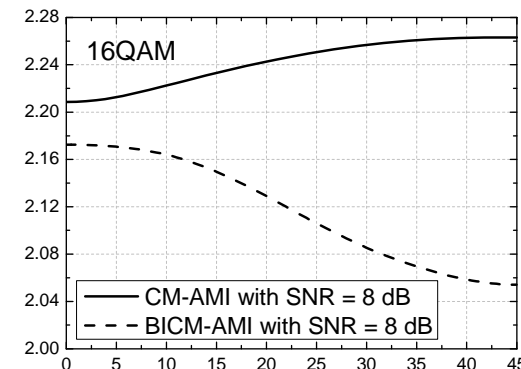
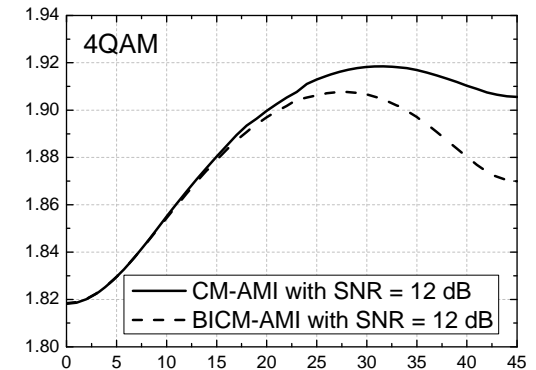
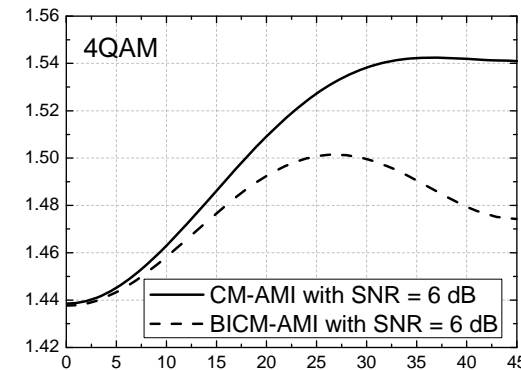
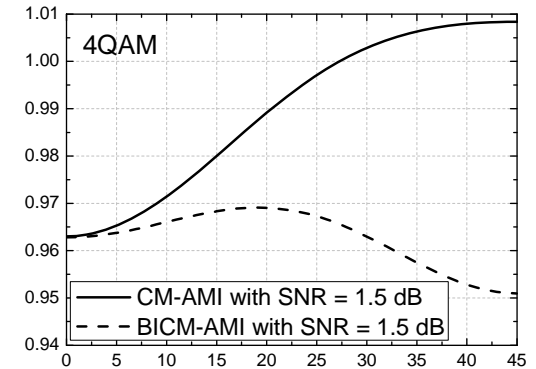
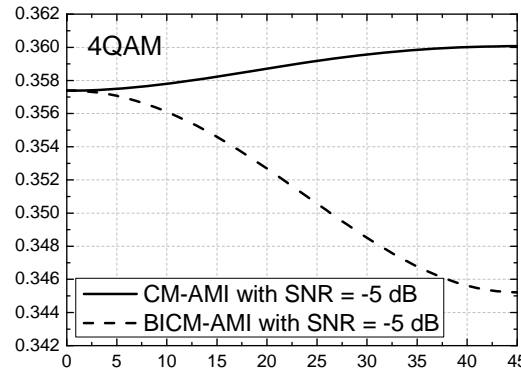
System model of coded modulation with SSD [4].

DCMC Capacity: Optimal Rotation Angle for SSD when using Square QAM. (2/3)

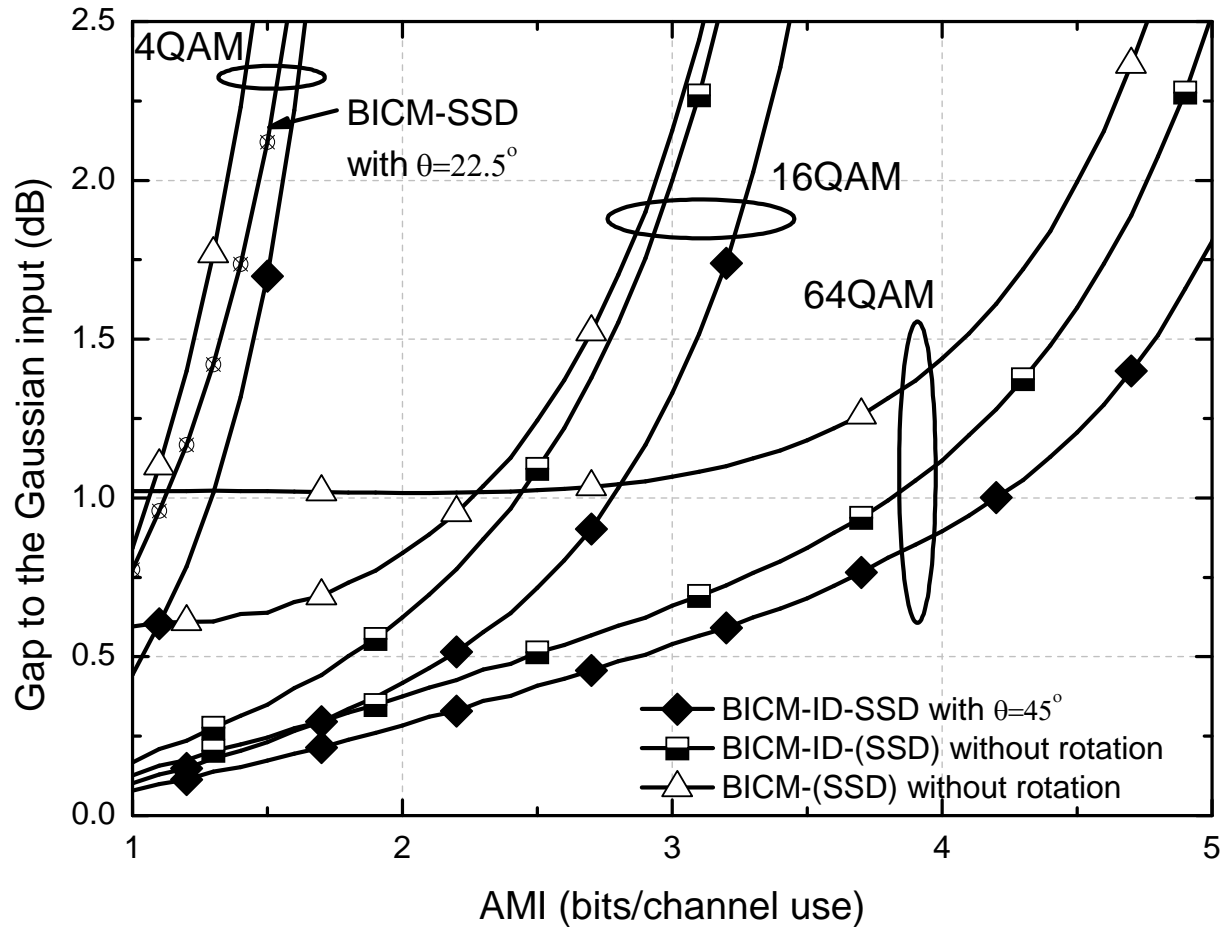
Optimal rotation angles [4]:

$I(X;Y|\wedge)$ and $I(B;L)$ vs the rotation angle.

