TTF

Vehicular Communications – Part II
Transmission Techniques for Fading Channels

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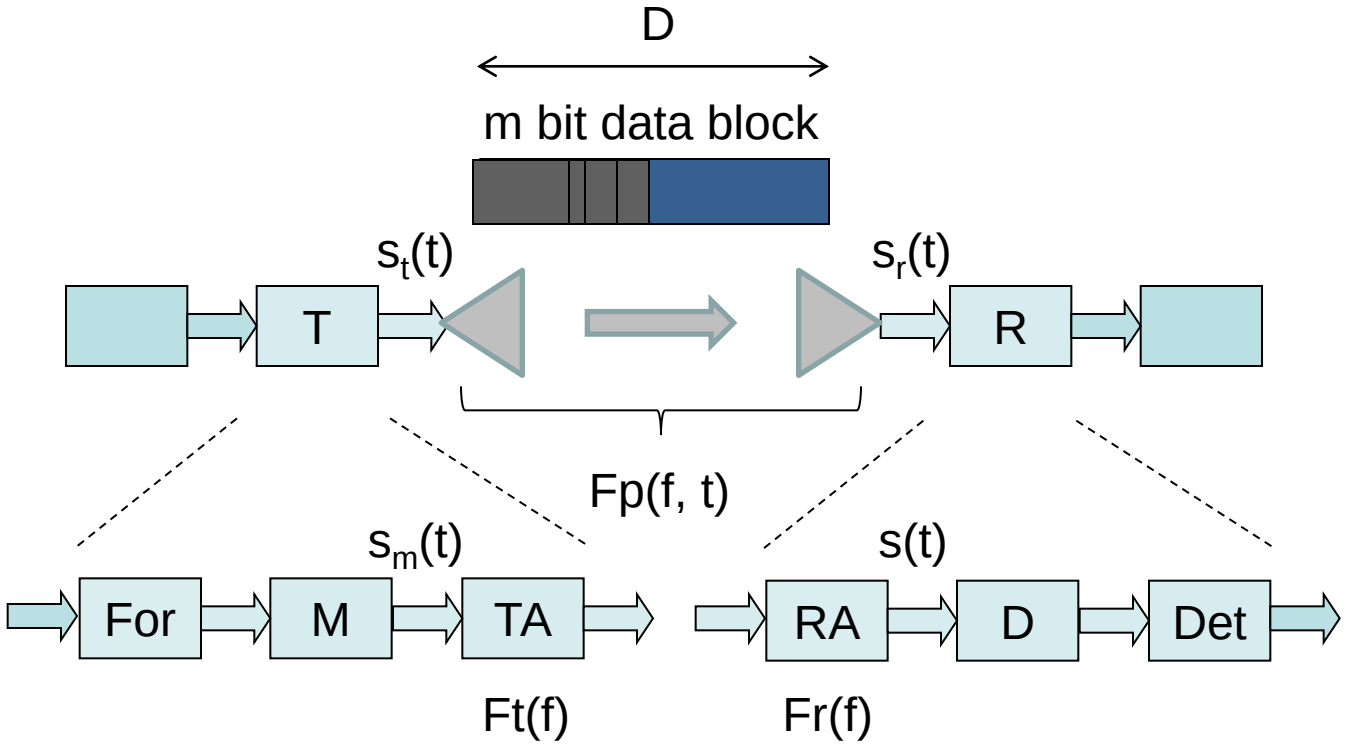
Outline

1. Interleaving
2. Diversity
3. Multi Carrier Modulation
4. Exercises

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.

