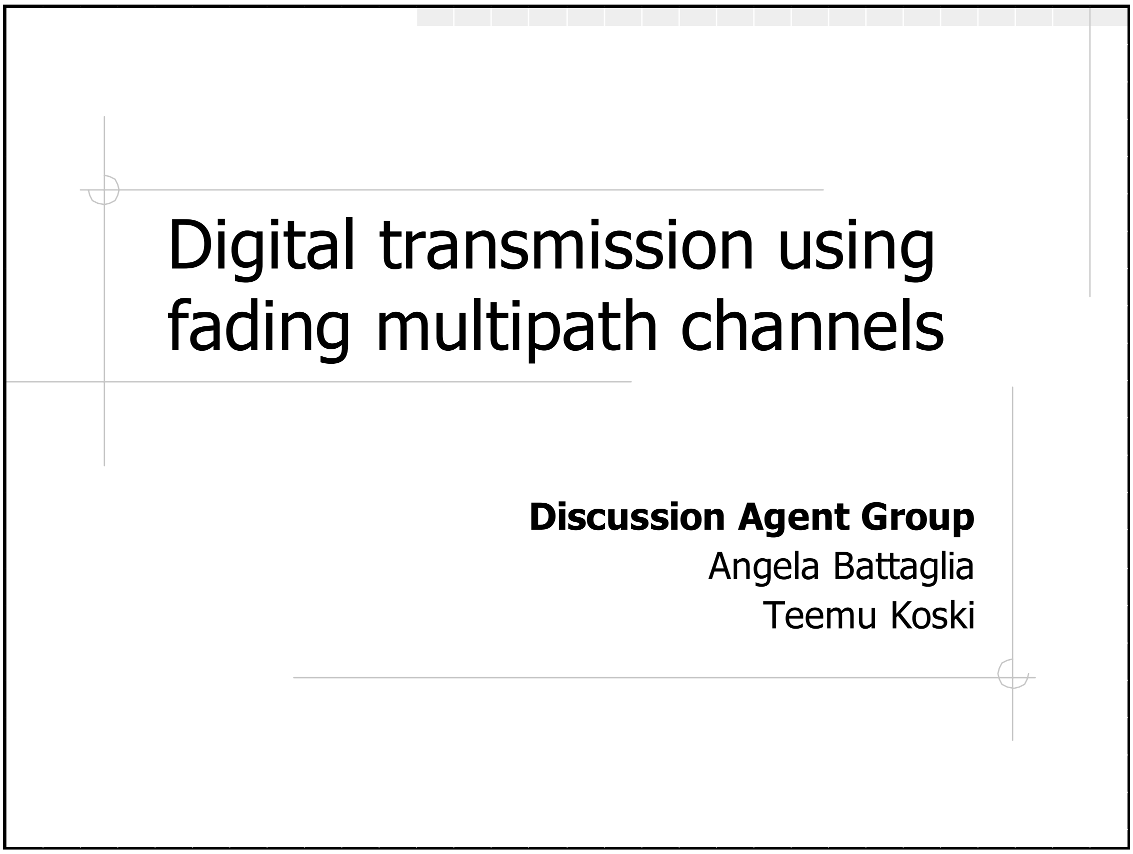
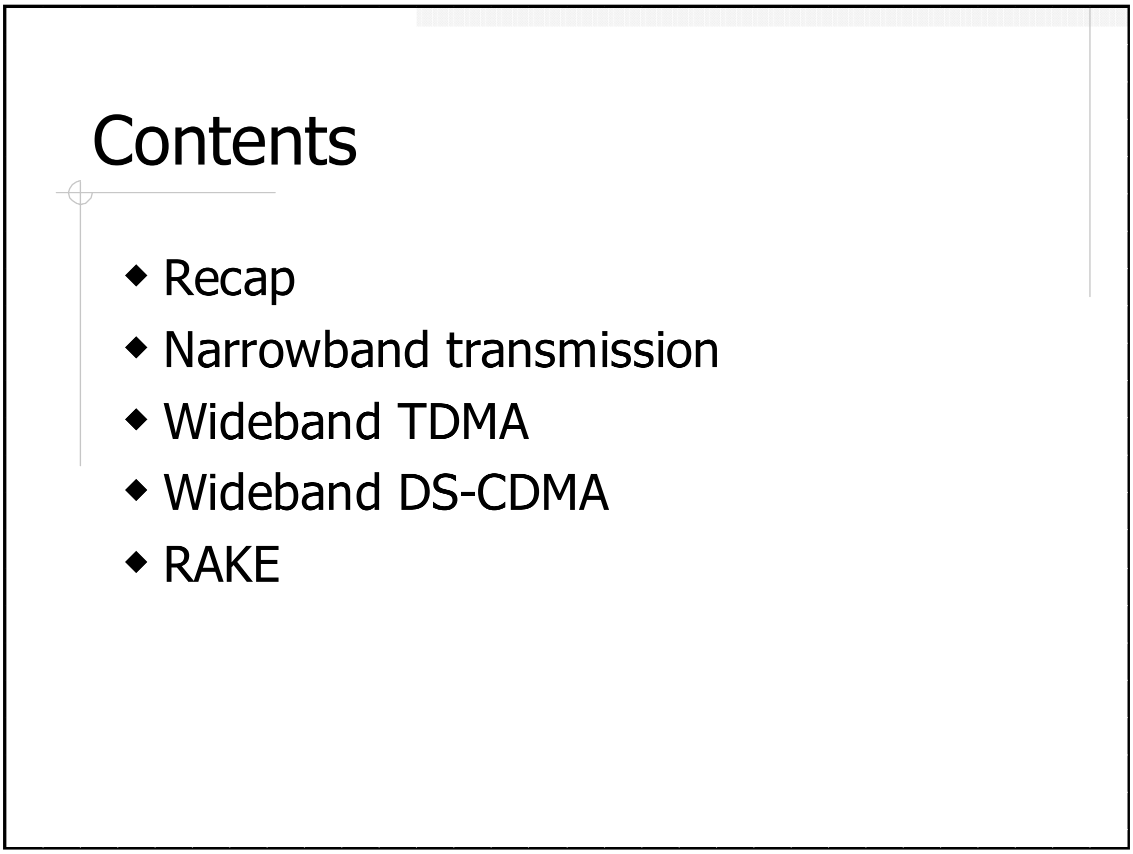


Digital transmission using fading multipath channels

Discussion Agent Group
Angela Battaglia
Teemu Koski



Contents

- Recap
- Narrowband transmission
- Wideband TDMA
- Wideband DS-CDMA
- RAKE

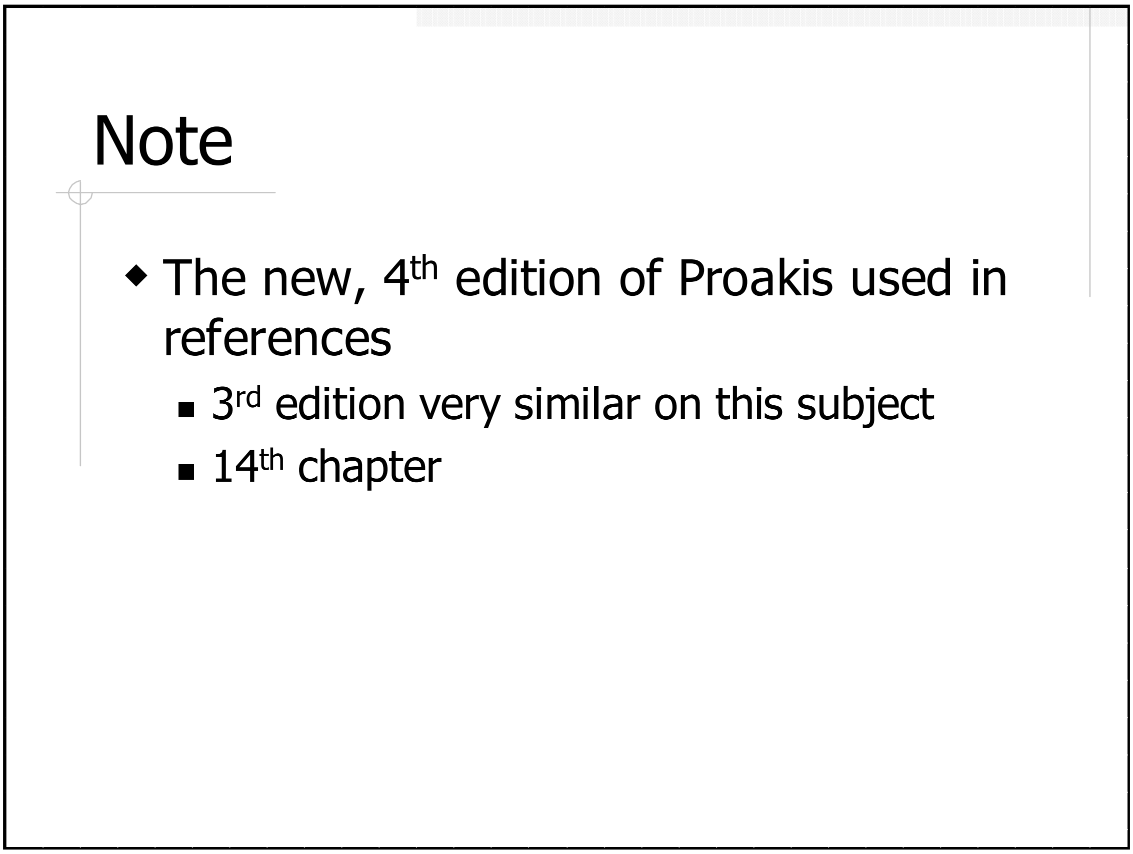
Contents

-First some important topics that you should already know

-The rest follows pretty much the organization of the lecture slides, RAKE being a big part of the discussion

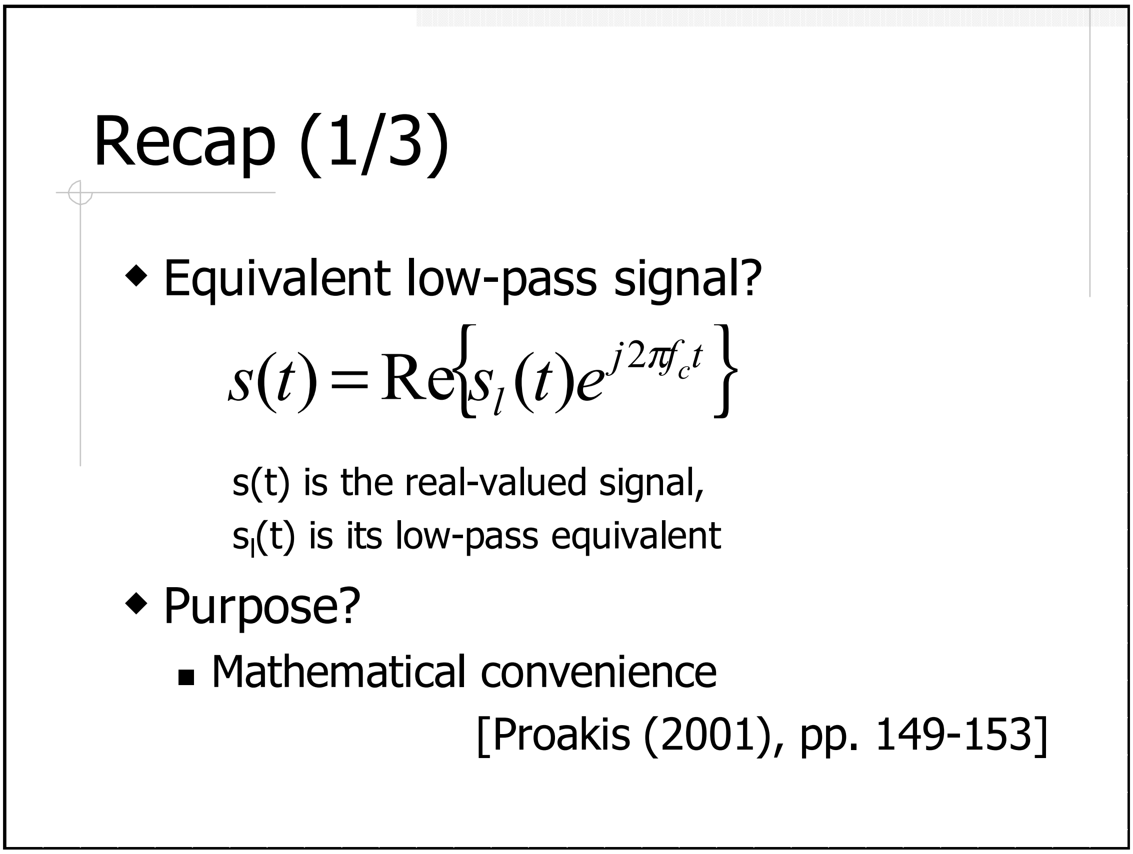
-We have tried to make the questions easy to answer, so that most of you can join the conversation and get the overall idea behind this lecture

