Simulation of Fading Radio Channels

Konrad Hofbauer

Graz University of Technology
SPSC – Signal Processing and Speech Communication laboratory

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Motivation

Problem

- Transmitted signal degrades due to the transmission chain.
- Transmission channel has strong impact on system performance.

Objective

Modelling and simulation
of the narrow-band aeronautic radio channel.

Used Example

- Aeronautical radio channel (aircraft to ground)
- Analogue AM voice radio
- Same effects for terrestrial channels and digital transm..

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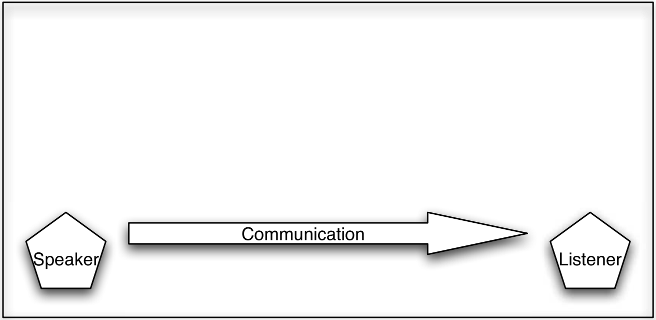

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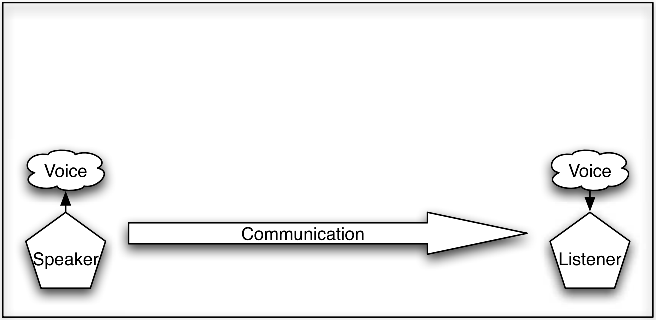

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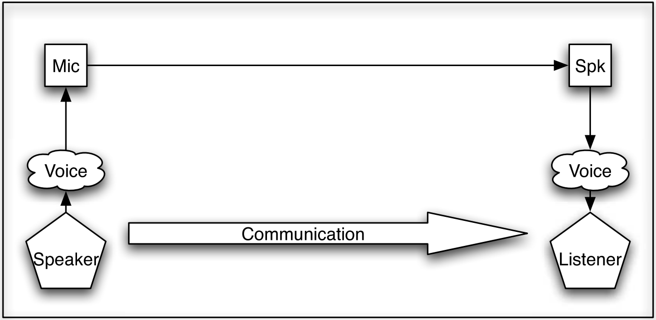

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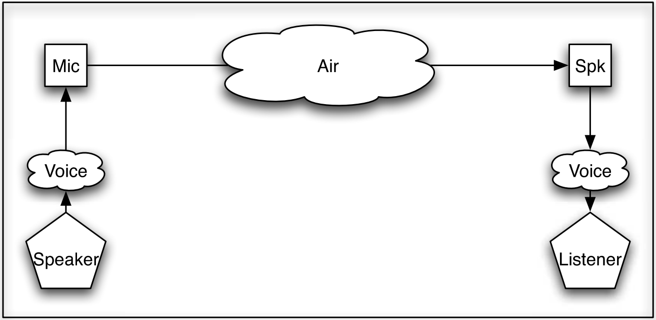

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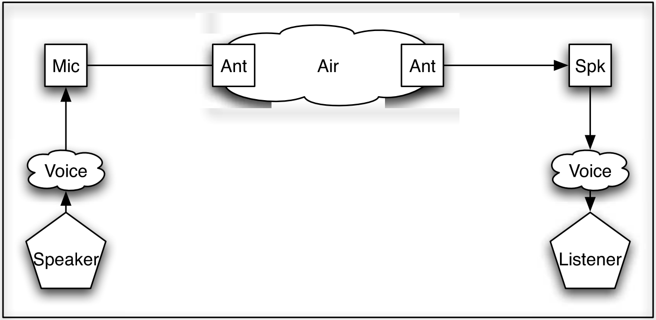

