LUND UNIVERSITY

Wireless Communications Channels
Lecture 1: Introduction

EITN85: Harsh Tataria (e-mail: harsh.tataria@eit.lth.se)
Department of Electrical and Information Technology, Lund University

1

Who am I?

Harsh Tataria – Assistant Professor of Communications Engineering

Room: E:2373

Under COVID-19 Regulations: Mostly on E-mail

E-mail: harsh.tataria@eit.lth.se

LUND UNIVERSITY

2

Lecture contents

- Course information and introduction
- Why care about wireless propagation channels?
- Review of concepts and techniques

LUND UNIVERSITY

3

Course website

- All course information is available at:

  http://www.eit.lth.se/course/EITN85

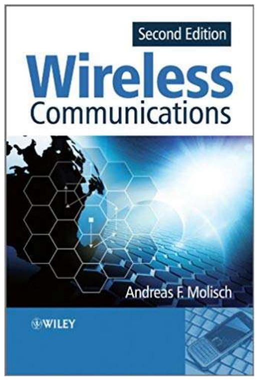
(or www.eit.lth.se, -Education, -Courses, -Wireless Prop.)

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

LUND UNIVERSITY

4

Course 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

5

Schedule

- Recurring components (with some exceptions)
  - **Lectures: Harsh Tataria**
    Mondays (13-15, Online)
    Tuesdays (13-15, Online) **(first two weeks only)**
    Fridays (10-12, Online)
  - **Exercise classes: Guoda Tian**
    Wednesdays (8-10), Online
- **Two** special components:
  - **Assignments/Projects:**
    ***Three* assignments, where *reports* are handed in**
  - **Oral exam**: week 11: Details TBA

LUND UNIVERSITY

6

Oral exam

- **How?**
  - Approximately 3 hours long
  - Both conceptual questions and calculations
  - "A group discussion", but also with individual questions
  - Prepare as for a written exam
  - No assignments, no oral exam!
- **When?**
  March 15
- **Where?**
  Online, further information closer to the date

LUND UNIVERSITY

7

Lectures

- Overview of the content in the textbook
- Important materials and explanations
- Chance to have a joint discussion about the principles learned
- Application examples

LUND UNIVERSITY

8

Exercise classes

- A selection of suitable exercises is listed on the course website
- 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

9

Assignments/Projects

- 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

10

Five rules of thumb for this course

1. **In this class, You are a Communications Engineer**
2. **You are here to listen to me, but I also want to listen to you**
3. **Do not be afraid to ask the wrong question**
4. **Learn not for the sake of passing exams, but for improving your knowledge and understanding**
5. **Your success is my success - ”a teacher only as good as his/her students.” L.J. Greenstein**

LUND UNIVERSITY

11

Wireless Propagation – Let’s begin!

But first....
What about Wired Channels?

LUND UNIVERSITY

12

Why worry about propagation channels?

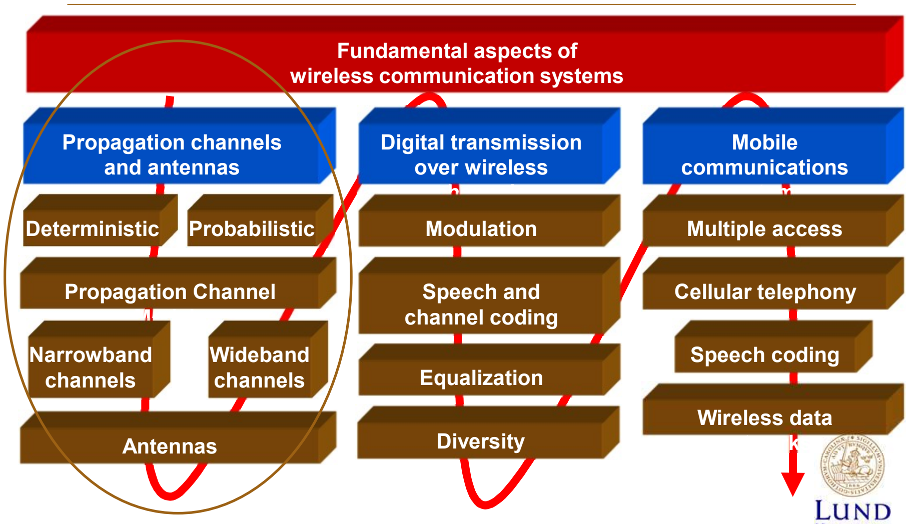
- **The performance of a radio system is ultimately determined by the channel over which communication takes place**
- **The radio channel is the basis for:**
  - system design, and field performance (bits/seconds)
  - architectures at both the transmitter and receiver
  - signal processing requirements/design at both link ends: channel estimation, power control, spatial beamforming, radio resource optimization
  - antenna design, the list goes on..
- **Knowledge about system and channel interaction is vital**

