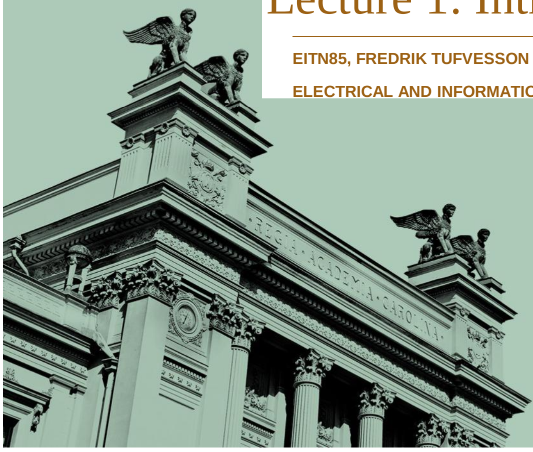
LUND UNIVERSITY

Wireless Communication Channels Lecture 1: Introduction

EITN85, FREDRIK TUFVESSON
ELECTRICAL AND INFORMATION TECHNOLOGY



Contents

- Course information
- Why channel modeling?
- Review of concepts

LUND UNIVERSITY

Course web-site

- All course information is available at:

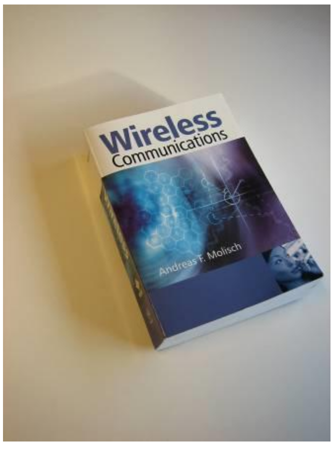
  http://www.eit.lth.se/course/ETIN85

(or www.eit.lth.se, -Education, -Courses, -Channel mod.)

- Most important:
  - Continuously updated schedule
  - Lecture handouts (available before each lecture)
  - Any additional material

LUND UNIVERSITY

Textbook



Andreas F. Molisch

Wireless Communications, 2nd ed

ISBN: 978-0-470-74186-3

Wiley/IEEE press

The second edition will be used!

- Available, e.g., through:
  - Lexis, www.lexis.se
  - Amazon U.K., www.amazon.co.uk
  - Wiley, eu.wiley.com
  - etc.

- Authored by Andreas F. Molisch, former professor of Radio Systems at Lund University/LTH.

LUND UNIVERSITY

Schedule

- Three recurring components (with some exceptions)
  - **Lectures**: Fredrik Tufvesson
    Mondays (13-15, E:3139) and
    Thursdays (8-10, E:2311)
  - **Exercise classes**: Xuhong Li
    Wednesdays (8-10), E:4118
- Two special components
  - **Assignments**:
    Three assignments, where reports are handed in
  - **Oral exam**: week 11

LUND UNIVERSITY

Oral exam

- How?
  - appr 3 hours
  - Both theoretical questions and calculations
  - "A group discussion", but with individual questions
  - Prepare as for a written exam
  - No assignments, no oral exam
- When?
  March 12-16, depending on the group.
- Where?
  Room E:2349

LUND UNIVERSITY

Lectures

- Overview of the content in the textbook
- Additional material
- Application examples

Lund University

Exercise classes

- A selection of suitable exercises is listed on the course web-site
- During exercise classes, some of the exercises will be analysed in detail
- By working through the exercises beforehand, it becomes easier to ask questions about the parts You find difficult.