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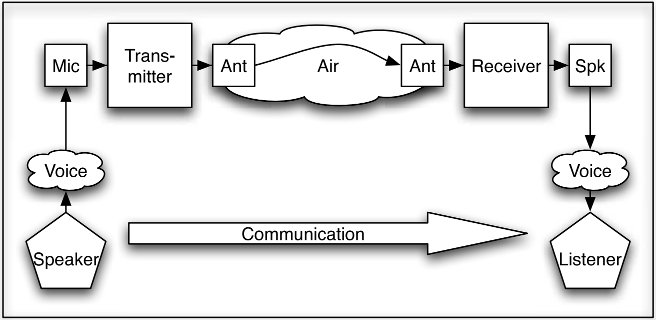
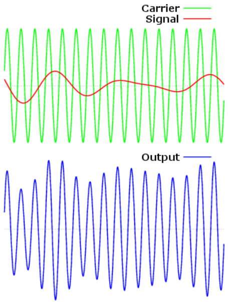


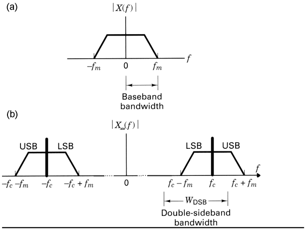
Amplitude Modulation

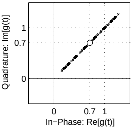


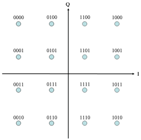
$$x_{AM}(t) = (A_0 + kx(t)) \cos(2\pi f_c t + \varphi_0)$$

- signal $x(t)$
- carrier amplitude A_0
- carrier frequency $f_c = 120\,\mathrm{MHz}$
- $\omega_c = 2\pi f_c$
- initial phase $\varphi_0 = \frac{\pi}{4}$

AM Spectrum and Complex Baseband







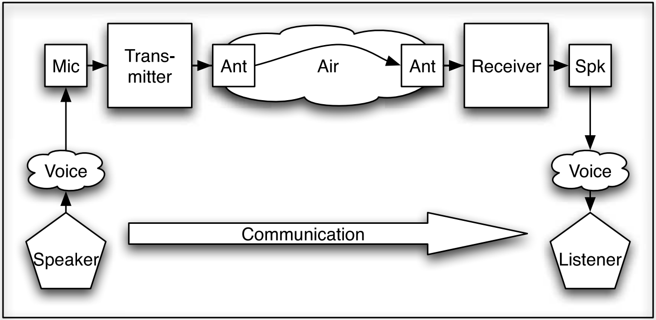
Complex baseband $g(t)$

$$x_{AM}(t) = Re\left\{(A_0 + kx(t))e^{j\omega_c t}e^{j\varphi_0}\right\}$$

$$s(t) = Re\left\{g(t)e^{j\omega_c t}\right\}$$

$$g_{AM}(t) = (A_0 + kx(t))e^{j\varphi_0}$$

Propagation Channel
Reminder



Channel Attenuation

- Path loss through distance
  - proportional to $\frac{1}{d^p}$
  - d is distance, p is path loss exponent
  - in free space: $p = 2$
- Shading (mountains, buildings, etc.)

Additive Noise

- Noise is added to the signal during transmission.
  - thermal noise (electronics)
  - atmospheric noise
  - channel interference
  - man-made noise
  - ...
- Often simply modeled as additive white gaussian noise (AWGN).

