INTRODUCTION TO MOBILE RADIO CHANNEL

Jarno Tanskanen

University of Kuopio
A. I. Virtanen Institute for Molecular Sciences
Department of Neurobiology
Cognitive Neurobiology Research Laboratory
Department of Biomedical NMR
OUTLINE

• Why to Know Your Radio Channel
• Basic Concepts
• Radio Channel Types
• Mobile Radio Channel Modeling
• Channel Sounding
• Comms Simulator Examples
WHY TO KNOW YOUR RADIO CHANNEL

To Know How Transmitted Signal Is Affected

⇒

Receive Bits Right
BASIC CONCEPTS

Radio Propagation Channel

e.g.

Physical Radio Channel

vs.

Logical Radio Channel
### BASIC CONCEPTS

<table>
<thead>
<tr>
<th>Extremely low frequency</th>
<th>Microwave</th>
<th>Ultra-violet</th>
<th>Gamma</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3</td>
<td>3x10³</td>
<td>3x10⁶</td>
</tr>
<tr>
<td>static</td>
<td>10⁶m</td>
<td>1 km</td>
<td>1 m</td>
</tr>
<tr>
<td></td>
<td>1,24x10⁻¹²</td>
<td>1,24x10⁻⁶</td>
<td>1,24</td>
</tr>
<tr>
<td></td>
<td>1,24x10⁻⁹</td>
<td>1,24x10⁻³</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radio frequency</td>
<td>3x10⁶</td>
<td>3x10⁹</td>
<td>3x10¹²</td>
</tr>
<tr>
<td>Infra-red</td>
<td>3x10¹⁵</td>
<td>3x10¹⁸</td>
<td>3x10²¹</td>
</tr>
<tr>
<td></td>
<td>1,24x10⁻⁹</td>
<td>1,24x10⁻³</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Microwave</td>
<td>3x10⁹</td>
<td>3x10¹²</td>
<td>3x10¹⁵</td>
</tr>
<tr>
<td>X-ray</td>
<td>3x10¹⁸</td>
<td>3x10²¹</td>
<td>3x10²¹</td>
</tr>
<tr>
<td></td>
<td>1,24x10⁻³</td>
<td>1,24x10³</td>
<td></td>
</tr>
<tr>
<td>Seen</td>
<td>1,24</td>
<td>1,24x10³</td>
<td></td>
</tr>
<tr>
<td>Wavelength</td>
<td>10⁻⁴ nm</td>
<td>10⁻¹⁴ nm</td>
<td></td>
</tr>
<tr>
<td>Ultraviolet</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visible</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visible</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency (Hz)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wavelength</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Photon energy (eV)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[ c = f \lambda \]
BASIC CONCEPTS

Channel capacity

Signal Representation Using

Carrier Frequency

Baseband

© 2002 Jarno M. A. Tanskanen
BASIC CONCEPTS

Envelope and Phase Description

\[ s = A(t) \cdot \cos(\omega_c t + \phi(t)) \]

- \( S \): Carrier frequency signal
- \( A(t) \): Envelope
- \( \omega_c \): Carrier frequency, \( \omega_c = 2\pi f_c \)
- \( \phi(t) \): Phase

© 2002 Jarno M. A. Tanskanen
BASIC CONCEPTS

\[ s = A(t)\cos(\omega_c t + \phi(t)) \]

⇔

\[ s = A(t)[\cos(\phi(t))\cos(\omega_c t) - \sin(\phi(t))\sin(\omega_c t)] \]
BASIC CONCEPTS

\[ s = A(t)\cos(\omega_c t + \phi(t)) \]

\[ \iff \]

\[ s = A(t)\cos(\phi(t))\cos(\omega_c t) - A(t)\sin(\phi(t))\sin(\omega_c t) \]

\[ \iff \]

\[ s = s_I(t)\cos(\omega_c t) - s_Q(t)\sin(\omega_c t) \]

where \( s_I = A(t)\cos(\phi(t)) \) and \( s_Q = A(t)\sin(\phi(t)) \)
BASIC CONCEPTS

