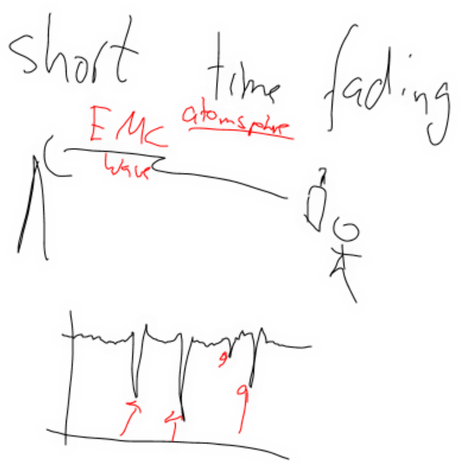
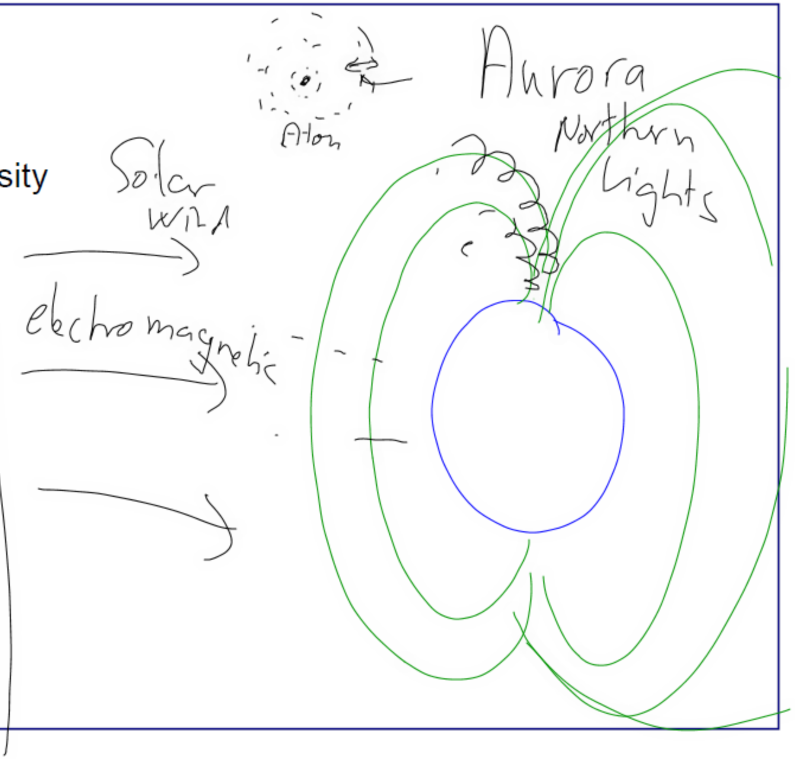
Agenda

- Introduction of fading
  - Effect of fading
- Diversity and types of diversity
- Combining techniques for diversity





Effect of fading (1)

- When signal varies, Signal-to-Noise Ratio (SNR) varies and Bit Error Rate (BER) varies over time.
- For BPSK modulation (details in Lec 6 - Modulation), probability of error –

$$p(e) = \frac{1}{2}\operatorname{erfc}\left(\sqrt{\gamma_0}\right) \quad , \quad \text{uten fading}$$