- i.i.d. Rayleigh channels.
- Ideal coordinate interleaving, i.e., the I/Q components are independent of each other.
- 4/16/64QAM.



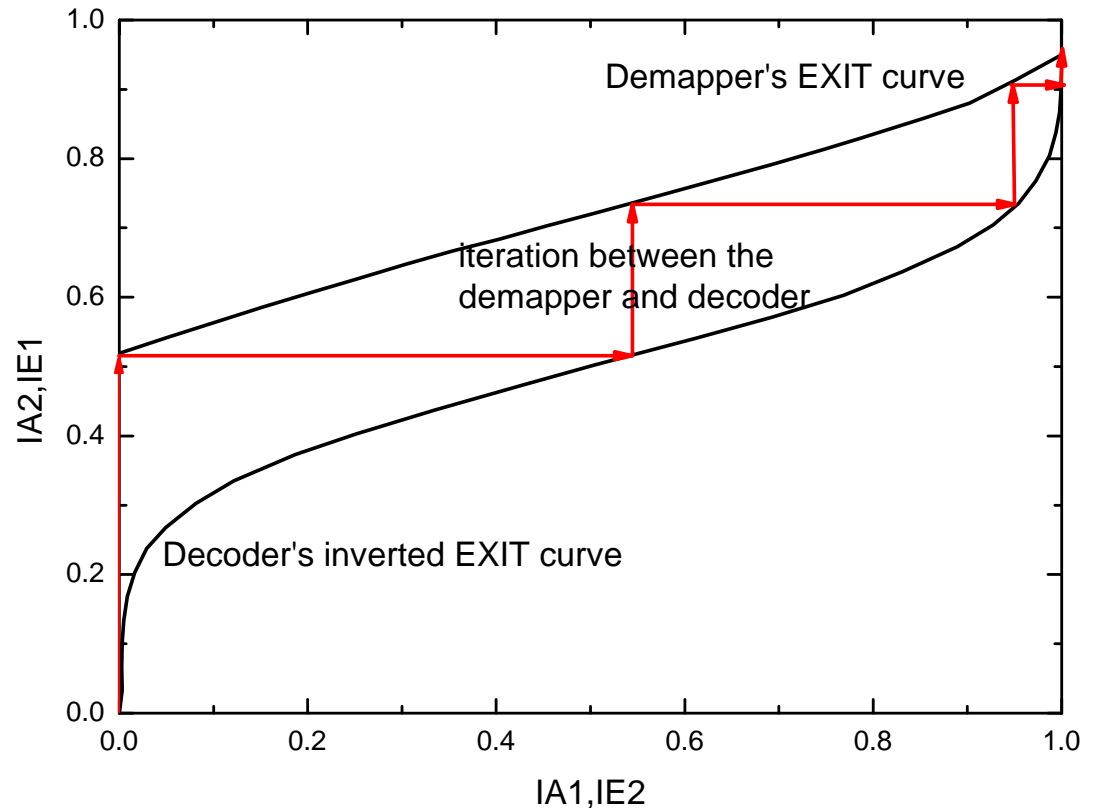
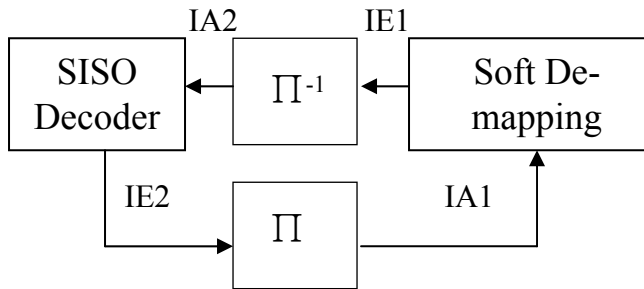
DCMC Capacity: Optimal Rotation Angle for SSD when using Square QAM. (3/3)



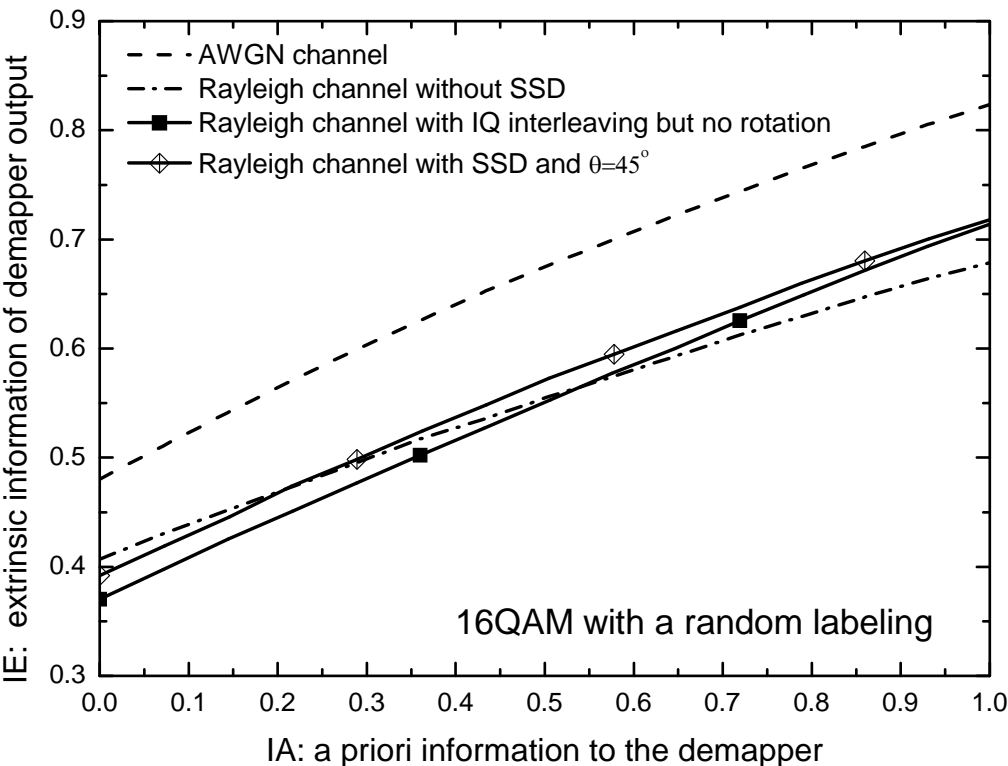
Gaps between the DCMC capacity to the i.i.d Rayleigh fading channel capacity when using SSD [4-5].

EXIT-Chart-Matching for BICM-ID Design

- By ten Brink [6], EXIT (extrinsic information transfer) chart is a powerful tool for analyzing the convergence behavior of iterative schemes, e.g., turbo codes or BICM-ID.
- To design a near-capacity BICM-ID, the crucial point is to **let the demapper's EXIT curve above the decoder's inverted EXIT curve, at a near-capacity SNR**, i.e., curve matching.



