## 2017 2Q

Wireless Communication Engineering

# \#10 Adaptive Modulation Coding 

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## Course Schedule (2)

|  | Date | Text | Contents |
| :--- | :--- | :--- | :--- |
| $\# 9$ | July 10 | 4.6 | Error correction coding |
| $\# 10$ | July 13 |  | Adaptive modulation coding |
|  | July 17 |  | No class |
| $\# 11$ | July 20 | 4.3 | Inter symbol interference and adaptive equalizer |
| $\# 12$ | July 24 | $3.6,4.5$ | Spread spectrum and code division multiple access <br> (CDMA) |
| \#13 | July 27 | 3.5 | Orthogonal frequency division multiplexing (OFDM) |
| $\# 14$ | July 31 |  | Collaborative exercise for better understanding 2 |
| $\# 15$ | TBD | All | Final examination |

## From Previous Lecture

■ Convolutional coding \& Viterbi decoding


■ Error rate of Viterbi decoding

$$
p_{\mathrm{e}}<\sum_{d=d_{\min }}^{\infty} 2^{d-d_{\min }} p_{2}(d) \quad p_{2}(d)=\sum_{k=d_{\mathrm{c}}+1}^{d}\binom{d}{k} p_{\mathrm{e}}^{k}\left(1-p_{\mathrm{e}}\right)^{d-k}
$$

■ Interleaver \& time diversity
Avoiding burst error $\quad p_{\mathrm{e}}\left(\gamma_{\text {bad }}\right)^{k} \longrightarrow p_{\mathrm{e}}\left(\gamma_{1}\right) \cdot p_{\mathrm{e}}\left(\gamma_{2}\right) \cdots p_{\mathrm{e}}\left(\gamma_{k}\right)$

## Contents

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


## QAM Modulation


$\log _{2} M=1$


$$
\log _{2} M=4
$$


$\log _{2} M=2$

$\log _{2} M=6$

## BER of Higher Order Modulation

BPSK modulation
$p_{\mathrm{eb}}(\gamma)=\frac{1}{2} \operatorname{erfc}(\sqrt{\gamma}) \quad \gamma=\frac{P|h|^{2}}{\sigma^{2}}$

QAM modulation

$$
\begin{aligned}
p_{\mathrm{eb}}(\gamma)= & \frac{2}{\log _{2} M}\left(1-\frac{1}{\sqrt{M}}\right) \\
& \cdot \operatorname{erfc}\left(\sqrt{\frac{3 \gamma}{2(M-1)}}\right)
\end{aligned}
$$

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

Throughput of QAM modulation


## BER in Fading Channel

BER of BPSK modulation

$$
p_{\mathrm{eb}}(\gamma)=\frac{1}{2} \operatorname{erfc}(\sqrt{\gamma}) \quad \gamma=\frac{P|h|^{2}}{\sigma^{2}}
$$

Rayleigh fading channel

PDF of Rayleigh fading channel

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

Average BER

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



## BER in Fading Channel



## Throughput in Fading Channel

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

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

Throughput estimation

$$
T P(\gamma, M)=\log _{2} M\left(1-p_{\mathrm{eb}}(\gamma)\right)^{L}
$$

BPSK $\quad p_{\mathrm{eb}}(\gamma)=\frac{1}{2} \operatorname{erfc}(\sqrt{\gamma})$
QAM $\quad p_{\mathrm{eb}}(\gamma)=\frac{2}{\log _{2} M}\left(1-\frac{1}{\sqrt{M}}\right)$

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

Table for adaptive modulation
SISO throuput in AWGN


Adaptive modulation Optimal modulation order

$$
\hat{M}=\arg \max _{M} T P(\gamma, M)
$$

## Throughput of Adaptive Modulation

Average throughput

$$
\bar{T} \bar{P}(\bar{\gamma}, M)=\int f(\gamma) T P(\gamma, M) \mathrm{d} \gamma
$$

PDF of Rayleigh fading

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

Average throughput of adaptive modulation

Table of adaptive modulation


SNR threshold

$$
\begin{aligned}
\overline{T P}(\bar{\gamma})= & \int_{0}^{\gamma_{1}} f(\gamma) T P(\gamma, 2) \mathrm{d} \gamma+\cdots \\
& +\int_{\gamma_{3}}^{\infty} f(\gamma) T P(\gamma, 64) \mathrm{d} \gamma \\
\gamma_{1}=10^{9.5 / 10} \quad & \gamma_{2}=10^{16 / 10} \quad \gamma_{3}=10^{22.5 / 10}
\end{aligned}
$$

| Inst. SNR | Modulation |
| :---: | :---: |
| -9.5 dB | BSPK |
| $9.5 \mathrm{~dB}-16 \mathrm{~dB}$ | QPSK |
| $16 \mathrm{~dB}-22.5 \mathrm{~dB}$ | 16 QAM |
| 22.5 dB | 64 QAM |

## 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

| $\mathrm{R}=1 / 2$ |  | $\mathrm{R}=2 / 3$ |  | $\mathrm{R}=3 / 4$ |  | $\mathrm{R}=4 / 5$ |  | $\mathrm{R}=5 / 6$ |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| P | $\mathrm{d}_{\text {free }}$ | P | $\mathrm{d}_{\text {free }}$ | P | $\mathrm{d}_{\text {free }}$ | P | $\mathrm{d}_{\text {free }}$ | P |  |
| 1 | 10 | $\mathrm{~d}_{\text {free }}$ |  |  |  |  |  |  |  |
| 1 | 10 | 11 | 6 | 110 | 5 | 1111 | 4 | 11010 | 4 |

## BER of Convolutional Coding



## Throughput of Convolutional Coding

Throughput performance in AWGN channel


## Adaptive Modulation Coding in Fading Channel

Performance in Rayleigh fading channel


## Summary

■ Throughput against modulation order

$$
T P(\gamma, M)=\log _{2} M\left(1-p_{\mathrm{eb}}(\gamma)\right)^{L}
$$

■ Adaptive modulation

$$
\hat{M}=\arg \max _{M} T P(\gamma, M)
$$

SNR Table for AMC


■ Throughput performance of AMC

$$
\overline{T P}(\bar{\gamma})=\int_{0}^{\gamma_{1}} f(\gamma) T P(\gamma, 2) \mathrm{d} \gamma+\cdots+\int_{\gamma_{3}}^{\infty} f(\gamma) T P(\gamma, 64) \mathrm{d} \gamma
$$

