UNIK4230: Mobile Communications

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Combating the Effect of Fading in Mobile Mobile Systems

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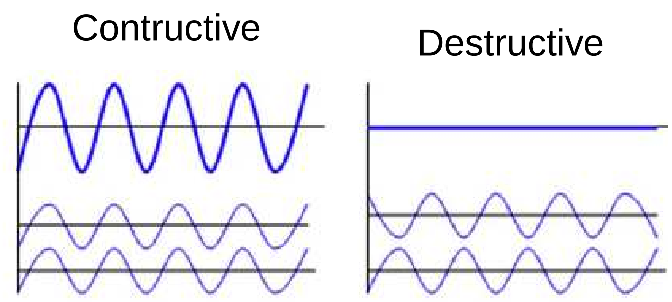
Agenda

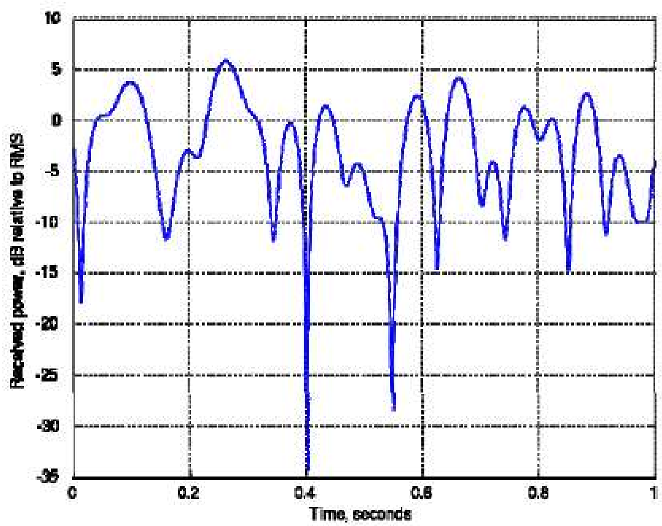
- Introduction of fading
  - Effect of fading
- Diversity and types of diversity
- Combining techniques for diversity

Introduction

- Fading leads to-
  - Quick signal variation (Rayleigh, short term)
  - Slow signal variation (lognormal, long-term)
  - Inter-Symbol Interference (ISI)

- Various ways to combat fading-
  - Micro diversity
  - Macro diversity
  - Channel equilizer





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 –

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

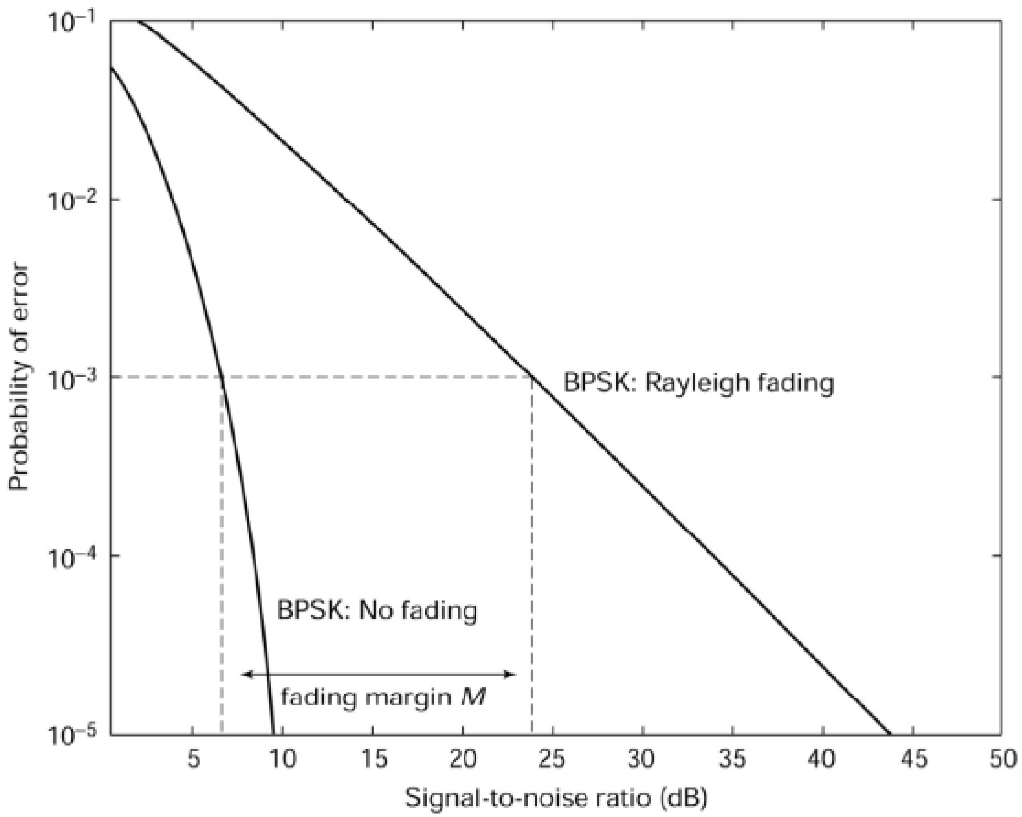
$$p_{fad}(e) = \frac{1}{2}\left[1 - \sqrt{\frac{\gamma_0}{1+\gamma_0}}\right], \quad \text{med fading}$$