SSD Effects to the Demapper's EXIT Curve



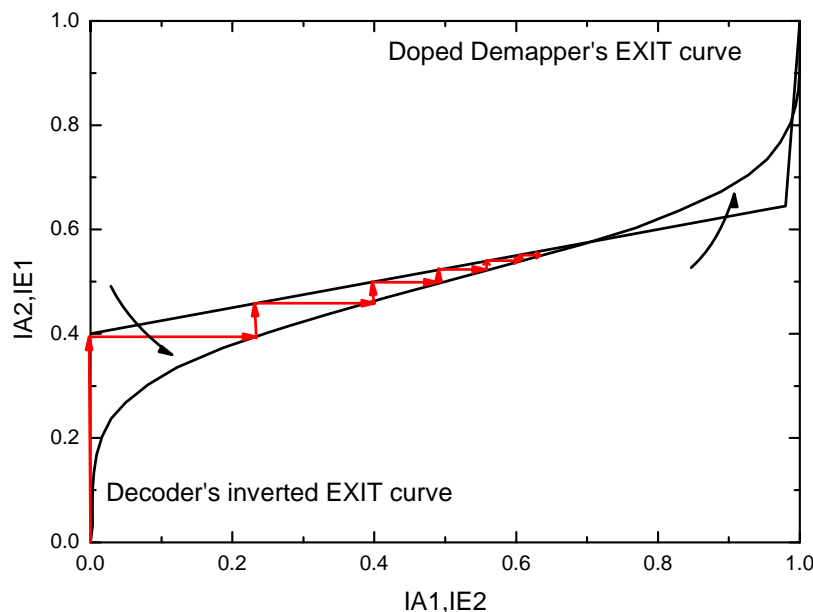
1. At the same DCMC capacity, the demapper's EXIT curve of fading channels without SSD has a smaller slope than that of AWGN channel.
2. SSD makes the demapper's EXIT curve slope larger, or above the original curve without adopting SSD.
3. To exhibit approximately the same slope for both AWGN fading channels, very high dimensional constellations is not needed.

Conclusion: SSD could make the BICM-ID scheme exhibit near-capacity performance under both AWGN and fading channels simultaneously.



EXIT-Chart-Aided Bit-to-Symbol Labeling Searching Algorithm: adaptive binary switch algorithm (ABSA)[5,7]

Goal: find labeling with demapper's EXIT curve to match the inverted EXIT curve of the outer decoder.



Procedures:

1. Based on an initial labeling and a given cost function, find a labeling using BSA [8].
2. Perform EXIT-chart analysis. If the labeling satisfies our goal, then output this labeling and stop. Otherwise, go on.
3. Based on the EXIT-chart analysis, **adaptively** modify the cost function and go back to the step 1.



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BICM-ID Design Examples

System Parameters

EXIT-Chart Analysis

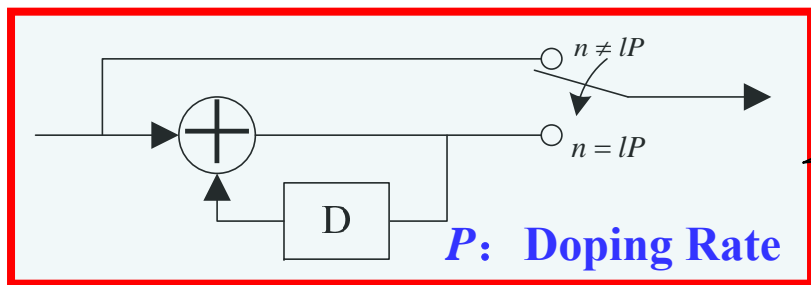
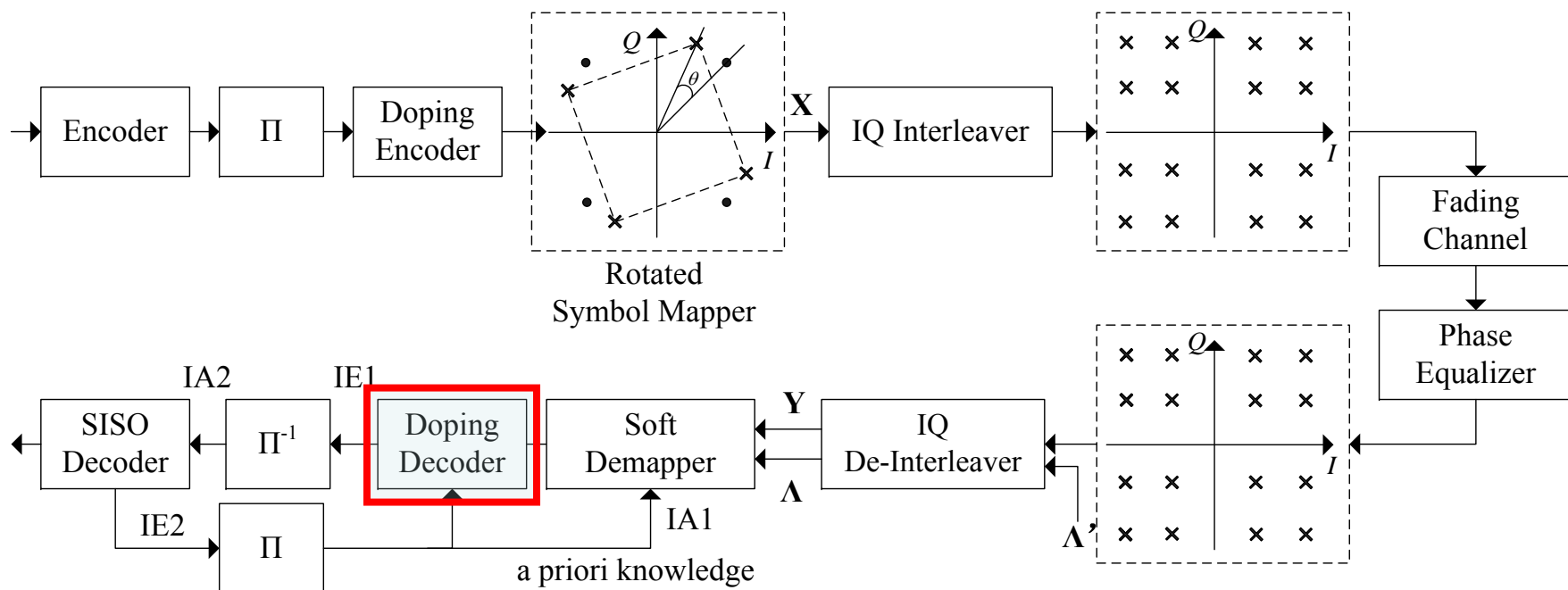
BER Simulation