Quadrature-Carrier Description

\[ s = s_I(t)\cos(\omega_c t) + s_Q(t)\cos(\omega_c t + 90^\circ) \]

Baseband Signal Components

In-phase component
\[ s_I = A(t)\cos(\phi(t)) \]

Quadrature component
\[ s_Q = A(t)\sin(\phi(t)) \]

Complex signal envelope
\[ s_Z = s_I + is_Q \]
BASIC CONCEPTS

Properties Affecting the Way Channel Looks

Communication System Properties

• Carrier Frequency
BASIC CONCEPTS

Properties Affecting the Way Channel Looks

Communication System Properties

• Carrier Frequency
• Bandwidth
BASIC CONCEPTS

Properties Affecting the Way Channel Looks

Communication System Properties

- Carrier Frequency
- Bandwidth
- Multiple access scheme
BASIC CONCEPTS

Properties Affecting the Way Channel Looks

Environmental Properties

• Indoor / Outdoor Environment
BASIC CONCEPTS

Properties Affecting the Way Channel Looks

Environmental Properties

- Indoor / Outdoor Environment
- Urban / Rural / Hilly Terrain
BASIC CONCEPTS

Properties Affecting the Way Channel Looks

Environmental Properties

- Indoor / Outdoor Environment
- Urban / Rural / Hilly Terrain
- Mobile Velocity
BASIC CONCEPTS

Properties Affecting the Way Channel Looks

Environmental Properties

- Indoor / Outdoor Environment
- Urban / Rural / Hilly Terrain
- Mobile Velocity
- Humidity

© 2002 Jarno M. A. Tanskanen
BASIC CONCEPTS

Properties Affecting the Way Channel Looks

Properties Dependent on Environment and Comms System

• Fading
BASIC CONCEPTS

Properties Affecting the Way Channel Looks

Properties Dependent on Environment and Comms System

- Fading
- Propagation Delay
BASIC CONCEPTS

Properties Affecting the Way Channel Looks

Properties Dependent on Environment and Comms System

- Fading
- Propagation Delay
- Doppler Spectrum
BASIC CONCEPTS

Properties Affecting the Way Channel Looks

Properties Dependent on Environment and Comms System

- Fading
- Propagation Delay
- Doppler Spectrum
- Coherence Time
BASIC CONCEPTS

Properties Affecting the Way Channel Looks

Properties Dependent on Environment and Comms System

- Fading
- Propagation Delay
- Doppler Spectrum
- Coherence Time
- Coherence Bandwidth
BASIC CONCEPTS

Uplink

Downlink

© 2002 Jarno M. A. Tanskanen
BASIC CONCEPTS

Uplink

Near-Far-Effect

Downlink

No Near-Far-Effect
BASIC CONCEPTS

Frequency Division Duplex (FDD)  Time Division Duplex (TDD)

\[ f_{c,\text{uplink}} \neq f_{c,\text{downlink}} \]

\[ f_{c,\text{uplink}} = f_{c,\text{downlink}} \]
RADIO CHANNEL TYPES

by Propagation Mode

Radio waves

Ground waves

Tropospheric waves

Direct waves

Ground reflected waves

Ionospheric waves = Sky waves

Space waves

Surface waves

© 2002 Jarno M. A. Tanskanen
Ionospheric waves
Tropospheric waves
Radio waves → Ground waves
RADIO CHANNEL TYPES

by Carrier Frequency

3-30 kHz      Very Low Frequency (VLF)

- Ionospheric wave guide
- Worldwide telegraphy
- Navigation systems
- Submarine communications
RADIO CHANNEL TYPES

by Carrier Frequency

30 kHz-3 MHz  Low Frequency (LM) & Medium Frequency (MF)

• LM
  • surface wave
  • long distance communications
  • navigation

• MF
  • ground & sky waves  ⇒  interference & fading
  • commercial AM radio
RADIO CHANNEL TYPES

by Carrier Frequency

3-30 MHz  High Frequency (HF)