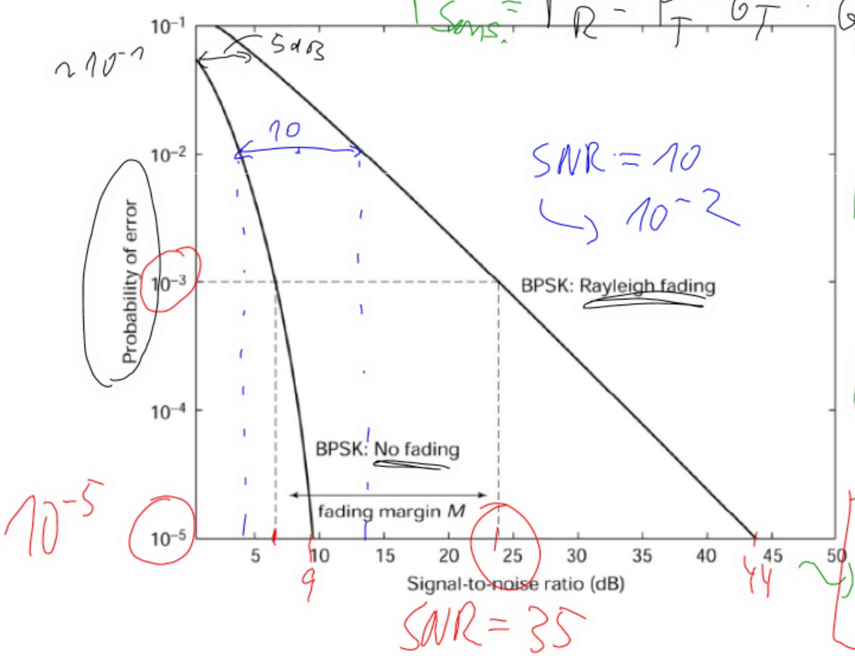
$$p_{fad}(e) = \frac{1}{2}\left[1 - \sqrt{\frac{\gamma_0}{1+\gamma_0}}\right], \quad \text{med fading}$$

Where γ_0 is the SNR

Effect of fading (2)

BER for BPSK modulation without fading and with Rayleigh-fading

Fade margin M for BER=10^{-3} is17 dB



$P_{Sens.} = P_R = P_T \cdot G_T \cdot G_R \cdot \left(\frac{\lambda}{4\pi r}\right)^2$