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

LUND UNIVERSITY

13

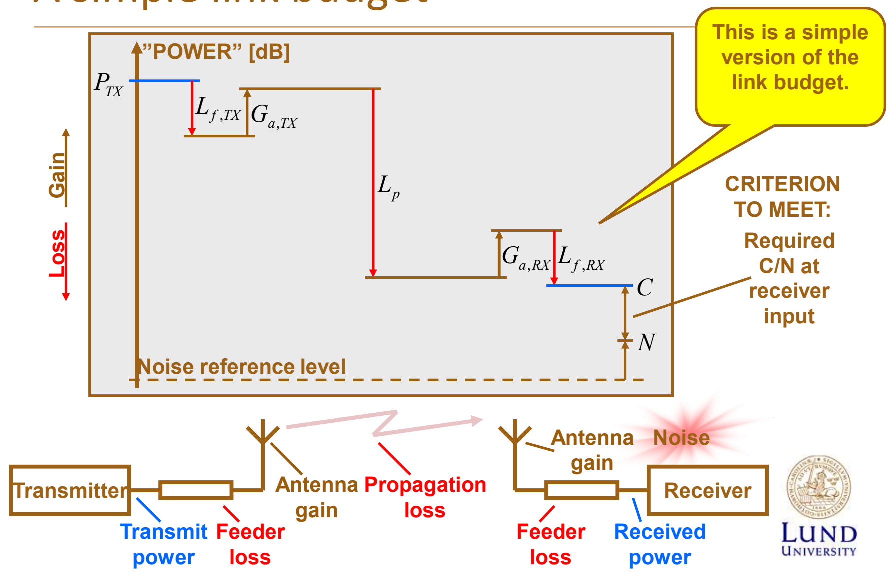
Different Aspects of Wireless Systems



LUND UNIVERSITY

14

THE RADIO CHANNEL
A simple link budget



LUND UNIVERSITY

15

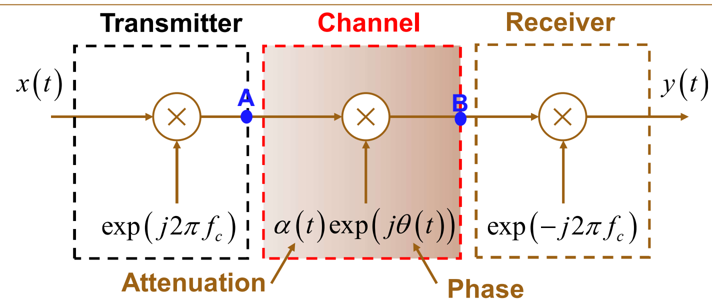
THE RADIO CHANNEL
It is more than just a loss

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

LUND UNIVERSITY

16

A narrowband system described in complex notation



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

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

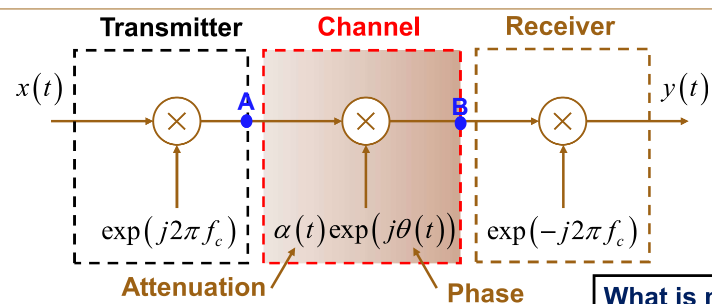
$= A(t)\alpha(t)\exp(j(\phi(t)+\theta(t)))$

It is the behavior of channel attenuation and phase variations we will investigate throughout the course.

LUND UNIVERSITY

17

A narrowband system described in complex notation



What is missing?

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 channel attenuation and phase variations we will investigate throughout the course.