BICM-ID Implementations and Applications

Conclusions



BICM-ID-SSD Examples: the System Model



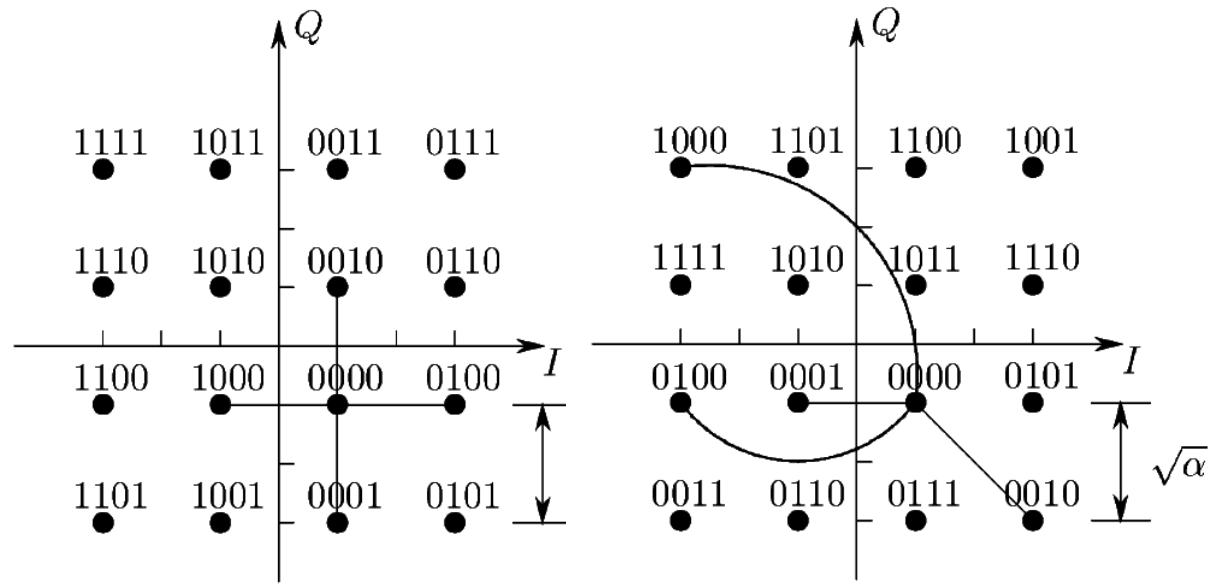
helps remove error floor

Labeling for BICM-ID

Constellation Labeling: the rule mapping the bits onto constellation symbols.

Information is passed between bits corresponding to the same symbols in BICM-ID, which strongly relies on the labeling.

For an M -ary constellation, there are $M!$ different labeling sets. It is hard to choose which one should use.



Gray labeling

SP labeling

BICM-ID-SSD Examples: the Constellation Labeling

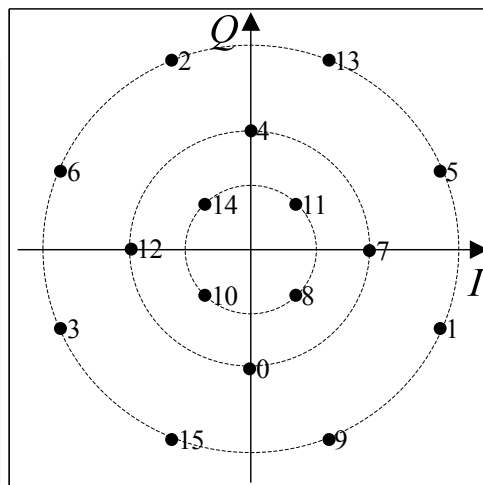
Constellation labeling examples using ABSA:

(a) 16APSK

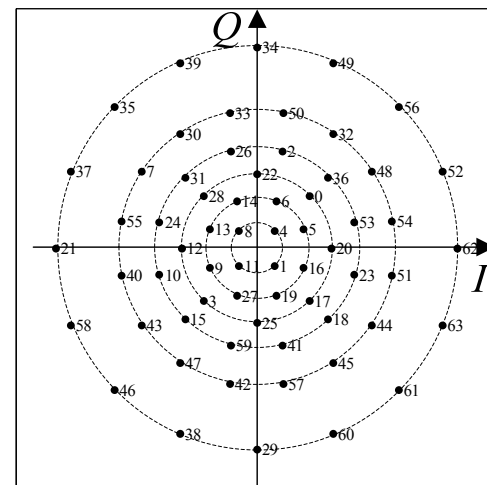
(b) 64APSK

(c) 16QAM

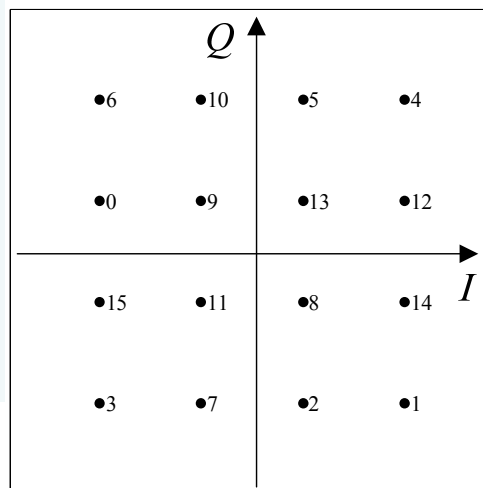
(d) 64QAM



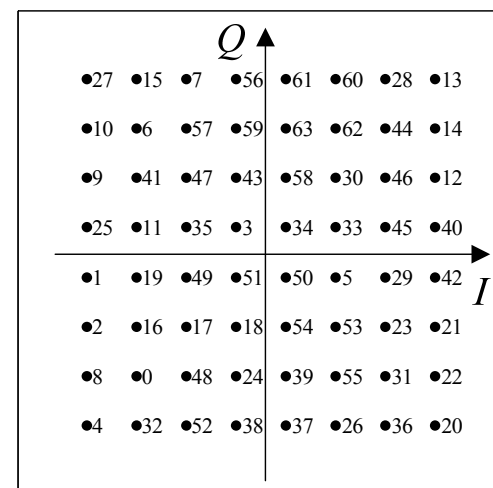
(a)



(b)