↝ SNR = 0

Receiver Sensitivity

$P_{Sens.} = -85$ dBm

Bluetooth

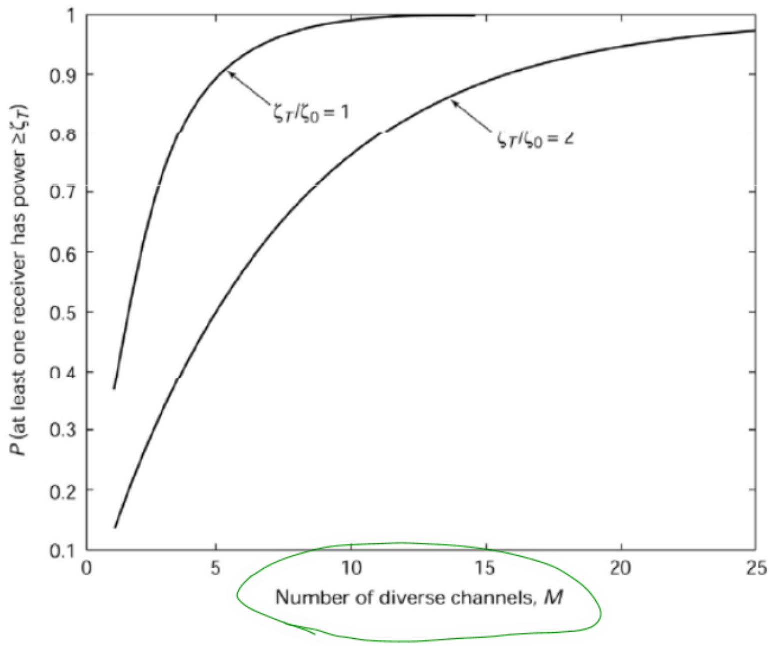
$P_{Fading\ Margin} = 5$ dB

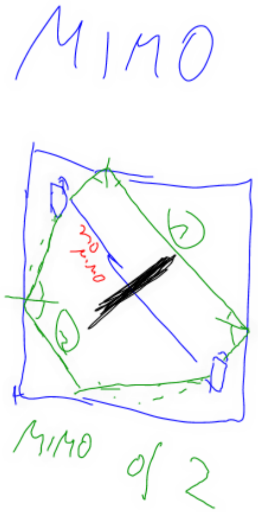
voice

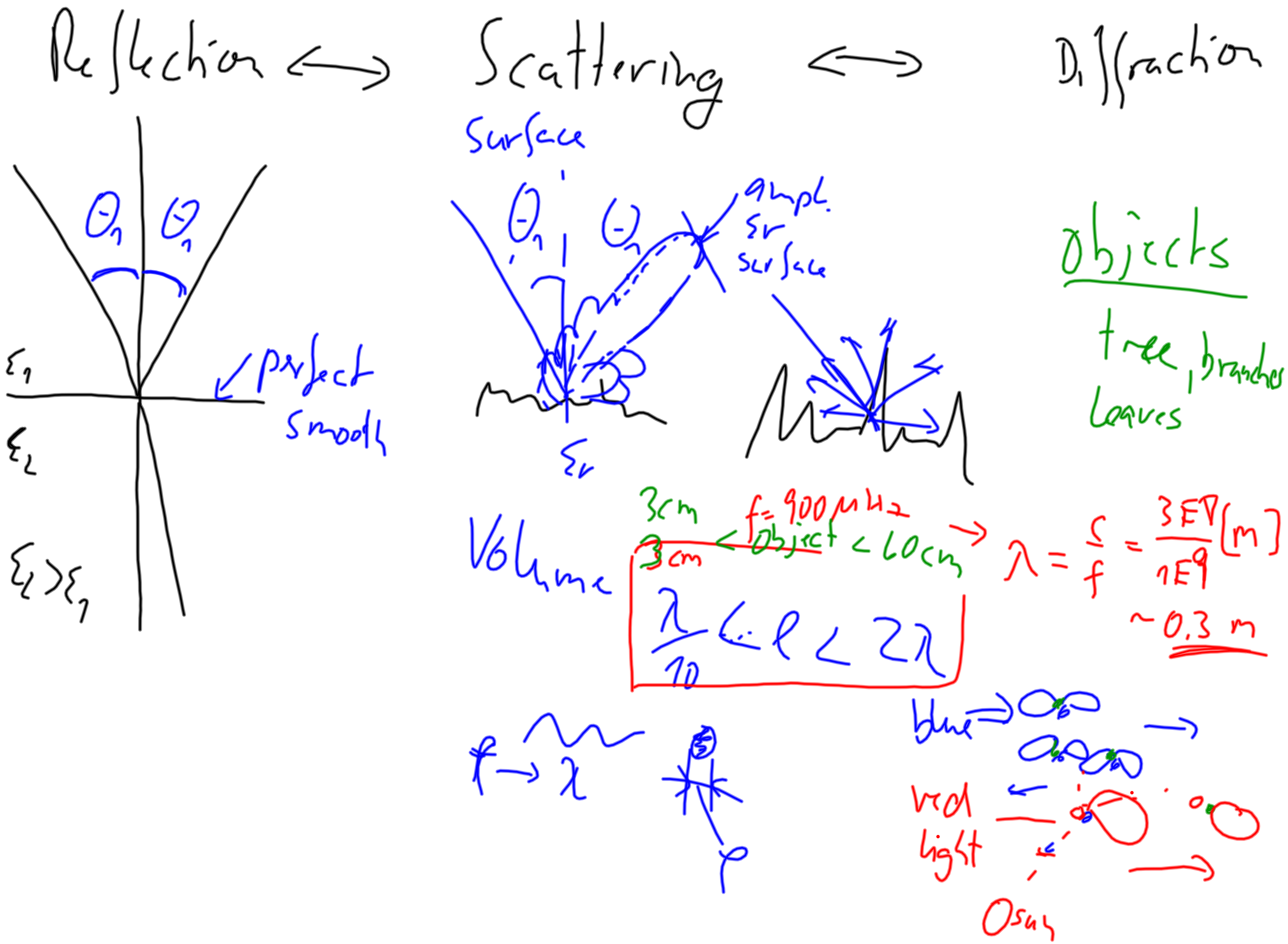