-You can ask your own questions at any time



Note

- The new, 4th edition of Proakis used in references
  - 3rd edition very similar on this subject
  - 14th chapter



Recap (1/3)

- Equivalent low-pass signal?

$$s(t) = \mathrm{Re}\left\{ s_l(t) e^{j2\pi f_c t} \right\}$$

s(t) is the real-valued signal,
$s_l(t)$ is its low-pass equivalent

- Purpose?
  - Mathematical convenience

[Proakis (2001), pp. 149-153]

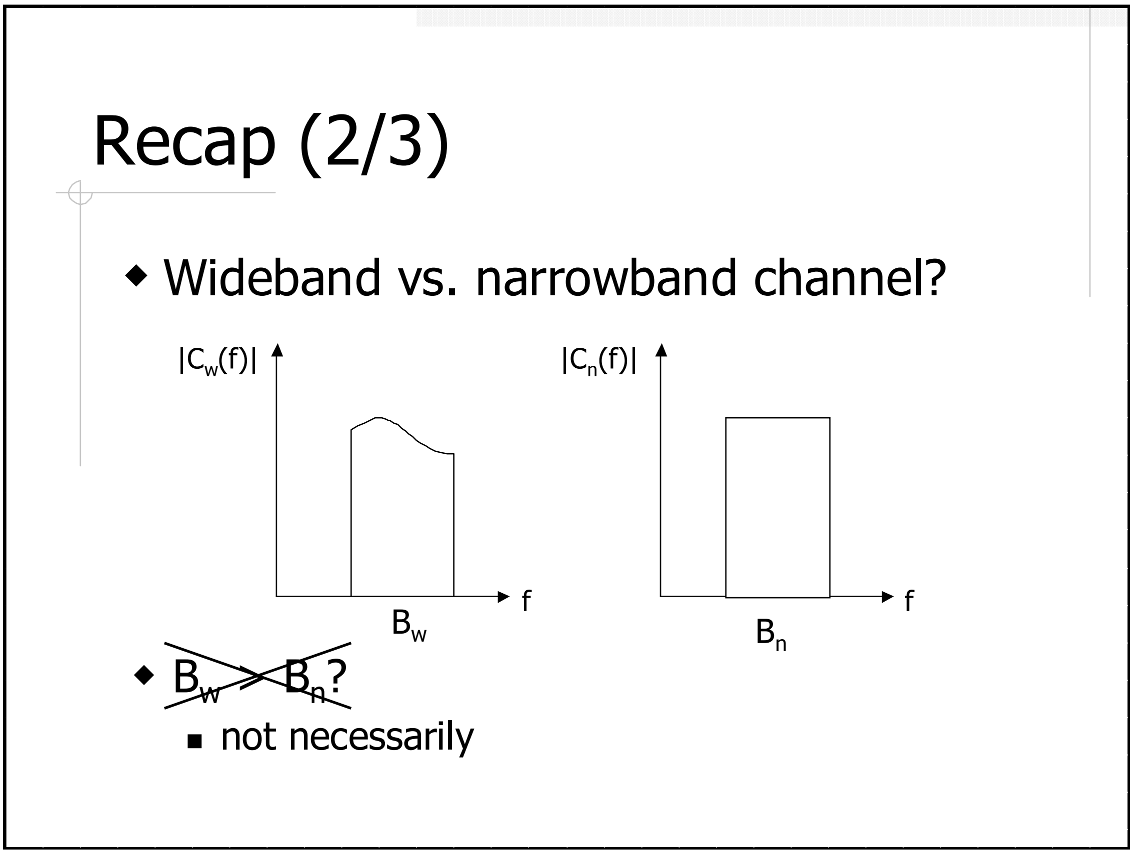
The concept of equivalent low-pass signal was used in the lecture. Most of you should know this already.

What is the equivalent low-pass signal for a bandpass signal?

The real-valued signal s(t) can be expressed with its low-pass equivalent $s_l(t)$ by the formula on the slide. The lowpass signal, $s_l(t)$, is usually called the complex envelope of the real signal.

Why is the concept of equivalent low-pass signal important?

For mathematical convenience it is desirable to reduce all bandpass signals and channels to equivalent low-pass expressions.



Recap (2/3)

- Wideband vs. narrowband channel?

- ~~$B_w > B_n$?~~
  - not necessarily

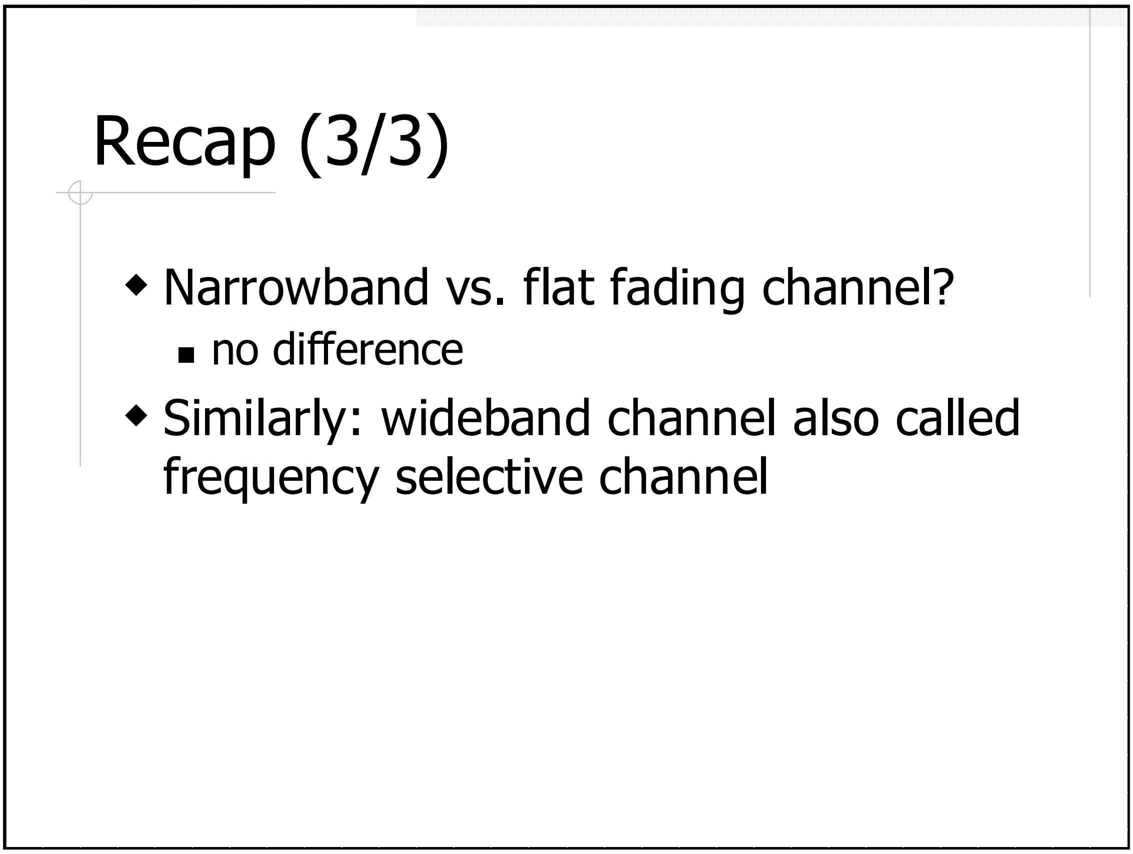
What is the difference between wideband and narrowband channel?

The definition of a narrowband signal: in the transmission frequencies, the channel transfer function is constant/flat.

For a wideband signal, the transfer function fluctuates.

What about the bandwidth? Is it larger for a wideband channel?

The bandwidth is not defined in any way. That is, a wideband channel may have a more narrow bandwidth than a narrowband signal. Both can be either time variant or time invariant.

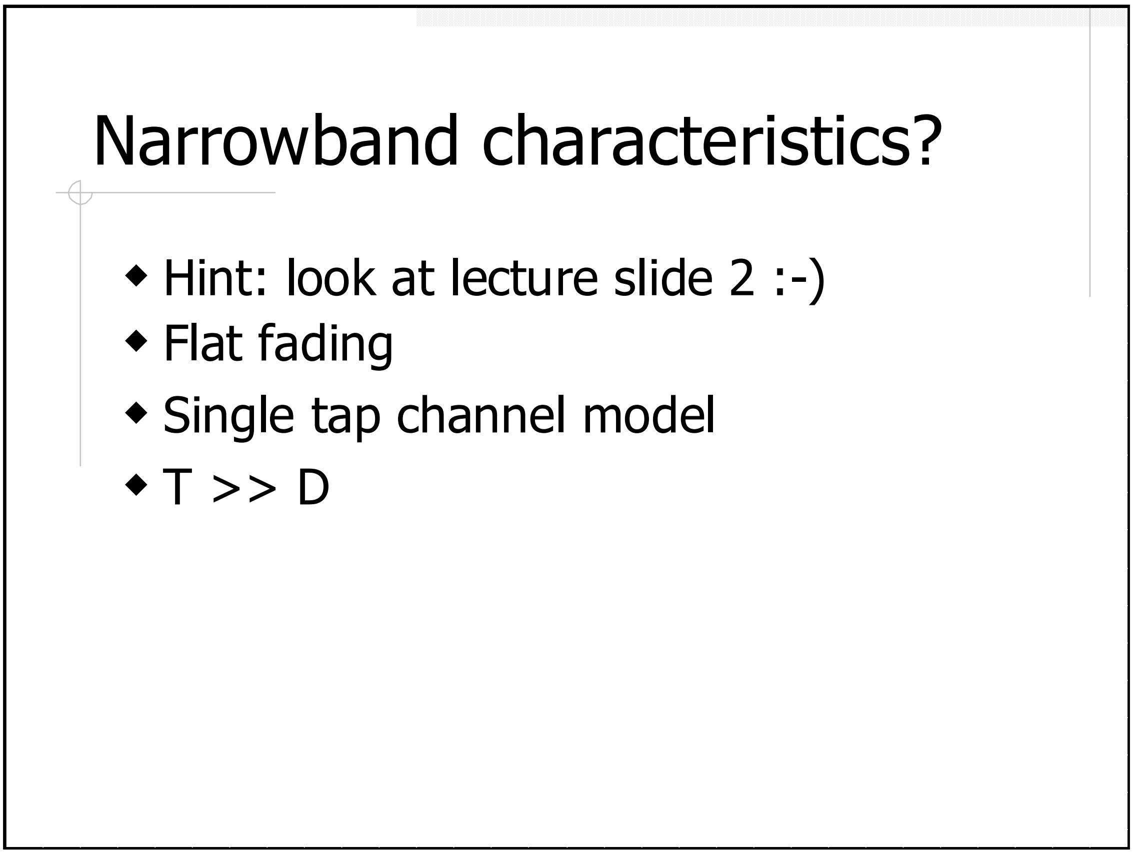


Recap (3/3)

- Narrowband vs. flat fading channel?
  - no difference
- Similarly: wideband channel also called frequency selective channel

What’s the difference between narrowband and flat fading channel, then?