LUND UNIVERSITY

18

THE RADIO CHANNEL
Some properties

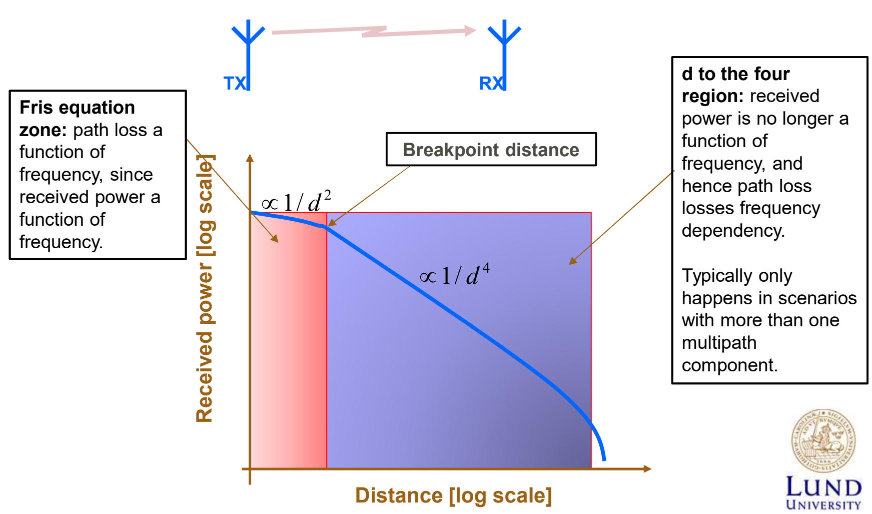
- **Path loss (a.k.a. geometric attenuation):**
  - Roughly speaking, received power decays exponentially with distance. Assuming there are no other impairments,

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

- **Large-scale fading:**
  - Caused by interacting objects which are of a large size in comparison to the wavelength
  - Obstructs the travelling signal enroute to the receiver.
- **Small-scale fading**
  - Objects reflecting, diffracting or refracting the signal causing multipath propagation from transmitter to receiver -> constructive and destructive (self-)interference.

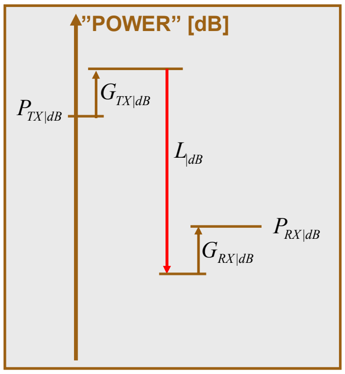
19

THE RADIO CHANNEL
Path loss – I



20

THE RADIO CHANNEL
Path loss – II



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

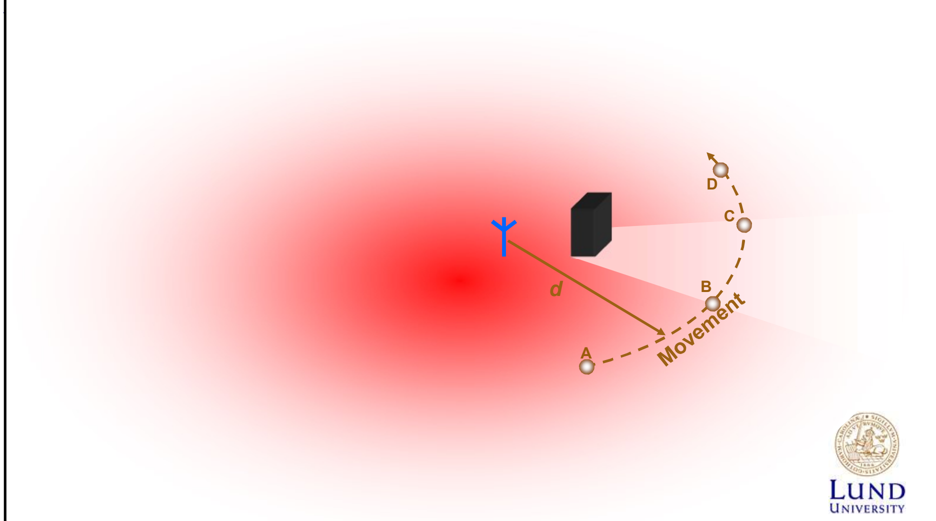
$$L_{|dB}(d) = \begin{cases} 20\log_{10}\left(\dfrac{4\pi d}{\lambda}\right) & \text{, free space} \\ 20\log_{10}\left(\dfrac{d^2}{h_{TX} h_{RX}}\right) & \text{, ground plane} \end{cases}$$

There are other models, which we will discuss later.