Lund University

Assignments

- There are three compulsory assingments.
- Performed in groups of two students.
- You will receive measured channel data in MATLAB-format,
  - analysis
  - parameter extraction
  - conclusions
- Short reports are handed in within 7 days.
- You are NOT allowed to share results or code between groups!
- **THIS IS A COMPULSORY PART OF THE COURSE!**
- **You need to submit the assignments in order to take the oral exam.**

LUND UNIVERSITY

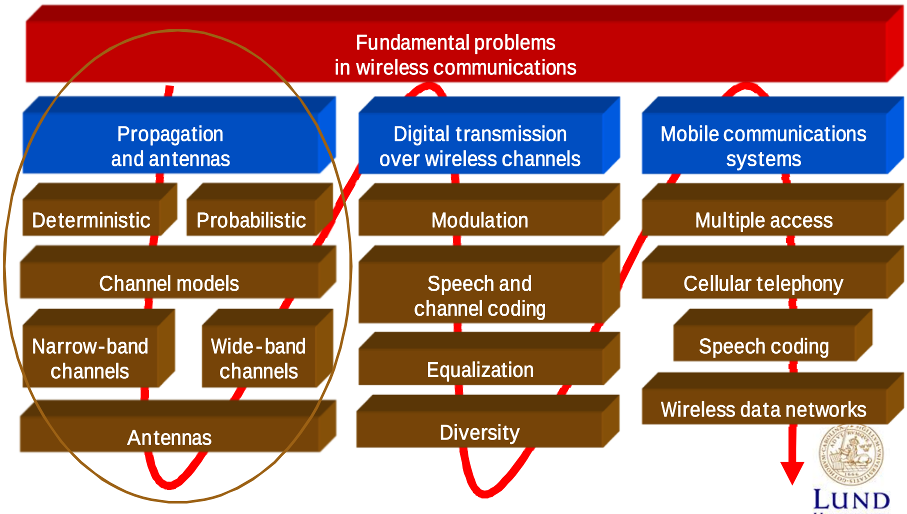
Why channel modeling?

- The performance of a radio system is ultimately determined by the radio channel!
- The channel model is the basis for
  - system design
  - algorithm design
  - antenna design etc.
- Knowledge about system and channel interaction is vital:
  - MIMO: multiple antenna systems
  - UWB: ultra wideband
  - Localization services
  - Beamforming techniques

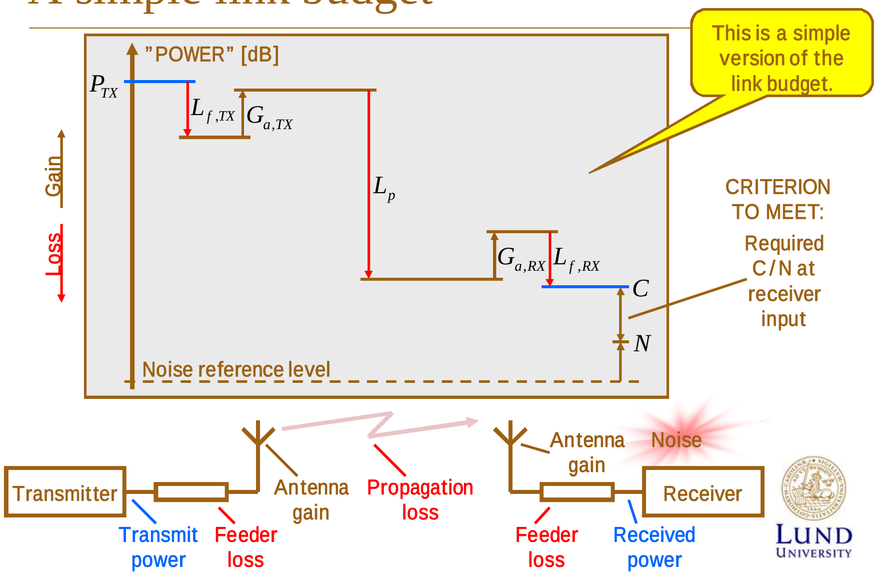
Without reliable channel models, it is difficult to design radio systems that work well in *real* environments.