↝ $P_R > P_{Se} + P_{Fan} = -80$ dB

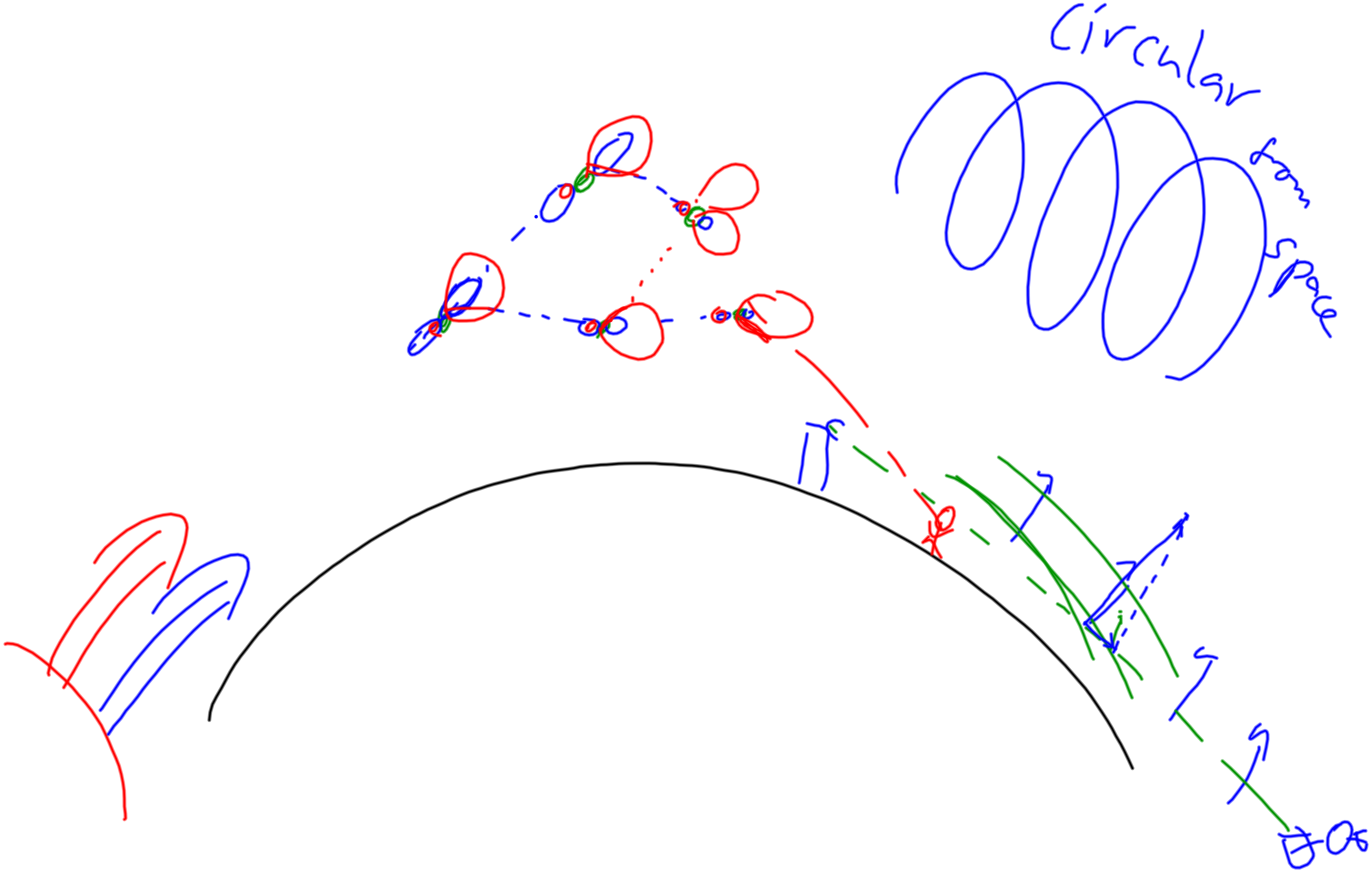
Diversity (2)

- The probability that at least one of M independent Rayleigh fading channels has the effect of ξ_T