LUND UNIVERSITY

21

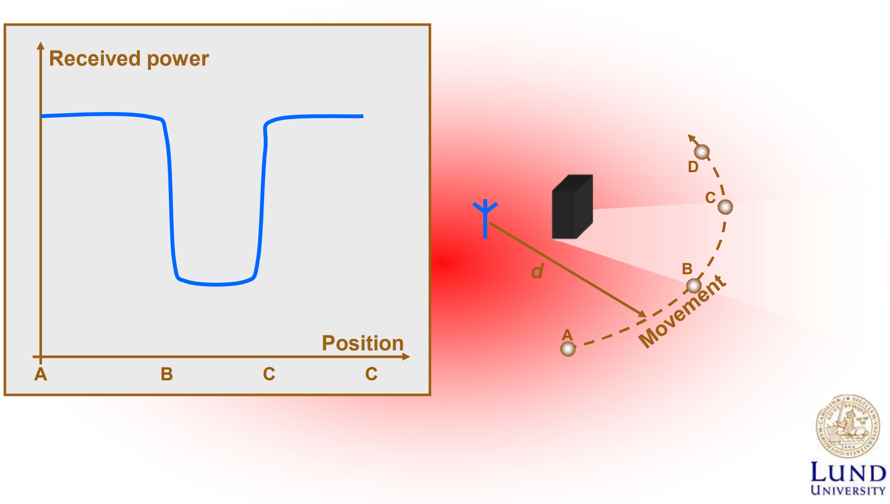
Shadow fading: The basic principle



LUND UNIVERSITY

22

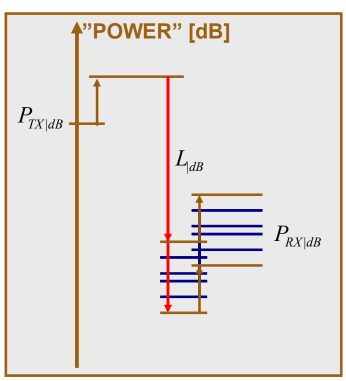
Shadow fading: The basic principle

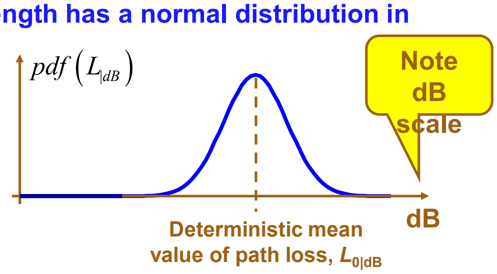


23

Shadow-fading Characterization: The 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.





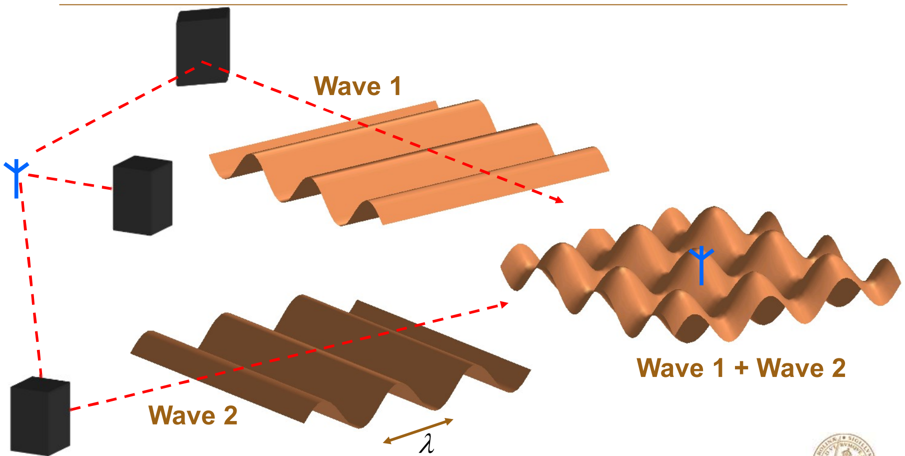
$$pdf\left(L_{|dB}\right)=\frac{1}{\sqrt{2\pi}\sigma_{F|dB}}\exp\left(-\frac{\left(L_{|dB}-L_{0|dB}\right)^2}{2\sigma_{F|dB}{}^2}\right)$$

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

Question!