LUND UNIVERSITY

A rough breakdown into areas



THE RADIO CHANNEL
A simple link budget

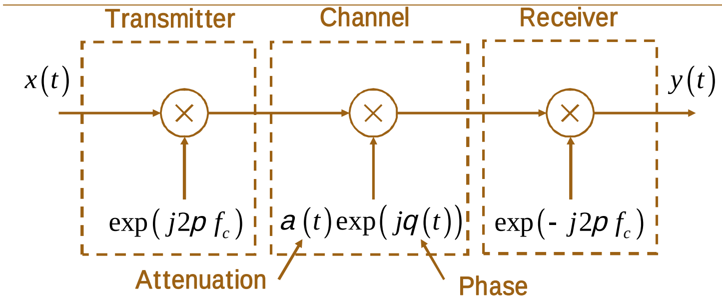


THE RADIO CHANNEL
It is more than just a loss

- Some examples:
  - behavior in time/space?
  - behavior in frequency?
  - directional properties?
  - bandwidth dependency?
  - behavior in delay?

LUND UNIVERSITY

A narrowband system described in complex notation (noise free)



In: $x(t) = A(t)\exp(j\phi(t))$

Out: $y(t) = A(t)\exp(j\phi(t))\cancel{\exp(j2\pi f_c t)}\alpha(t)\exp(j\theta(t))\cancel{\exp(-j2\pi f_c t)}$

$= A(t)\alpha(t)\exp(j(\phi(t)+\theta(t)))$

It is the behavior of the channel attenuation and phase we are going to model.

LUND UNIVERSITY

THE RADIO CHANNEL
Some properties

- Path loss
  - Roughly, received power decays exponentially with distance

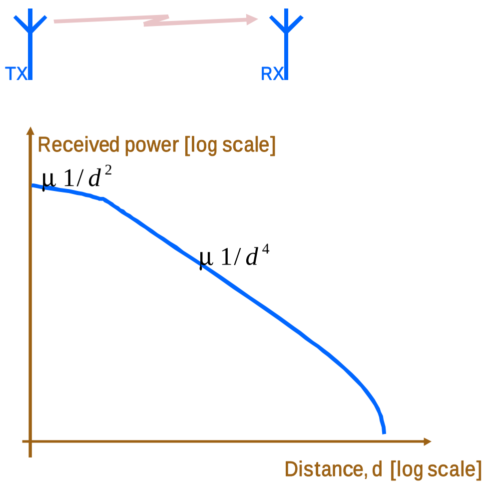
$$\text{Received power} \propto \text{Transmitted power} \times \text{Distance}^{-\text{Propagation exponent}}$$

- Large-scale fading
  - Large objects, compared to a wavelength, in the signal path obstruct the signal

- Small-scale fading
  - Objects reflecting the signal causes multipath propagation from transmitter to receiver -> constructive and destructive (self-)interference.

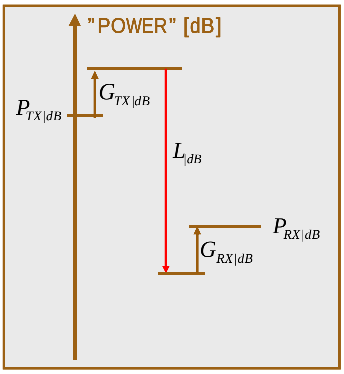
LUND UNIVERSITY

THE RADIO CHANNEL
Path loss



LUND UNIVERSITY

THE RADIO CHANNEL
Path loss



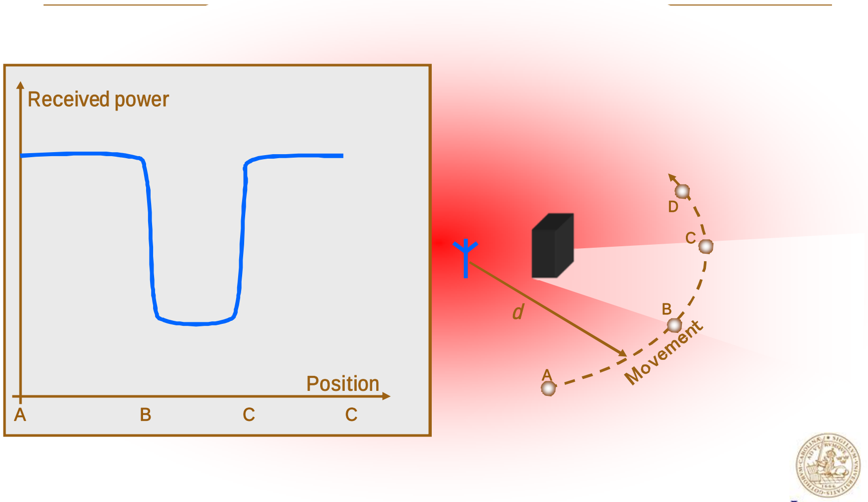
Two theoretical expressions for the deterministic propagation loss as functions of distance:

$$L_{|dB}(d) = \begin{cases} 20\log_{10}\left(\frac{4\pi d}{\lambda}\right) & \text{, free space} \\ 20\log_{10}\left(\frac{d^2}{h_{TX} h_{RX}}\right) & \text{, ground plane} \end{cases}$$

There are other models, which we will discuss later.

LUND UNIVERSITY

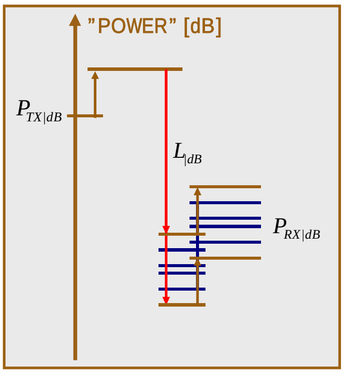
Large-scale fading
Basic principle

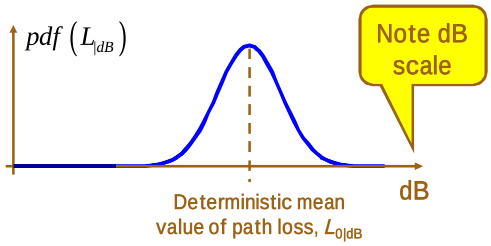


LUND UNIVERSITY

Large-scale fading
Log-normal distribution

Measurements confirm that in many situations, the large-scale fading of the received signal strength has a normal distribution in the dB domain.



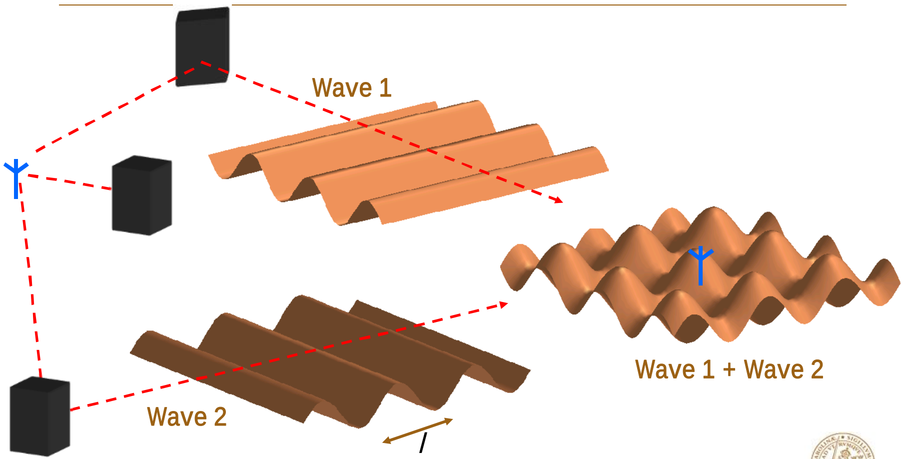


$$pdf\left(L_{|dB}\right) = \frac{1}{\sqrt{2\pi}\sigma_{F|dB}} \exp\left(-\frac{\left(L_{|dB} - L_{0|dB}\right)^2}{2\sigma_{F|dB}^2}\right)$$