This is a trick question, there’s no difference. Both terms are used during the DAG. Similarly, wideband channel is also called frequency selective.



Narrowband characteristics?

- Hint: look at lecture slide 2 :-)
- Flat fading
- Single tap channel model
- T >> D

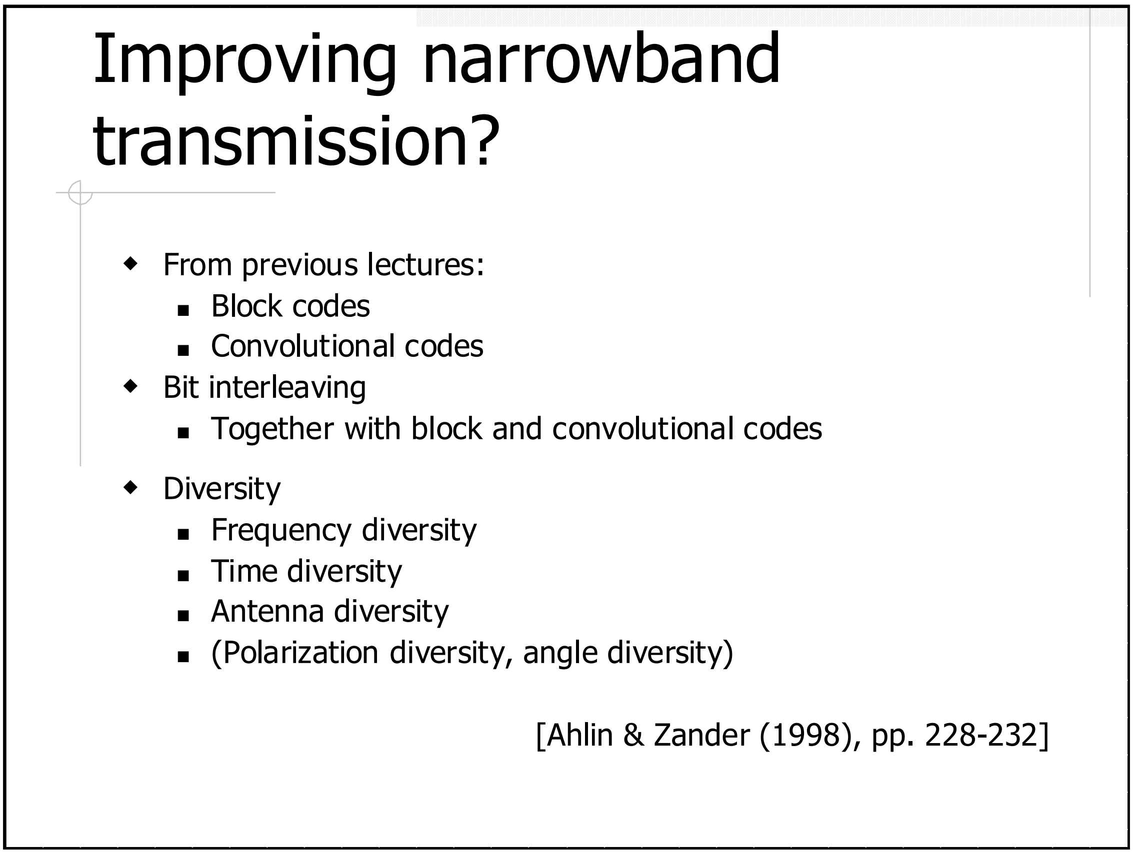
What is meant by digital transmission over a narrowband channel?

In other words, describe the characteristics of digital transmission over a narrowband channel.

-The channel is flat fading

-Channel can be modeled with a single-tap

-Most importantly: T >> D, symbol duration is considerably longer than the delay spread of the channel



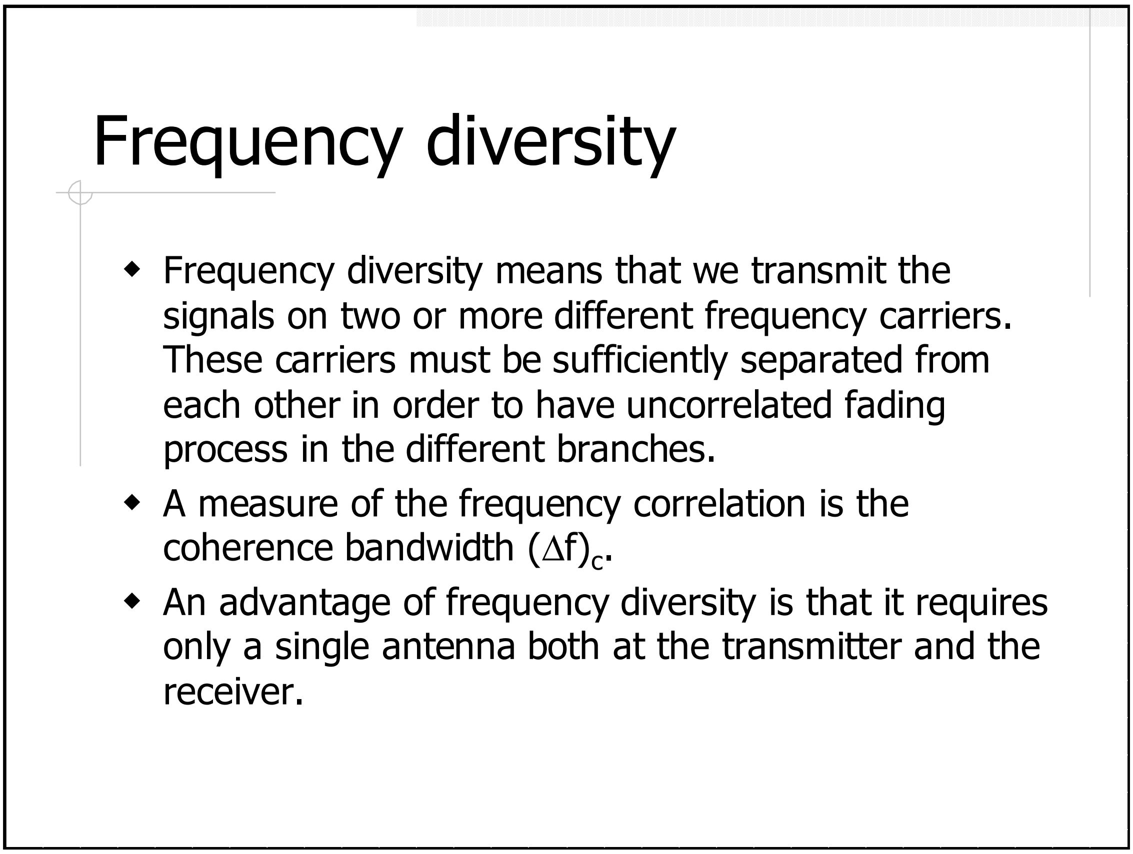
Improving narrowband transmission?

- From previous lectures:
    - Block codes
    - Convolutional codes
- Bit interleaving
    - Together with block and convolutional codes
- Diversity
    - Frequency diversity
    - Time diversity
    - Antenna diversity
    - (Polarization diversity, angle diversity)

[Ahlin & Zander (1998), pp. 228-232]

How can transmission performance over a narrowband channel be improved?

To reduce the effect of fading there are several methods. From previous lectures we know that we can use block codes and convolutional codes together with bit interleaving. But there are also other solutions called diversity methods. These include time diversity, frequency diversity, antenna or space diversity, polarization diversity and angle diversity.



Frequency diversity

- Frequency diversity means that we transmit the signals on two or more different frequency carriers. These carriers must be sufficiently separated from each other in order to have uncorrelated fading process in the different branches.
- A measure of the frequency correlation is the coherence bandwidth $(\Delta f)_c$.
- An advantage of frequency diversity is that it requires only a single antenna both at the transmitter and the receiver.

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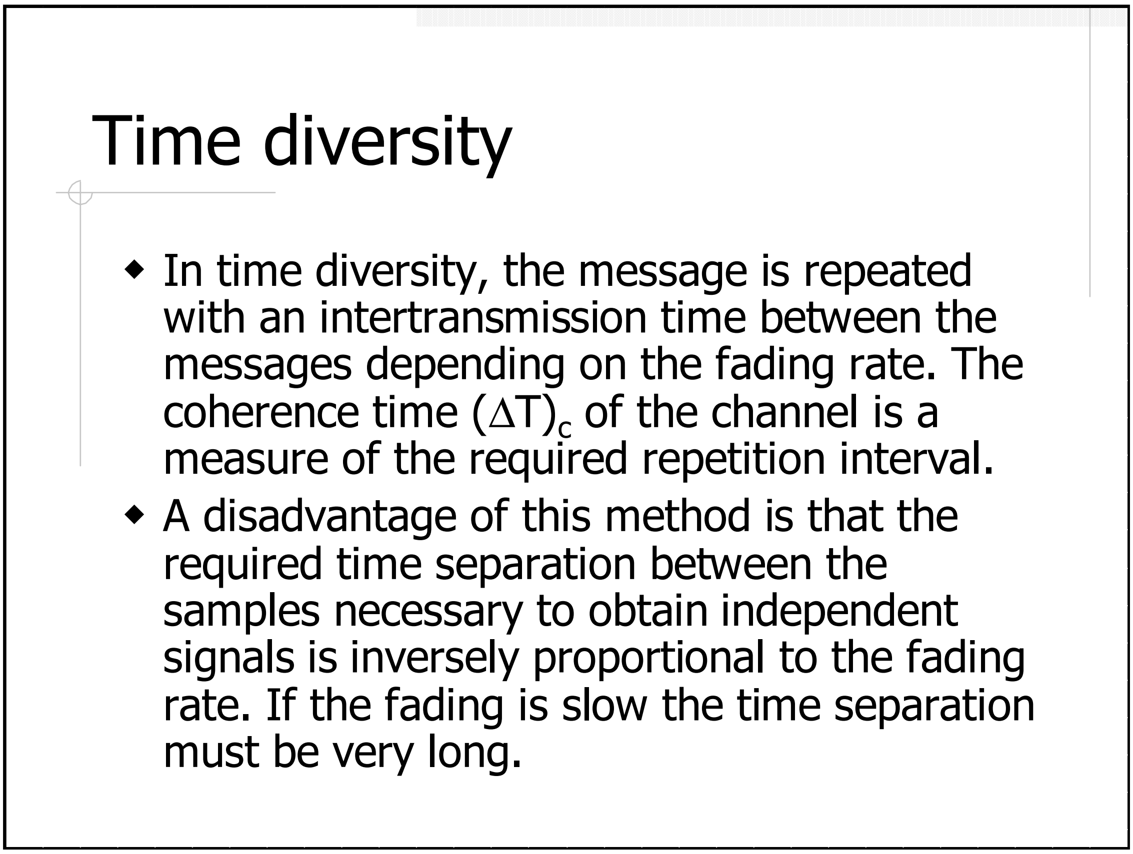

Time diversity

- In time diversity, the message is repeated with an intertransmission time between the messages depending on the fading rate. The coherence time $(\Delta T)_c$ of the channel is a measure of the required repetition interval.
- A disadvantage of this method is that the required time separation between the samples necessary to obtain independent signals is inversely proportional to the fading rate. If the fading is slow the time separation must be very long.