- Ground wave exists
- Sky wave dominant
- Almost worldwide communications
  - hops via ionospheric layers
- Not used for civilian land mobile radio
RADIO CHANNEL TYPES

by Carrier Frequency

3 MHz-3 GHz  Very High Frequency (VHF) & Ultra High Frequency (UHF)

- Space wave dominant

Ionospheric waves = Sky waves

Tropospheric waves

Direct waves

Space waves

Ground reflected waves

Radio waves

Ground waves

Surface waves
RADIO CHANNEL TYPES

by Carrier Frequency

3 MHz-3 GHz  Very High Frequency (VHF) & Ultra High Frequency (UHF)

- Space wave dominant
- Propagation restricted within radio horizon
- Reflections & diffraction
- FM radio & television channels, etc.
RADIO CHANNEL TYPES

by Carrier Frequency

3-30 GHz Super High Frequency (microwaves: 15–30 GHz)

- Line-of-sight (LOS) required
- High-gain antennas
- Satellite communications
- Point-to-point terrestrial links
- Radars
- Short-range communications
RADIO CHANNEL TYPES

by Carrier Frequency

30-300 GHz Extra High Frequency (i.e. millimeter wave)

- Lot’s of bandwidth available
- Line-of-sight communications
- Precipitation scattering
- Fog, water, oxygen absorption (e.g. 60 GHz)
- Very short range secure communications
- Satellite-to-satellite communications
“Why 60GHz”
A white paper in layman's term
Factors Influencing the Paradigm Shift

- Physical Fiber Replacing Long-Haul Segments
- Bandwidth Demand Forces True Fiber Speed Capacity for “Final Mile”
- Multi-user Demand Forces Dense Deployments of Co-located Systems
- Safety Concerns Limit Transmit Power (Maximum Permissible Exposure)
- Two-way Communication Forces Targeted Communication Links
- Universal Access demands Terminal Cost Reduction
- Aesthetic Concerns demand Smaller Size Antennae and Systems

The Rediscovery of the Radio Wave under The New Paradigm

Traditionally, wireless telecommunications services were confined to regulated spectrum allocations from 2GHz to 30GHz. These frequency slices, typically ≤ 50 MHz wide, were adequate for data transmission capacities of up to 155Mbps.

The exploding demand for bandwidth combined with fiber based data transport backbone has recently demonstrated the inadequacy of the traditional microwave frequency allocations. Due to the scarcity of unallocated spectrum and the need for interference free channel separation the wireless industry has begun to focus on higher previously unallocated portions of the spectrum. For several reasons The Millimeter wave frequency region from 30 GHz to 300GHz, is the logical choice available for applying the new paradigm.

Because of high levels of atmospheric RF energy absorption, the millimeter wave region of the RF spectrum proved unusable for the long-haul wireless segments of the old paradigm. However, the atmospheric absorption phenomenon of the millimeter wave region, particularly in the 60GHz oxygen absorption region makes it ideal for the new paradigm. The atmospheric absorption for millimeter frequencies is shown in Figure 1.
Oxygen Absorption vs. Radio Interference

The scientists and engineers at Harmonix Corporation realize that under the, short haul and high-density deployment requirements of the new paradigm, 60GHz is the natural choice to avoid interference since 98% of the transmitted energy is absorbed by oxygen molecules in the atmosphere within the first Kilometer.

![Graph showing frequency reuse and oxygen absorption](source: FCC OET Bulletin 70a)

Figure 2. Frequency Reuse.

Figure 2. Illustrates the distance relationship between the frequency reuse range (green region) and the working range (blue region) at the 60GHz oxygen absorption frequency. Oxygen absorption maximizes reuse of the same frequency within the localized region of air space.