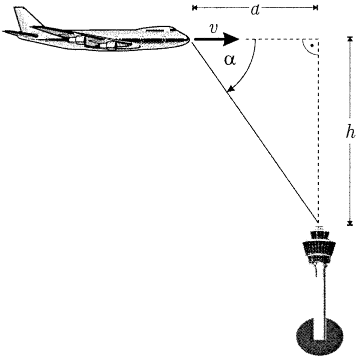
Doppler Effect

Frequency shift f_D due to movement v

$$f_D = f_{D,max} \cos(\alpha)$$

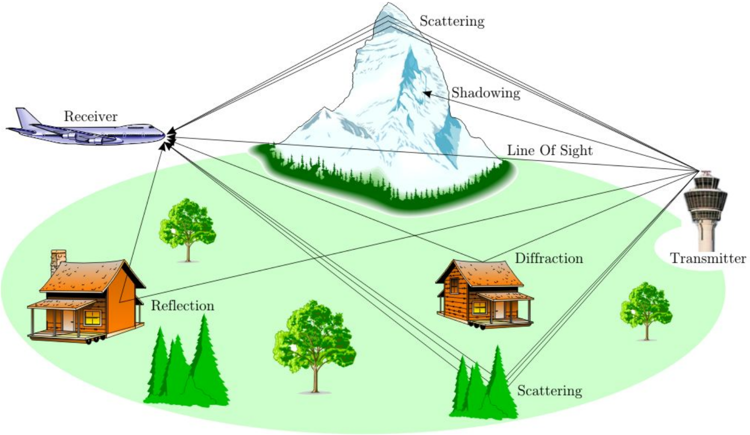
Maximum Doppler shift

$$f_{D,max} = \frac{v}{c} f_c$$



Multipath Propagation

Reflection – Scattering – Diffraction – Absorption



Multipath Propagation

- Time delays between wavefronts
  - Phase shifts
  - Constructive / destructive interference
  - Channel is a ‘fading channel’
- Time Spread > Symbol Length
  - Channel is *frequency-selective*
- Different directions of arrival
  - Different Doppler shifts
  - Frequency dispersion

Time Variation

Time Variant Channel

All parameters vary over time, and so does the channel !!!

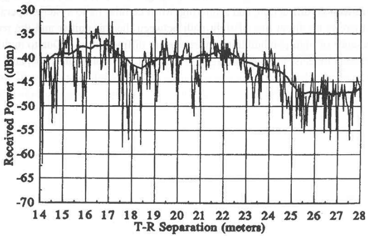


Figure 4.1 Small-scale and large-scale fading.

Channel Modelling
Slow Fading

- Large Scale Area Fading
  - *Slow* fluctuation of local mean due to *shadowing*
  - Lognormally distributed
- Important for channel availability and network planning
- Geometric modelling is done in some applications.
  - Millions of parameters
  - Specific to one situation
- Stochastic models as alternative
  - Various modesl exist, e.g. Okomura, Hata, COST231

Channel Modelling

Fast Fading

- Small Scale Area Fading
  - Local mean of envelope is constant
  - Fast signal fluctuation due to multipath
- Important for design of (digital) transmission techniques
- Stochastic Models
  - Distribution of parameters instead of prediction.
  - Adaptable to many situations.

Fast Fading Reference Model

- Line-of-sight signal (unmodulated carrier):

$$\text{LOS:} \qquad m(t) = A_0 e^{j(2\pi f_D + \varphi_0)}$$

- Assumption: *Many* scatter components!
- Sum of *all* scatter components ($\mu_{1,2}$ are zero-mean Gaussian processes):

$$\text{Scatter:} \qquad \mu(t) = \mu_1(t) + j\mu_2(t)$$

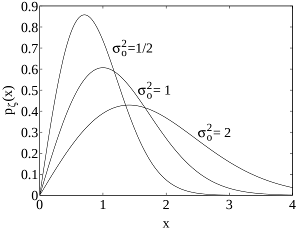
- Sum of Scatter and LOS component: Rician channel
- Only Scatter: Rayleigh channel (LOS blocked)
- Only LOS: Deterministic signal