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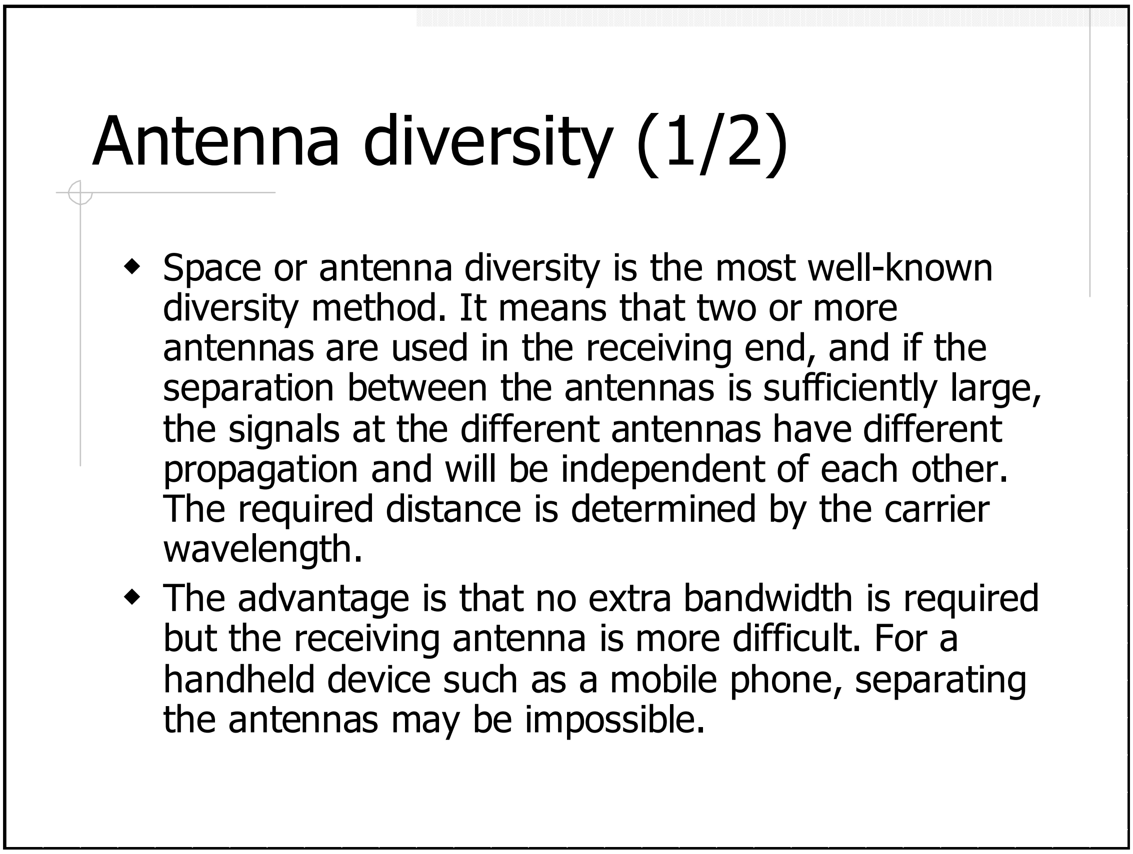

Antenna diversity (1/2)

- Space or antenna diversity is the most well-known diversity method. It means that two or more antennas are used in the receiving end, and if the separation between the antennas is sufficiently large, the signals at the different antennas have different propagation and will be independent of each other. The required distance is determined by the carrier wavelength.
- The advantage is that no extra bandwidth is required but the receiving antenna is more difficult. For a handheld device such as a mobile phone, separating the antennas may be impossible.

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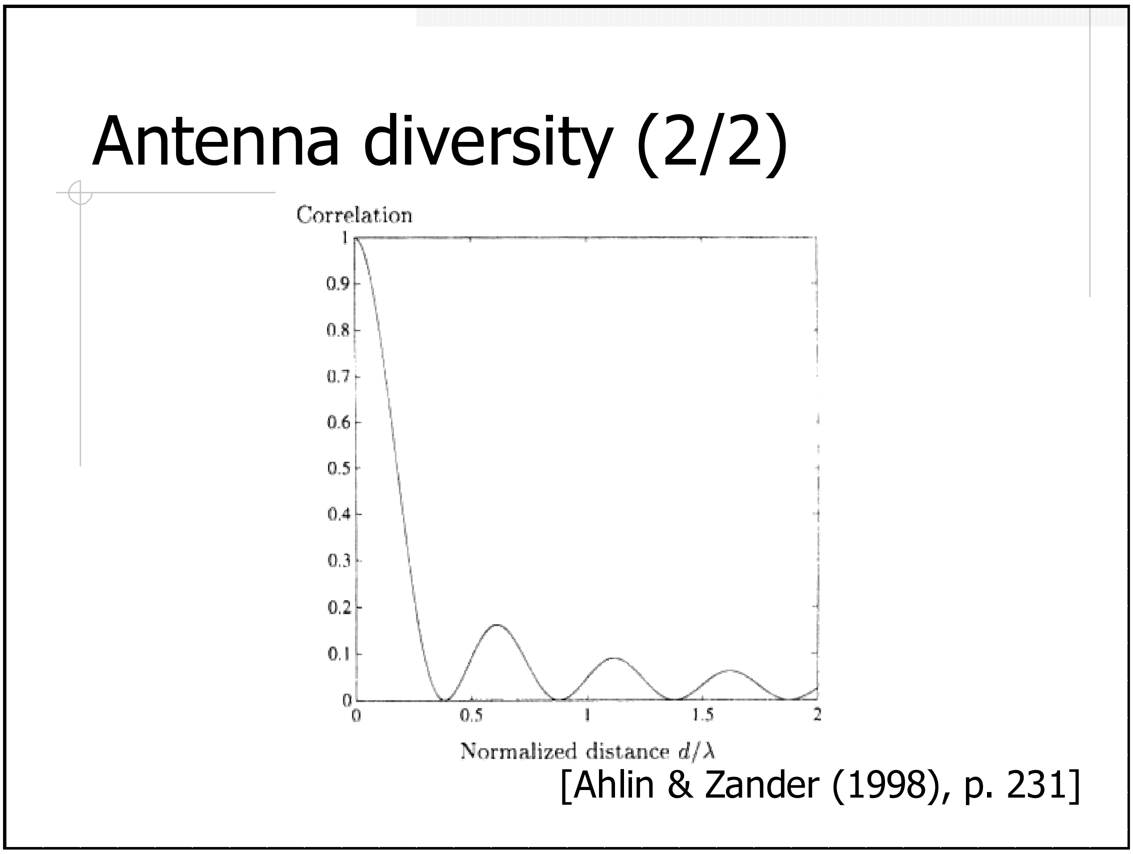


Antenna diversity (2/2)

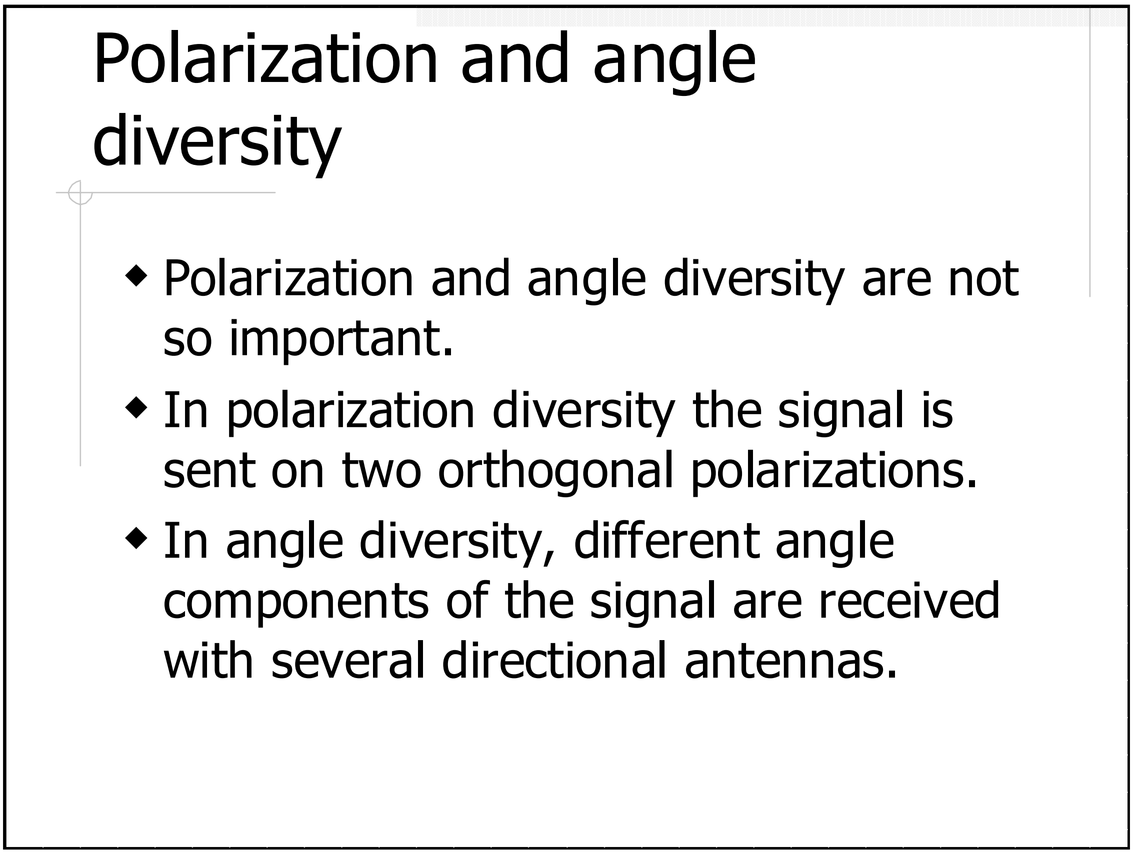
[Ahlin & Zander (1998), p. 231]

This is a figure from the Ahlin & Zander’s book. The figure shows the correlation function between the antennas as a function of their distance (normalized to the wavelength).

From the figure one can see that a separation of about half a wavelength is required for the correlation to be close to zero. For example, for a 500 MHz carrier the separation must be at least 30 cm.

What about GSM?

~17 cm



Polarization and angle diversity

- Polarization and angle diversity are not so important.
- In polarization diversity the signal is sent on two orthogonal polarizations.
- In angle diversity, different angle components of the signal are received with several directional antennas.