In simpler terms, operation in the 60GHz millimeter wave region of the RF spectrum makes possible very dense deployments of radio terminals operating on the same frequency while minimizing the probability of interference. This attribute satisfies the “Dense Deployment” aspect of the new paradigm.
<table>
<thead>
<tr>
<th>Extremely low frequency</th>
<th>Radio frequency</th>
<th>Microwave</th>
<th>Ultra-violet</th>
<th>Gamma</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3</td>
<td>3x10^3</td>
<td>3x10^6</td>
<td>3x10^9</td>
</tr>
<tr>
<td>static</td>
<td>10^6 m</td>
<td>1 km</td>
<td>1 m</td>
<td>1 mm</td>
</tr>
<tr>
<td></td>
<td>1,24x10^-12</td>
<td>1,24x10^-6</td>
<td>1,24x10^-3</td>
<td>1,24x10^-9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Longwave</td>
<td>Shortwave</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Frequency (Hz), Wavelength, Photon energy (eV)

Shortwave = HF
Here, 2,5 Mhz, 20 MHz

Longwave = LF
Here, 60 kHz
RADIO CHANNEL TYPES

Land Mobile Communications

- Indoor / Outdoor
- Urban / Rural / Hilly Terrain
- Pedestrian / Residential Vehicle / Highway / Bullet Trains
RADIO CHANNEL TYPES

Mobile Communications

- Indoor / Outdoor
- Urban / Rural / Hilly Terrain
- Pedestrian / Residential Vehicle / Highway / Bullet Trains
- Narrowband / Wideband
RADIO CHANNEL TYPES

Mobile Communications

- Indoor / Outdoor
- Urban / Rural / Hilly Terrain
- Pedestrian / Residential Vehicle / Highway / Bullet Trains

- Narrowband / Wideband

- Uplink / Downlink
- E.g., WCDMA: Frequency Division Duplex (FDD) / Time Division Duplex (TDD)

© 2002 Jarno M. A. Tanskanen
MOBILE RADIO CHANNEL MODELING

Received Power $P_R$ in Free Space

$$P_R = P_T \cdot ?$$

$P_R$ Received power
$P_T$ Transmitted power

© 2002 Jarno M. A. Tanskanen
MOBILE RADIO CHANNEL MODELING

Received Power $P_R$ in Free Space

$$P_R = P_T \cdot G_R G_T \cdot ?$$

$P_R$  Received power
$P_T$  Transmitted power
$G_R$  Receiver antenna gain
$G_T$  Transmitter antenna gain
MOBILE RADIO CHANNEL MODELING

Received Power $P_R$ in Free Space

$$P_R = P_T \cdot G_R G_T \left(\frac{\lambda}{4\pi \cdot d}\right)^2$$

- $P_R$  Received power
- $P_T$  Transmitted power
- $G_R$  Receiver antenna gain
- $G_T$  Transmitter antenna gain
- $\lambda$  Wavelength
- $d$  Distance between transmitter and receiver antennas
MOBILE RADIO CHANNEL MODELING

Path Loss in Free Space

\[
\frac{P_R}{P_T} = G_R G_T \left( \frac{\lambda}{4\pi \cdot d} \right)^2
\]

\[
L_F = 10 \log_{10} \left( \frac{P_T}{P_R} \right)
= -10 \log_{10} G_T - 10 \log_{10} G_R + 20 \log_{10} f + 20 \log_{10} d + k
\]

A lot of different path loss models

© 2002 Jarno M. A. Tanskanen
MOBILE RADIO CHANNEL MODELING

• Channel Measurements (Sounding)
• Ray Tracing
• Statistical
MOBILE RADIO CHANNEL MODELING

- Channel Measurements (Sounding)
- Ray Tracing
- Statistical
- Baseband / Carrier Frequency
MOBILE RADIO CHANNEL MODELING

• Channel Measurements (Sounding)
• Ray Tracing
• Statistical

• Baseband / Carrier Frequency
• Indoor / Outdoor Environment
• Urban / Rural / Hilly Terrain
• Mobile Velocity
MOBILE RADIO CHANNEL MODELING

- Channel Measurements (Sounding)
- Ray Tracing
- Statistical
- Baseband / Carrier Frequency
- Indoor / Outdoor Environment
- Urban / Rural / Hilly Terrain
- Mobile Velocity
- Fading (i.e., Attenuation)
- Propagation Delay
- Doppler
STATISTICAL CHANNEL MODELING

Attenuation Due to \textit{Distance}

\[ A_d(t) \propto d(t)^{-a} \]