Standard deviation: $\sigma_{F|dB}$ is typically 3-10 dB

LUND UNIVERSITY

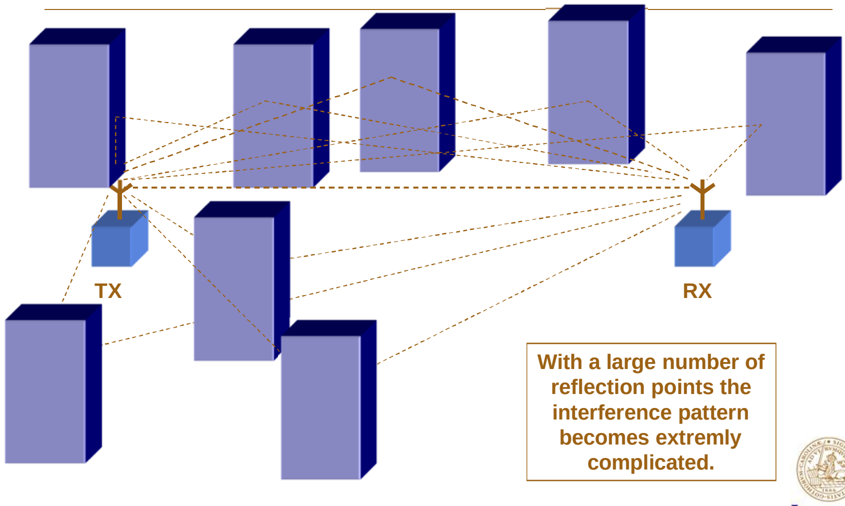
Small-scale fading
Two waves



At least in this case, we can see that the interference pattern changes on the wavelength scale.

LUND UNIVERSITY

THE RADIO CHANNEL
Small-scale fading (cont.)

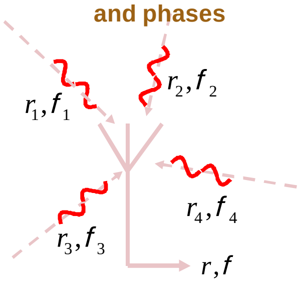


With a large number of reflection points the interference pattern becomes extremly complicated.

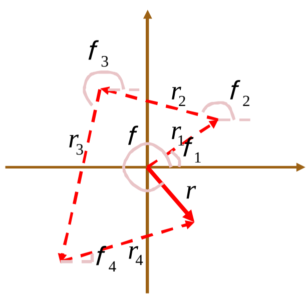
LUND UNIVERSITY

Small-scale fading
Many incoming waves

Many incoming waves with independent amplitudes and phases



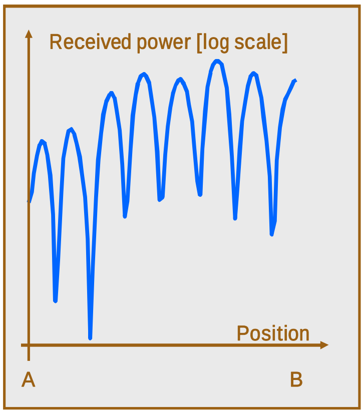
Add them up as phasors

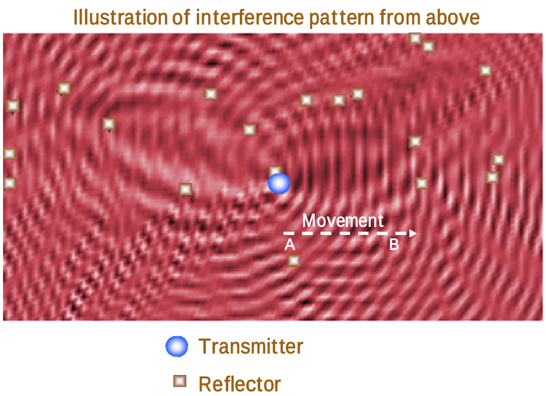


$$r \exp(jf) = r_1 \exp(jf_1) + r_2 \exp(jf_2) + r_3 \exp(jf_3) + r_4 \exp(jf_4)$$

LUND UNIVERSITY

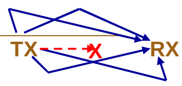
THE RADIO CHANNEL
Small-scale fading (cont.)





