2016 2Q

Wireless Communication Engineering

#8 Adaptive Modulation Coding

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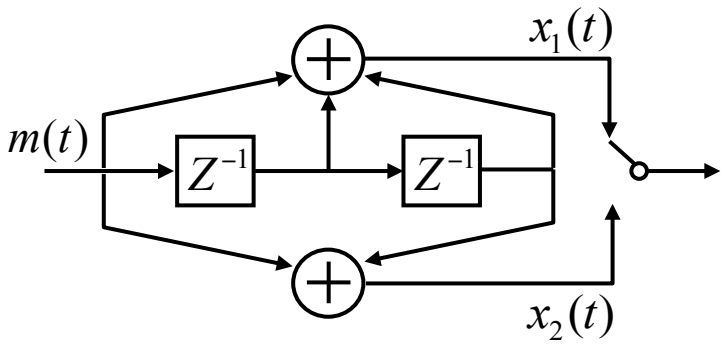
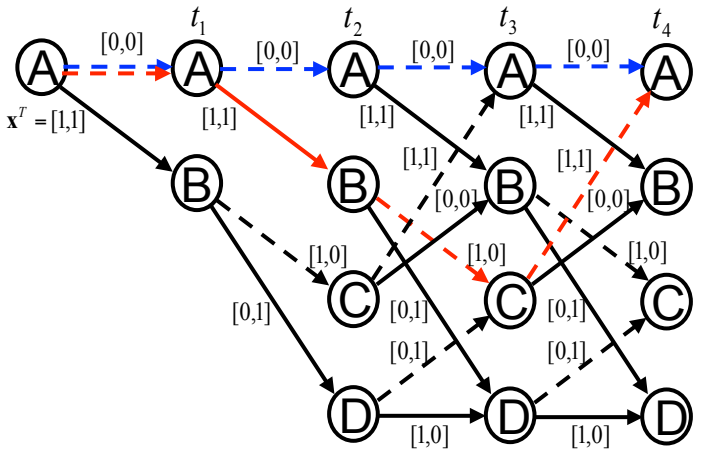
Course Schedule (2)

	Date	Text	Contents
#7	July 15	4.6	Error correction coding
#8	July 15		Adaptive modulation coding
#9	July 22	4.3	Inter symbol interference and adaptive equalizer
#10	July 22	3.6, 4.5	Spread spectrum and code division multiple access (CDMA)
#11	July 29	3.5	Orthogonal frequency division multiple access (OFDM)
#12	July 29		Array signal processing and MIMO spatial multiplexing
#13	TBD	all	Final examination

From Previous Lecture

- Convolutional coding & Viterbi decoding





- Error rate of Viterbi decoding

$$P_e < \sum_{d=d_{\min}}^{\infty} 2^{d-d_{\min}} P_2(d)$$

Hard detection: $P_2(d) = \sum_{k=d_c+1}^{d} \binom{d}{k} P_e^k (1-P_e)^{d-k}$

Soft detection: $P_2(d) = \frac{1}{2}\operatorname{erfc}\left(\sqrt{\gamma d}\right)$

- Interleaver & time diversity

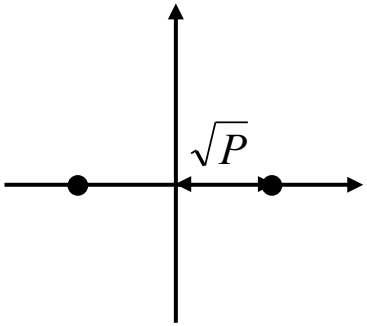
Avoiding burst error by interleaving $P_2(d) = \frac{1}{2}\operatorname{erfc}\left(\sqrt{\sum_{i=1}^{d}\gamma_i}\right)$

Contents

- Throughput of higher order modulation
- Throughput in fading channel
- Adaptive modulation
- Adaptive modulation coding