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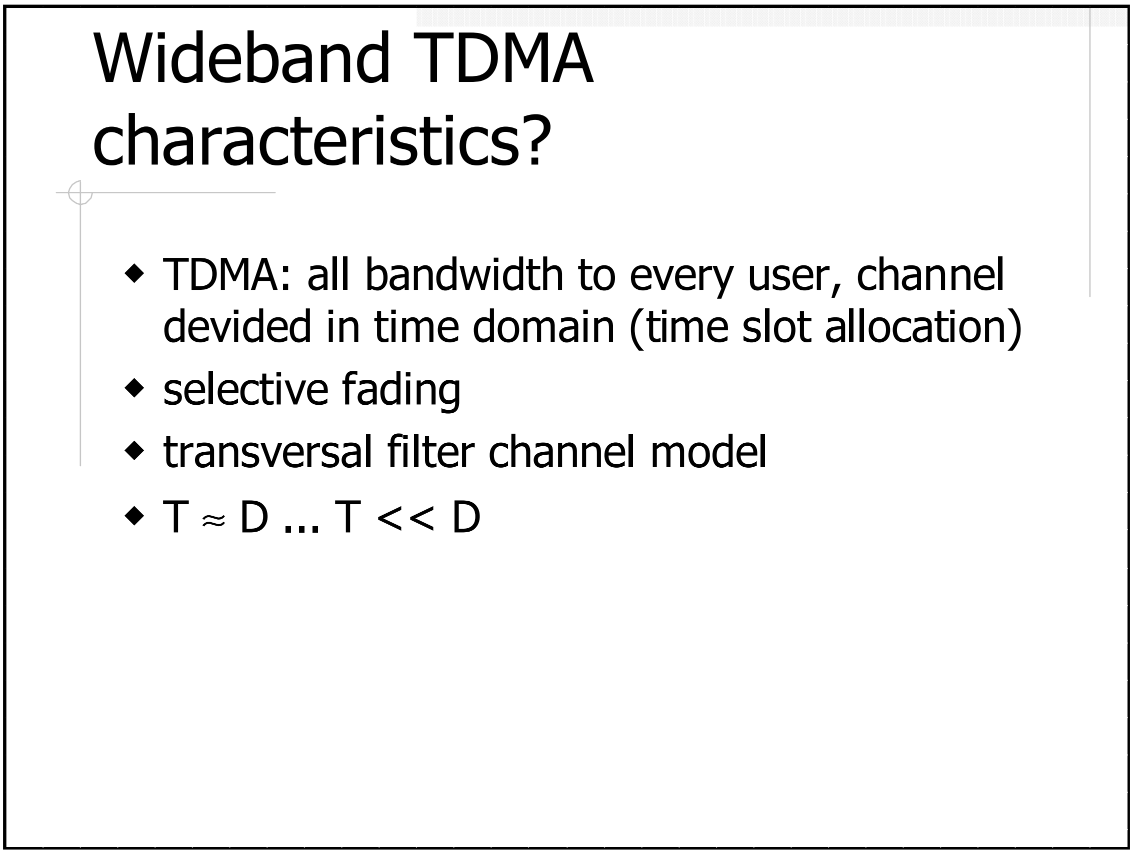


Wideband TDMA characteristics?

- TDMA: all bandwidth to every user, channel devided in time domain (time slot allocation)
- selective fading
- transversal filter channel model
- $T \approx D$ ... $T << D$

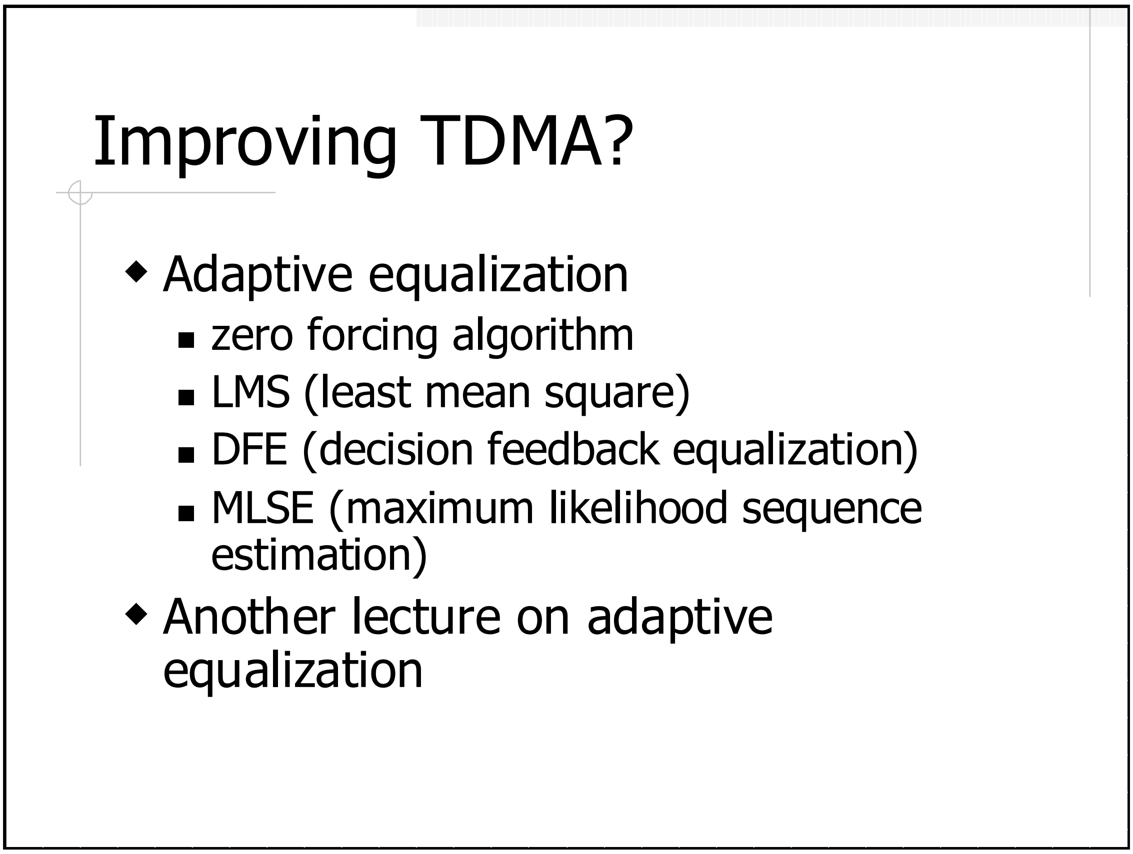
What does TDMA transmission over a wideband channel mean?

-TDMA (time division multiple access), as most of you know, means that the channel is divided between the users in time domain.

-Wideband ie. flat fading

-Channel can be modelled with a transversal filter

-Most importantly, the delay spread is typically longer than the symbol duration



Improving TDMA?

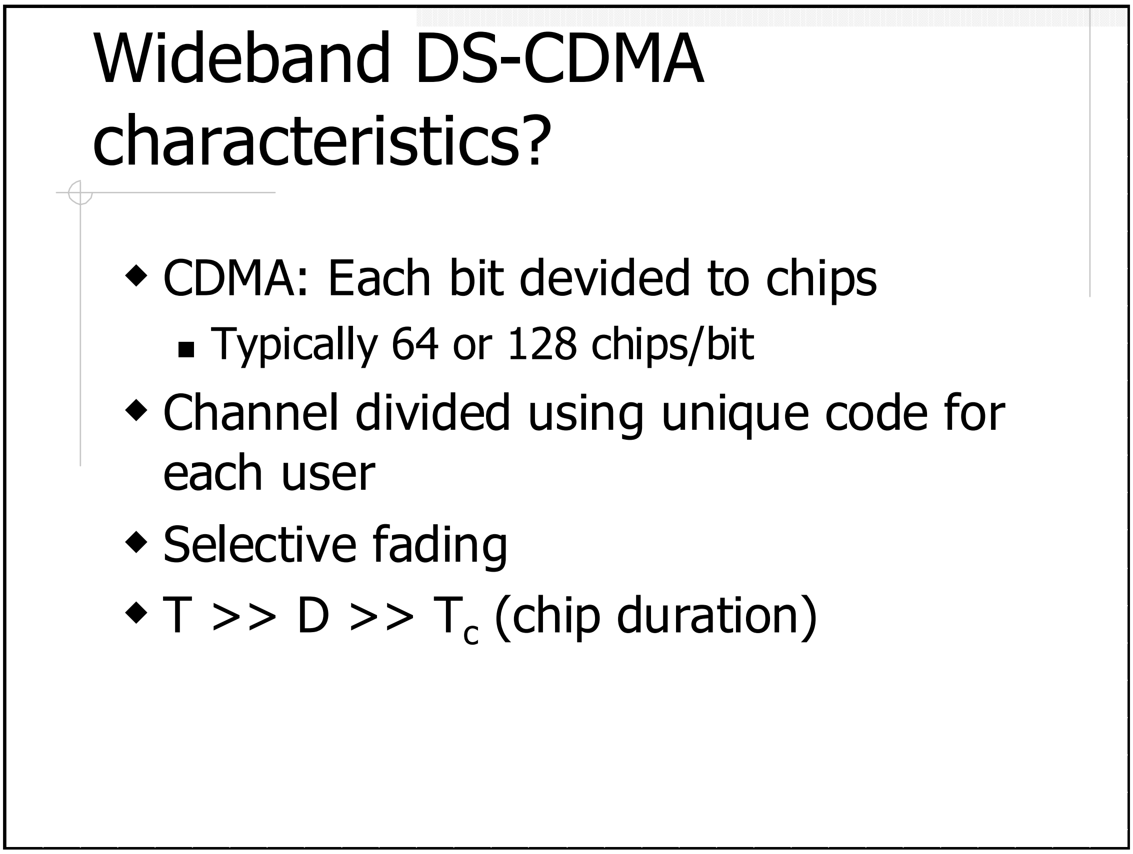
- Adaptive equalization
  - zero forcing algorithm
  - LMS (least mean square)
  - DFE (decision feedback equalization)
  - MLSE (maximum likelihood sequence estimation)
- Another lecture on adaptive equalization

How can TDMA transmission performance over a wideband channel be improved?

In most real systems we have unavoidably residual ISI (intersymbol interference), due to incomplete knowledge of the channel characteristics, changes in the channel characteristics, and so on.

To overcome these problems, we use an adaptive filter. This process is called adaptive equalization. The idea is that we adjust the filter taps so that the tail of the previous symbols is zero at every sampling period. There are different algorithms, such as zero forcing algorithm, least mean square algorithm, decision feedback equalization and maximum likelihood sequence estimation.

Adaptive equalization will be discussed in detail in a future lecture.

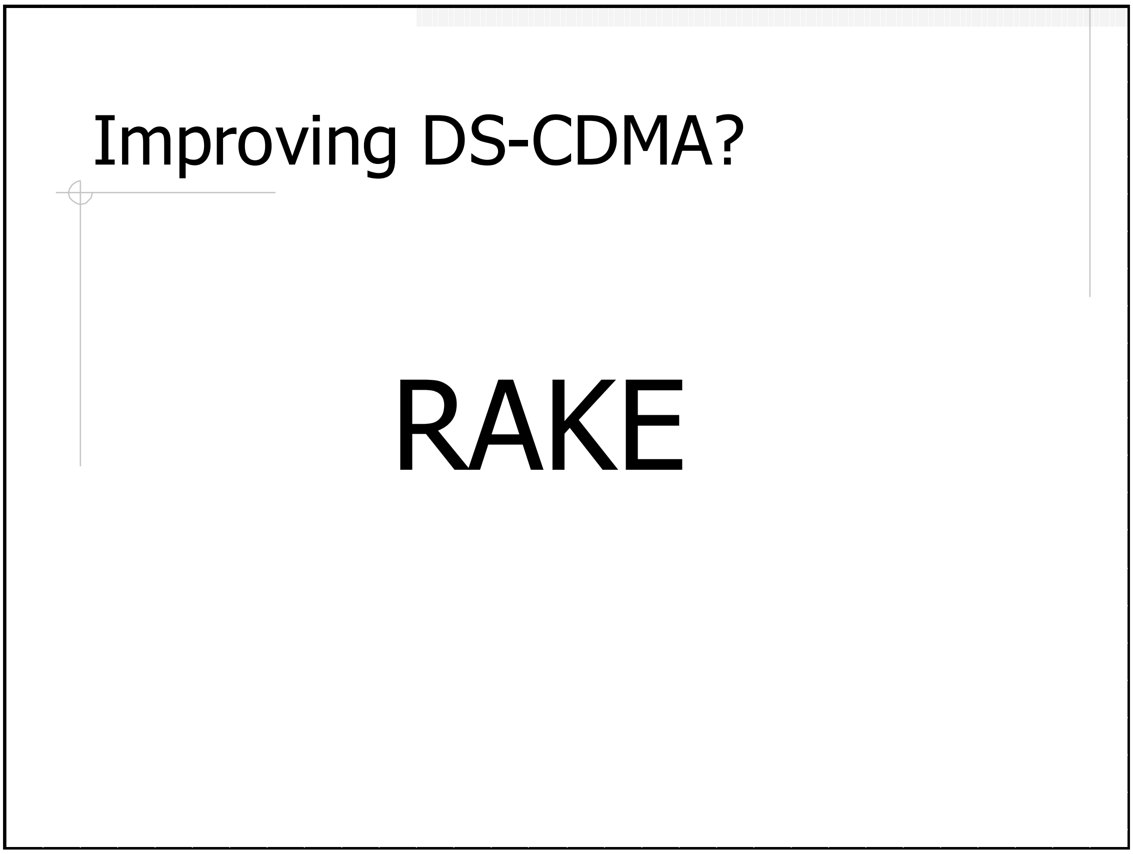


Wideband DS-CDMA characteristics?