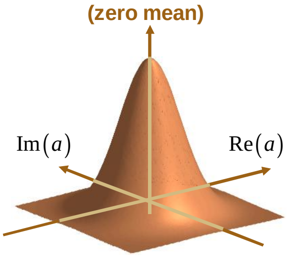
LUND UNIVERSITY

Small-scale fading
Rayleigh fading



No dominant component (no line-of-sight)

Tap distribution
2D Gaussian
(zero mean)

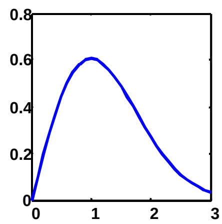


$r = |a|$

No line-of-sight component

Amplitude distribution

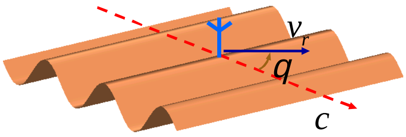
Rayleigh



$$pdf(r) = \frac{r}{\sigma^2}\exp\left(-\frac{r^2}{2\sigma^2}\right)$$

LUND UNIVERSITY

Small-scale fading
Doppler shifts



Receiving antenna moves with speed v_r at an angle θ relative to the propagation direction of the incoming wave, which has frequency f_0.

Frequency of received signal:

$$f = f_0 + \nu$$

where the Doppler shift is

$$\nu = -f_0 \frac{v_r}{c} \cos(\theta)$$

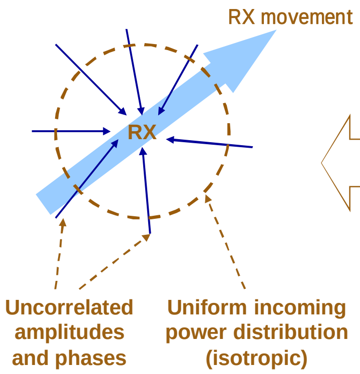
The maximal Doppler shift is

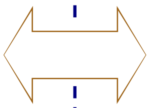
$$\nu_{max} = f_0 \frac{v}{c}$$

LUND UNIVERSITY

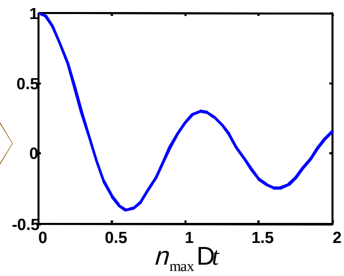
Small-scale fading
Doppler spectrum

Isotropic uncorrelated scattering





Time correlaion



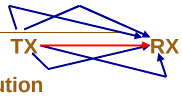
$\nu_{max} \Delta t$

$$\rho(\Delta t) = E\{a(t)a^*(t+\Delta t)\} \propto J_0(2\pi \nu_{max} \Delta t)$$

J_0 is the Bessel function of the first kind.

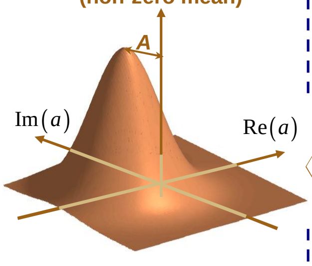
LUND UNIVERSITY

Small-scale fading
Rice fading



A dominant component, (line of sight)

Tap distribution
2D Gaussian
(non-zero mean)

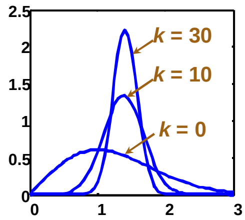


Line-of-sight (LOS) component with amplitude *A*.

$r = |a|$

Amplitude distribution

Rice



$$pdf(r) = \frac{r}{\sigma^2}\exp\left(-\frac{r^2+A^2}{2\sigma^2}\right) I_0\left(\frac{rA}{\sigma^2}\right)$$

$$k = \frac{\text{Power in LOS component}}{\text{Power in random components}} = \frac{A^2}{2\sigma^2}$$

LUND UNIVERSITY

LUND UNIVERSITY