\( a \) path loss exponent, \( a \in [2,5] \)
\( d(t) \) distance

© 2002 Jarno M. A. Tanskanen
STATISTICAL CHANNEL MODELING

Attenuation Due to Distance

\[ A_d(t) \propto d(t)^{-a} \]

- **\( a \)**: path loss exponent
- **\( d(t) \)**: distance

- **Free space**: 2
- **Ideal specular reflection**: 4
- **Urban cells**: 2.7 – 3.5
- **Urban cells, shadowed**: 3-5
- **In building, LOS**: 1.6-1.8
- **In building, obstructed path**: 4-6
- **In factory, obstructed path**: 2-3
Fading due to hills, forests, etc.

**Slow Fading, i.e., Shadowing**

• Lognormal process, e.g.

\[ A_s(t) \propto 10^{x(t)/20} \]

\( x(t) \) Gaussian signal
Original program courtesy of M. Rintamäki, Signal Processing Laboratory, HUT, and B. Makarevitch, Communications Laboratory, HUT
Fading due to man made objects

**Fast Fading, i.e., Multipath Fading**

![Diagram of channel model with Mobile station, Line of sight (LOS) path, Obstacle, and Base station with multipath and frequency and time shifts.](image_url)
Fast Fading Statistics

- **No Line-of-Sight (LOS) path** or specular reflected component

  $\Rightarrow$ **Rayleigh** distributed amplitude

![Rayleigh distribution](image)
Fast Fading Statistics

- **LOS** or specular reflected component
  
  \[ \Rightarrow \text{Rician distributed amplitude} \]
Doppler Effect

Max. Doppler shift

\[ f_{D, \text{max}} = \frac{v}{\lambda} \]

E.g., \( v = 50 \text{ km/h} \approx 14 \text{ m/s} \)

\( c = f \lambda \)

\( f_c = 1.8 \text{ GHz} \Rightarrow \lambda \approx 16.67 \text{ cm} \)

\( f_{D, \text{max}} \approx 84 \text{ Hz} \)
Doppler Effect

Max. Doppler shift

\[ f_{D,\text{max}} = \frac{v}{\lambda} \]

Doppler Shift

\[ f_D = f_{D,\text{max}} \cos \alpha \]
Doppler Spectrum, e.g.,

\[ S(f) = \frac{3}{f_{D,\text{max}} \sqrt{1 - \left(\frac{f}{f_{D,\text{max}}}\right)^2}} \]
Doppler Spectrum, e.g.,

\[ S(f) = \frac{3}{f_{D,\text{max}} \sqrt{1 - \left(\frac{f}{f_{D,\text{max}}}\right)^2}} \]
STATISTICAL CHANNEL MODELING

Rayleigh Fading Generator with Noise

\[ \text{AWGN}_i \]

\[ \text{WGN}_i \rightarrow \text{NSF}_i \rightarrow + \rightarrow (\cdot)^2 \]

\[ \text{WGN}_q \rightarrow \text{NSF}_q \rightarrow + \rightarrow (\cdot)^2 \]

\[ \text{AWGN}_q \]

(A)WGN  (Additive) White Gaussian Noise

NSF  Noise Shaping Filter

© 2002 Jarno M. A. Tanskanen
STATISTICAL CHANNEL MODELING

Jakes’ Rayleigh Fading Generator

Osc1, …, Osc8, Oscm
S1, …, S8, Sm, C1, …, C8, Cm
M
Osccc

Sinusoid oscillators
Coefficients
Modulator
Carrier oscillator
STATISTICAL CHANNEL MODELING

Distance + Shadowing + Fast Fading =

© 2002 Jarno M. A. Tanskanen
Tapped Delayline Model
Tapped Delayline Model
MOBILE RADIO CHANNEL MODELING

Tapped Delayline Model
MOBILE RADIO CHANNEL MODELING

Tapped Delayline Model

Transmitted signal

\[ A_1(t) \]

\[ A_2(t) \]

\[ A_3(t) \]

\[ \ldots \]

\[ A_N(t) \]

Received signal

© 2002 Jarno M. A. Tanskanen
A large number of paths (20) in each model ensure that the correlation properties in the frequency domain are realistic. Path powers follow the exponential channel shapes in the COST 259 model. The delay spreads for each model are close to expected medians when applying the COST 259 model in reasonably sized macrocells. In the rural model a direct path is present, resulting in Rice-type fading when filtered to wideband channels. The hilly terrain model consists of two clusters, a typical situation in these environments.