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



Diversity (1)

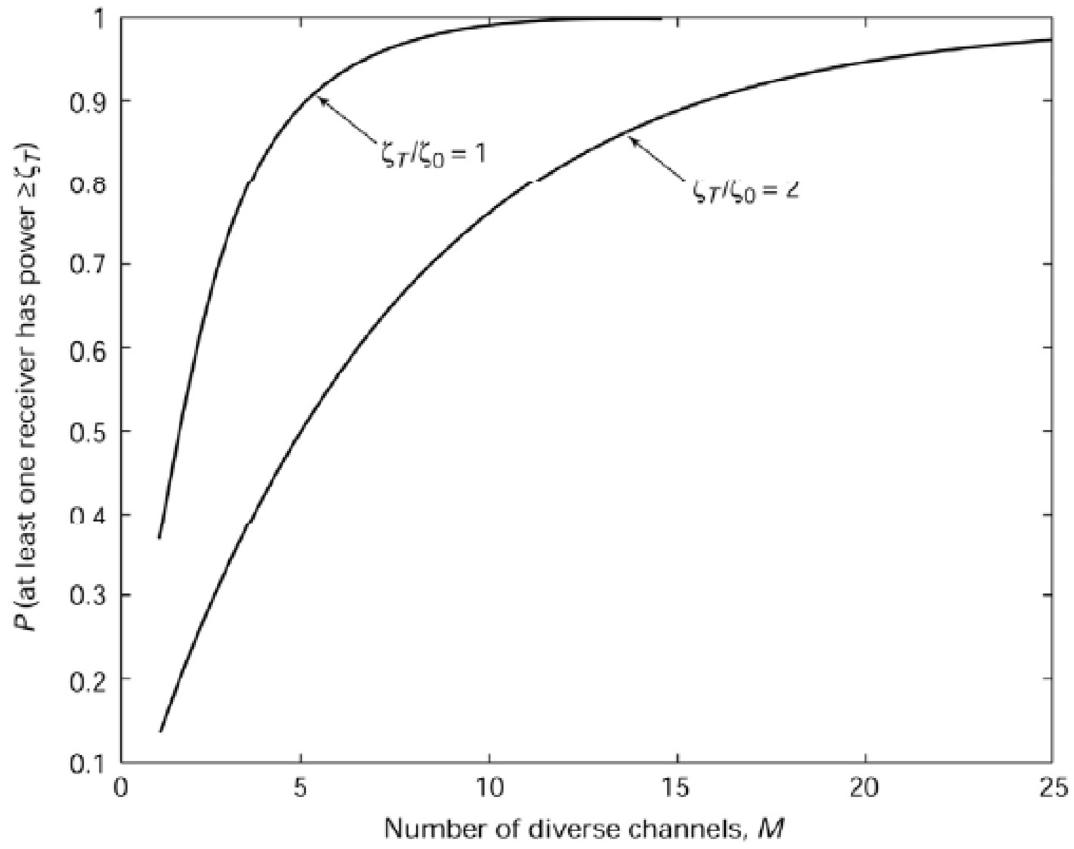
- Diversity means the combination of independent copies of the received signal, for example, by using multiple reciver antenna
- The main idea is the probability that several independent versions of the signal has very low signal level at the same time is small.
- For example, the probability that M independent Rayleigh distributed signals at the same time is below a threshold value ξ_T is-

$$P_M(\zeta_T) = \left[1 - \exp\left(-\frac{\zeta_T}{\zeta_0}\right)\right]^M$$

Where ξ_0 is average effect

Diversity (2)

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



Diversity (3)

