

**LCF**

# Radio Networks

## Link Level: Countermeasures to Fading

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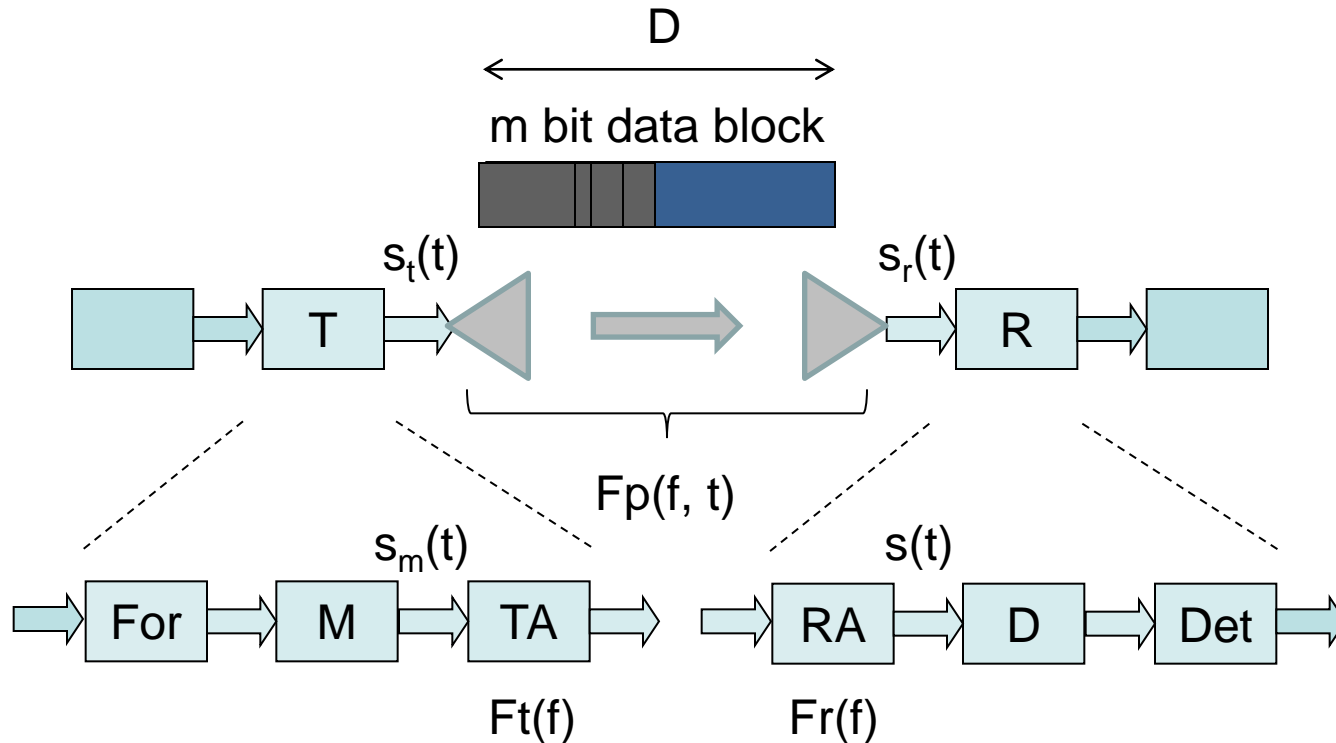
# Outline

1. Interleaving
2. Adaptive Modulation and Coding
3. Diversity
4. Direct Sequence Spread Spectrum
5. Frequency Hopping Spread Spectrum
6. Multi Carrier Modulation
7. Link Performance with FEC and Diversity
8. System Model Revisited

**The scope of this lecture block is to introduce the fundamentals of those techniques that at the PHY layer are used as countermeasures to fading.**

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# System Model



**Data Block Duration:  $D = m / R_b$**

**$m = 100 - 10000$  bits**

**$R_b = 10$  Kbit/s –  $400$  Mbit/s**



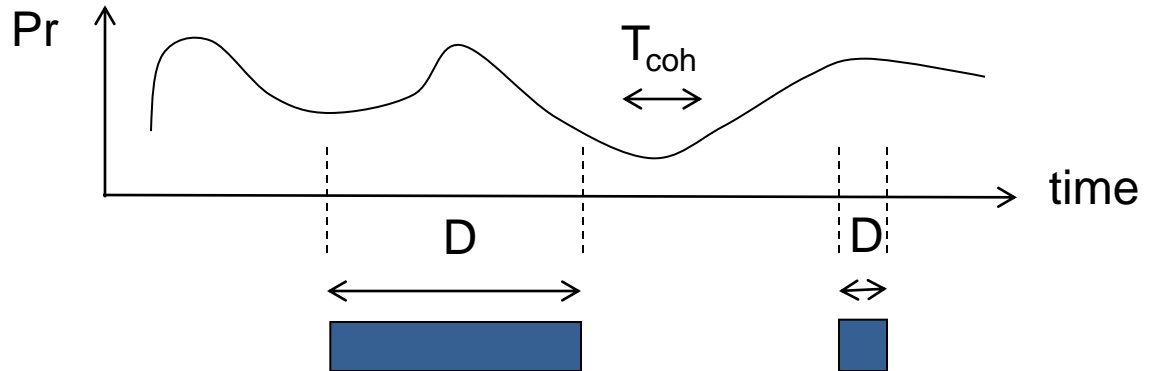
**$D = 0.25 \mu\text{s} - 1 \text{ s}$  (normally  $0.1 - 10 \text{ ms}$ )**

# Radio Channel

Frequency bands from 400 MHz to 4 GHz

		Fading	Shadowing
Coherence Time	$T_{coh}$	0.1 – 100 ms	1 – 10 s
Coherence Band	$B_{coh}$	0.1 – 10 MHz	10 – 100 MHz
Coherence Space	$S_{coh}$	0.1 – 10 m	10 – 100 m

**Slow Fading:**  $T_{coh} \gg D$   
**Fast Fading:**  $T_{coh} < D$



# 1. Interleaving

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## Interleaving (bit interleaving)

Bits of a given data block are transmitted over the radio channel with an order different from the one after channel encoding.