With the chosen parameters the models will be quite similar to the GSM channel models [2], after filtering to the GSM bandwidth.

In Section 5, the channel models are specified explicitly. The tap delays have been determined by generating 20 independent identically distributed values from a uniform distribution in the interval \([0, 4 \cdot \sigma_D]\), where \(\sigma_D\) is the rms delay spread. For the Hilly Terrain channel 10 paths have been generated for each cluster and for the Rural Area model there is a total of 10 taps. Relative powers have then been calculated using the channel shapes in Annex A, Table A.3. The channels have been normalised so that the total power in each channel is equal to one.

## 5 Channel model descriptions

Radio wave propagation in the mobile environment can be described by multiple paths which arise due to reflection and scattering in the mobile environment. Approximating these paths as a finite number of \(N\) distinct paths, the impulse response for the radio channel may be written as:

\[
h(\tau) = \sum_{i=1}^{N} a_i \delta(\tau - \tau_i)
\]

which is the well known tapped-delay line model. Due to scattering of each wave in the vicinity of a moving mobile, each path \(a_i\) will be the superposition of a large number of scattered waves with approximately the same delay. This superposition gives rise to time-varying fading of the path amplitudes \(a_i\), a fading which is well described by Rayleigh distributed amplitudes varying according to a classical Doppler spectrum:

\[
S(f) \propto 1/(1 - (f / f_D)^2)^{0.5}
\]

where \(f_D = v / \lambda\) is the maximum Doppler shift, a function of the mobile speed \(v\) and the wavelength \(\lambda\). In some cases a strong direct wave or specular reflection exists which gives rise to a non-fading path, then the Doppler spectrum is:

\[
S(f) = \delta(f - f_s)
\]

where \(f_s\) is the Doppler frequency of the direct path, given by its direction relative to the mobile direction of movement.

The channel models presented here will be described by a number of paths, having average powers \(\|a_i\|^2\) and relative delays \(\tau_i\), along with their Doppler spectrum which is either classical or a direct path. The models are named TUx, RAx and HTx, where \(x\) is the mobile speed in km/h. Default mobile speeds for the models are according to Table 5.1. The relative position of the taps is for each model listed with a 0.001 \(\mu\)s resolution.

### Table 5.1: Default mobile speeds for the channel models.

<table>
<thead>
<tr>
<th>Channel model</th>
<th>Mobile speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>TUx</td>
<td>3 km/h</td>
</tr>
<tr>
<td></td>
<td>50 km/h</td>
</tr>
<tr>
<td></td>
<td>120 km/h</td>
</tr>
<tr>
<td>RAx</td>
<td>120 km/h</td>
</tr>
<tr>
<td></td>
<td>250 km/h</td>
</tr>
<tr>
<td>HTx</td>
<td>120 km/h</td>
</tr>
</tbody>
</table>
The models may in certain cases be simplified to a specific application to allow for less complex simulations and testing. The simplification should be done with a specific time resolution $\Delta T$, which should be stated to avoid confusion: e.g. $RAX(\Delta T=0.1\mu s)$. An example of such a simplified model is shown in Annex B.