System Model



Data Block Duration: D = m / Rb

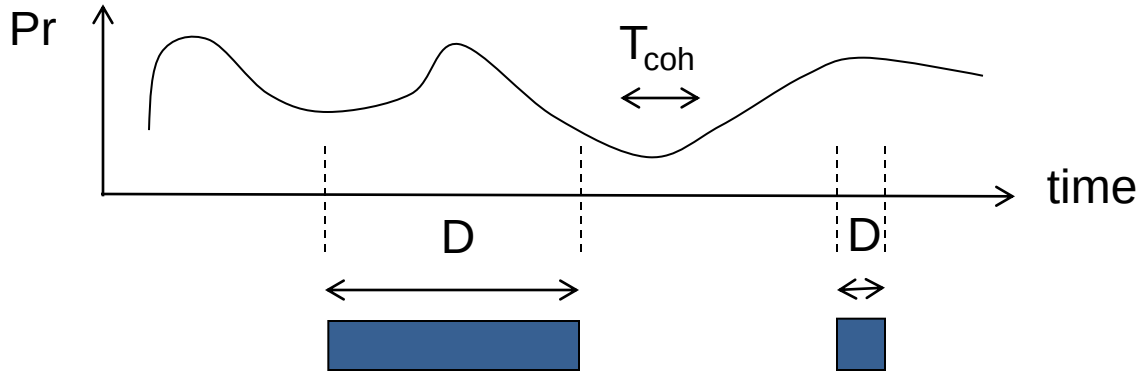
m = 100 – 10000 bits
Rb = 10 Kbit/s – 400 Mbit/s ⇨ **D = 0.25 μs – 1 s (normally 0.1 – 10 ms)**

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: $T_{coh} >> D$
Fast Fading: $T_{coh} < D$



1. Interleaving

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.

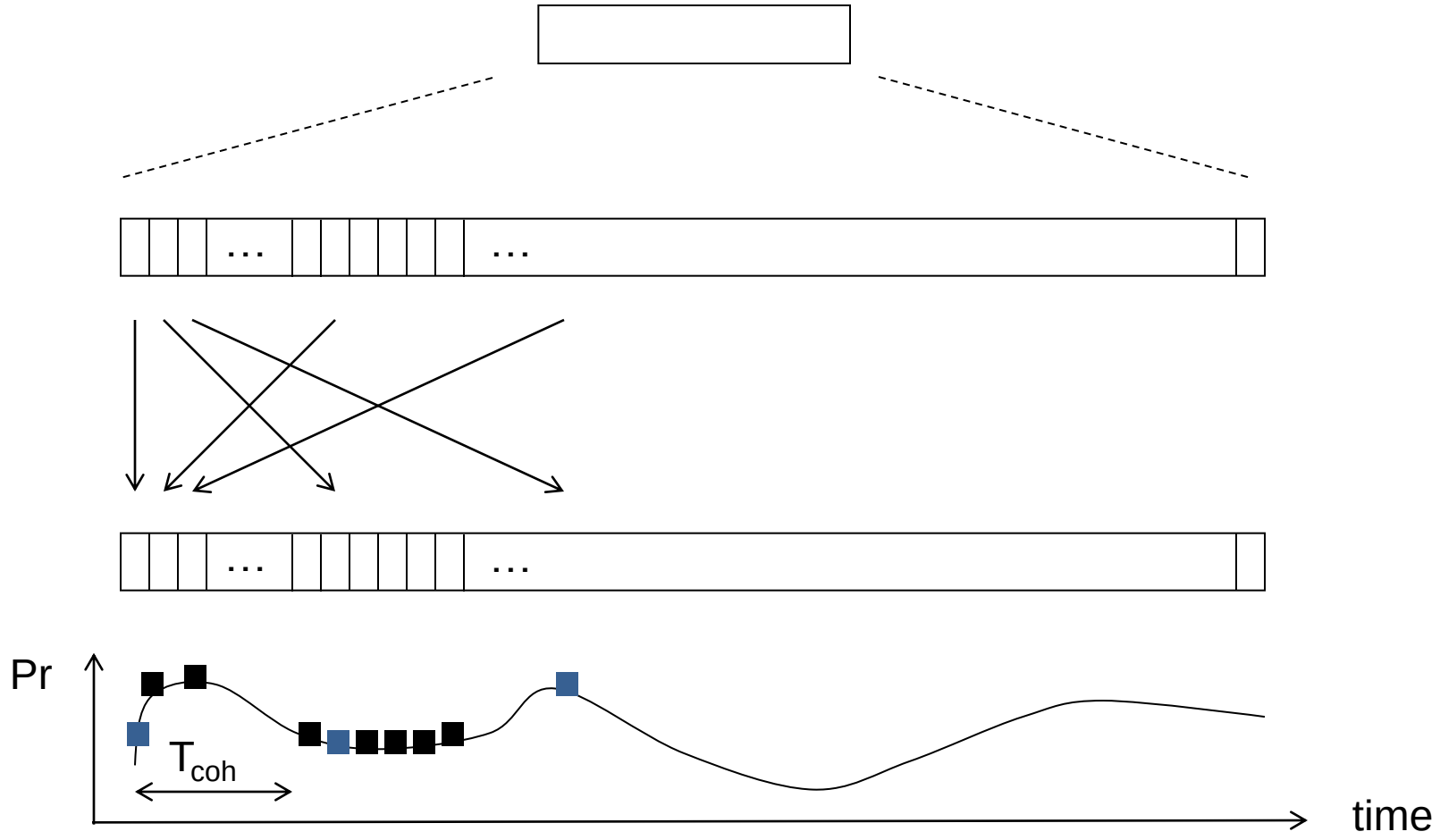
Scope of bit interleaving: to break the time coherence of fading.