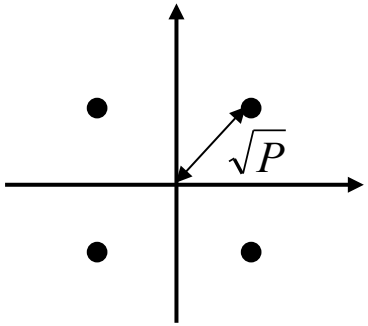
Higher Order Modulation

BPSK



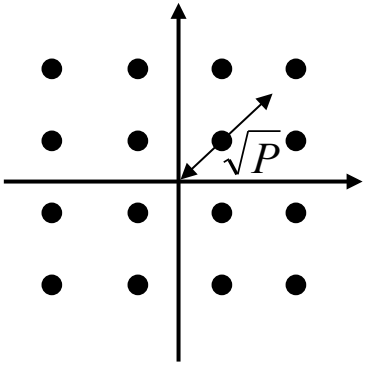
$\log_2 M_{\text{ary}} = 1$

QPSK



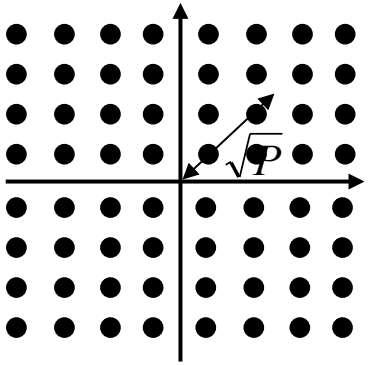
$\log_2 M_{\text{ary}} = 2$

16QAM



$\log_2 M_{\text{ary}} = 4$

64QAM



$\log_2 M_{\text{ary}} = 6$

BER of Higher Order Modulation

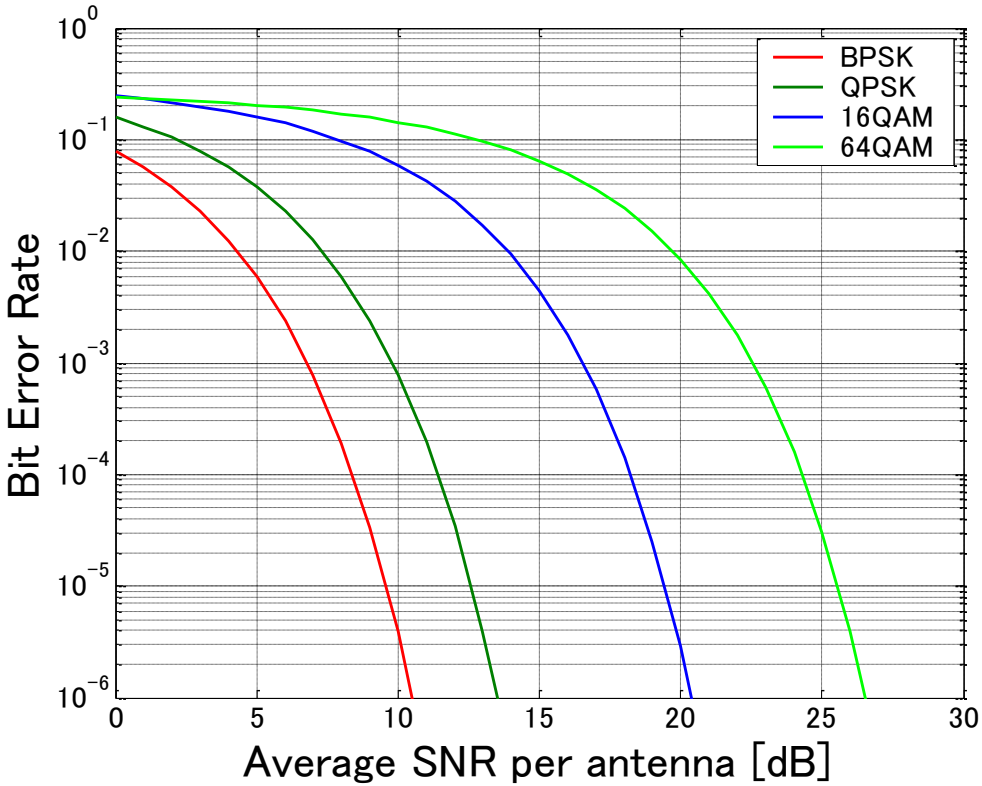
BPSK modulation

$$P_{\mathrm{eb}}(\gamma) = \frac{1}{2}\mathrm{erfc}\left(\sqrt{\gamma}\right) \qquad \gamma = \frac{P|h|^2}{\sigma^2}$$

QAM modulation

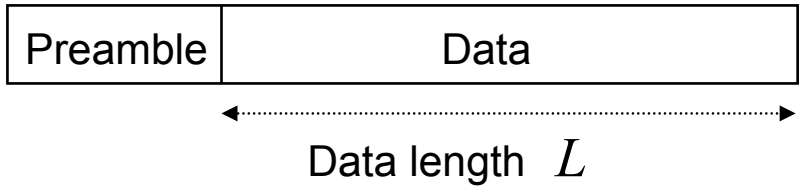
$$P_{\mathrm{eb}}(\gamma) = \frac{2}{\log_2 M^{\mathrm{ary}}}\left(1 - \frac{1}{\sqrt{M^{\mathrm{ary}}}}\right) \cdot \mathrm{erfc}\left(\sqrt{\frac{3\gamma}{2\left(M^{\mathrm{ary}} - 1\right)}}\right)$$

BER of QAM modulation



Throughput of Higher Order Modulation

Frame structure



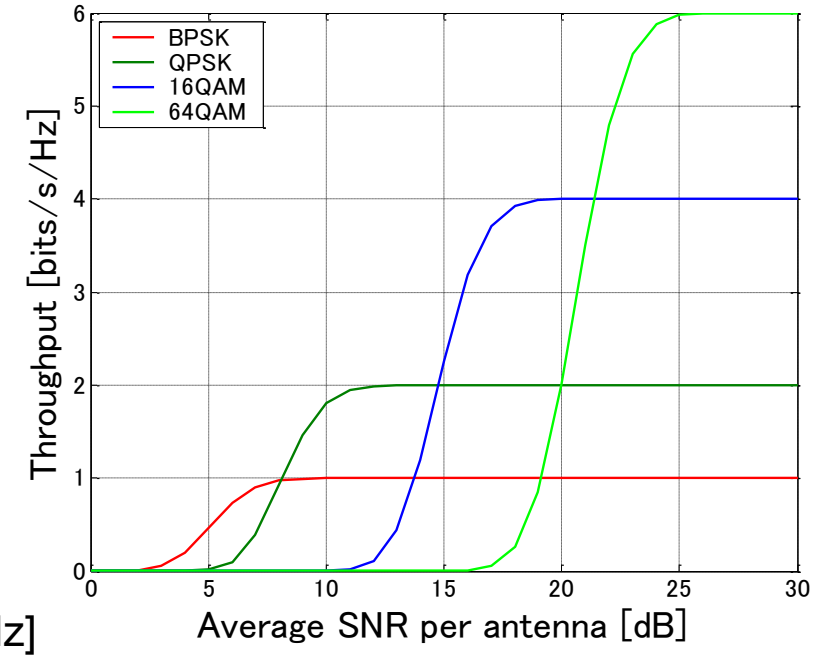
Packet Error Rate (PER)

$$P_{\mathrm{ep}}(\gamma) = 1 - \left(1 - P_{\mathrm{eb}}(\gamma)\right)^{L}$$

Throughput

$$TP(\gamma) = \log_2 M_{\mathrm{ary}} \left(1 - P_{\mathrm{eb}}(\gamma)\right)^{L} \quad \text{[bits/s/Hz]}$$

Throughput of QAM modulation



BER in Fading Channel

BER of BPSK modulation

$$P_{\text{eb}}(\gamma) = \frac{1}{2}\operatorname{erfc}\left(\sqrt{\gamma}\right) \qquad \gamma = \frac{P|h|^2}{\sigma^2}$$