**Scope of bit interleaving: to break the time coherence of fading.**

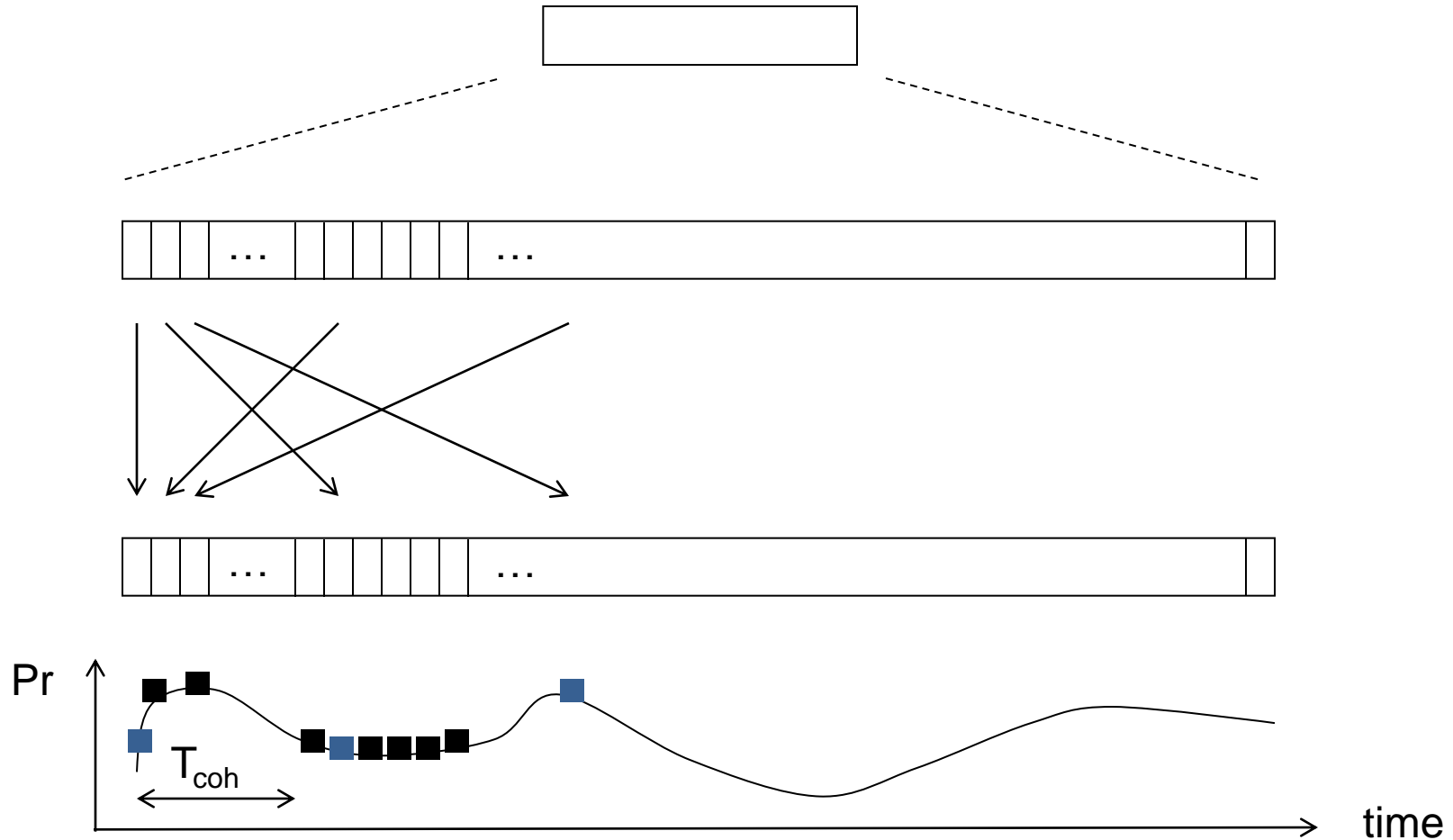
**Correction at the receiver side of data blocks encoded according to FEC, is more efficient (i.e. the number of bits that can be corrected,  $t$ , is larger) if errors do not occur in bursts. Therefore, independence between errors at adjacent bits is helpful.**

**If fading varies during data block transmission, independence can be obtained by scrambling at transmitter the order of transmission of bits. At receiver, the correct order has to be re-established. The two actions are named *interleaving* and *de-interleaving*. Both actions introduce processing delay.**