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.

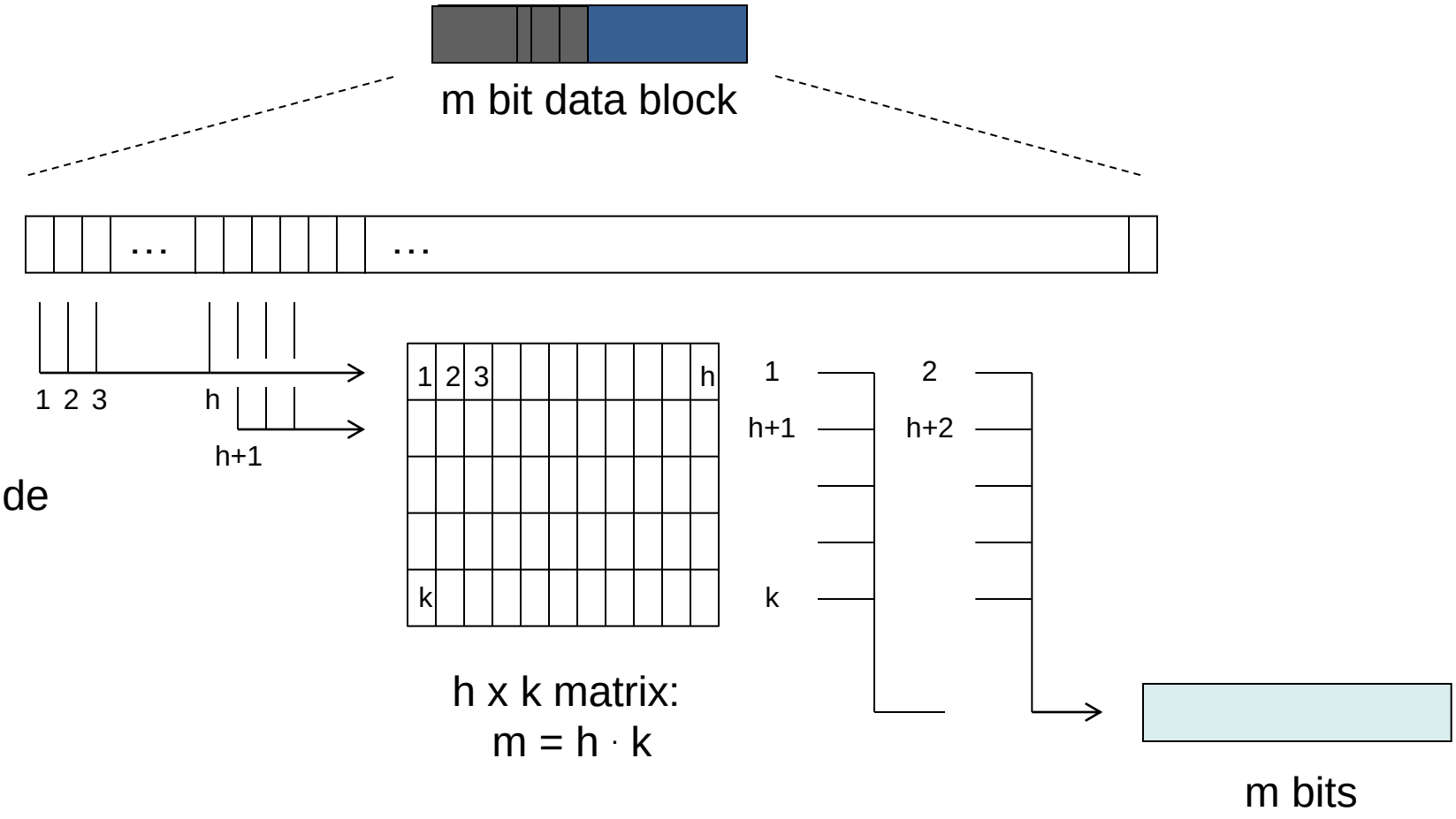
If fading varies during data block transmission, independence can be obtained by scrambling at transmitter the order of transmission of bits. At receiver, the correct order has to be re-established. The two actions are named *interleaving* and *de-interleaving*. Both actions introduce processing delay.