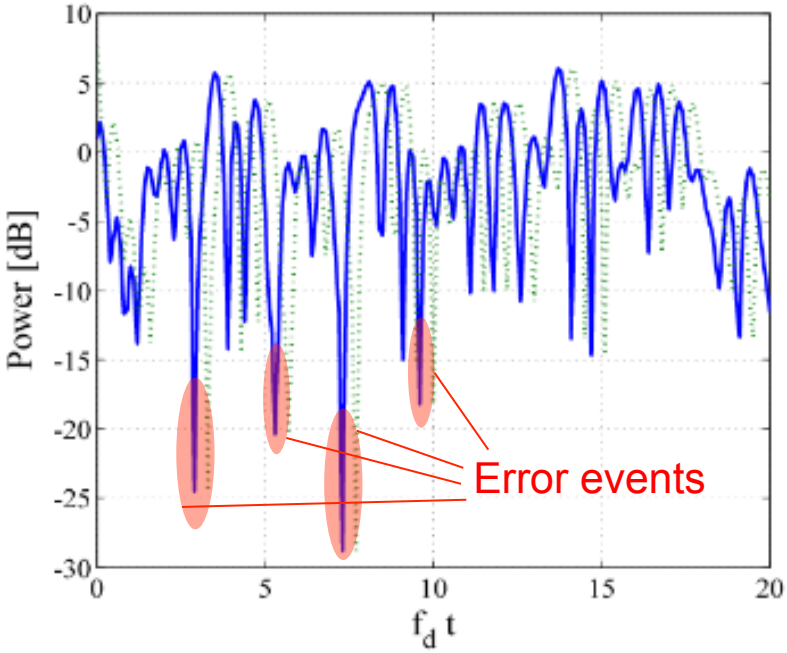
PDF of Rayleigh fading channel

$$f(\gamma) = \frac{1}{\bar{\gamma}}\exp\left(-\frac{\gamma}{\bar{\gamma}}\right) \qquad \bar{\gamma} = \mathrm{E}\left[\frac{P|h(t)|^2}{\sigma^2}\right]$$

Average BER

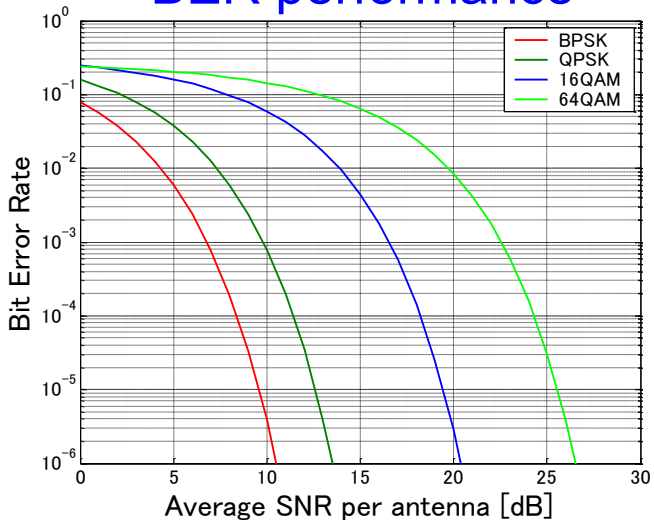
$$\bar{P}_{\text{eb}}(\bar{\gamma}) = \int P_{\text{eb}}(\gamma) f(\gamma)\mathrm{d}\gamma = \frac{1}{2}\left(1 - \sqrt{\frac{\bar{\gamma}}{1+\bar{\gamma}}}\right)$$