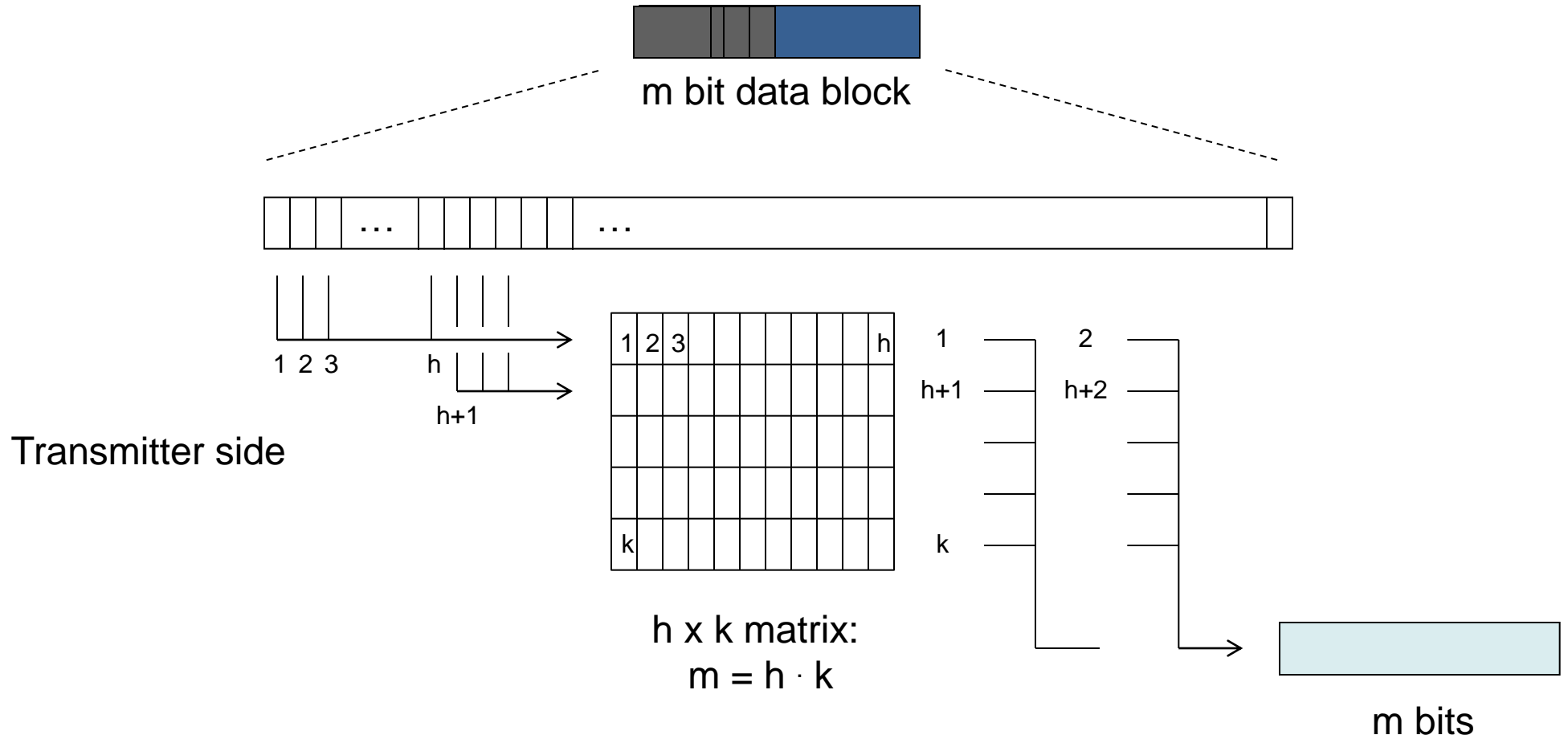
**Efficient technique against Fast Flat Fading**

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# Interleaving (bit interleaving)