Efficient technique against Fast Flat Fading

Interleaving (bit interleaving)

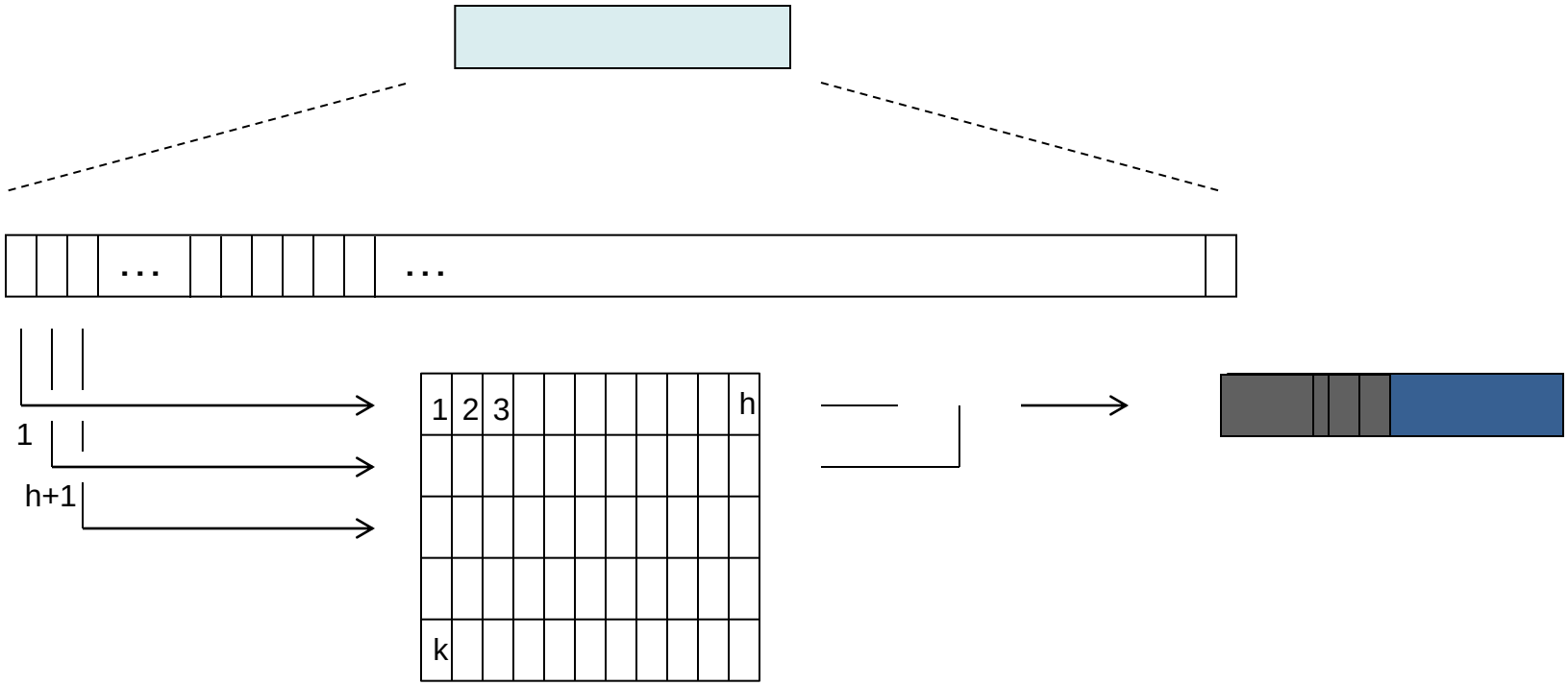


Interleaving (bit interleaving)



Transmitter side

Interleaving (bit de-interleaving)



Receiver side

h x k matrix:

$m = h \cdot k$

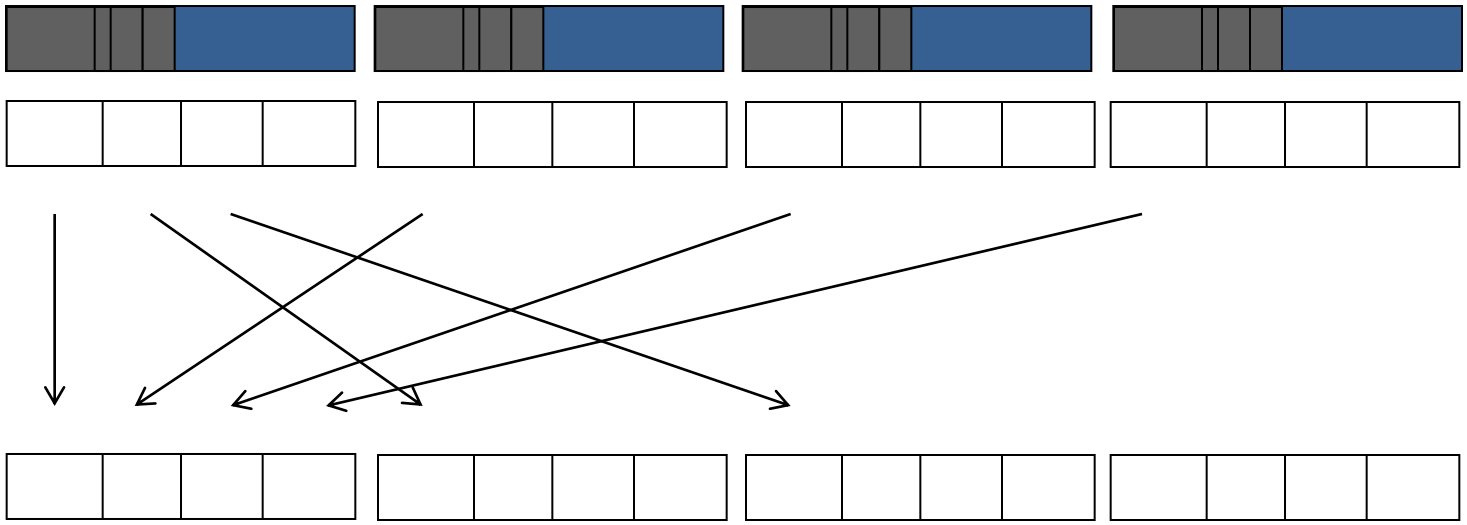
Interleaving (block interleaving)