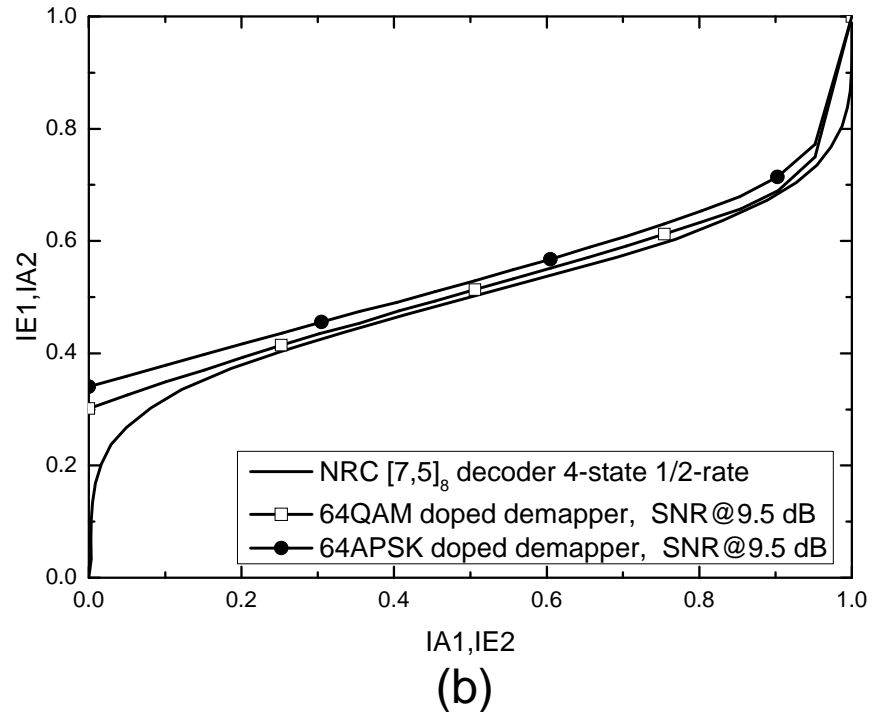
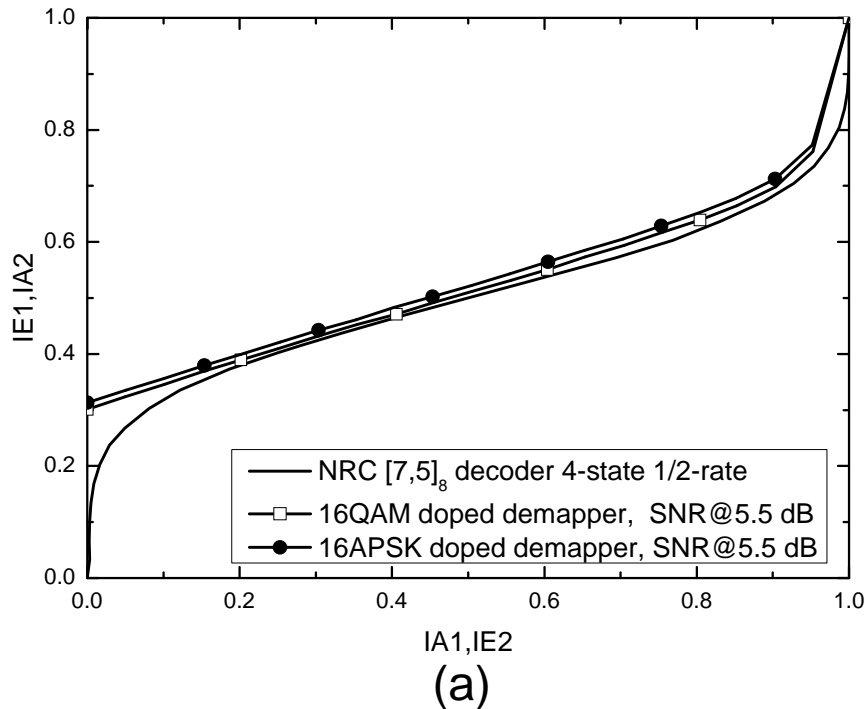
(c)



(d)



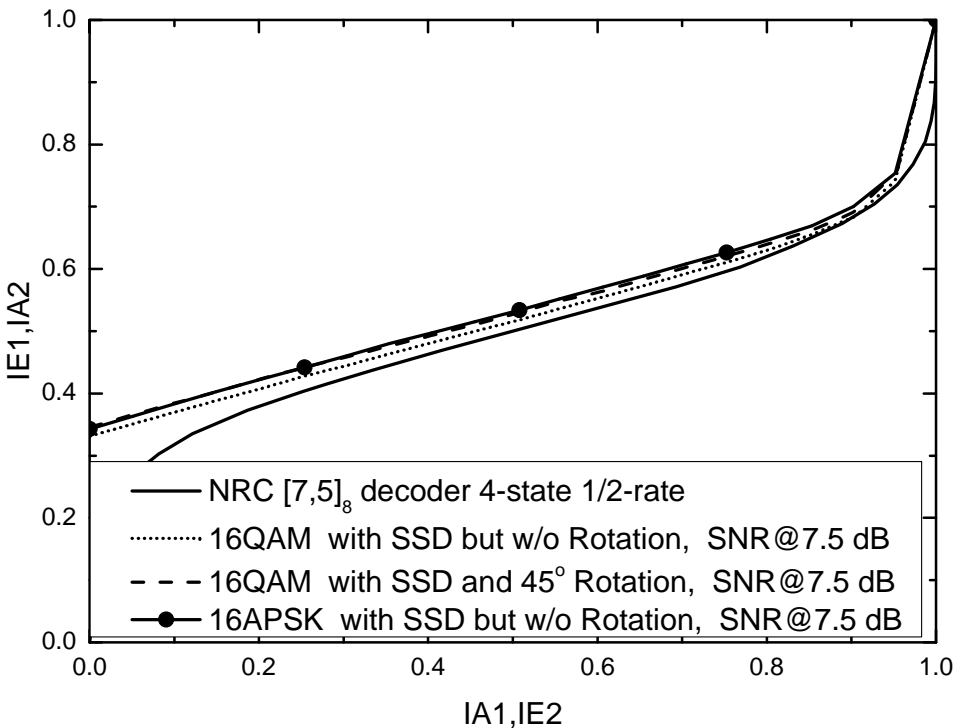
BICM-ID-SSD Examples: EXIT-Chart Analysis. (1/2)



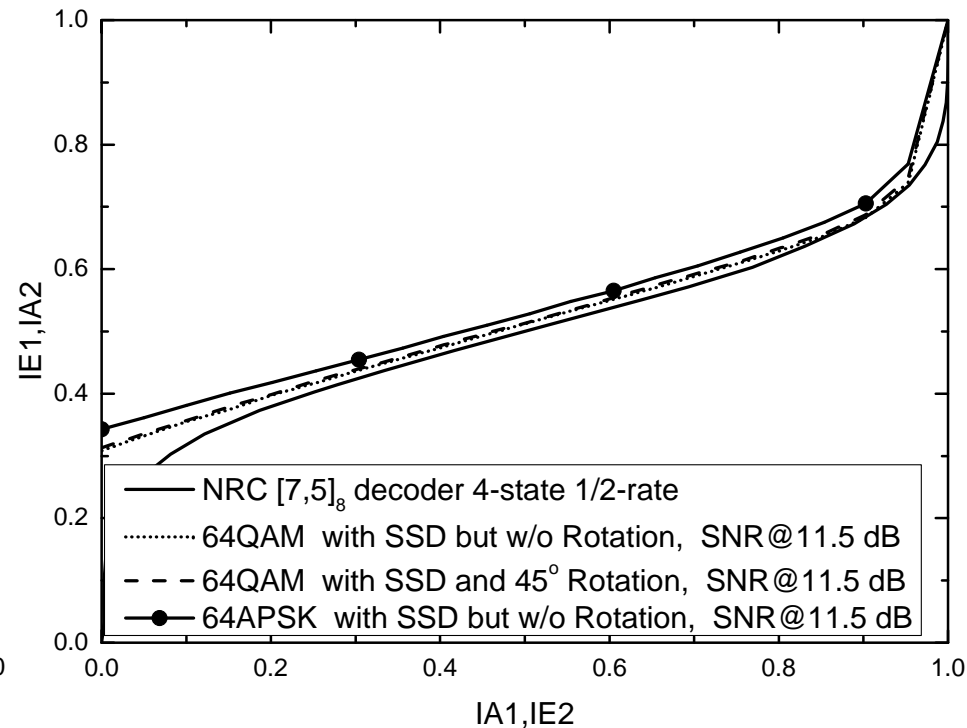
EXIT-chart analysis under AWGN channels, (a) 16-ary, (b) 64-ary.

- The outer NRC code uses the standard BCJR decoding method.
- Inner doped demapper uses so-called serial detection method [3]. $P = 100$.