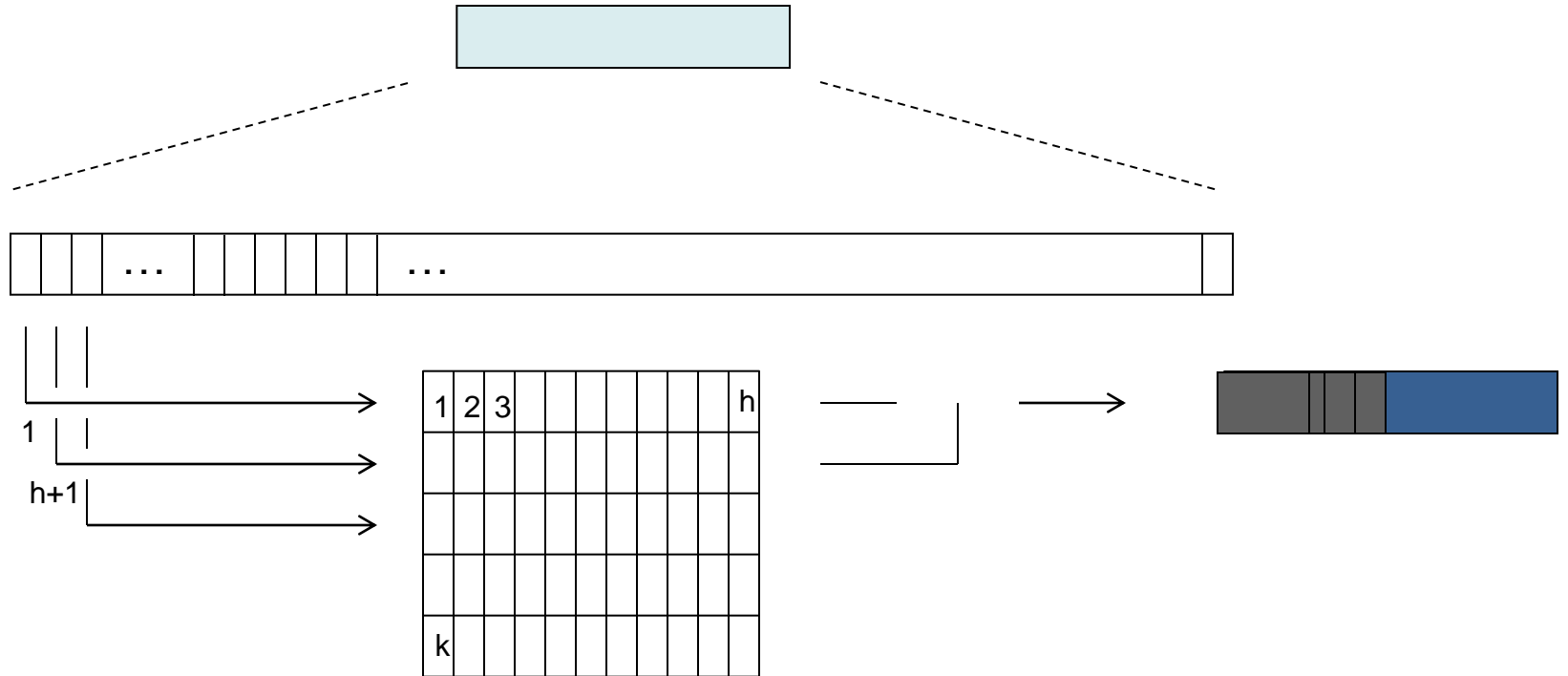


# Interleaving (bit interleaving)





# Interleaving (bit de-interleaving)



Receiver side

$h \times k$  matrix:  
 $m = h \cdot k$

## Interleaving (block interleaving)

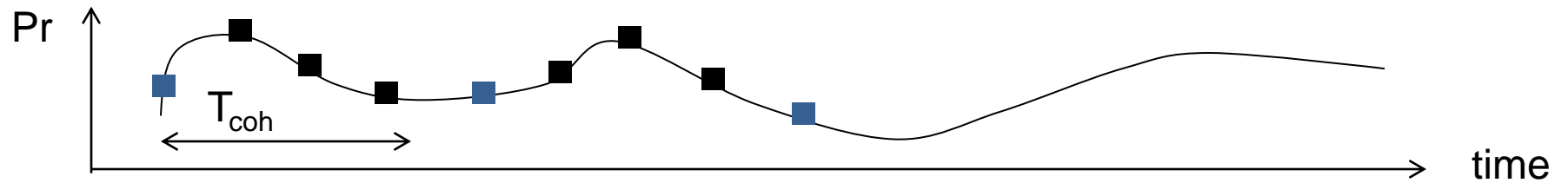
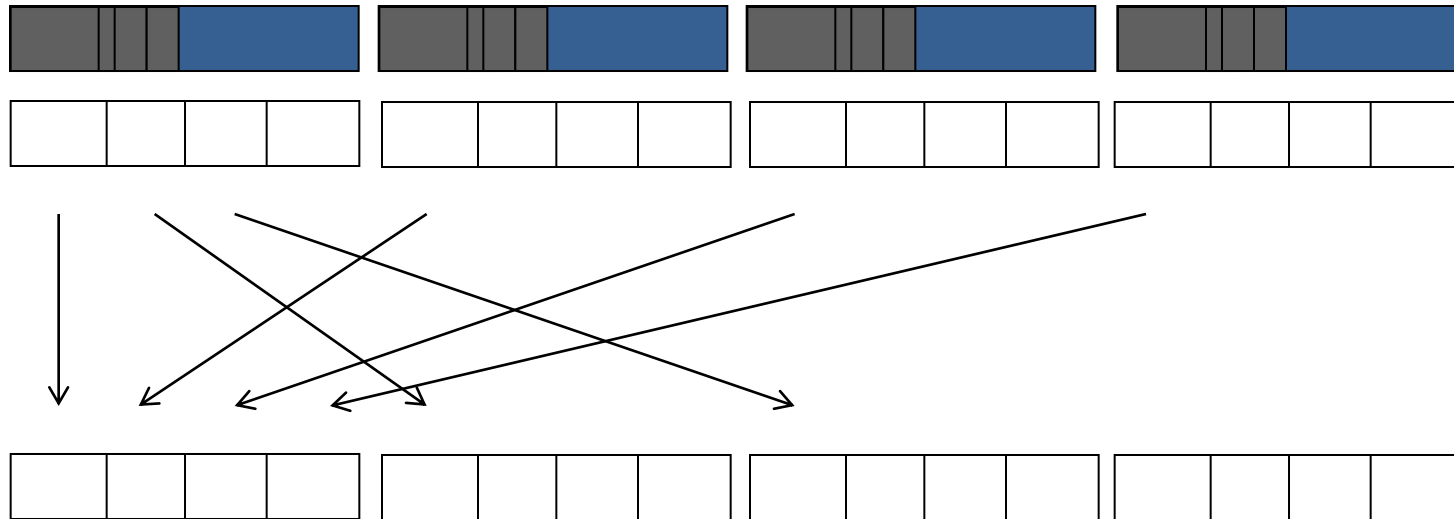
Bursts of a given data block are transmitted over the radio channel with an order different from the one after channel encoding.

**Scope of block interleaving: to break further the time coherence of fading.**

**If fading varies too slow during the data block transmission, the data block can be split into bursts and bursts of subsequent data blocks are interleaved. Processing delay is increased. Furthermore, data block transmission time is also increased.**

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# Interleaving (block interleaving)



## 2. Adaptive Modulation and Coding

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# Adaptive Modulation and Coding

The modulation format is adapted to the link quality. In noise limited systems, link quality is measured through the SNR. The higher the SNR is, the higher the modulation level, or the lower the code ratio, implemented. The choice of a Modulation and Coding Scheme is denoted as MCS.