Rayleigh fading channel

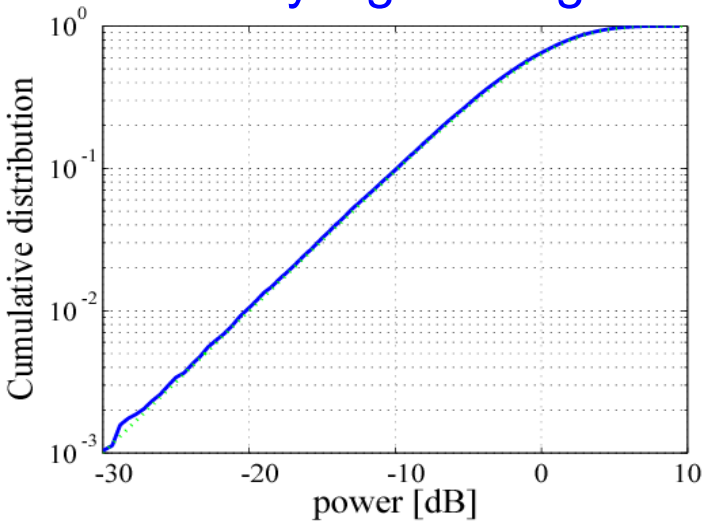


BER in Fading Channel

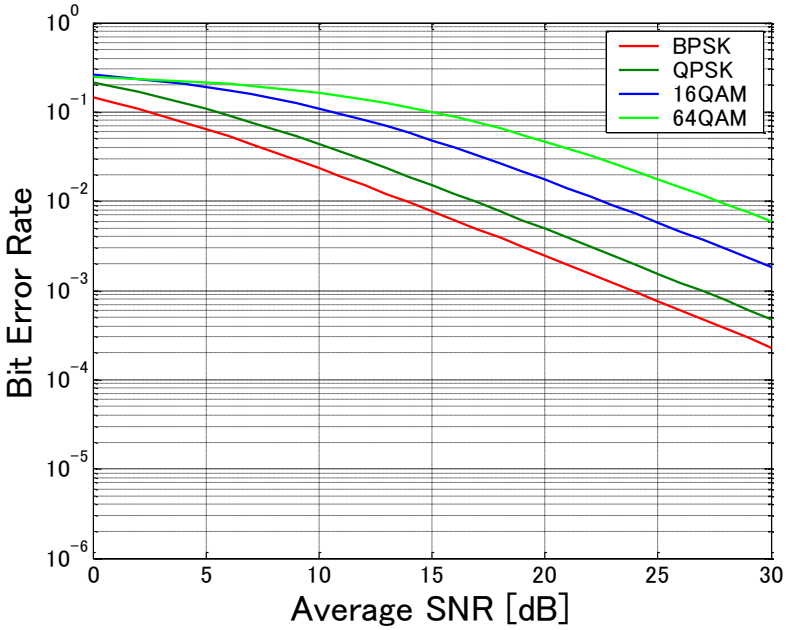
BER performance



Rayleigh fading

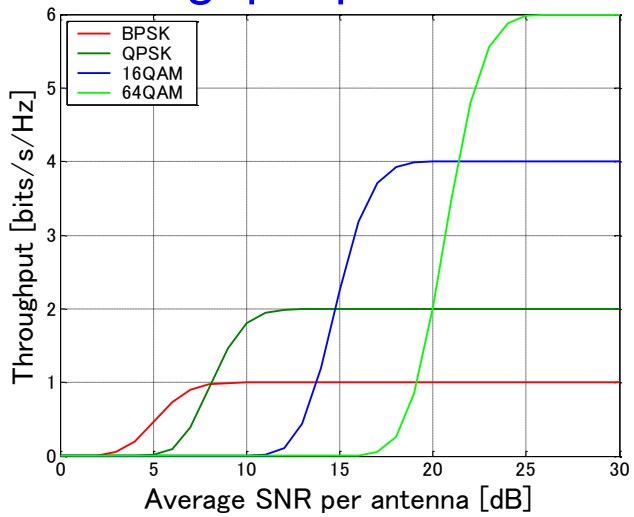


Average BER performance

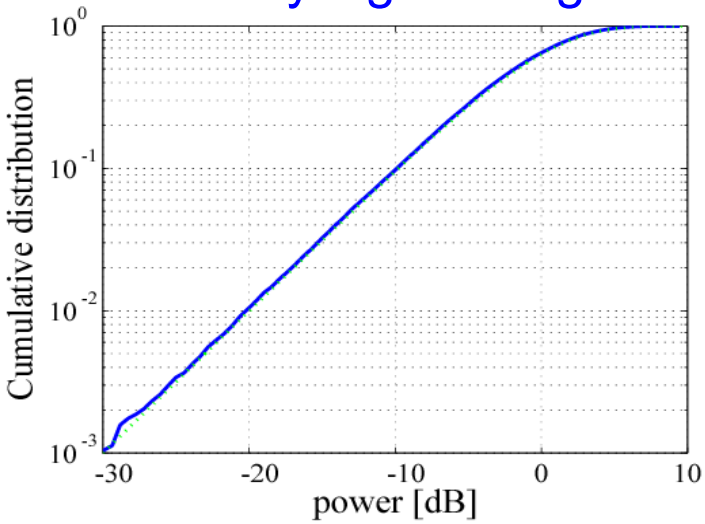


Throughput in Fading Channel

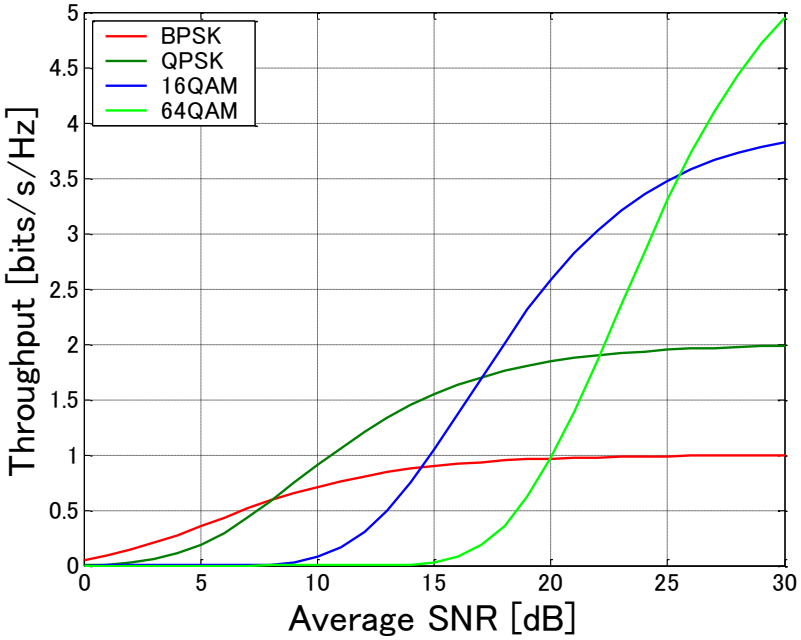
Throughput performance



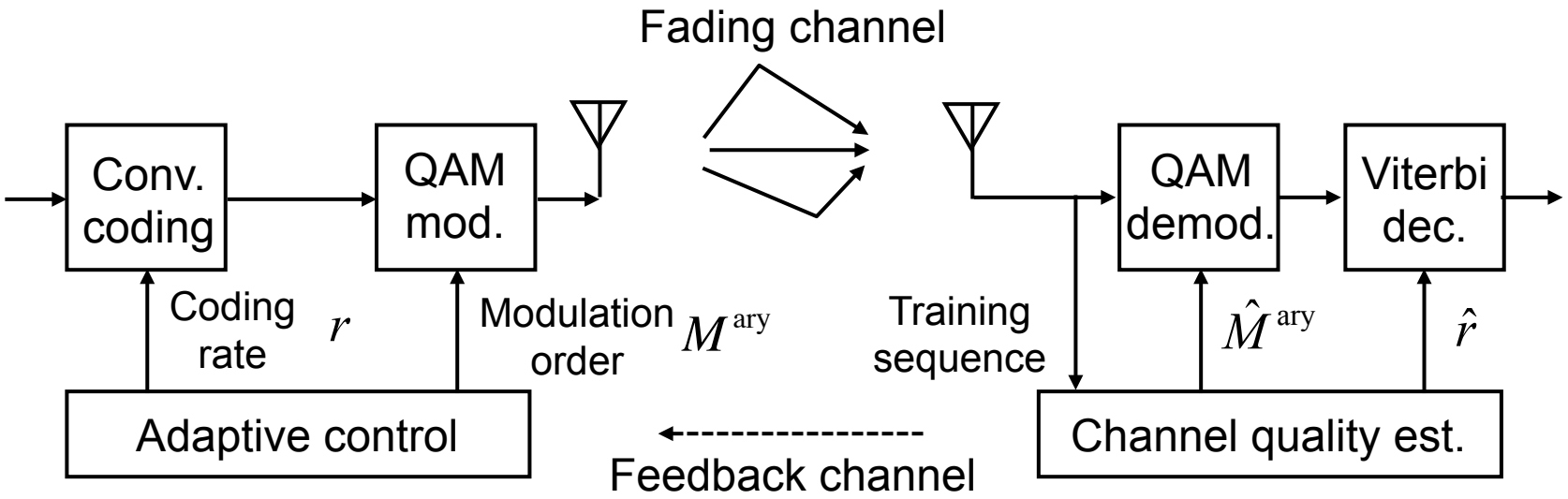
Rayleigh fading



Average throughput performance



Structure of Rate Adaptation



Adaptive control

Maximization of transmit data rate by adaptive control of modulation order of QAM and coding rate of channel coder in accordance with the channel variation (by using feedback channel)

Channel quality estimation

One of receiver function to estimate optimal transmit rate (modulation order, coding rate) based on instantaneous SNR estimated using training sequence and to tell transmitter about their optimal values via feedback channel

Adaptive Modulation

SNR estimation