24

Small-scale fading: A two path illustration



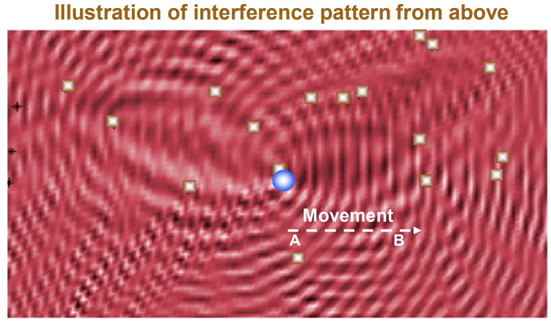
At least in this case, we can see that the interference pattern changes on the wavelength scale.

LUND UNIVERSITY

25

THE RADIO CHANNEL Small-scale fading (cont.)

Illustration of interference pattern from above



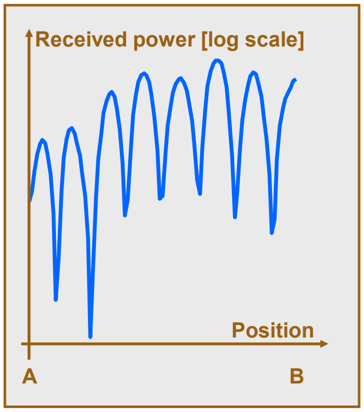
Transmitter

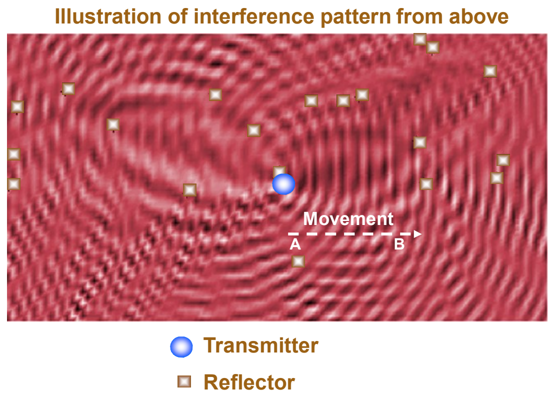
Reflector

LUND UNIVERSITY

26

THE RADIO CHANNEL
Small-scale fading (cont.)

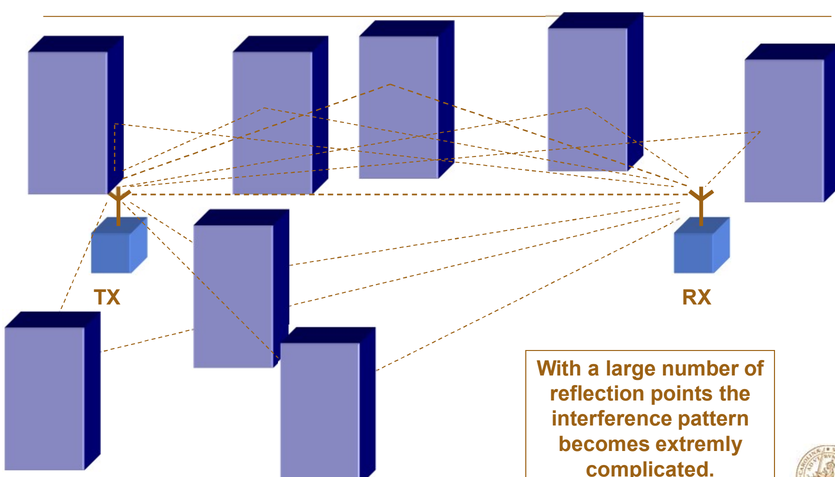




LUND UNIVERSITY

27

THE RADIO CHANNEL
Small-scale fading (cont.)



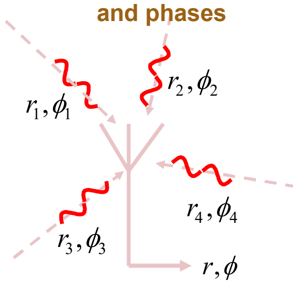
With a large number of reflection points the interference pattern becomes extremly complicated.