## Scope of AMC:

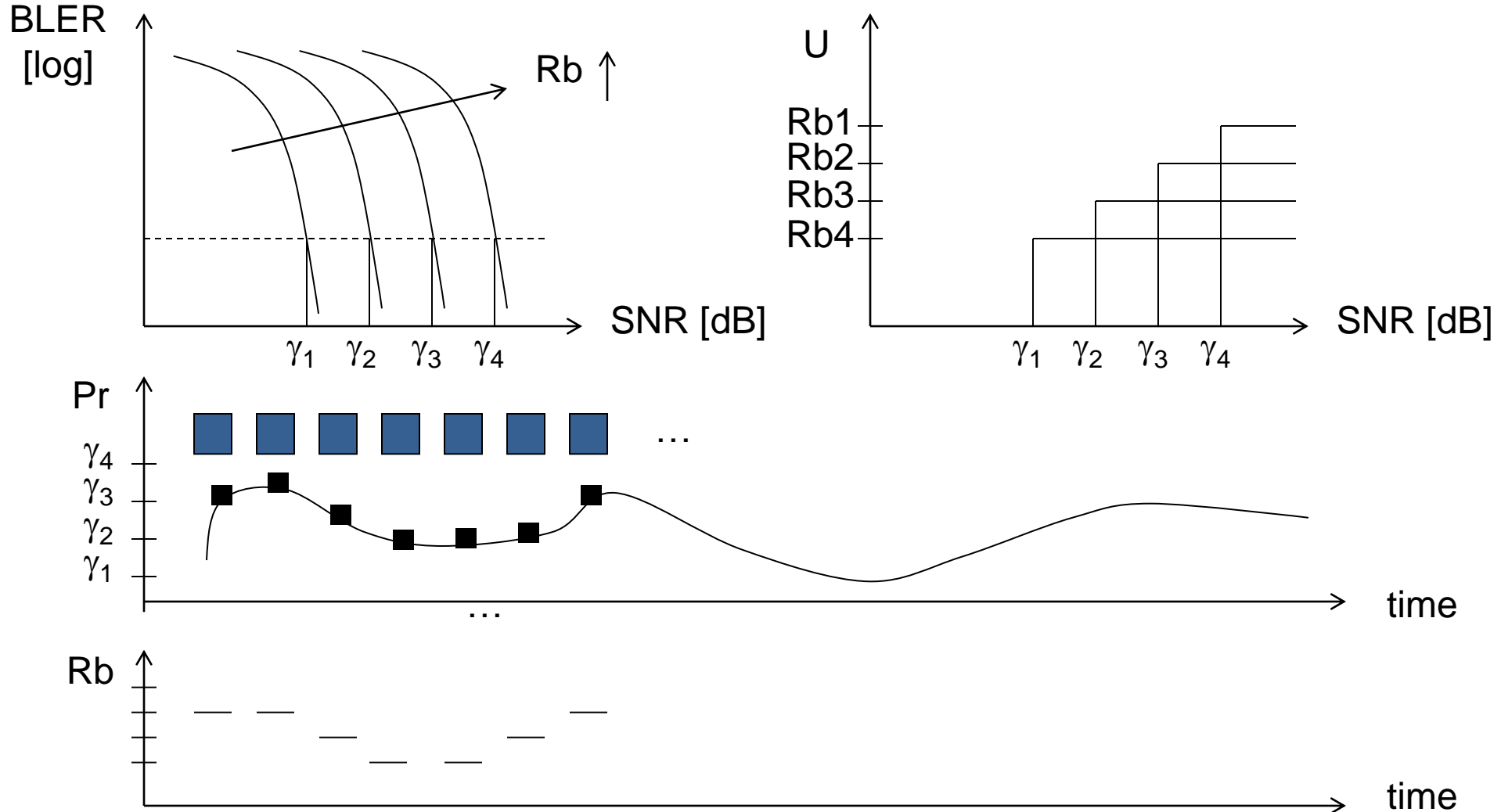
- achievement of maximum instantaneous throughput possible

Adaptation is required each time the channel varies. Changing during the data block transmission is however complex since the receiver must be warned of any change in the MCS to detect the data burst.

**Efficient technique against Slow Flat Fading**

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# Adaptive Modulation and Coding



# 3. Diversity

## Diversity (SIMO)

Combination of separate received replicas of the same data block.  
Uncorrelated replicas are sought.

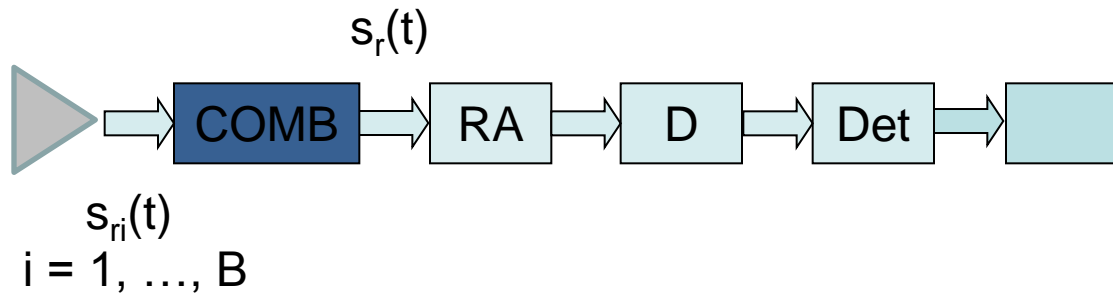
- **Base Station Diversity**
  - **Antenna Diversity**
  - **Frequency Diversity**
  - **Polarization Diversity**
  - **Time Diversity (forced or natural)**
- } **Space Diversity**
- **Post-detection Combining (Selection)**
  - **Pre-detection Combining (Selection, Maximal Ratio)**
- **Diversity Gain**