$$\gamma(t) = \frac{P\left|\hat{h}(t)\right|^2}{\sigma^2}$$

Throughput estimation

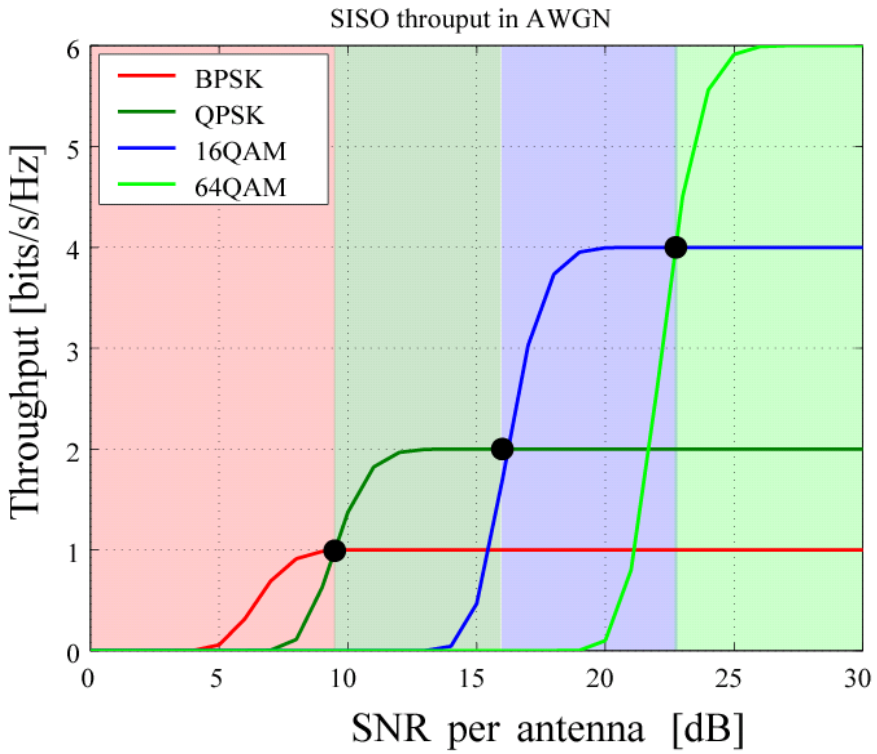
$$TP\left(\gamma, M^{\text{ary}}\right) = \log_2 M^{\text{ary}}\left(1 - P_{\text{eb}}(\gamma)\right)^L$$

BPSK $$P_{\text{eb}}(\gamma) = \frac{1}{2}\operatorname{erfc}\left(\sqrt{\gamma}\right)$$

QAM $$P_{\text{eb}}(\gamma) = \frac{2}{\log_2 M^{\text{ary}}}\left(1 - \frac{1}{\sqrt{M^{\text{ary}}}}\right)$$

$$\operatorname{erfc}\left(\sqrt{\frac{3\gamma}{2\left(M^{\text{ary}} - 1\right)}}\right)$$

Table for adaptive modulation



Adaptive modulation

$$\hat{M}^{\text{ary}} = \arg\max_{M_{\text{ary}}} TP\left(\gamma, M^{\text{ary}}\right)$$

Optimal modulation order

Throughput of Adaptive Modulation

Average throughput

$$\overline{TP}(\bar{\gamma}, M^{\text{ary}}) = \int f(\gamma) TP(\gamma, M^{\text{ary}}) \mathrm{d}\gamma$$

PDF of Rayleigh fading

$$f(\gamma) = \frac{1}{\bar{\gamma}} \exp\left(-\frac{\gamma}{\bar{\gamma}}\right) \qquad \bar{\gamma} = \mathrm{E}\left[\frac{P|h(t)|^2}{\sigma^2}\right]$$