- Type of diversity
  - Space diversity – Antenna separted in distance
  - Angular diversity – Antennas with different pointing directions
  - Frequency diversity – The same signal is transmitted at different frequencies
  - Polarization diversity- Antennas with different polarization (field orientation)
  - Time diversity – The same signal is repeated at different times
  - Multi-path diversity – Signals with different propagation paths are combined

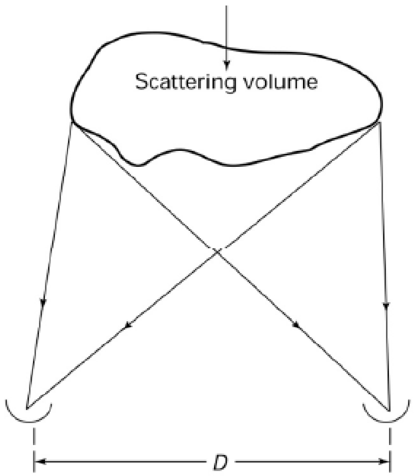
Spase diversity

- Two or more antennas in different positions have uncorrelated fading patterns if separation is large enough
- Required separation depends on the angle signal components arriving within.

  Extremes are:

  • If multi-path components arriving with equal probability from all directions is necessary distance between two antennas λ / 2

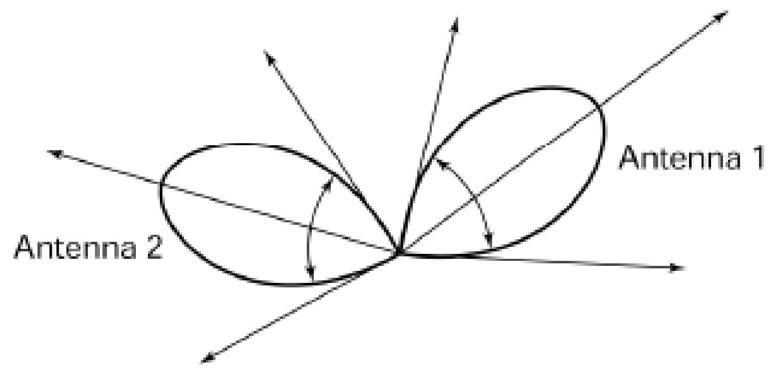
  • If all signal components arrive from the same direction space diversity will have no effect, no separation is large enough



Spase diversity at BTS

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

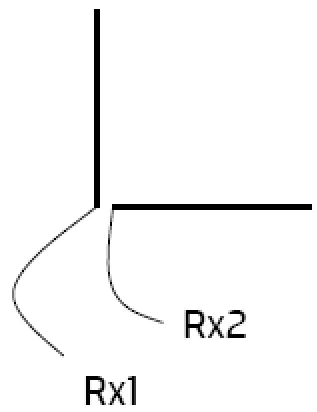


Frequency diversity

- The same signal is sent on different frequencies, with so much distance that the signals are uncorrelated fading
  The disadvantages of this method is
  • bandwidth requirement is necessary to send several frequencies, and
  • complexity of the receiver must be able to receive on multiple frequencies simultaneously

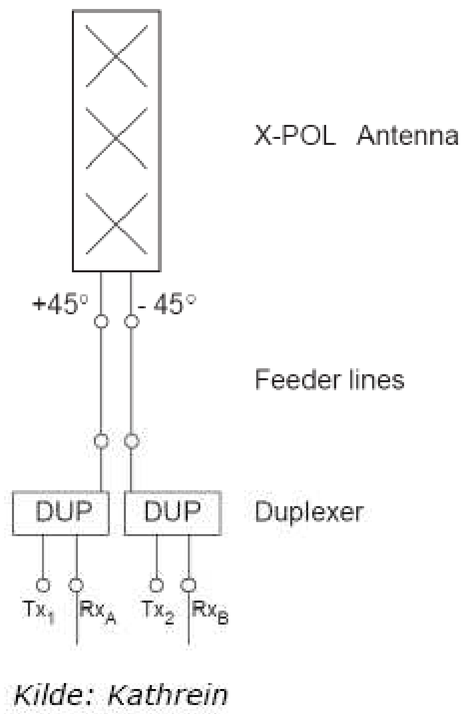
Polarization diversity (1)

- Signal at different polarization has uncorrelated fading
- Vetical polarization & horizontal polarization
- Disadvantage of this method is that a maximum of 2 uncorrelated polarization can exist (diversity of order 2)



Polarization diversity (2)

- Polarization diversity used in BTS (figure)
- Cross polar antenna used increasingly to save space
  - +/- 45 degree is normal



Time diversity

The same signal is sent several times, with a difference that exceeds the channel coherence time