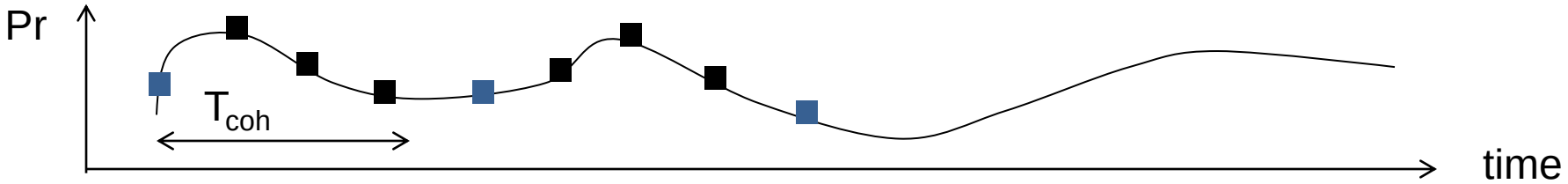
Bursts of a given data block are transmitted over the radio channel with an order different from the one after channel encoding.

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.

Interleaving (block interleaving)





2. Diversity

Diversity (SIMO)

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

- **Base Station Diversity**
- **Antenna Diversity**

} **Space Diversity**

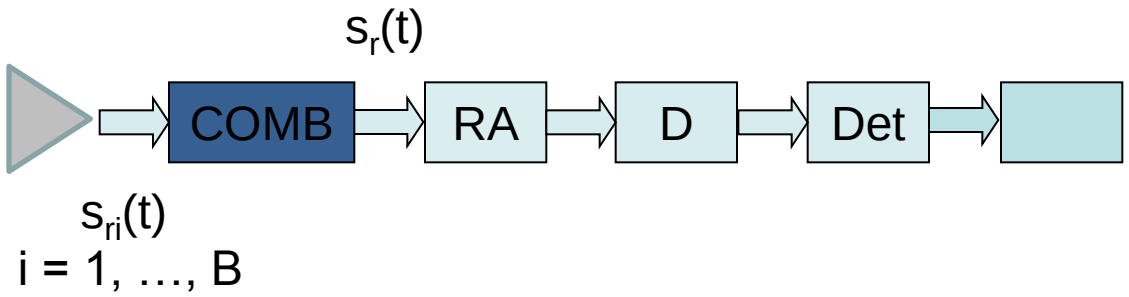
- **Frequency Diversity**
- **Polarization Diversity**
- **Time Diversity (forced or natural)**

- **Post-detection Combining (Selection)**
- **Pre-detection Combining (Selection, Maximal Ratio)**