LUND UNIVERSITY

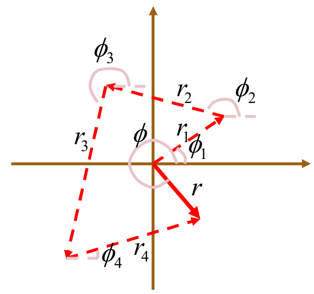
28

Small-scale fading: Many wavefronts
Mathematical Treatment

Many incoming waves with independent amplitudes and phases



Add them up as phasors



$$r\exp(j\phi) = r_1\exp(j\phi_1) + r_2\exp(j\phi_2) + r_3\exp(j\phi_3) + r_4\exp(j\phi_4)$$

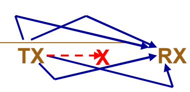
What do we really have? Random angles and magnitudes multiplying and adding, due to the different arriving multipath components, with their underlying propagation processes.

What does this mean regarding the distribution of the real and imaginary components?

LUND UNIVERSITY

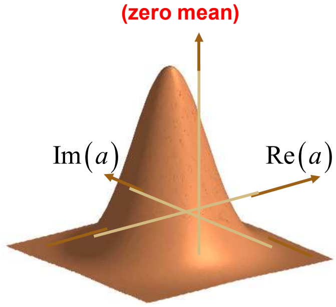
29

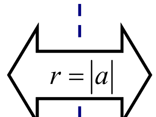
Small-scale fading
Rayleigh fading characterization



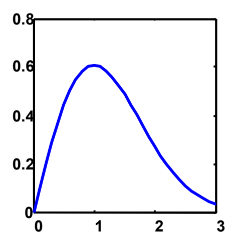
No dominant component (no line-of-sight)

Tap distribution 2D Gaussian (zero mean)





Amplitude distribution Rayleigh



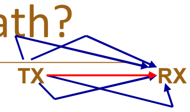
This is since the behaviour of most RXs is determined by the magnitude of the field strength phasors

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

LUND UNIVERSITY

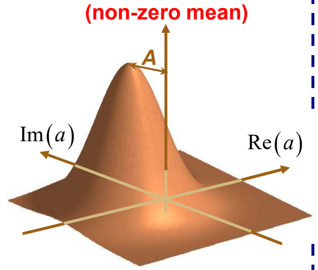
30

What happens with a dominant path?

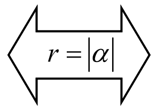


Line-of-sight path plus diffuse paths

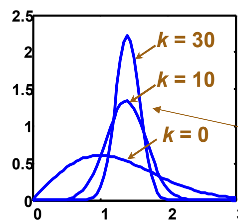
Tap distribution
2D Gaussian
(non-zero mean)



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



Amplitude distribution
Rice



Note the shift in the mean!

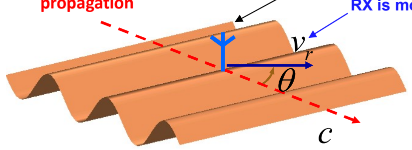
$$pdf(r) = \frac{r}{\sigma^2}\exp\left(-\frac{r^2 + A^2}{2\sigma^2}\right) I_0\left(\frac{rA}{\sigma^2}\right)$$

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

LUND UNIVERSITY

31

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

Question: What do we expect to happen to the **received signal** in such a scenario?

Frequency of received signal:

$$f = f_0 + \nu$$

Frequency offset Due to movement

where the Doppler shift is

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

Speed of light

The maximal Doppler shift is

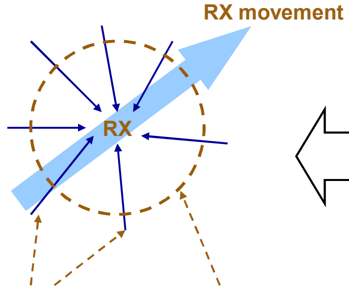
$$\nu_{\max} = f_0 \frac{v}{c}$$

LUND UNIVERSITY

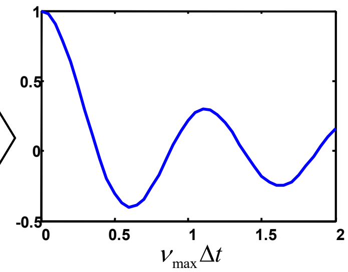
32

Small-scale fading: Doppler spectrum

Isotropic uncorrelated scattering



Time correlation



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

J_0 is the Bessel function of the first kind.

33

LUND UNIVERSITY

34