The advantage of the method, compared with the other methods mentioned, is that only one antenna is required

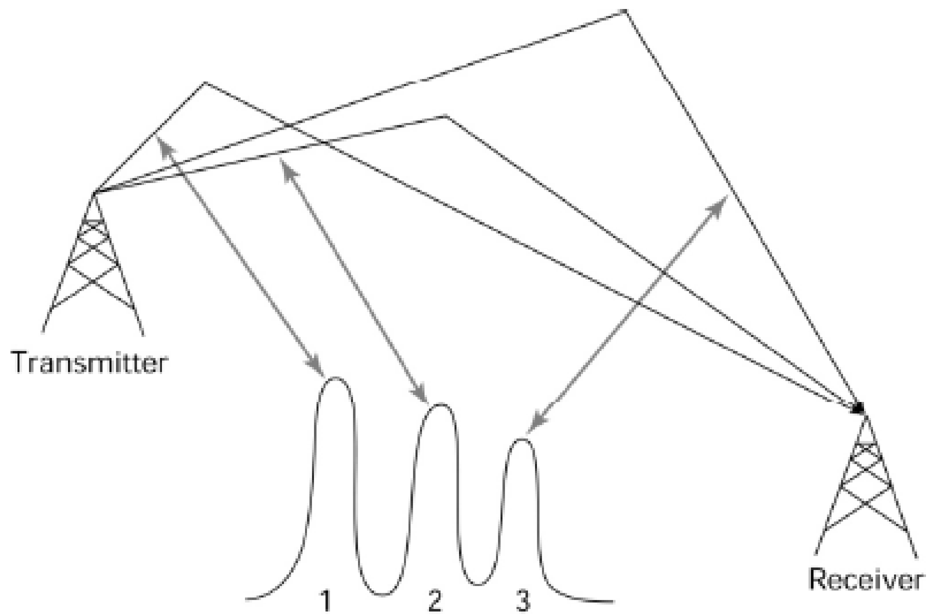
The disadvantage is the high memory requirements in the receiver for temporary data storage

Final fix coding can be viewed as a form of time diversity

Multipath diversity

If multi-path components have a large enough separation that the can be distinguished from each other, they can be combined in the receiver

This is used in RAKE receivers, which are widely used in CDMA systems (Chapter 6 – course book)



Combining techniques for diversity

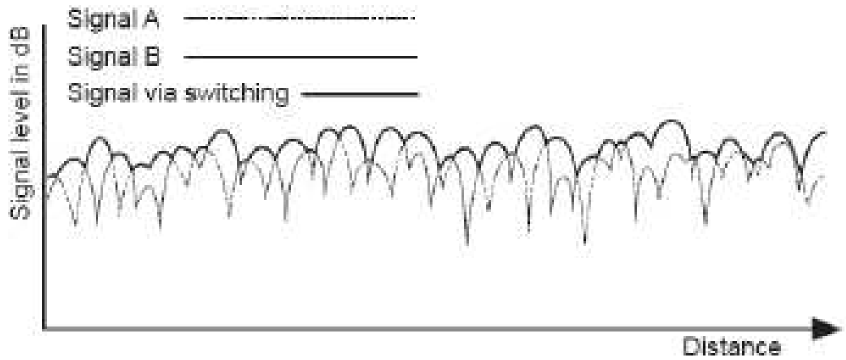
Selection (selection combining - SC)
- Selects all times the strongest signal (branch)

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

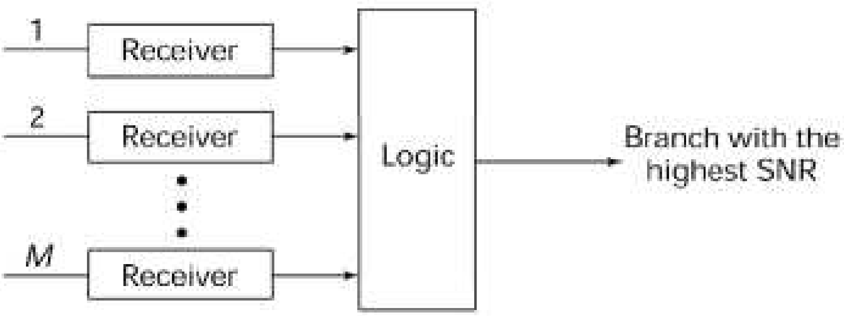
Equal-gain combining (EGC)
- Adds all branches of equal weight

Selection combining

Choose the diversity branch with the strongest SNR
Possible solution to allow continuous testing of all branches: Use same branch until it goes below a given threshold value, and only then test all the stuff and select the strongest.