### 5.1 Typical Urban channel model (TUx)

#### Table 5.2: Channel for urban area

<table>
<thead>
<tr>
<th>Tap number</th>
<th>Relative time ($\mu s$)</th>
<th>average relative power (dB)</th>
<th>doppler spectrum</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>-5.7</td>
<td>Class</td>
</tr>
<tr>
<td>2</td>
<td>0.217</td>
<td>-7.6</td>
<td>Class</td>
</tr>
<tr>
<td>3</td>
<td>0.512</td>
<td>-10.1</td>
<td>Class</td>
</tr>
<tr>
<td>4</td>
<td>0.514</td>
<td>-10.2</td>
<td>Class</td>
</tr>
<tr>
<td>5</td>
<td>0.517</td>
<td>-10.2</td>
<td>Class</td>
</tr>
<tr>
<td>6</td>
<td>0.674</td>
<td>-11.5</td>
<td>Class</td>
</tr>
<tr>
<td>7</td>
<td>0.882</td>
<td>-13.4</td>
<td>Class</td>
</tr>
<tr>
<td>8</td>
<td>1.230</td>
<td>-16.3</td>
<td>Class</td>
</tr>
<tr>
<td>9</td>
<td>1.287</td>
<td>-16.9</td>
<td>Class</td>
</tr>
<tr>
<td>10</td>
<td>1.311</td>
<td>-17.1</td>
<td>Class</td>
</tr>
<tr>
<td>11</td>
<td>1.349</td>
<td>-17.4</td>
<td>Class</td>
</tr>
<tr>
<td>12</td>
<td>1.533</td>
<td>-19.0</td>
<td>Class</td>
</tr>
<tr>
<td>13</td>
<td>1.535</td>
<td>-19.0</td>
<td>Class</td>
</tr>
<tr>
<td>14</td>
<td>1.622</td>
<td>-19.8</td>
<td>Class</td>
</tr>
<tr>
<td>15</td>
<td>1.818</td>
<td>-21.5</td>
<td>Class</td>
</tr>
<tr>
<td>16</td>
<td>1.836</td>
<td>-21.6</td>
<td>Class</td>
</tr>
<tr>
<td>17</td>
<td>1.884</td>
<td>-22.1</td>
<td>Class</td>
</tr>
<tr>
<td>18</td>
<td>1.943</td>
<td>-22.6</td>
<td>Class</td>
</tr>
<tr>
<td>19</td>
<td>2.048</td>
<td>-23.5</td>
<td>Class</td>
</tr>
<tr>
<td>20</td>
<td>2.140</td>
<td>-24.3</td>
<td>Class</td>
</tr>
</tbody>
</table>

### 5.2 Rural Area channel model (RAx)

#### Table 5.3: Channel for rural area

<table>
<thead>
<tr>
<th>Tap number</th>
<th>Relative time ($\mu s$)</th>
<th>average relative power (dB)</th>
<th>doppler spectrum</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>-5.2</td>
<td>Direct path $f_s = 0.7 \cdot f_D$</td>
</tr>
<tr>
<td>2</td>
<td>0.042</td>
<td>-6.4</td>
<td>Class</td>
</tr>
<tr>
<td>3</td>
<td>0.101</td>
<td>-8.4</td>
<td>Class</td>
</tr>
<tr>
<td>4</td>
<td>0.129</td>
<td>-9.3</td>
<td>Class</td>
</tr>
<tr>
<td>5</td>
<td>0.149</td>
<td>-10.0</td>
<td>Class</td>
</tr>
<tr>
<td>6</td>
<td>0.245</td>
<td>-13.1</td>
<td>Class</td>
</tr>
<tr>
<td>7</td>
<td>0.312</td>
<td>-15.3</td>
<td>Class</td>
</tr>
<tr>
<td>8</td>
<td>0.410</td>
<td>-18.5</td>
<td>Class</td>
</tr>
<tr>
<td>9</td>
<td>0.469</td>
<td>-20.4</td>
<td>Class</td>
</tr>
<tr>
<td>10</td>
<td>0.528</td>
<td>-22.4</td>
<td>Class</td>
</tr>
</tbody>
</table>
MOBILE RADIO CHANNEL MODELING

Simplest Models

- Single tap Rayleigh fading
- Additive white Gaussian noise

\[ A(t) \] Rayleigh distributed

Transmitted signal \( A(t) \) \rightarrow \times \rightarrow \text{Received signal}
MOBILE RADIO CHANNEL MODELING

Ray Tracing

• Map based
• 2D / 3D
• Attenuation
• Number of reflections
• Phase
MOBILE RADIO CHANNEL MODELING