Fast Fading Reference Model

Rice and Rayleigh – LOS or not

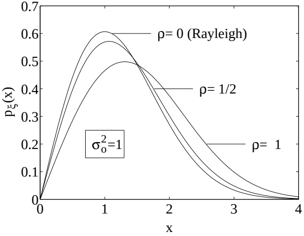
Scatters only

Ampl. is Rayleigh distributed



LOS + Scatters

Amplitude is Rice distributed



Leads to:

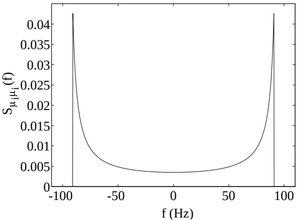
- Computation of level crossing rate, average duration of fades, etc.
- Important for design of coding and error concealment systems

Doppler Spectrum

Power Spectral Density (PSD) of the Received Signal (LOS + Scatters)

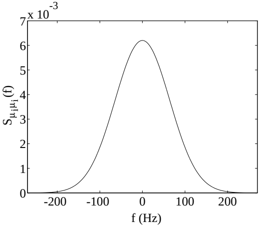
Scatters with uniformly distr. angles of arrival

Jakes PSD



More realistic

Gaussian PSD



- Gaussian PSD possibly unsymmetric and/or shifted, depending on distribution of angles of arrival
- Characteristic figures: *average Doppler shift* and *Doppler spread* (the mean and the variance of the PSD).

Frequency Nonselective Channel
Flat Fading

- Scatter components arrive *roughly* at the same time in repsect to symbol interval length.

$$\text{Signal Bandwidth} < \frac{1}{\text{Multipath Spread}} \quad (=\text{Coherence Bandwidth})$$

- All frequency components are affected equally!
- Model: Multiply channel input with a stochastic model process
  - Rayleigh and Rice
  - Suzuki Models (contains Lognormal and Rayleigh)
  - Loo Models (more flexible)
- How to generate the model processes in a simulation?

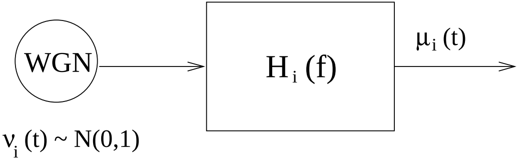
Deterministic Simulation Model

Theory of Deterministic Processes

- Efficient computation of realisations of stochastic process needed!
- Computation is inherently *deterministic.*
- *Deterministic processes* approximate the properties of the stochastic model processes.
- Most model processes are based on coloured Gaussian processes.

Filter Method

Filter *white* Gaussian noise, so that the output has the desired PSD



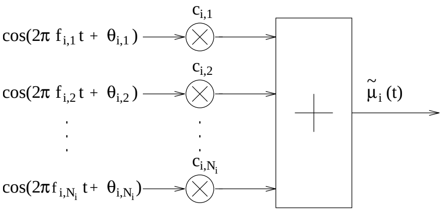
Difficulties:

- Filter design problem (with well-understood limitations)
- How to compute the WGN (efficiently)?

Sum of Sinusoids Method

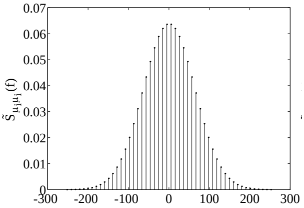
Rice Principle

The superposition of an infinite number of weighted sinusoids with equidistant frequencies and random phases gives a coloured Gaussian process.



The weights $c_{i,n} = 2\sqrt{\Delta f_i S_{\mu_i\mu_i}(f_{i,n})}$ are determined by the desired PSD.

Sum of Sinusoids - Realisation



- Goals
  - Approximate ideal PSD as closely as possible
  - Minimise the number of sinusoids (for efficiency)
- Determine for each sinusoid:
  - Discrete Frequency f_i
  - Amplitude (weigth) c_i
  - Initial Phase θ_i

Big effort made and large number of algorithms available to determine the best parameters.