- CDMA: Each bit devided to chips
  - Typically 64 or 128 chips/bit
- Channel divided using unique code for each user
- Selective fading
- T >> D >> T_c (chip duration)

What does DS-CDMA transmission over a wideband channel mean?

In CDMA every bit is divided to chips. Typically there are 64 or 128 chip for bit. We have selective fading and transversal filter channel model just like in TDMA. Now, the symbol duration (T) is much longer than the delay spread, but the duration of each chip (T_c) is very small.

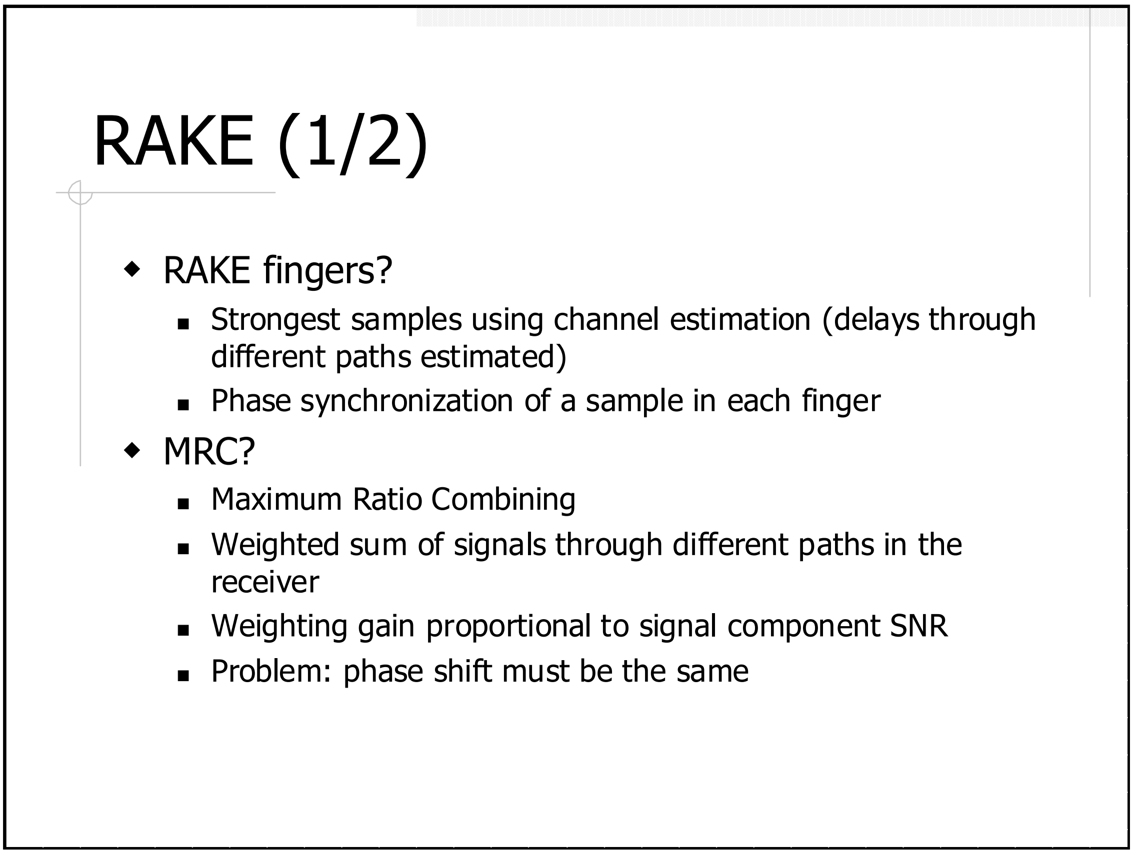


Improving DS-CDMA?

RAKE

How can DS-CDMA transmission performance over a selectively fading channel be improved?

Use a RAKE receiver.



RAKE (1/2)

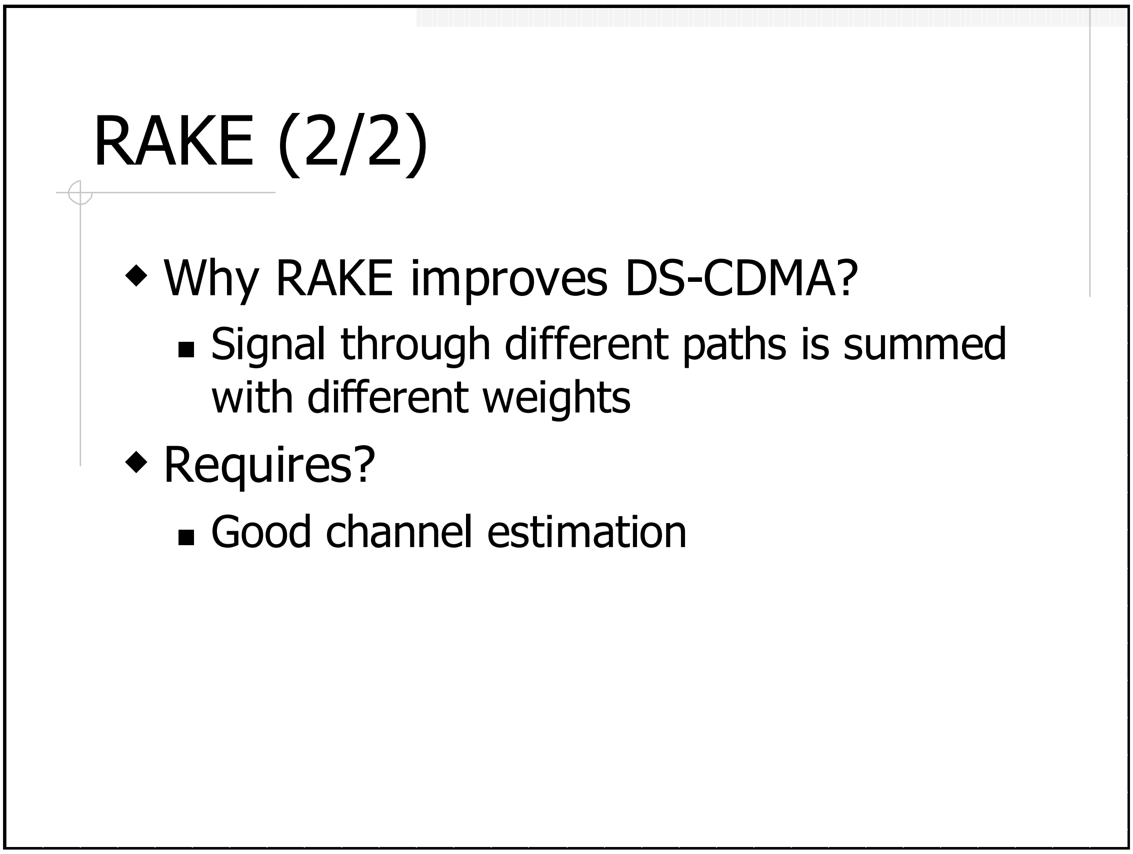
- RAKE fingers?
    - Strongest samples using channel estimation (delays through different paths estimated)
    - Phase synchronization of a sample in each finger
- MRC?
    - Maximum Ratio Combining
    - Weighted sum of signals through different paths in the receiver
    - Weighting gain proportional to signal component SNR
    - Problem: phase shift must be the same

Before discussing the RAKE receiver itself, let’s first go through the important concepts needed.

What are the RAKE fingers?

What is MRC?

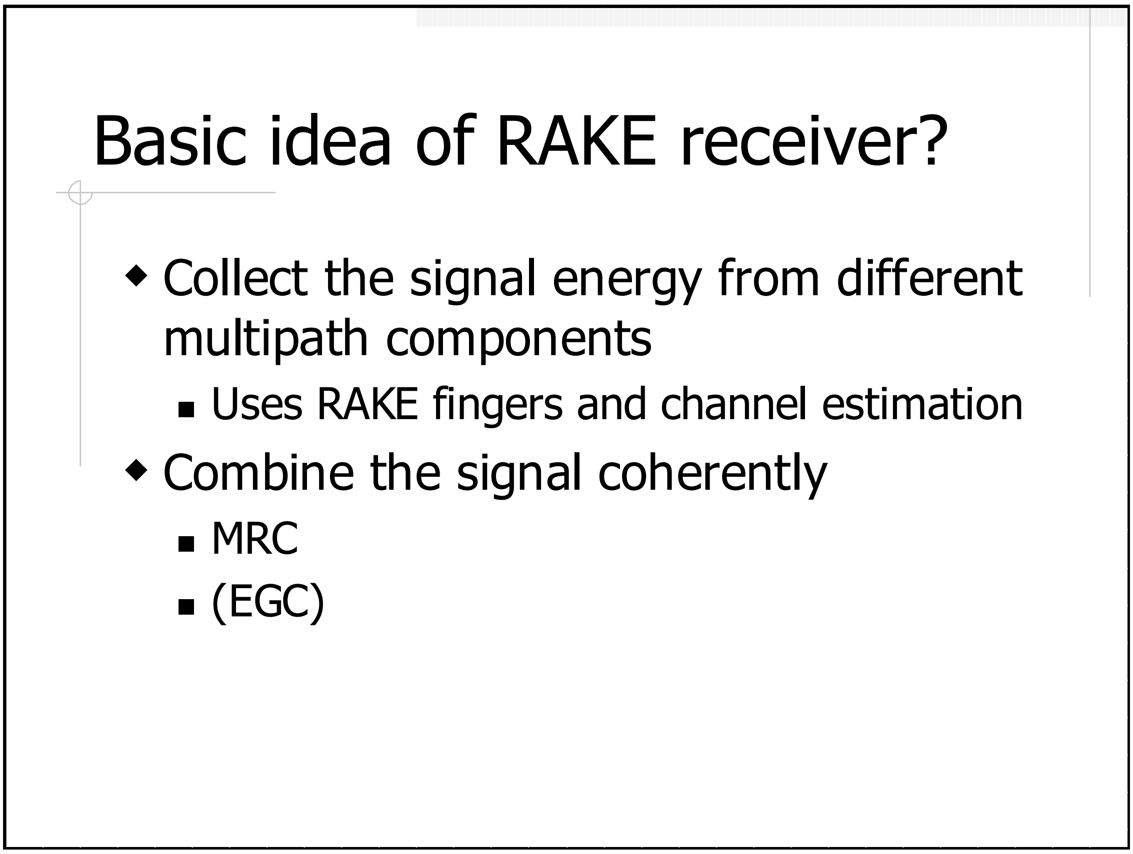
MRC is Maximum Ratio Combining. What this means is that in the receiver we make a weighted sum of a set of signals received through different paths. The gain given to each signal component is proportional to its SNR. The problem in MRC is that the phase shift must be the same for each signal component. This is done in each RAKE finger before maximum ratio combining.