Ray Tracing

- Map based
- 2D / 3D
- Attenuation
- Number of reflections
- Phase
- Diffraction
- Scattering
MOBILE RADIO CHANNEL MODELING

Ray Tracing

© 2002 Jarno M. A. Tanskanen
MOBILE RADIO CHANNEL MODELING

Ray Tracing
MOBILE RADIO CHANNEL MODELING

Ray Tracing
MOBILE RADIO CHANNEL MODELING

Narrowband Channel

Bandwidth < Coherence Bandwidth
MOBILE RADIO CHANNEL MODELING

Wideband Channel

Bandwidth > Coherence Bandwidth
MOBILE RADIO CHANNEL MODELING

Wideband Channel Model

\[ W \quad \text{bandwidth, e.g., 5 MHz} \]
\[ A_1, \ldots, A_N \quad \text{Rayleigh / Rician & Lognormal & Weight} \]
MOBILE RADIO CHANNEL MODELING

Wideband Channel Model

Transmitted signal

\[ \frac{1}{W} \]

\[ A_1(t) \]

\[ A_2(t) \]

\[ A_3(t) \]

\[ \ldots \]

\[ A_N(t) \]

Received signal

\[ \frac{1}{W} \]

\[ \frac{1}{W} \]

\[ \frac{1}{W} \]

\[ \frac{1}{W} \]

\[ A_1, \ldots, A_N \]

Uncorrelated Rayleigh signals

Partially correlated Lognormal signals

© 2002 Jarno M. A. Tanskanen
COMPUTING THE CHANNEL MODEL

Channel Models Computationally Expensive

- Computational complexity?
- Parallel processing?
- Hardware / Software simulator?

\[ \text{square size } \propto \lambda \]

full model for each BS in each square
CHANNEL SOUNDING

Wideband / Narrowband Sounding

Sounding system example\(^1\)

- \(f_c = 2,154\) GHz
- 30 Mchips/s
- 33 ns delay resolution

\(^1\) Courtesy of J. Kivinen, Radio Laboratory, HUT. From paper: J. Kivinen, P. Suvikunnas, D. Perez, C. Herrero, K. Kalliola, P. Vainikainen "Characterization system for MIMO channels"
Courtesy of J. Kivinen, Radio Laboratory, HUT. From paper: J. Kivinen, P. Suvikunnas, D. Perez, C. Herrero, K. Kalliola, P. Vainikainen "Characterization system for MIMO channels"
COMMS SIMULATOR EXAMPLES

Transmitter Power Control Simulation
One base station, many mobiles

From other users' channels + noise

To other users' receivers
Overview of (FDD mode) WCDMA Closed Loop Power Control

Based on Concept Group Alpha Wideband Direct-Sequence CDMA (WCDMA) Evaluation Document (3.0) ETSI SMG, Meeting no 24 Madrid, Spain, 15.-19.12.97

Jarno Tanskanen, 5.3.1998

- chip rate: 4.096 Mcps (expandable to 8.102 Mcps and 16.384 Mcps)
- minimum band 2x5 MHz (FDD)
- PC rate: 1.6 kHz (poss. variable 500 Hz-2 kHz)
- PC step: 0.25-1.5 dB
- PC dynamic range:
  - UL: 80 dB, DL: 30 dB
- connection quality estimation depends on service combination

Abbreviations

| BER | Bit-Error-Rate |
| DPCCH | Dedicated Physical Control Channel |
| ETSI | European Telecommunications Standards Institute |
| FDD | Frequency Division Duplex |
| FER | Frame-Error-Rate |
| Mcps | Mega chips per second |
| MS | Mobile Station |
| MUD | Multi-User Detection |
| PC | Power Control |
| SIR | Signal-to-Interference Ratio |
| SMG | Special Mobile Group |
| TDD | Time Division Duplex |
| UL | Uplink |
| WB | WideBand |
| WCDMA | Wideband Code-Division-Multiple-Access system |

Color codes for the issues covered in text

- possible predictor application point
- subsystem of interest in applying predictors
- information flow

© 2002 Jarno M. A. Tanskanen


© 2002 Jarno M. A. Tanskanen