BICM-ID-SSD Examples: EXIT-Chart Analysis. (2/2)



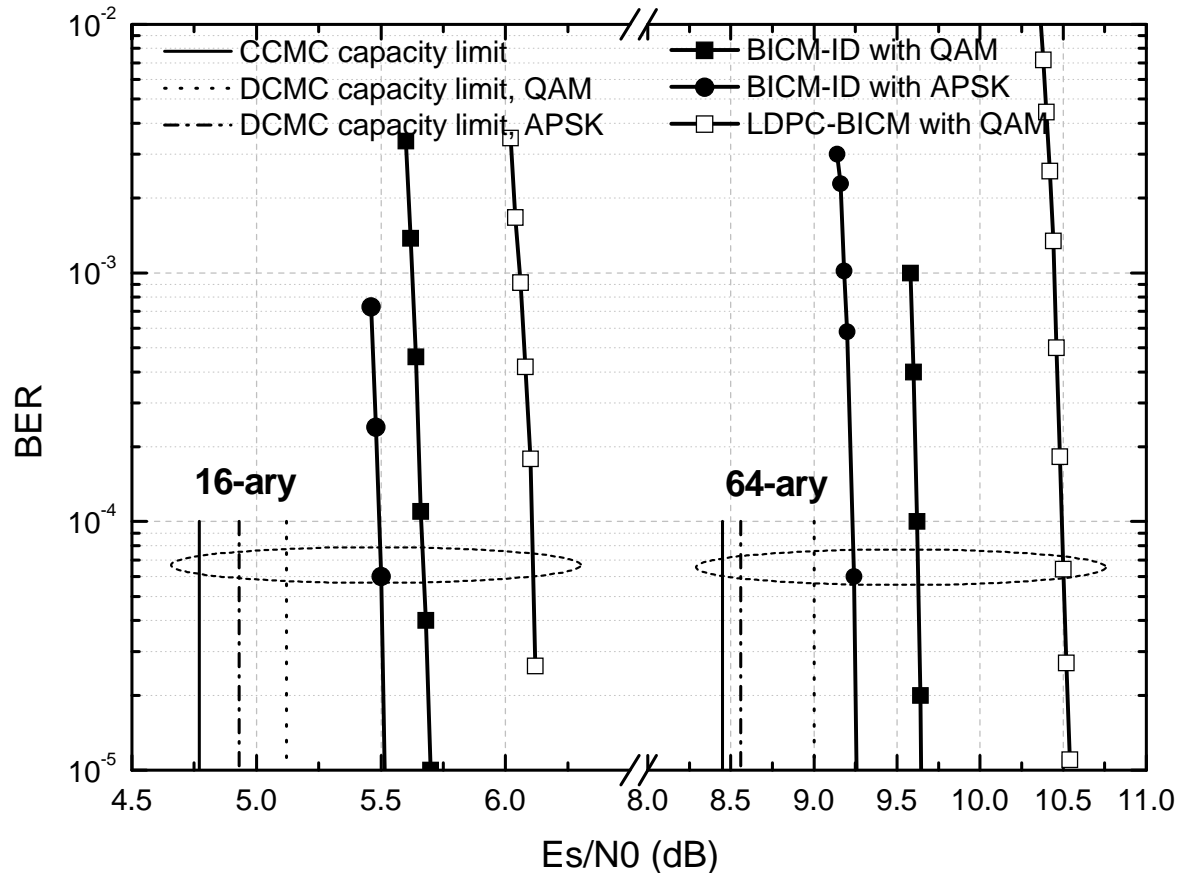
(a)



(b)

EXIT-chart analysis under Rayleigh channels, (a) 16-ary, (b) 64-ary.

BICM-ID-SSD Examples: BER simulations. (1/2)



BER simulations

Length: 64800 bits

Iteration: 100

S-random interleaver.

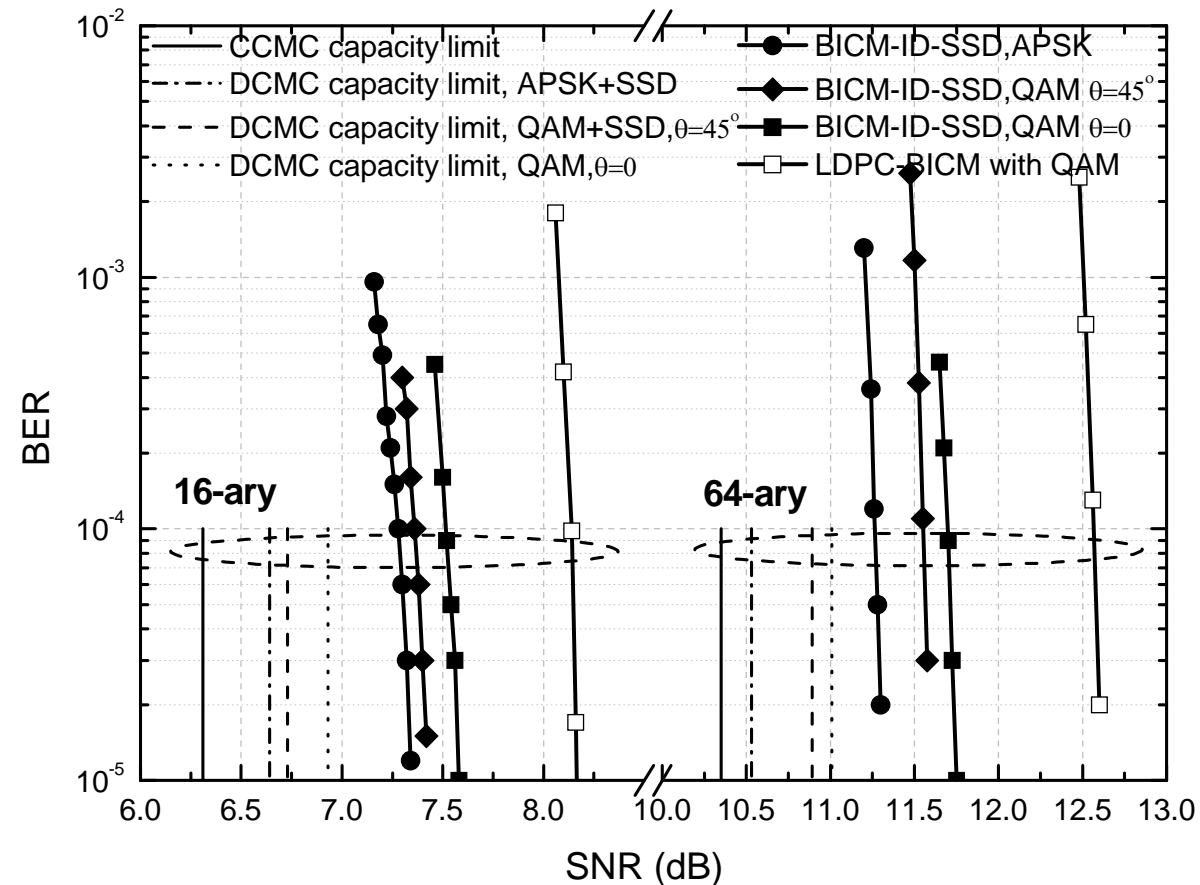
Rate: 1/2

DVB-T2 LDPC coded BICM also simulated as a reference.

AWGN channels.



BICM-ID-SSD Examples: BER simulations. (2/2)



BER simulations

Length: 64800 bits

Iteration: 100

S-random interleaver.