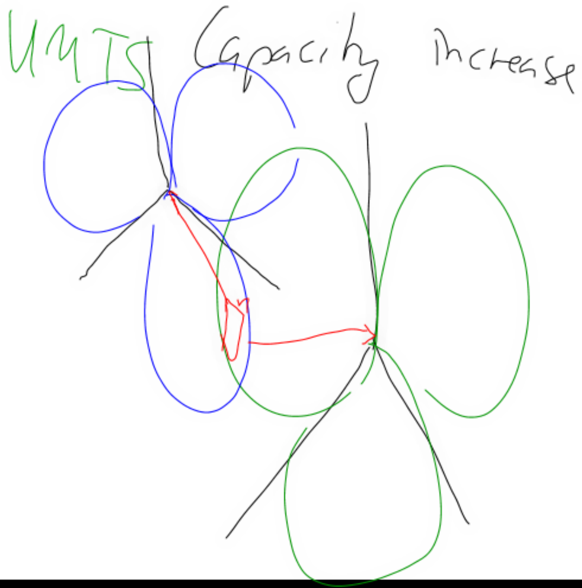

Reflection ⟷ Scattering ⟷ Diffraction
θ1 θ1
ε1
ε2
ε2 > ε1
perfect smooth
Surface
θ1 θ1
ampl. εr surface
εr
objects
tree, branches, leaves
Volume
3cm
f = 900 MHz
3cm < object < 60cm
λ = c/f = 3E8/1E9 [m]
~0,3 m
λ/10 < l < 2λ
f → λ
blue
red light
Osun

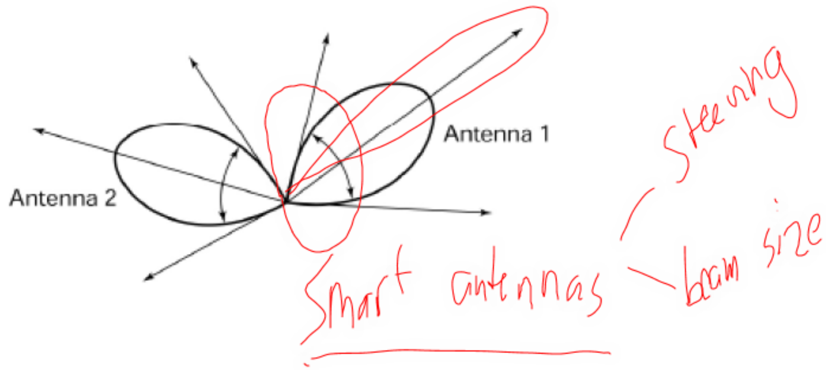


Circular
from
space

Angular diversity

- The receiving antennas have different pointing direction.
- The signal components arriving from different directions is normally uncorrelated
- Angle diversity requires no physical distance between the antennas, and can therefore easier implemented on a mobile station



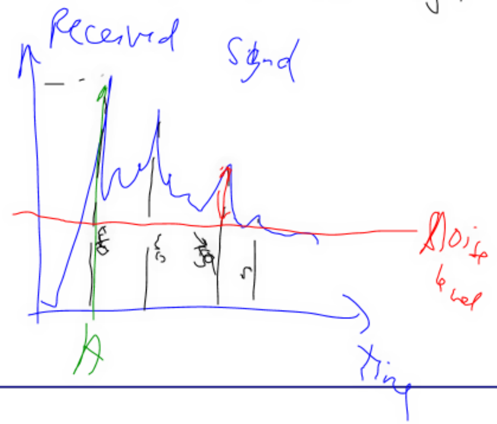


Combining techniques for diversity

Selection (selection combining - SC)
- Selects all times the strongest signal (branch)

Maximum-ratio combining (MRC)
- Adds all branches with different weight based on SNR

Equal-gain combining (EGC)
- Adds all branches of equal weight

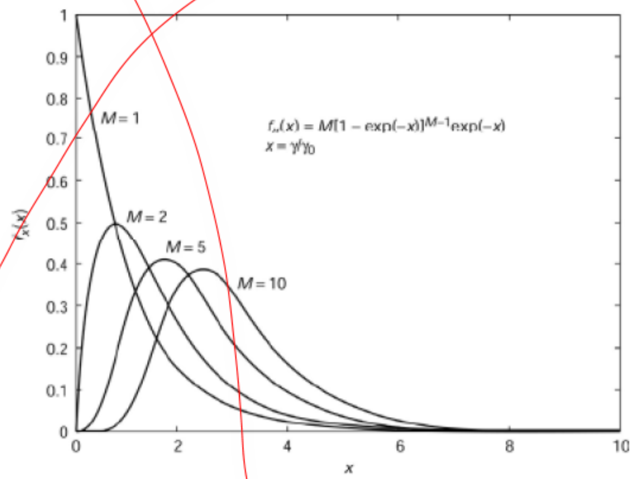


Selection combining

Average improvement using selection diversity:

$$\frac{\gamma_{se}}{\gamma_0} = \sum_{n=1}^{M} \frac{1}{n}$$

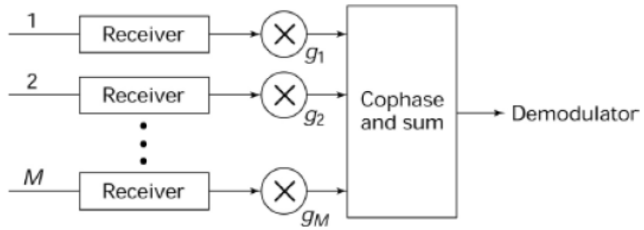
Probability density function for Υ_{se}/Υ_0



Maximum-ratio combining (MRC)

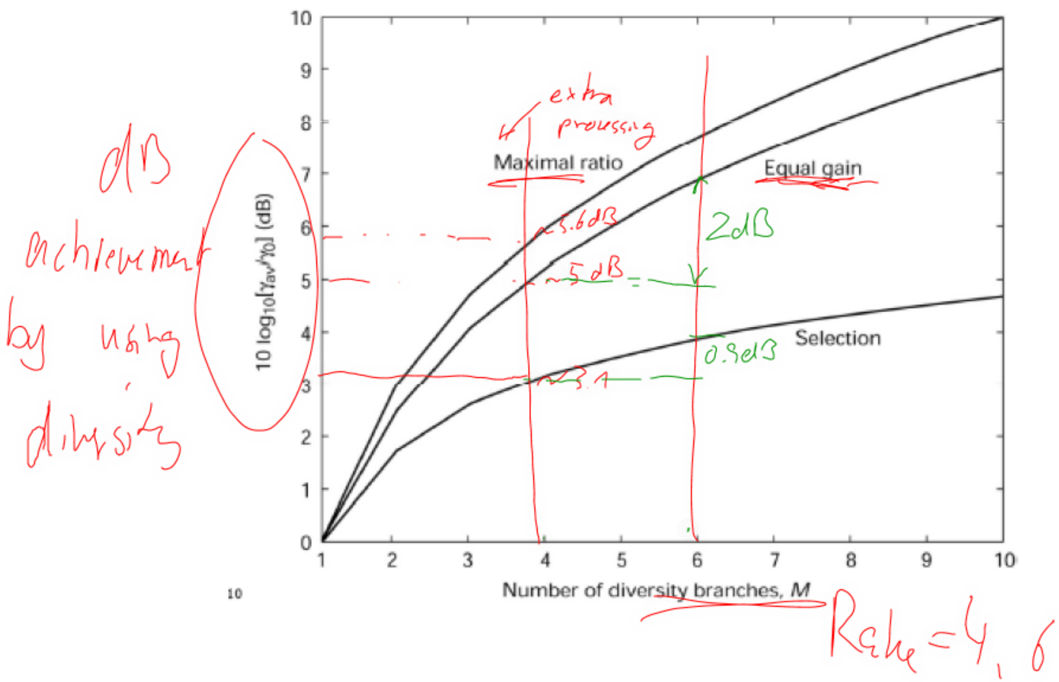
Scales all the branches by a factor g_n (figure) that is proportional with SNR of each branch

This is an optimal way to combine the signals of more complex than selection



Comparison between methods

All results are for an assumption of uncorrelated branches, with
a correlation equal to ρ, performance is reduced approx. a factor √ (1-ρ)2