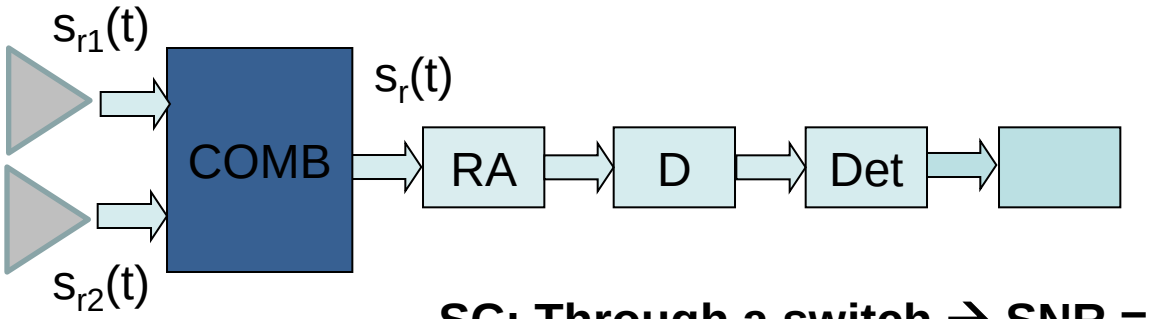
- **Diversity Gain**

Efficient technique against Slow Flat Fading

Diversity: Pre-detection

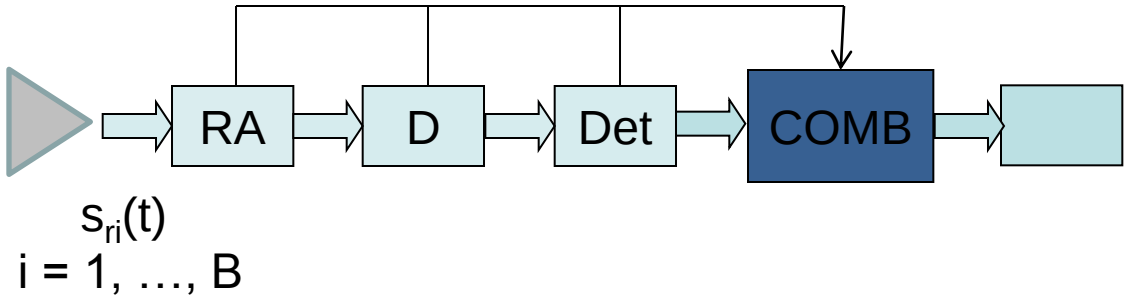


e.g. Antenna diversity, B = 2 branches



SC: Through a switch → SNR = max (SNR_1, SNR_2)
MRC: Through a Rake → SNR = SNR_1 + SNR_2