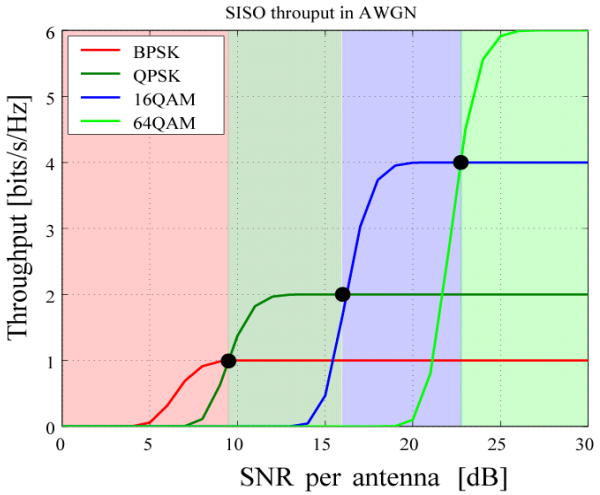
Average throughput of adaptive modulation

$$\overline{TP}(\bar{\gamma}) = \int_0^{\gamma_1} f(\gamma) TP(\gamma, 2) \mathrm{d}\gamma + \cdots$$

$$+ \int_{\gamma_3}^{\infty} f(\gamma) TP(\gamma, 64) \mathrm{d}\gamma$$

$$\gamma_1 = 10^{9.5/10} \qquad \gamma_2 = 10^{16/10} \qquad \gamma_3 = 10^{22.5/10}$$

Table of adaptive modulation

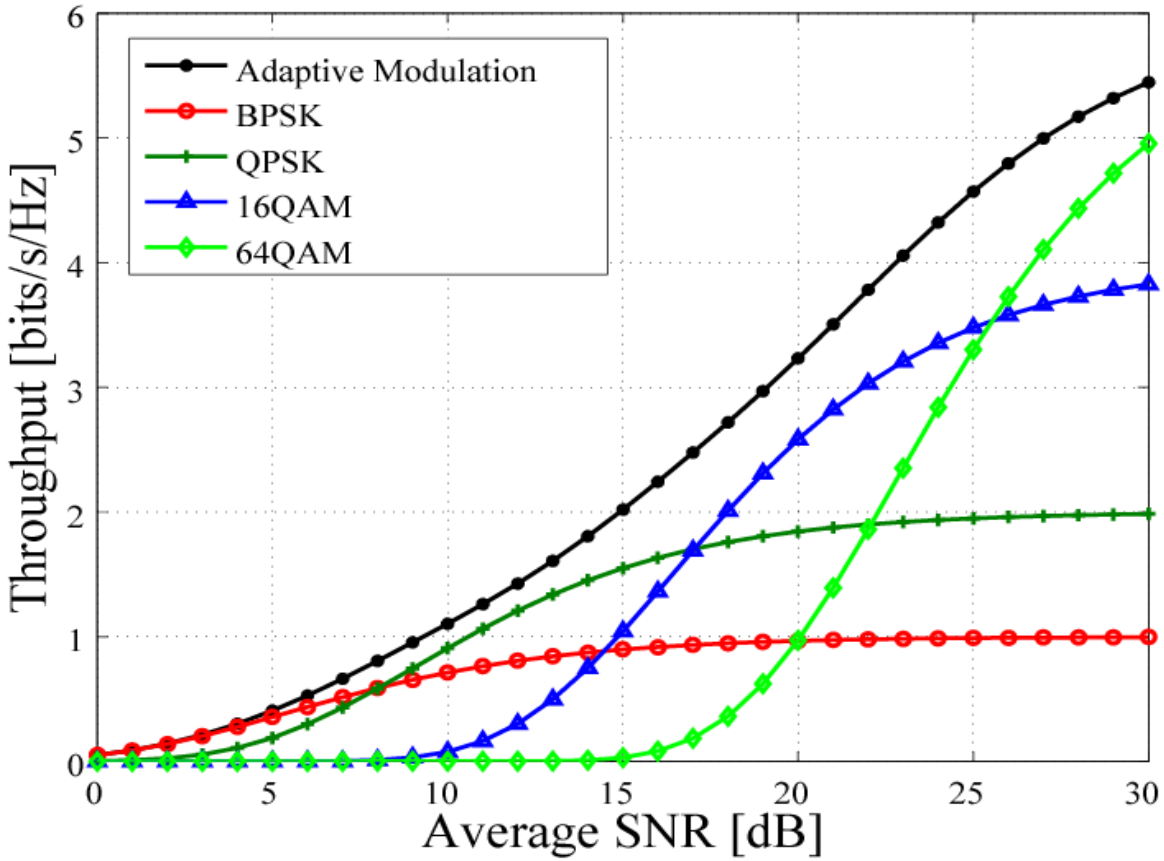


SNR threshold

Inst. SNR	Modulation
- 9.5dB	BSPK
9.5dB – 16dB	QPSK
16dB – 22.5dB	16QAM
22.5dB	64QAM

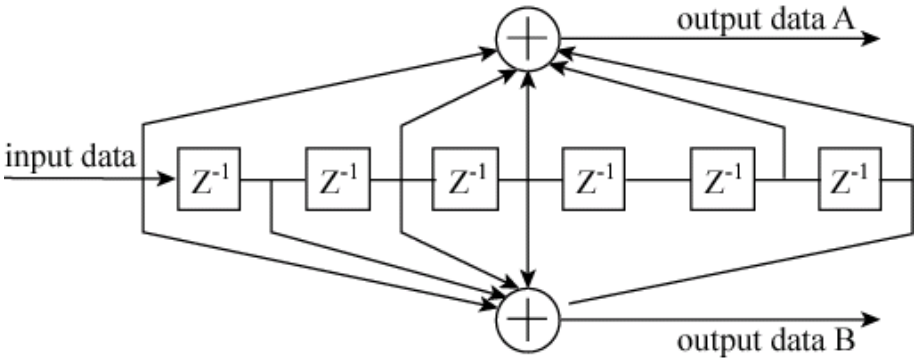
Adaptive Modulation in Fading Channel

Fixed modulations & Adaptive modulation



Convolutional Coding & Puncture

Convolutional coding (constraint length 7)