Source: William C.Y. Lee, Mobile Communications Design Fundamentals

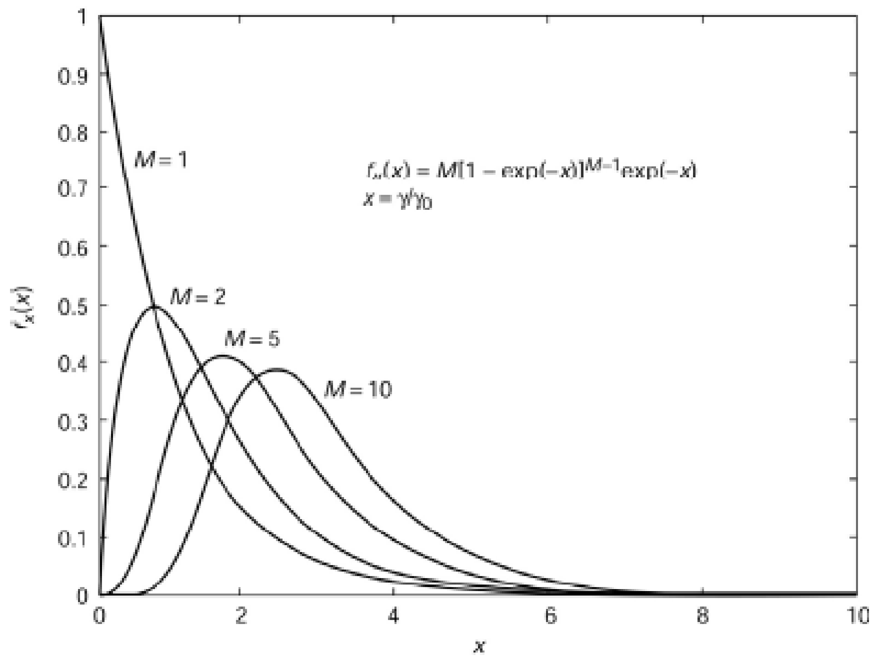


Selection combining

Average improvement using selection diversity:

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

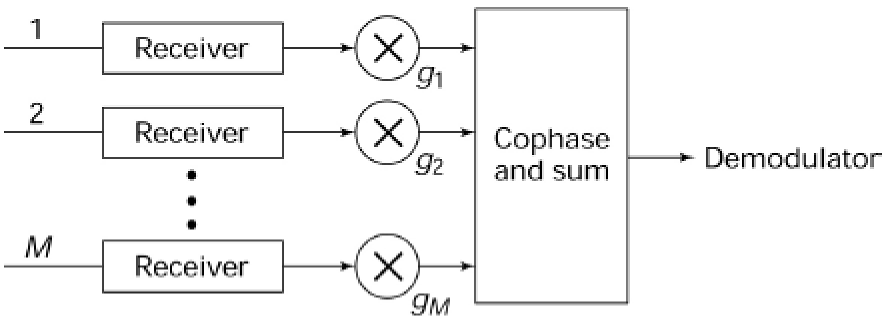
Probability density function for Υ_{se}/Υ_0



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

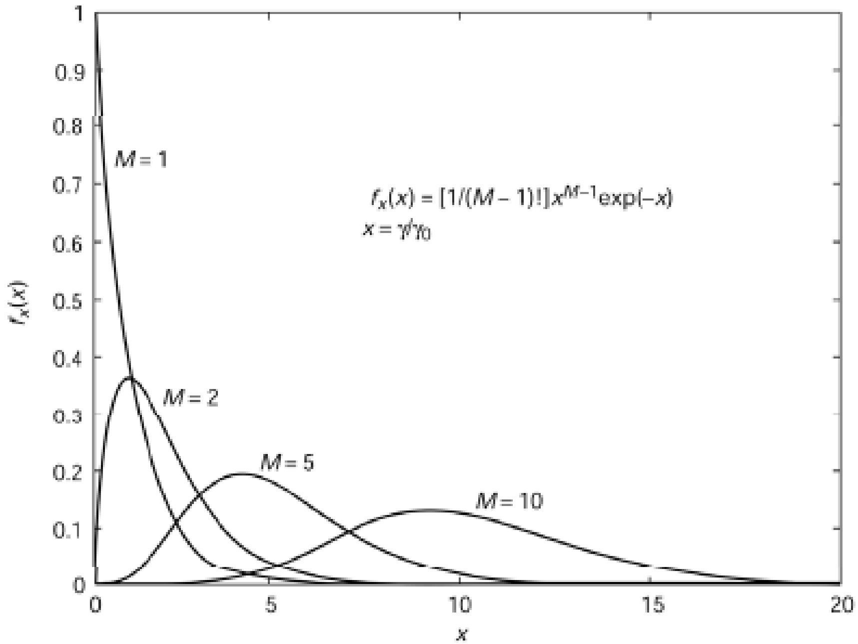


Maximum-ratio combining (MRC)