Rate: 1/2

DVB-T2 LDPC coded BICM also simulated as a reference.

i.i.d. Rayleigh fading channels



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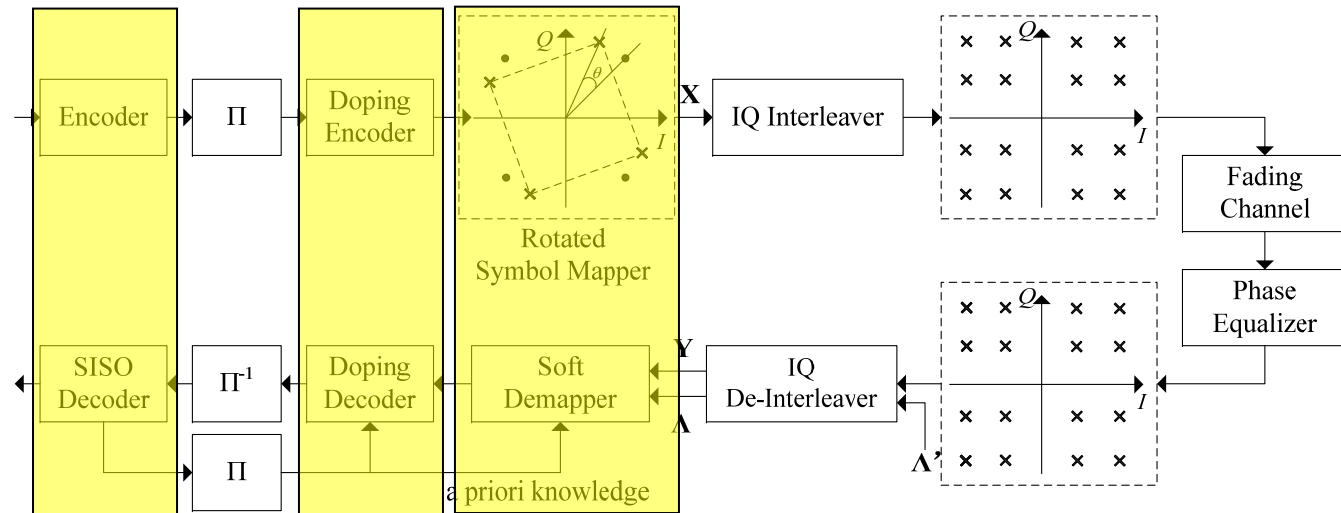
Implementation Aspects

Further Applications

Conclusions



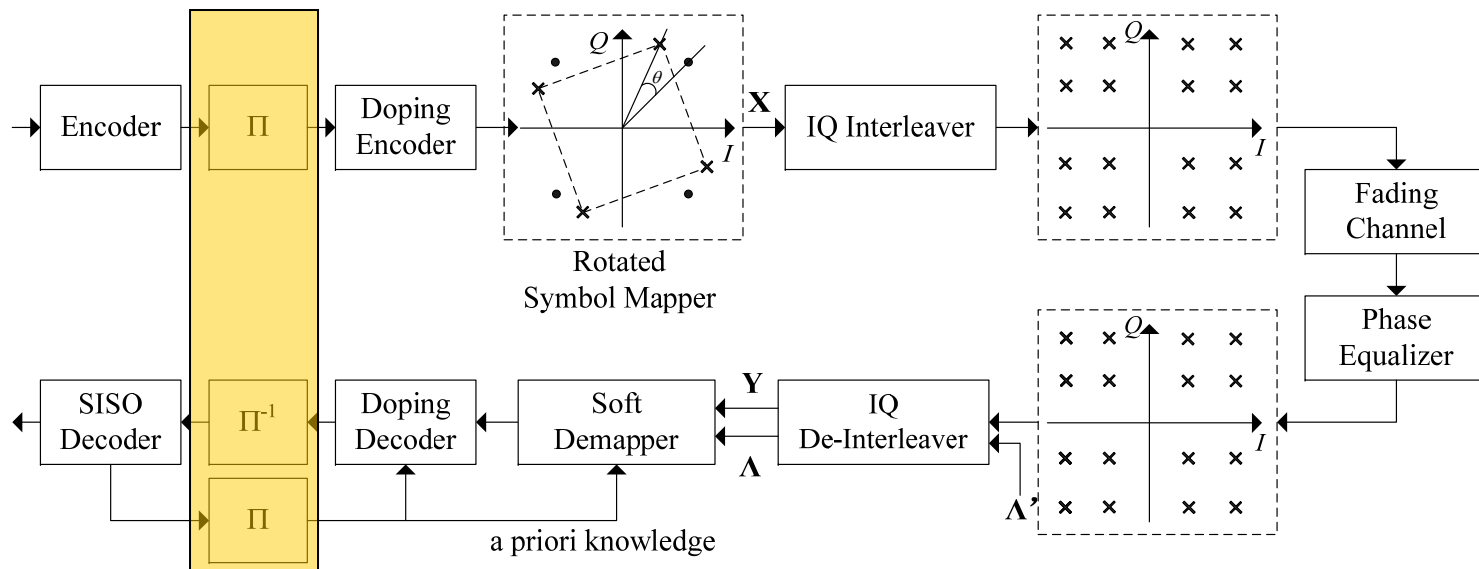
Complexity of BICM-ID-SSD



Our proposal is much less complex than that in [9] because:

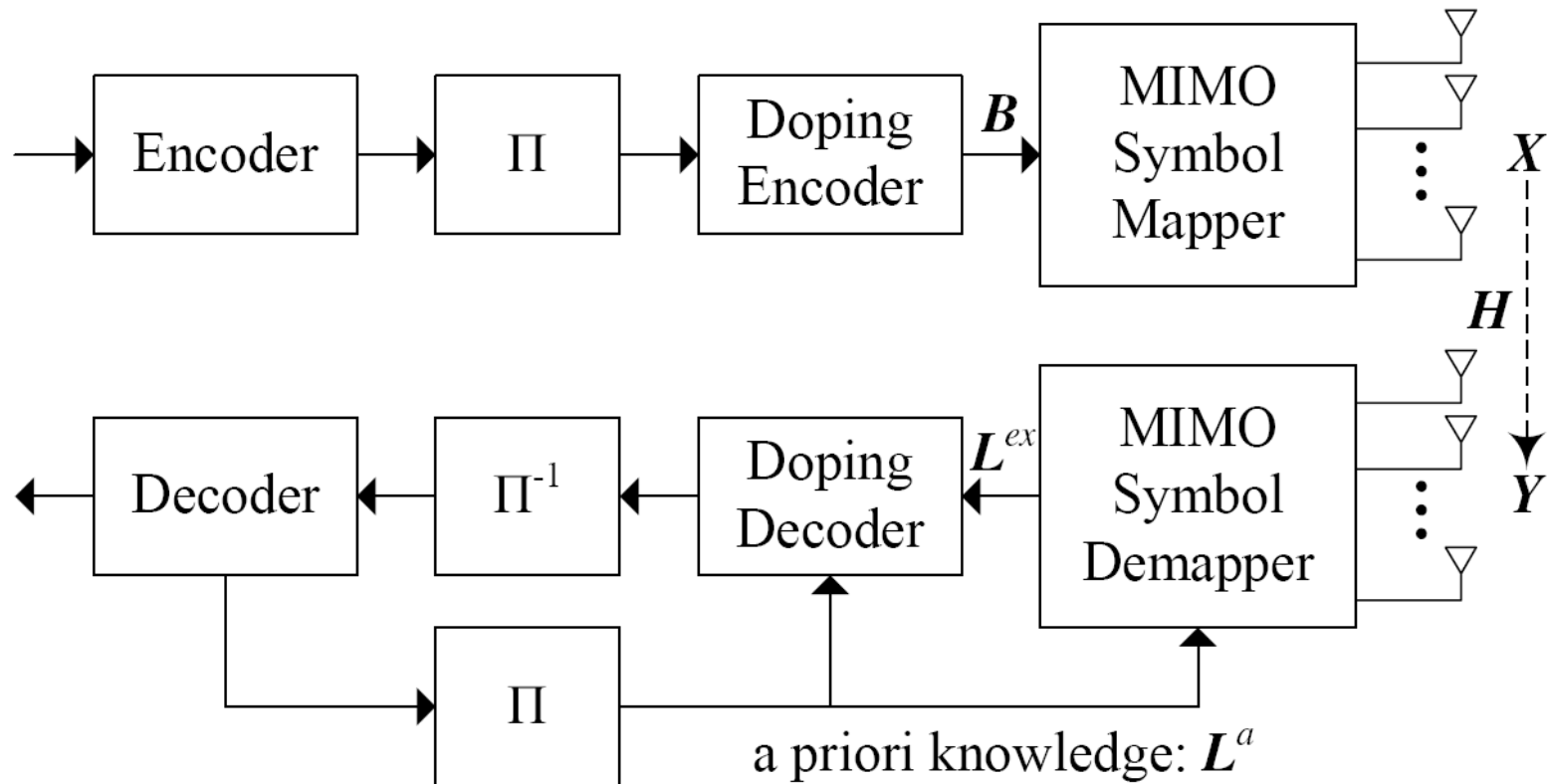
1. Our design is a regular design, which neither uses a mixture of outer codes nor uses a mixture of several doping codes or labeling functions.
2. The outer code and the doping code are two simple convolutional codes with quite limited number of states.

Throughput of BICM-ID-SSD



High throughput interleavers, such as quadratic polynomial permutation (QPP), almost regular permutation (ARP) [10], can be used. The throughput is neither a bottleneck.

BICM-ID Further Applications: MIMO Channels.



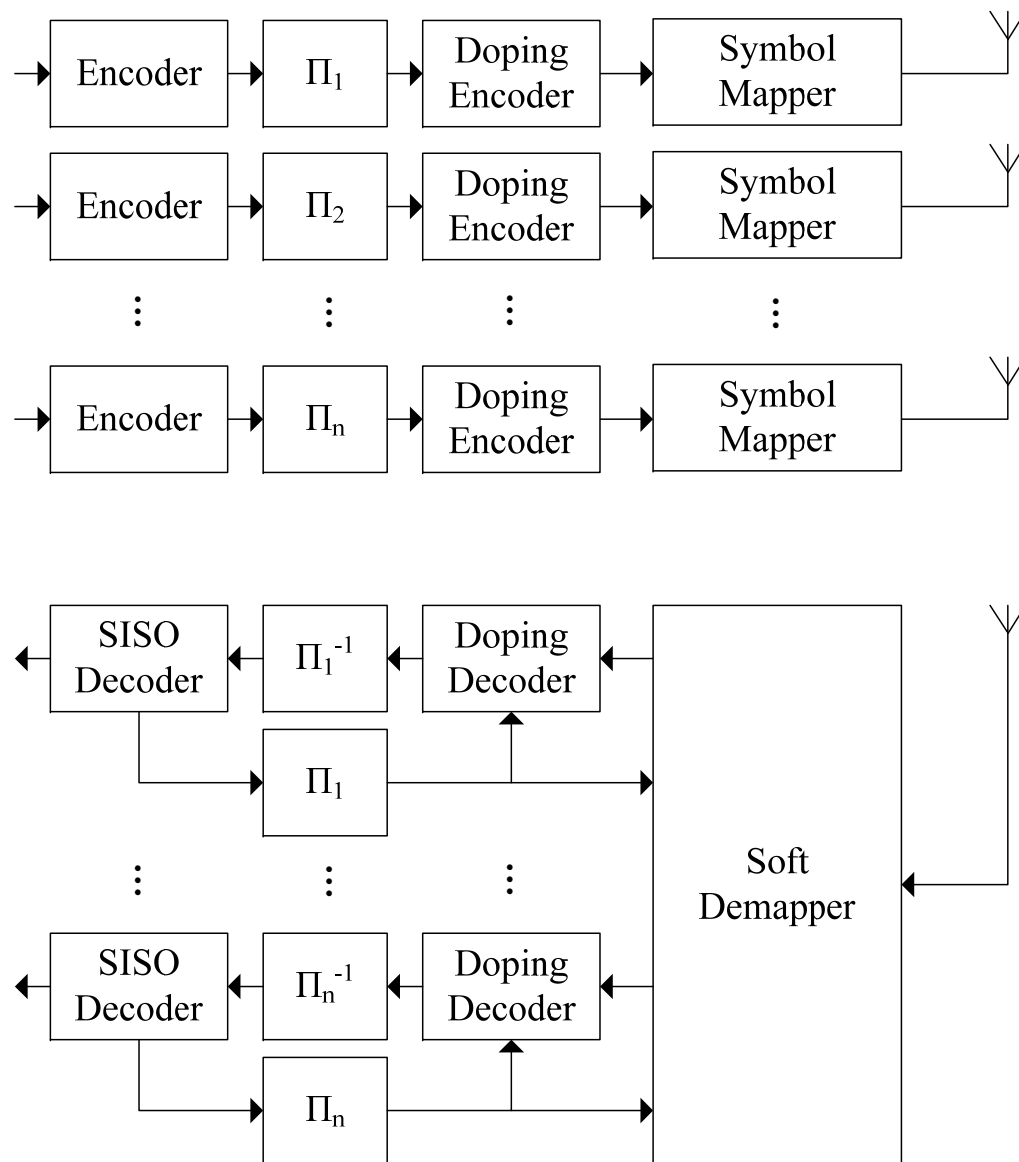
System model of BICM-ID for MIMO channels: **a simple structure yet a near-capacity performance.**



BICM-ID Further Applications: Multi-user Systems.

System model of BICM-ID for multiple access channels (MACs):

very easy to be combined with iterative multi-user interference cancellation.



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Conclusions

- BICM-ID potentially achieves near-capacity performance for future DTTB systems under AWGN & fading channels.
- Three crucial problems in BICM-ID were addressed,
 1. APSK constellations providing higher DCMC capacities,
 2. ABSA searching for constellation labeling to match outer code,
 3. SSD to ensure BICM-ID exhibiting near-capacity performance under both AWGN and fading channels.
- Low-complex, high throughput near-capacity BICM-ID scheme could be obtained, suitable for implementation.
- BICM-ID is easy to applied to MIMO or multiple access systems.

References

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Collaborators: Qiuliang Xie, Kewu Peng, Zhixing Yang,
Zhaocheng Wang, and Fang Yang

Thanks

Q&A