10

Performance improvement – BER at diversity

Average BER for a diversity method can be found from following expression:

$$p_{av}(e) = \int_0^\infty p(e) f(\gamma) d\gamma$$

Convolution

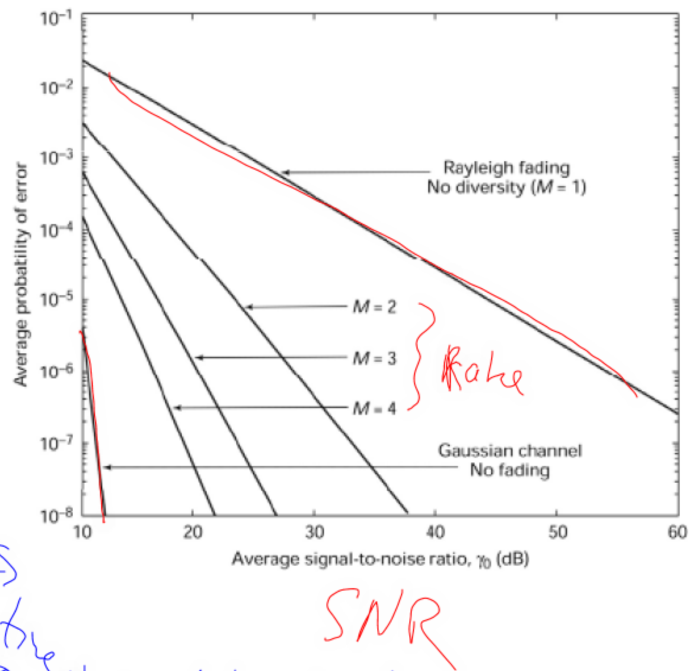
→ correlation

Where p(e) is the bit error probability as a function of SNR, γ and f(γ) is the probability density distribution of the SNR.

BER = f (probability (SNR), probability distrib)

Performance improvement - SC

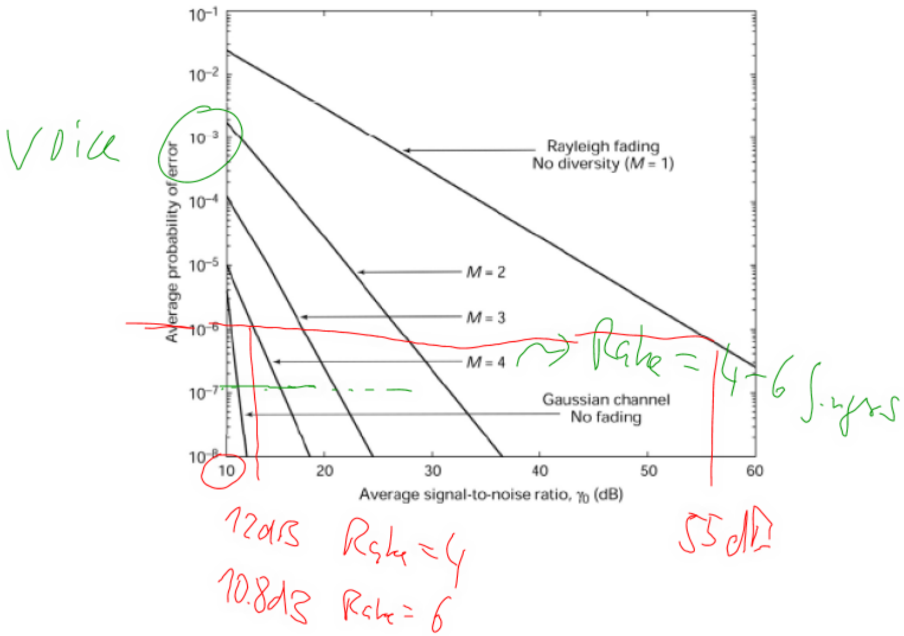
Performance improvement in terms of BER at diversity – SC -
Average BER for occupational testing for different number of diversity diversity channels (BPSK modulation):



Σ rate ~ closer to the non-fading channel

Performance improvement – MRC (1)

Performance improvement in terms of BER at diversity - MRC (I) -
Average BER for maximum-ratio combining for different number of diversity channels (BPSK modulation):



Summary

- short time - EMC always (SNR)

- long term fading: Reflection, Scattering, Diffraction

space
time
frequency
code
polarization
(narrow) angle

adding independent contributions
M (Rate, # antennas, # channels, ...)

Voice 10^{-2} (10^{-3}) ✓ ← P_{Fading} ~ 0 ... 5 dB

Data 10^{-6} 10^{-7} M = 4 ← 12 dB
M = 6

↳ selective
max. ratio
mean/linear

$P_{received} > P_{Sen} + P_{Fading}$

Diffraction