Diversity: Post-detection



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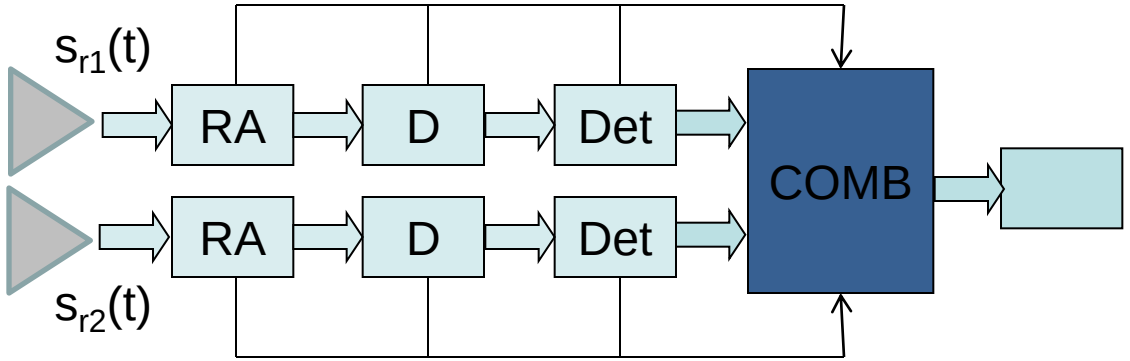
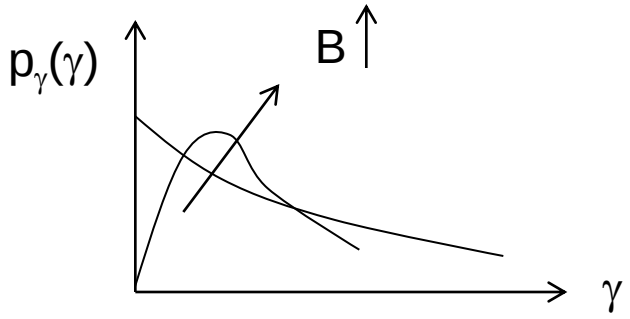
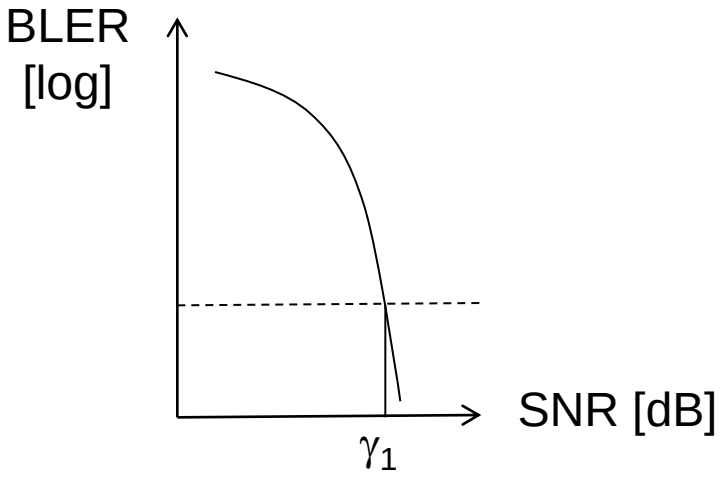
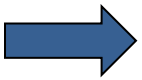
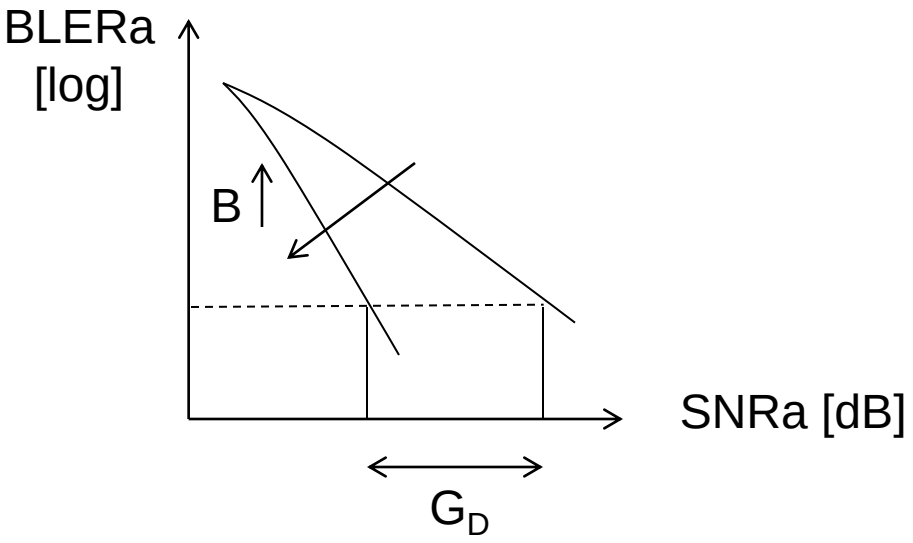