**Efficient technique against Slow Flat Fading**

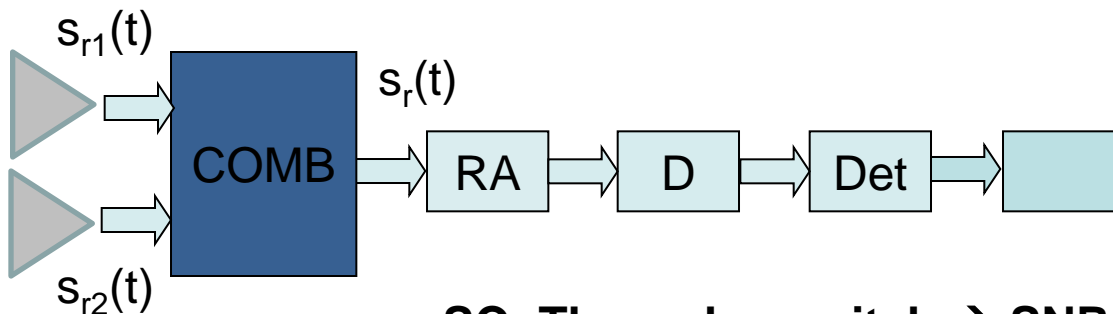
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# Diversity: Pre-detection

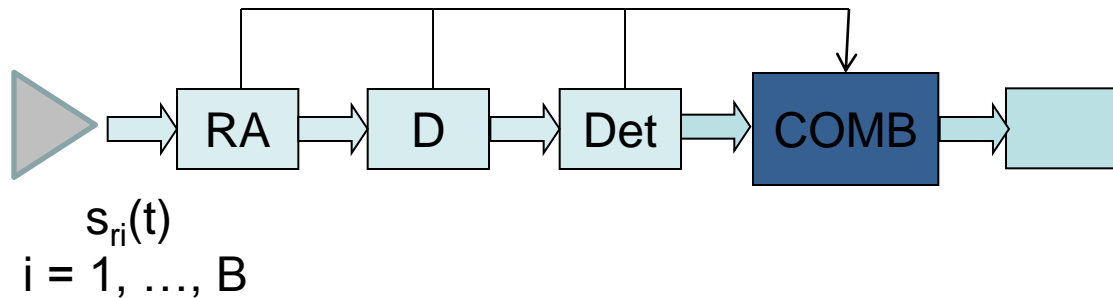


**e.g. Antenna diversity,  $B = 2$  branches**

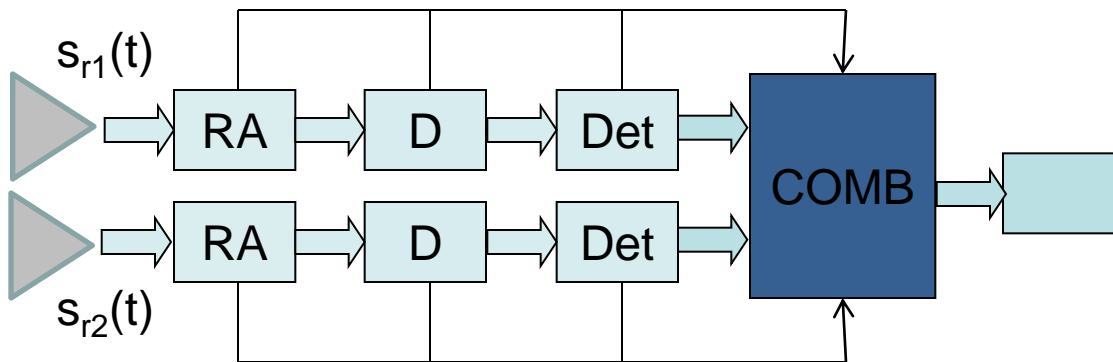


**SC: Through a switch  $\rightarrow$   $SNR = \max(SNR_1, SNR_2)$**   
**MRC: Through a Rake  $\rightarrow$   $SNR = SNR_1 + SNR_2$**