Average SNR by using MRC is –

$$\gamma_{MR} = \sum_{n=1}^{M} \gamma_n = M\gamma_0$$

Probability Density Function for Y_{MR}/Y_0 –



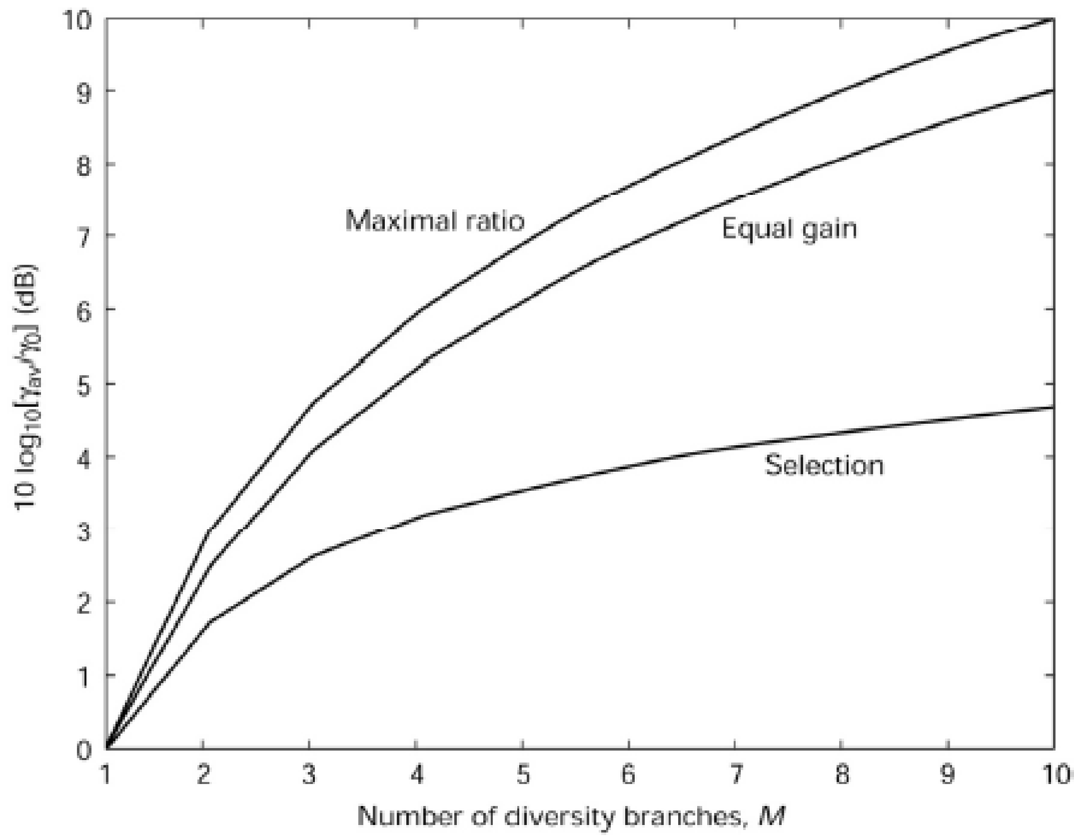
Equal gain combining (EGC)

Scales all branches of the same weight
Performance is worse than the MRC, but better than SC
Less complex than MRC
Performance that is between the SC and the NRC, the average SNR by using EGC is:

$$\gamma_{EC} = \gamma_0 \left[1 + \frac{\pi}{4} (M - 1) \right]$$

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



Performance improvement – BER at diversity

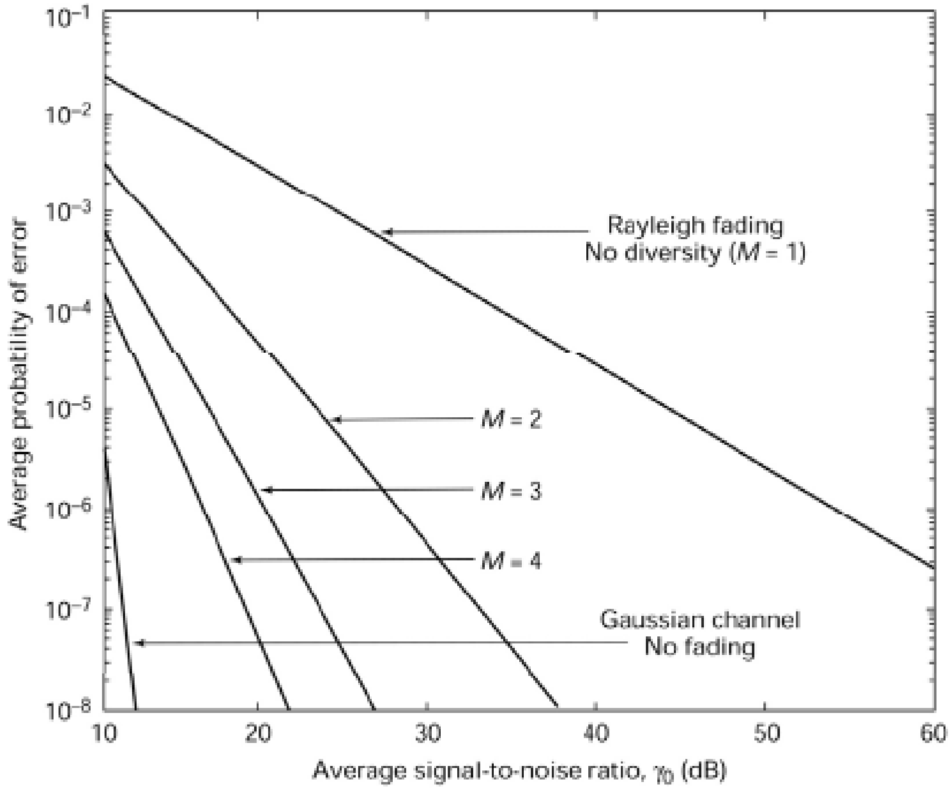
Average BER for a diversity method can be found from following expression:

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

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

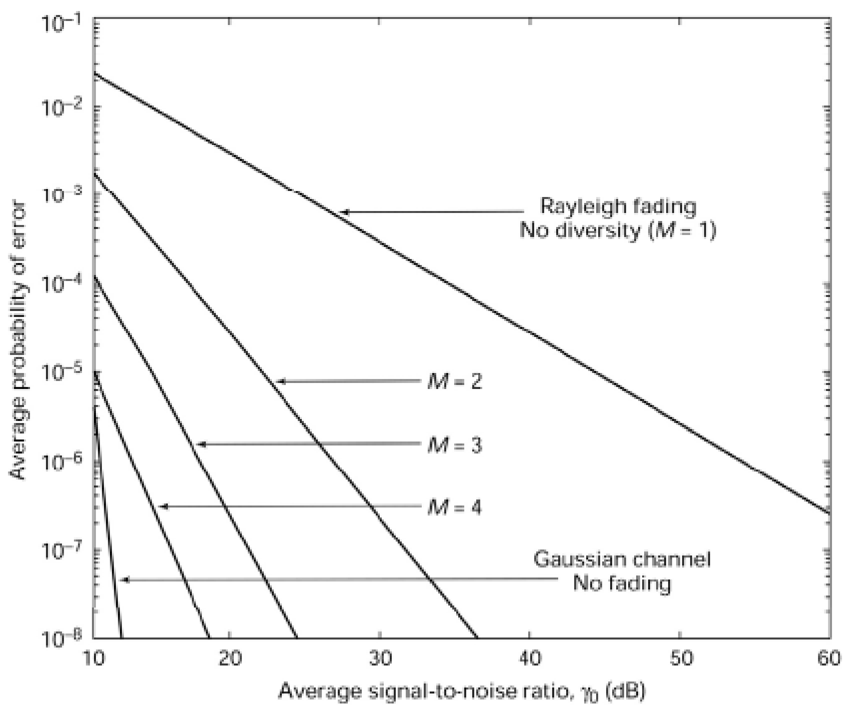
Performance improvement - SC

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



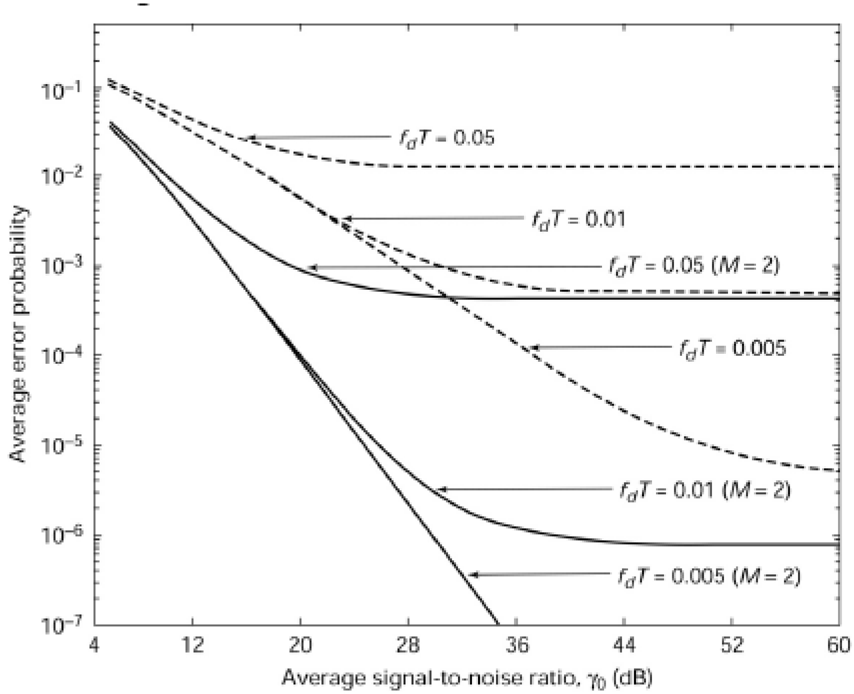
Performance improvement – MRC (1)

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



Performance improvement – MRC (2)

Performance improvement in terms of BER at diversity - MRC (II) -
Average BER without diversity and with two-branch maximal ratio-combining
Diversity reduces "floor“ for the bit error rate -



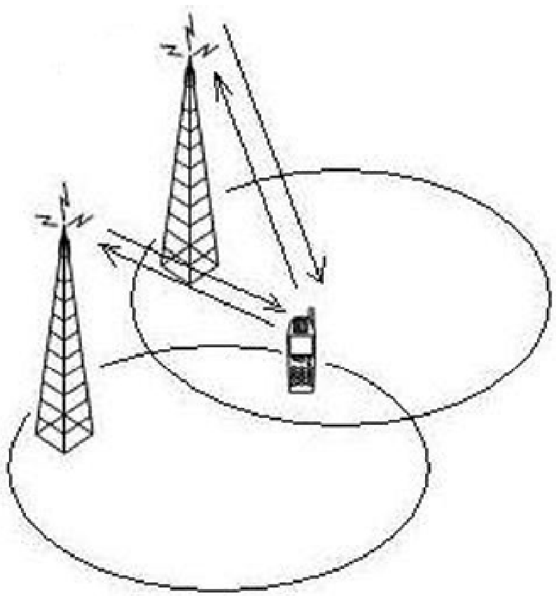
Macro-diversity

The techniques discussed so far fights fast (short-term) fading

To combat slow (long term) fading required separation between recipients who are high in relation to terrain and building formations affects the signal distribution

This is called macro-diversity, or the base station diversity and is usually based on communication with two or more base stations

Hand-over of the mobile systems can be seen as a form of macro diversity



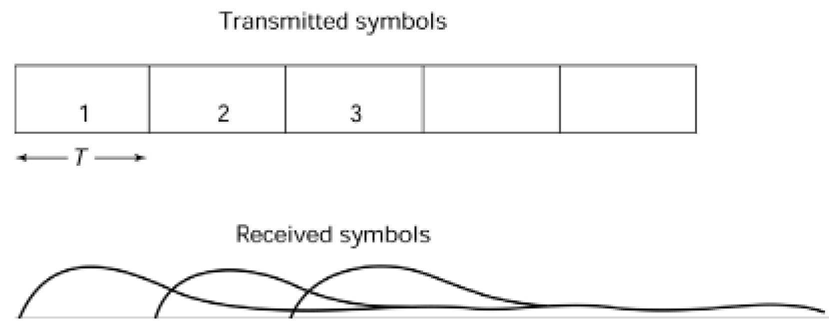
Channel equalization

Now the time dispersion is significant in relation to the symbol length in transfer leads to the Inter-Symbol Interference (ISI)\

In the frequency domain, this corresponds to the coherence bandwidth is less than the information bandwidth, which leads to frequency selective fading

ISI particular problem at high speed, when the symbols are short

ISI can be countered by using channel bonding, which means filter the signal so that it counteracts the frequency-selective fading and ISI



Equilization

- The channel is time-varying, so that the filter must be adaptive