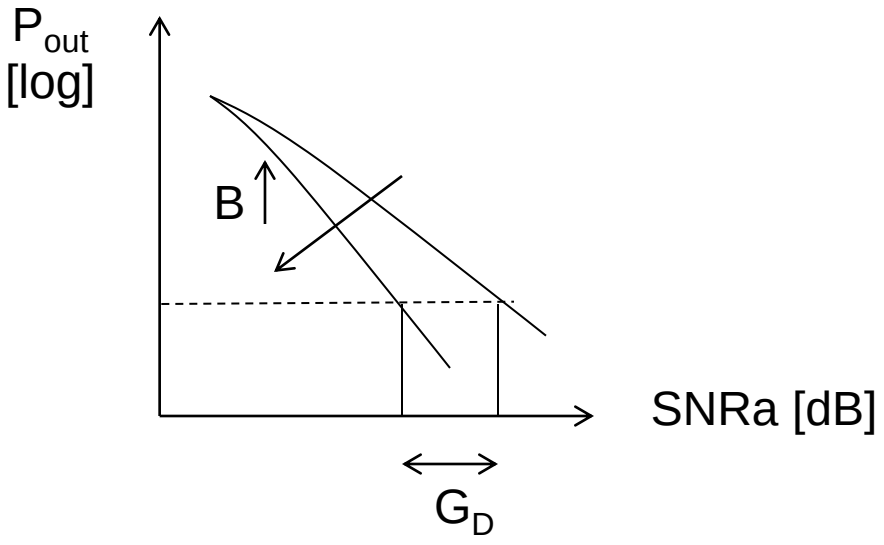
Diversity Gain











Math. derivation

MIMO

Multiple antennas both at Tx (nt) and RX (nr) side.

SIMO:

→ Diversity Gain

MISO:

Beamforming
Space Time Coding (e.g. Alamouti scheme)

→ Array and Directivity Gain

MIMO:

Capacity is asimptotically proportional to min[nt,nr]
[Telatar, 1995]

→ Array, Directivity and Diversity Gain

Efficient technique against Fast Flat Fading

3. Multi Carrier Modulation

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

4. Exercises

Exercise TTF#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?