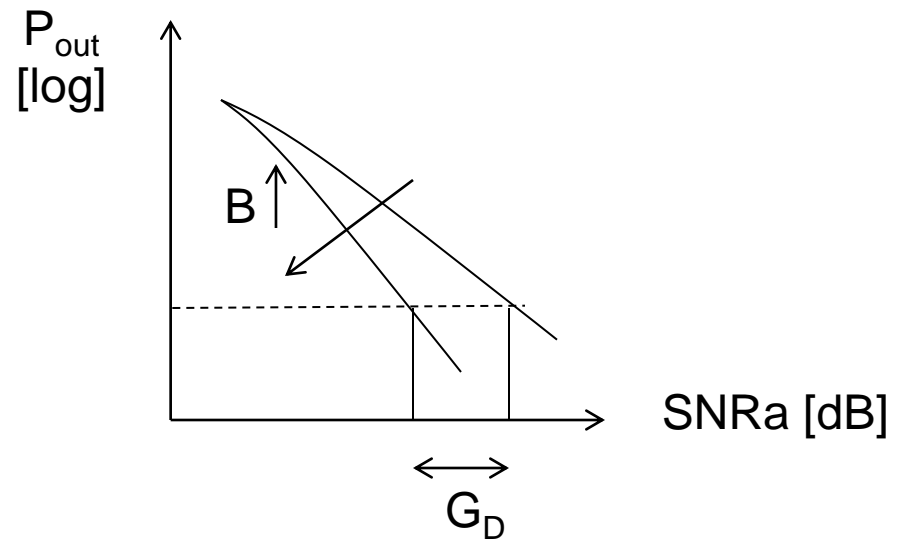
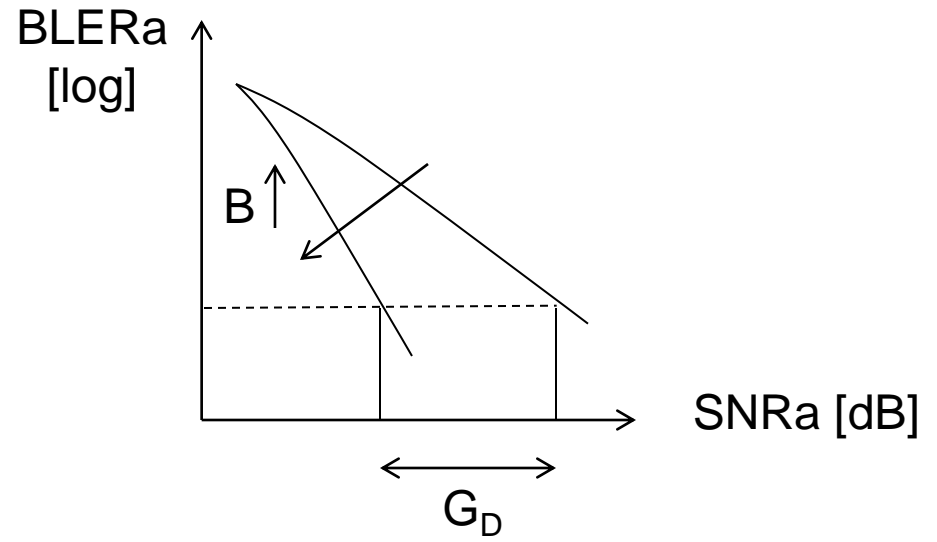
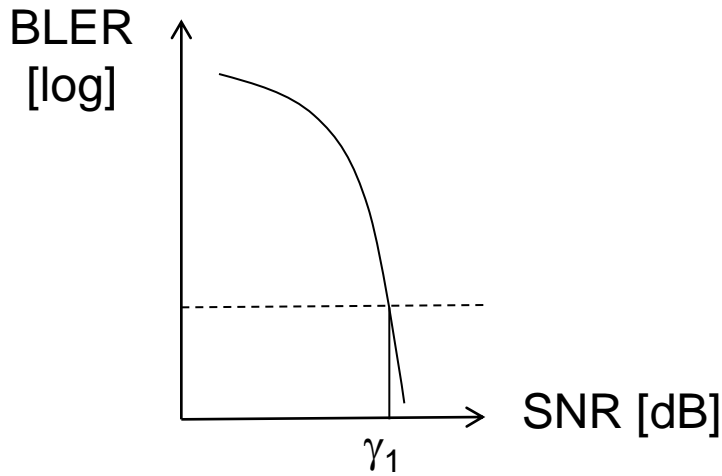
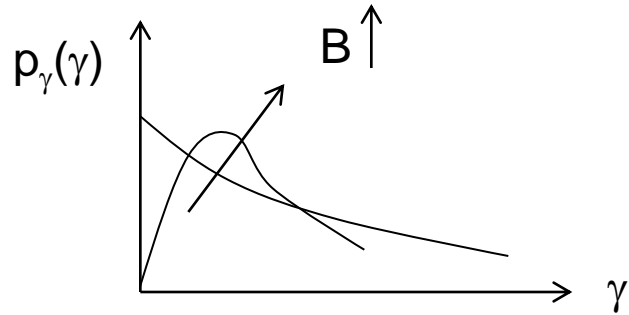
# Diversity: Post-detection



**e.g. Antenna diversity,  $B = 2$  branches**



# Diversity Gain



Math. derivation

## MIMO\*

Multiple antennas both at Tx ( $n_t$ ) and RX ( $n_r$ ) side.

### SIMO:

→ Diversity Gain

### MISO:

Beamforming

Space Time Coding (e.g. Alamouti scheme)

→ Array and Directivity Gain

### MIMO:

Capacity is asymptotically proportional to  $\min[n_t, n_r]$   
[Telatar, 1995]

→ Array, Directivity and Diversity Gain

Efficient technique against Fast Flat Fading

# 4. Direct Sequence Spread Spectrum

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# Direct Sequence Spread Spectrum

Unique code (sequence of binary chips of length  $Q$ ) assigned to links.

Code used to generate bimodal ( - 1; + 1 ) PAM signal  $c(t)$  with rate  $R_c = R_s * P$  where  $P \gg 1$  ( $Q$  chosen as multiple of  $P$ , or  $P = Q$ );  $c(t)$  multiplies the narrowband signal carrying the data.

At the receiver side multiplication again for the same PAM signal  $c(t)$ .  
DSSS can be applied to any modulation technique.

Transmitted signal has spectrum  $P$  times larger than narrowband signal.  
→  $P$  is said **spreading factor**.

Resolution of multipath components is possible through rake receiver.

Over AWGN channel, BER with DSSS is equal to BER without DSSS.

Math. derivation

Efficient technique against Frequency Selective Fading

# 5. Frequency Hopping Spread Spectrum

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# Frequency Hopping

Data blocks are transmitted by hopping on the frequency carrier.

**Slow FH:** each data block transmitted on separate frequency channel.

**Fast FH:** each set of symbols transmitted on separate frequency channel.

**FH averages the perceived link quality over the different realisations of fading occurring at different frequency bands owing to multipath.**

**Efficient technique against Slow Flat Fading**

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# 6. Multi Carrier Modulation

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## Multi Carrier Modulation\*

Data flow split into (many) multiple parallel low-data rate flows.

Each transmitted over a separate adjacent frequency channel.