Attention: Do not forget the initial assumptions made! (-> Java animation)

Frequency Nonselective Channel
Flat Fading

- Scatter components arrive *roughly* at the same time in repsect to symbol interval length.
- All frequency components are affected equally!

- Multiply channel input with a stochastic (deterministic) model process!

- For frequency nonselective channels (flat flading), this is all!

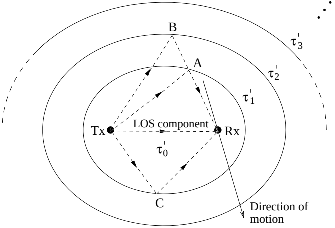
Frequency Selective Channel

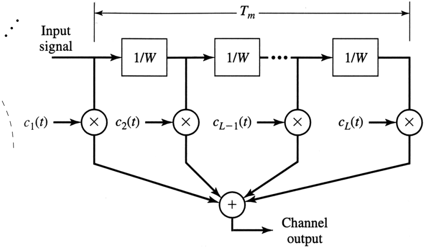
- High bandwidth, high data rate systems:
  - Digital symbol intervals become as short as multipath propagation delays
  - Frequency components are affected differently
- Again, the channel is *time-variant!*

Ellipses Model

- For all scatter objects on one given ellipse:
  - Identical path delays
  - Different Doppler shifts
  - Sum is complex Gaussian (central limit theoreme)

$\Rightarrow$ Tapped delay line structure





WSSUS Model

- Channel as linear time-variant filter
  - with time-variant impulse responses $h(t, \tau)$ or
  - with stochastic system function $h(t, \tau)$
- WSSUS model
  - Simplification of stochastic system functions, assuming
    - $h(t, \tau)$ is wide-sense stationary (WSS)
    - scattering components are uncorrelated (US)
  - System fully defined by e.g. Scattering function
  - All other parameters are derived from this (Delay PSD, Doppler PSD, correlation fcts., ...)
  - Example: COST 207
- DGUS model (Deterministic Gaussian, Uncorrelated Scattering)
  - Deterministic realisation of WSSUS model

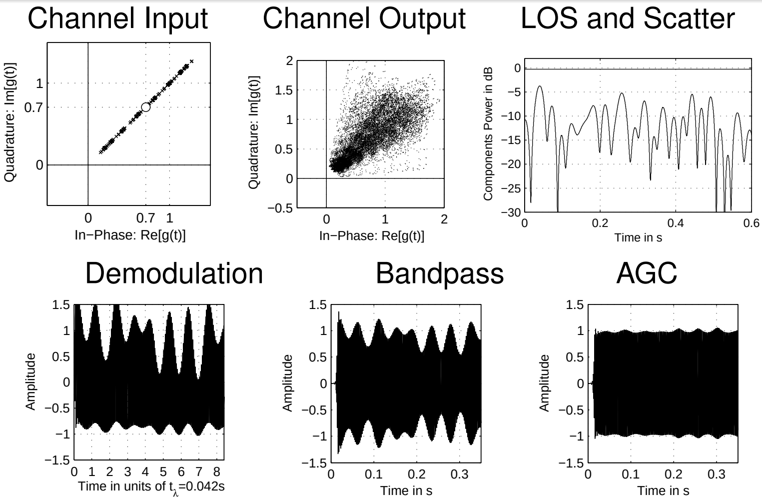
Simulation Implementations

- Generic Channel Sounder
  - old FAA/Mitre/MIT channel simulator software in ANSI C
  - Erroneous results
    - probably due to legacy platform issues
- Matlab Communications Toolbox
  - results as expected, easy to use, show example
- Direct Matlab implementation of reference models (from Pätzold)
  - confirmed results

Simulation Scenario

- VHF voice channel with sinusoidal input
- Aircraft with $v = 60\,\frac{\mathrm{m}}{\mathrm{s}}$ and maximum Doppler of $f_{D,max} = 24\,\mathrm{Hz}$
- Frequency nonselective Rician channel with $k = 12\,\mathrm{dB}$
- Computer based

Simulation Example



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