Input data

0	1	2	3	4	5	6	7	8	9

Encoded data with puncture 2/3 3/4

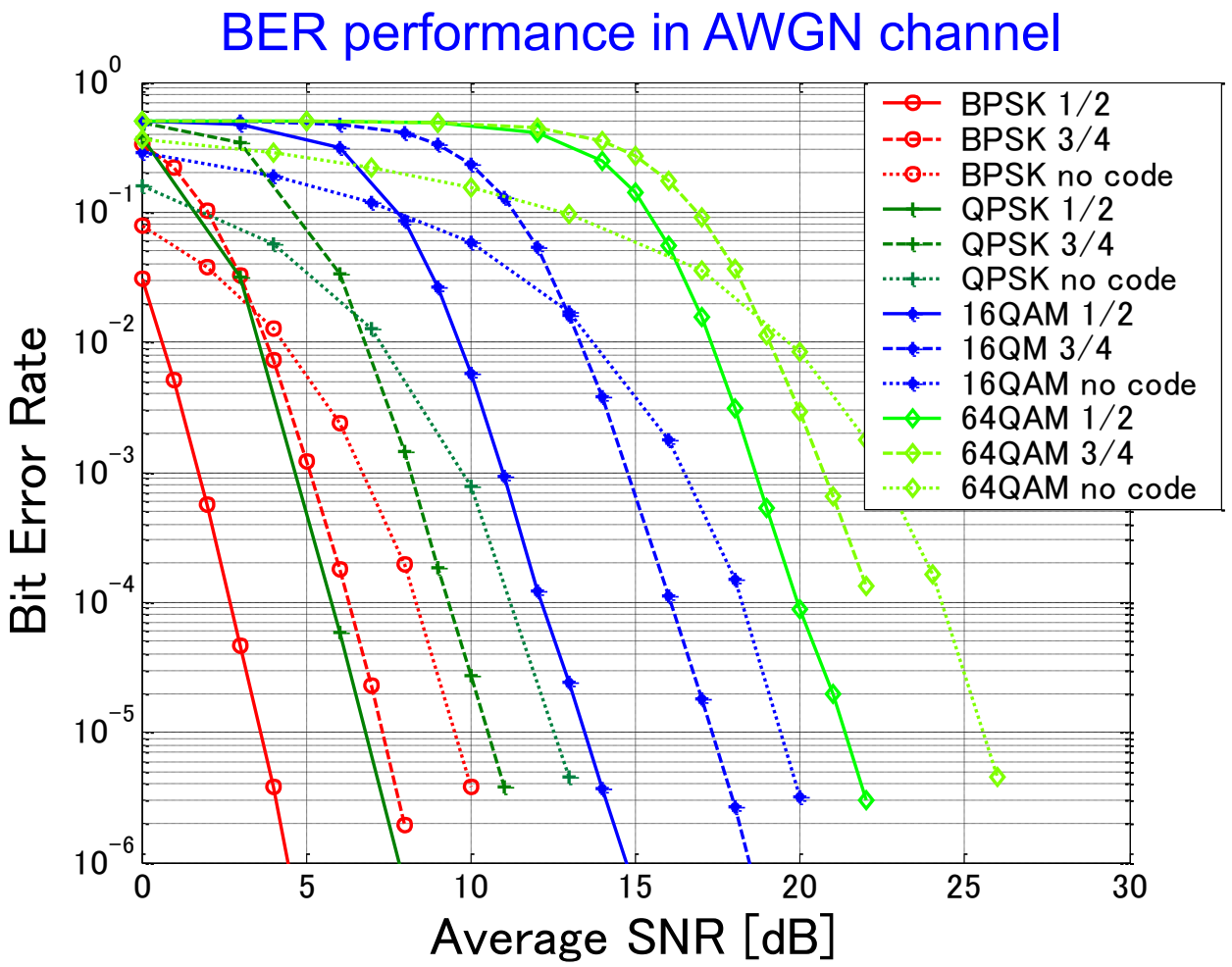
A	0	1	2	3	4	5	6	7	8	9

B	0	1	2	3	4	5	6	7	8	9

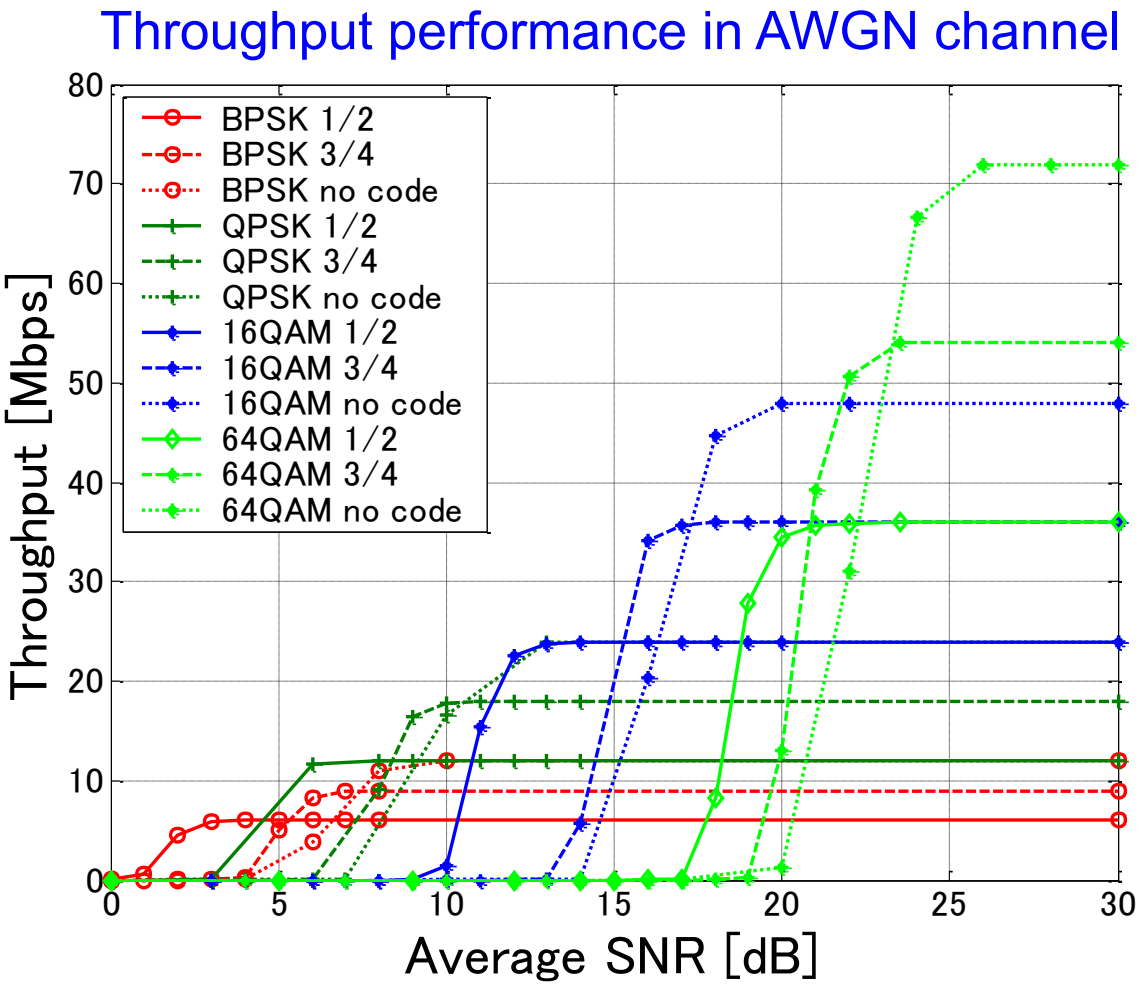
Puncture matrix

R=1/2		R=2/3		R=3/4		R=4/5		R=5/6	
P	d_{free}	P	d_{free}	P	d_{free}	P	d_{free}	P	d_{free}
1 1	10	10 11	6	110 101	5	1111 1000	4	11010 10101	4

BER of Convolutional Coding

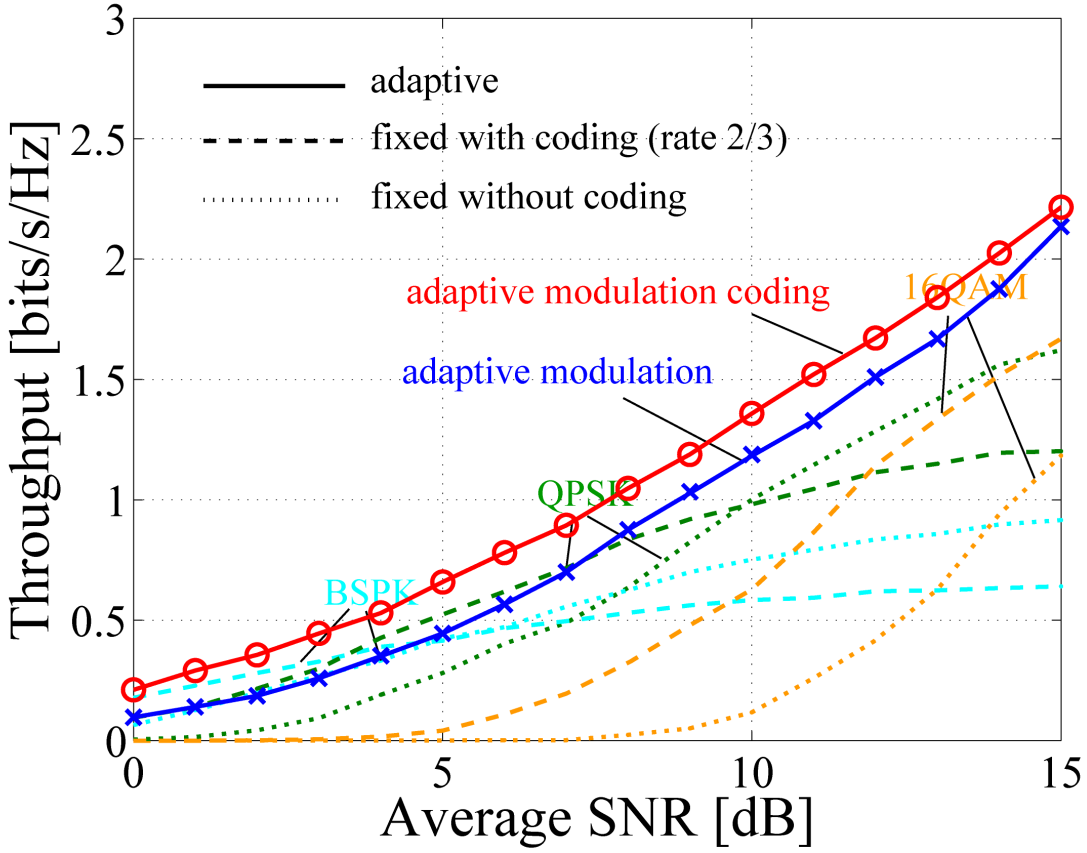


Throughput of Convolutional Coding



Adaptive Modulation Coding in Fading Channel

Performance in Rayleigh fading channel



Summary

- Throughput against modulation order

$$TP\left(\gamma, M^{\text{ary}}\right) = \log_2 M^{\text{ary}} \left(1 - P_{\text{eb}}\left(\gamma\right)\right)^L$$

- Adaptive modulation

$$\hat{M}^{\text{ary}} = \arg\max_{M_{\text{ary}}} TP\left(\gamma, M^{\text{ary}}\right)$$

- Throughput performance of AMC

$$\overline{TP}(\bar{\gamma}) = \int_0^{\gamma_1} f(\gamma) TP(\gamma, 2) \mathrm{d}\gamma + \cdots + \int_{\gamma_3}^{\infty} f(\gamma) TP(\gamma, 64) \mathrm{d}\gamma$$

SNR Table for AMC