**OFDM: Orthogonal Frequency Division Multiplex**

**IDFT at TX side and DFT at RX side**

**Efficient technique against Frequency Selective Fading**

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# 7. Link Performance with FEC and Diversity

## FEC, ARQ with Fading

**FEC requires combination with interleaving and/or frequency hopping.**

**ARQ works better if fading is faster than re-transmissions.**

**Performance with fading can be evaluated in terms of link outage probability (computer-oriented applications) or average BLER (human-oriented applications).**

**Example: average BLER for human-oriented applications**

Math. derivation

**Efficient technique against Fast Flat Fading**

## AMC with Fading

Performance with fading can be evaluated in terms of link outage probability (computer-oriented applications) or average BLER (human-oriented applications).

**Example: average user throughput for human-oriented applications**

Math. derivation

**Efficient technique against Slow Flat Fading**

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## Diversity with Fading

Performance with fading can be evaluated in terms of link level outage probability (computer-oriented applications) or average BLER (human-oriented applications).

**Example: link level outage probability for computer-oriented applications**

Math. derivation

**Efficient techniques against Flat Fast Fading**

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## Inquiry Based Session

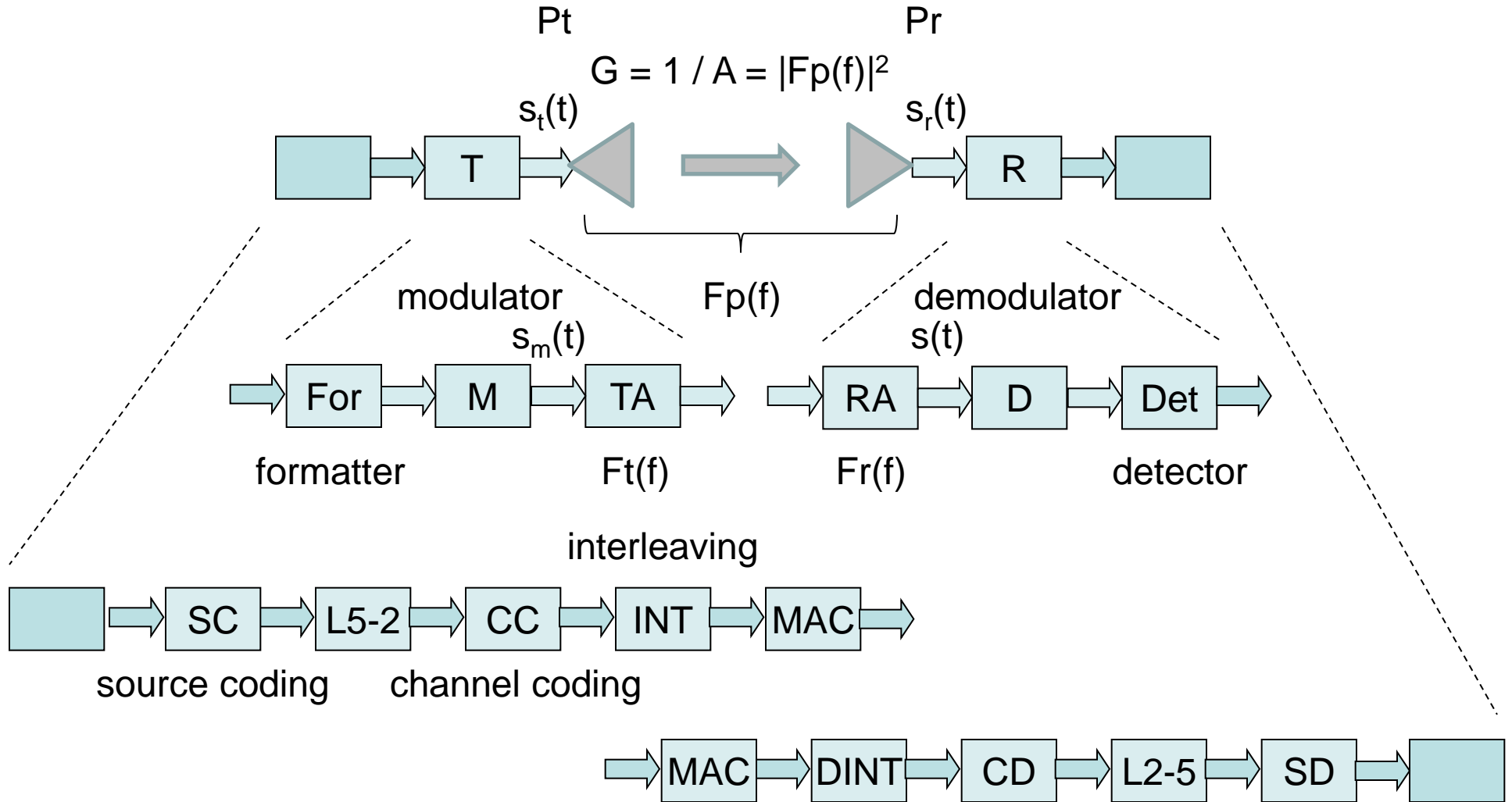
**Which among the previous techniques can be used to counteract / adapt to the slow variations of shadowing?**

- **FEC with bit/burst interleaving**
  - **FEC with Frequency Hopping**
  - **AMC**
  - **Diversity**
  - **MIMO**
  - **DS-SS**
  - **FH-SS**
  - **Multicarrier Modulation**
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# 8. System Model Revisited



# System Model Revised



## Exercise LCF#1

**A bidirectional link is symmetric (same long term average channel gain in the forward and reverse links), and uses antenna diversity in the reverse link, with  $B$  branches. Assume the two links have the same receiver sensitivity, while the forward link, which has link level outage probability equal to 0.01, has higher transmit power, 6 dB larger than the reverse link. Assuming pre-detection selection combining, and Rayleigh fading in the radio channel, how many branches are needed to ensure link level outage probability lower than 0.01 in the reverse link?**

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# Radio Networks

## Link Level: Countermeasures to Fading

The End