RAKE (2/2)

- Why RAKE improves DS-CDMA?
  - Signal through different paths is summed with different weights
- Requires?
  - Good channel estimation

Why does the RAKE receiver improve DS-CDMA transfer?
Different multipath propagations are summed with different weights. This makes the bit error probability considerably smaller.
What does this require to work?
RAKE requires good channel estimation. We must estimate the delays through different paths to find the strongest signal components.



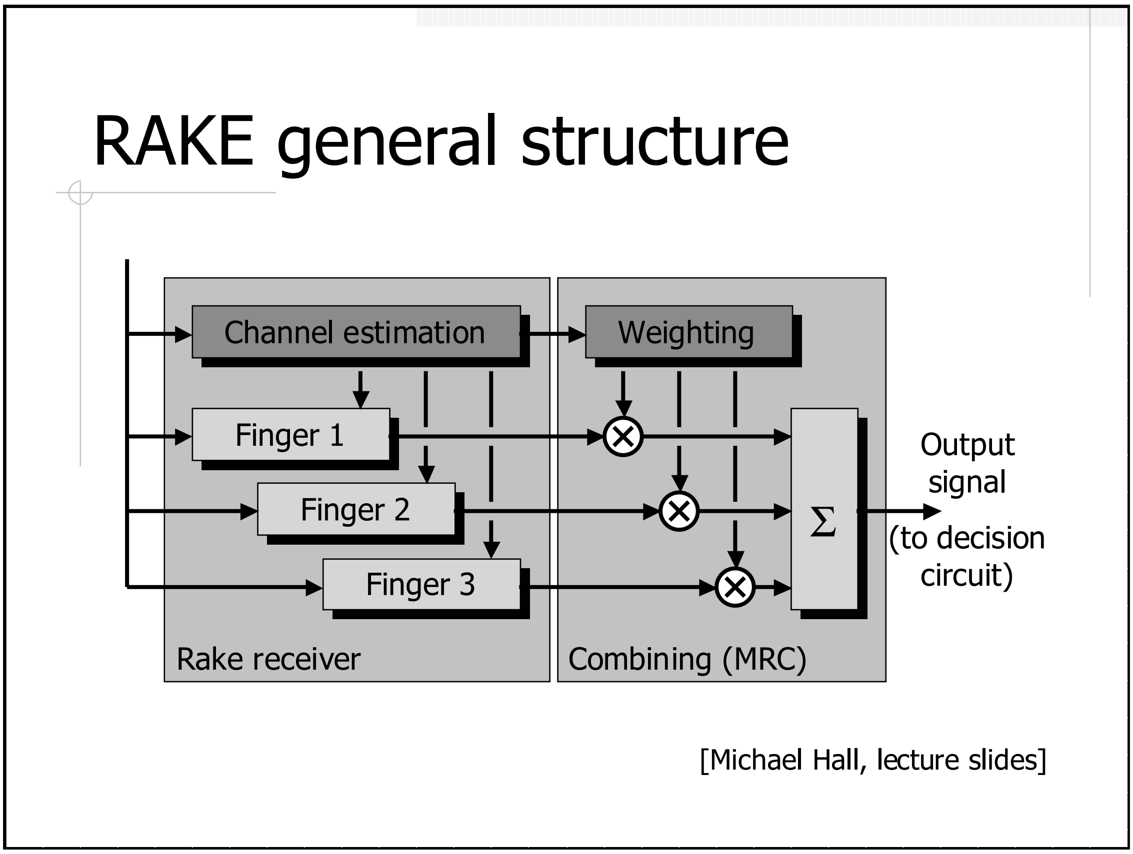
Basic idea of RAKE receiver?

- Collect the signal energy from different multipath components
    - Uses RAKE fingers and channel estimation
- Combine the signal coherently
    - MRC
    - (EGC)

What is the basic idea and structure of the RAKE receiver? How does it work?

The receiver collects the signal energy from different multipath components and coherently combine the signal.

In combining the signal it uses Maximum Ratio Combining or Equal Gain Combining (EGC).



RAKE general structure

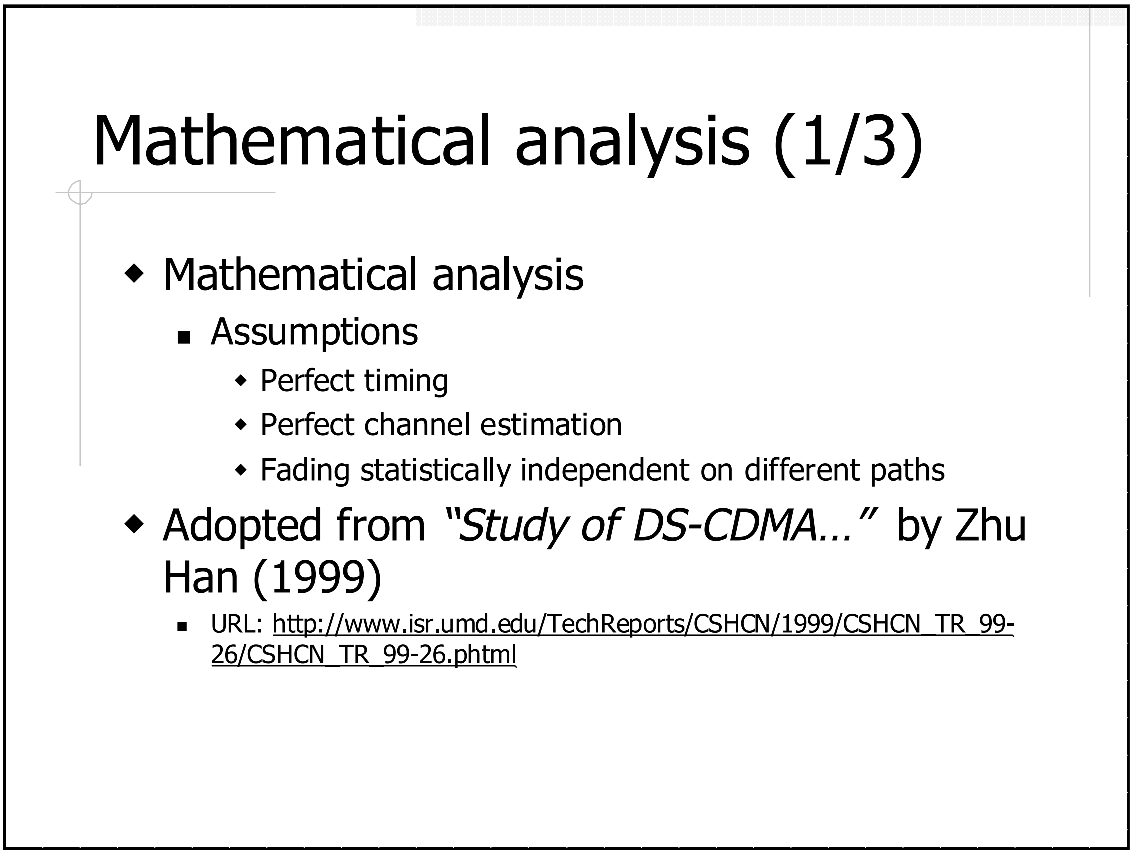
[Michael Hall, lecture slides]

Here’s the general structure directly from the lecture slides.

How can the channel estimation be done?

For example using training sequences together with adaptive filters.

A good paper on channel estimation can be found from the Internet,
URL: http://www.dmi.tut.fi/~simona/PRESENTATIONS/report_ss.pdf



Mathematical analysis (1/3)

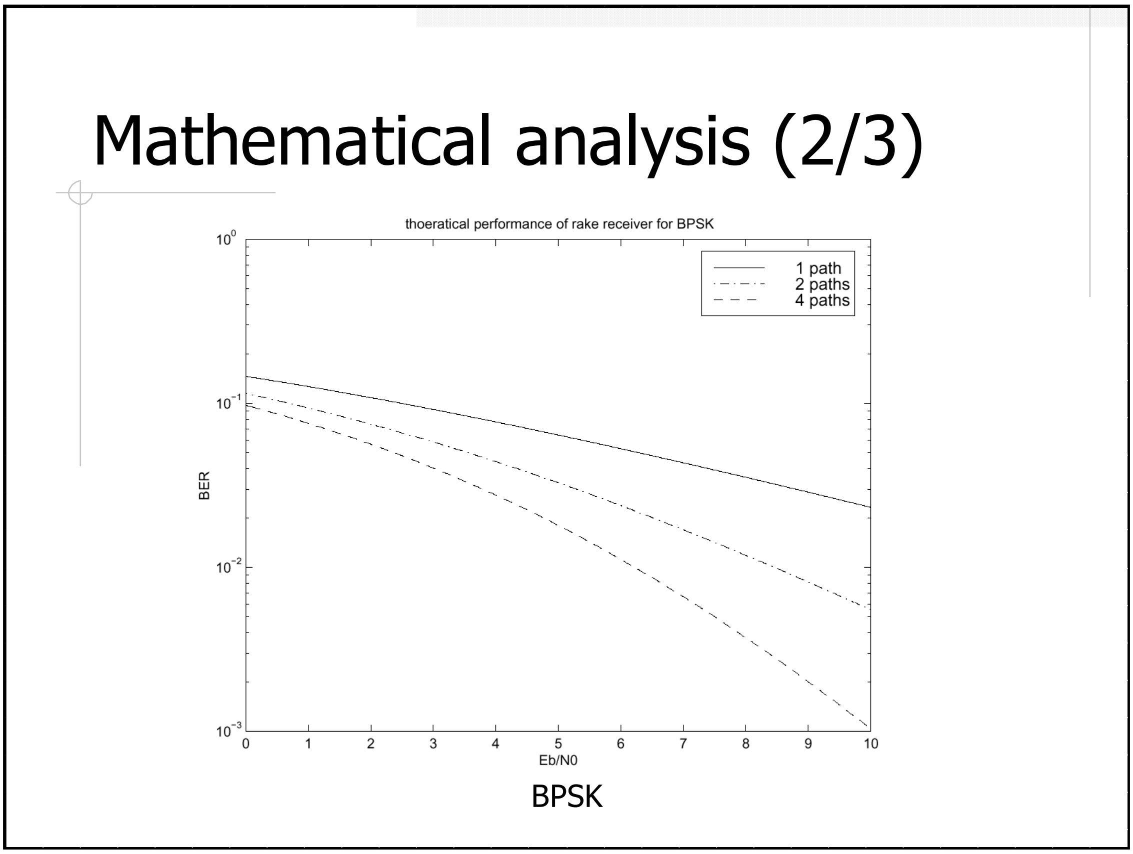
- Mathematical analysis
  - Assumptions
    - Perfect timing
    - Perfect channel estimation
    - Fading statistically independent on different paths
- Adopted from *"Study of DS-CDMA…"* by Zhu Han (1999)
  - URL: http://www.isr.umd.edu/TechReports/CSHCN/1999/CSHCN_TR_99-26/CSHCN_TR_99-26.phtml

Now that we know the idea and the structure of the RAKE receiver, it would be interesting to know, how much it actually improves the transmission. But this wasn't presented in the lecture.

Let's measure the performance with BER as a function of SNR. The analysis assumes that we have perfect timing and channel estimation. Fading in the different paths is also assumed to be mutually statistically independent.

This analysis is similar to what was shown when we discussed different modulation methods in previous lectures.

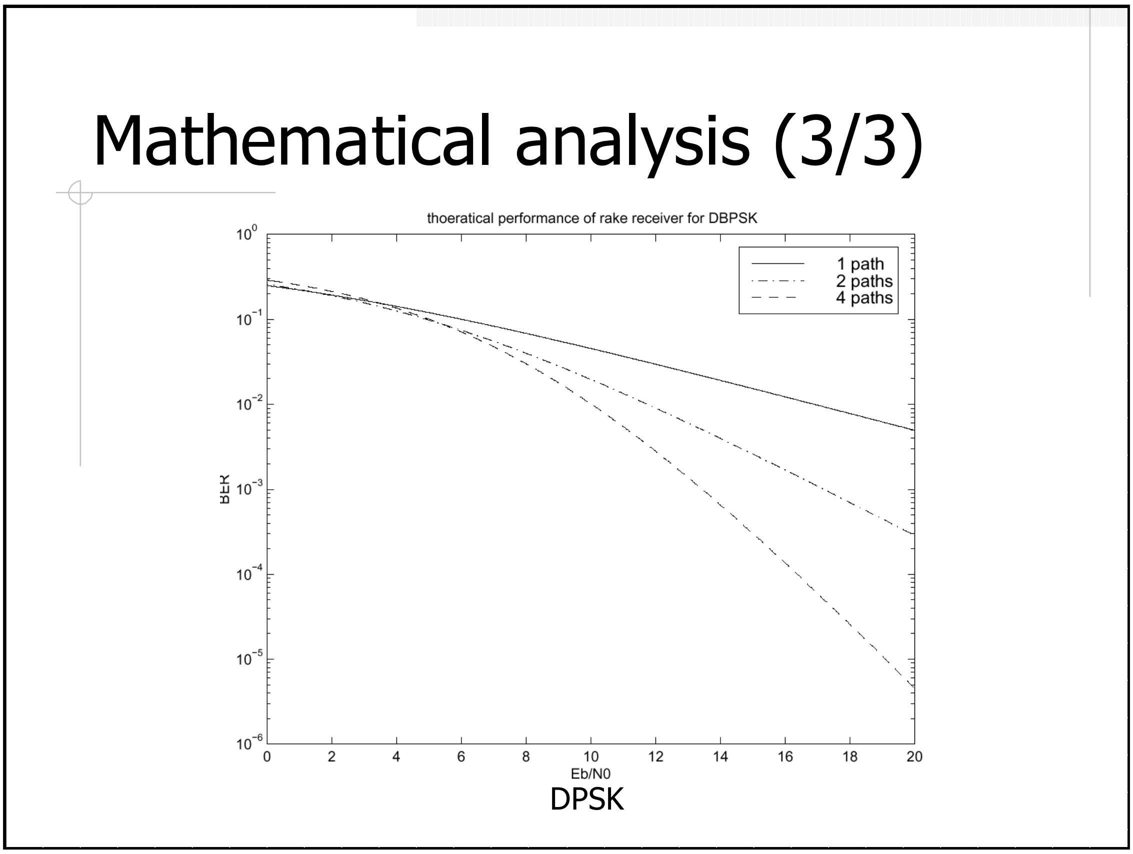
It is adopted from the abovementioned web link. You can look into the details, we'll only show the results.



Mathematical analysis (2/3)

BPSK

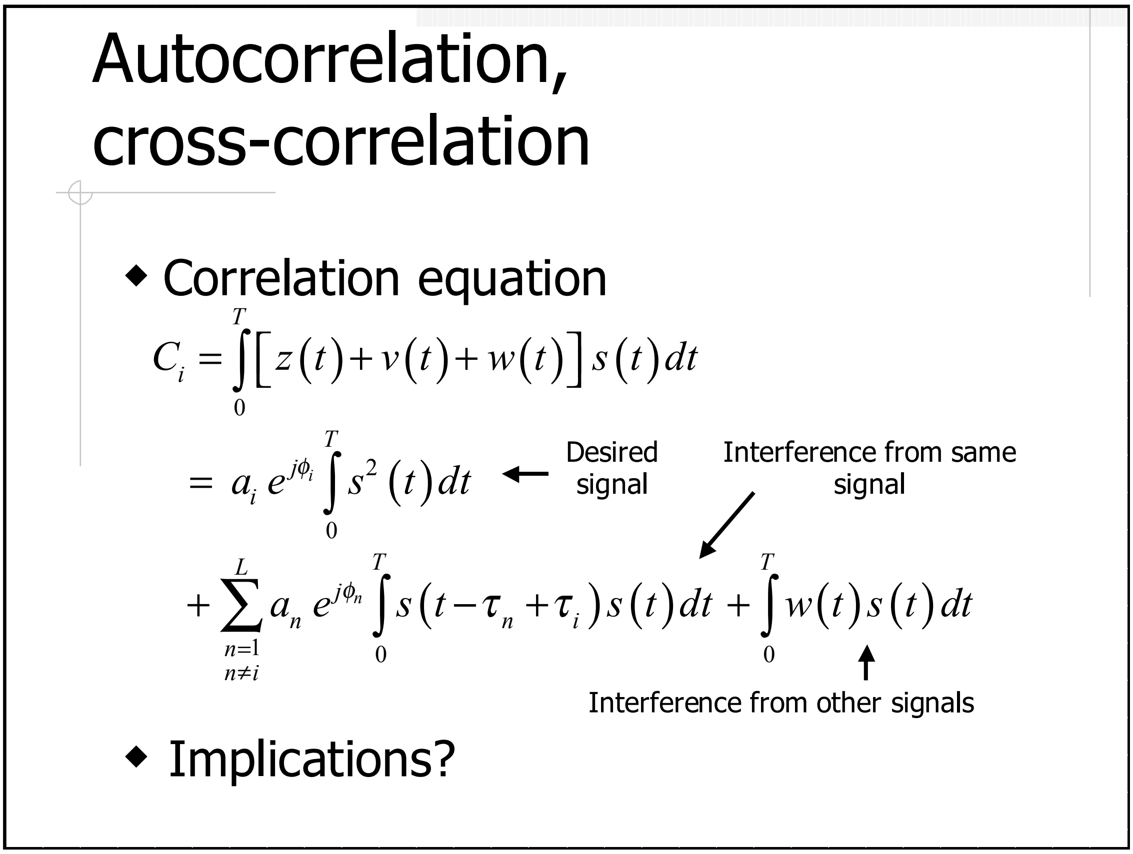
Here’s how RAKE improves BPSK (binary phase shift keying). When the SNR is about ten, there’s almost a tenfold difference between 1 and 2 paths (or fingers in the receiver).



Mathematical analysis (3/3)

DPSK

Here’s similar analysis for DPSK (differentially coherent phase shift keying). The scaling is unfortunately different from the BPSK analysis but the improvement in performance using RAKE receiver can easily be seen.



Autocorrelation, cross-correlation

- Correlation equation

$$C_i = \int_0^T \left[z(t) + v(t) + w(t) \right] s(t)\,dt$$

$$= a_i\, e^{j\phi_i} \int_0^T s^2(t)\,dt \leftarrow$$

Desired signal

Interference from same signal

$$+ \sum_{\substack{n=1 \\ n \neq i}}^{L} a_n\, e^{j\phi_n} \int_0^T s(t - \tau_n + \tau_i)\, s(t)\,dt + \int_0^T w(t)\, s(t)\,dt$$

Interference from other signals

- Implications?

This is the correlation result equation given in the lecture slides.

What are the implications of autocorrelation and cross-correlation on transmission performance?

-Small autocorrelation improves transmission performance

-Small cross-correlation improves transmission performance

What's the ideal situation when the cross-correlation is concerned?

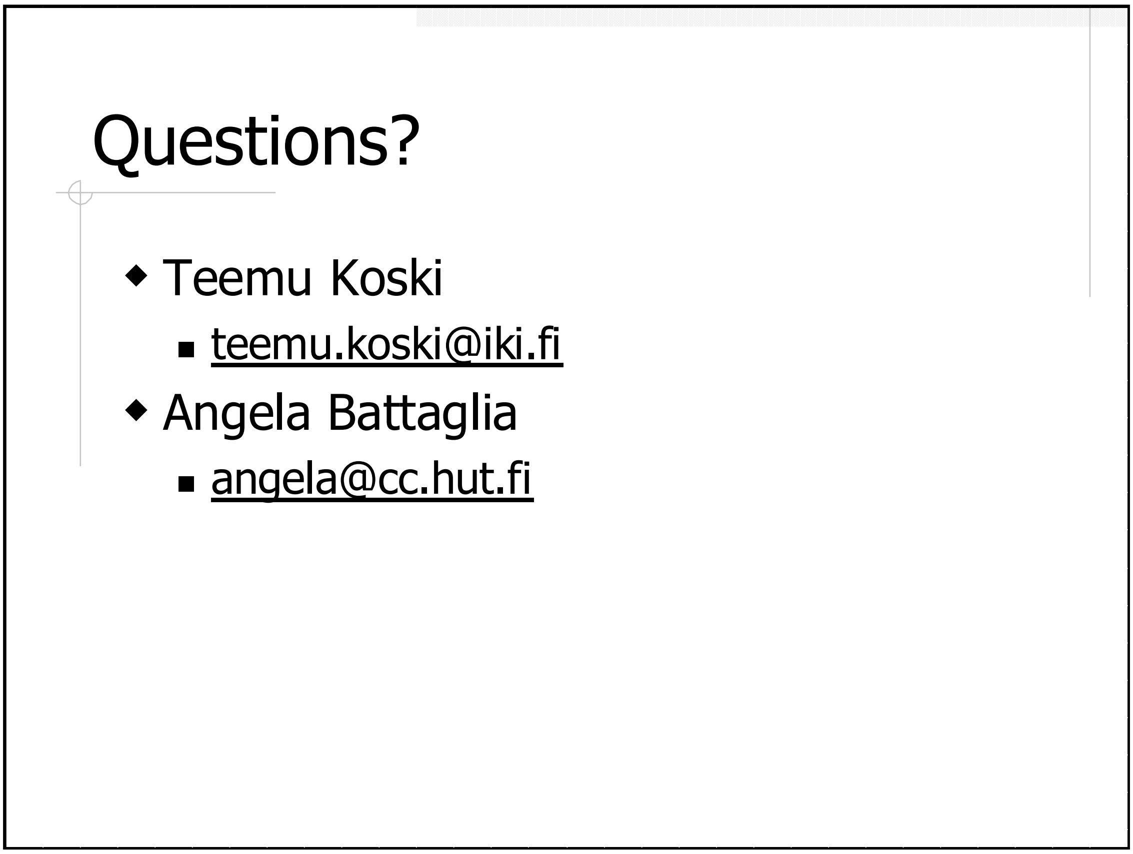
-When all the codes are orthogonal. This means that the interference from other signals is zero.

Why aren't the codes orthogonal for DS-CDMA?

-The codes are picked at random, so they are not always orthogonal. This means that some users will interfere with each other.

Suggested reading

- Ahlin and Zander: *Principles of Wireless Communications,* McGraw-Hill (1998).
  - Diversity (Chapter 5), MRC, adaptive equalization
  - Well-written, easy to understand
- Proakis, *Digital Communications*, 4th edition, McGraw-Hill (2001).
  - Chapter 14, some 100 pages (RAKE: 14.5)
  - for mathematic enthusiasts



Questions?

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