HOCHSCHULE
HANNOVER
UNIVERSITY OF
APPLIED SCIENCES
AND ARTS
–
*Fakultät IV
Wirtschaft und
Informatik*

Fahrzeugvernetzung – V2X

Lecture 5: Physical Layer and Channel Propagation Modeling

Hugues Tchouankem, 02.11.2022

Lecture 5
Previous Lecture

- **Multiple Access**

- **Random Access Protocols**
  - Pure ALOHA, Slotted ALOHA
- **Reservation-based Access Protocols**
  - TDMA, FDMA, CDMA
- **Carrier Sense Multiple Access**
  - CSMA
- **Hidden/Exposed Terminal Problem**

Lecture 5
Outline

- ► Overview Physical Layer
  - ► IEEE 802.11p
- ► Propagation Characteristics
- ► Multipath Propagation
- ► Orthogonal Frequency-Division Multiplexing
- ► Channel Propagation Models

Lecture 5

IEEE 802.11p (1/2)

- An approved amendment to the well-known **IEEE 802.11** standard introducing several modifications
  - Adapt the **physical (PHY) layer** and **Medium Access Control (MAC)** sublayer to the requirements of **highly dynamic** vehicular environment
  - Derived from **802.11a**
- Operation in the **5.9 GHz band**
- **10MHz physical layer (PHY)** mode with all timings doubled for greater robustness against delay-spread
- **No synchronization, authentication and association** with an access point as in 802.11a
  - These procedures are **very time-intensive**

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IEEE 802.11p (2/2)

- A new operation mode in the **MAC layer** (*managed, monitor, ad-hoc*)
  - **Outside-the-context-of-a-BSS** mode
    - Allows **immediate** communication without connection setup
    - Stations can operate **without being part of a BSS** (Basic Service Set)
    - No authentication/association procedures as a station may never join a BSS
  - Stations transmit/receive using **pre-agreed PHY parameters** or using a signaling channel to agree on such **parameters**

- Enhanced Distributed Channel Access (EDCA) for Quality of Service (QoS) that allows to prioritize safety messages
  - **Frames** classified into four distinct **access categories** w.r.t to different channel access parameters (handled in the last lecture)

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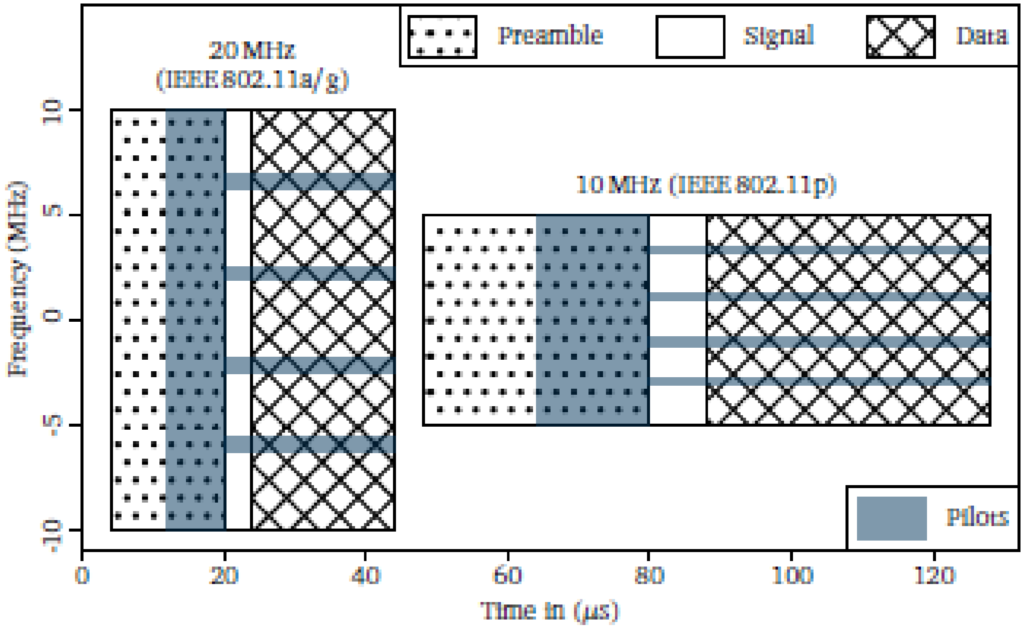
Physical Layer

- The PHY of IEEE 802.11p is based on **IEEE 802.11a**
  - but with all timings doubled, transforming the 20MHz channels of IEEE 802.11a into the 10MHz channels of IEEE 802.11p
  - Doubling the **timings** stretches the frame in **time domain** and shrinks it in **frequency** domain. The area in time-frequency domain remains **constant**
    - Spectral efficiency in **bits per Hertz per second** remains also constant



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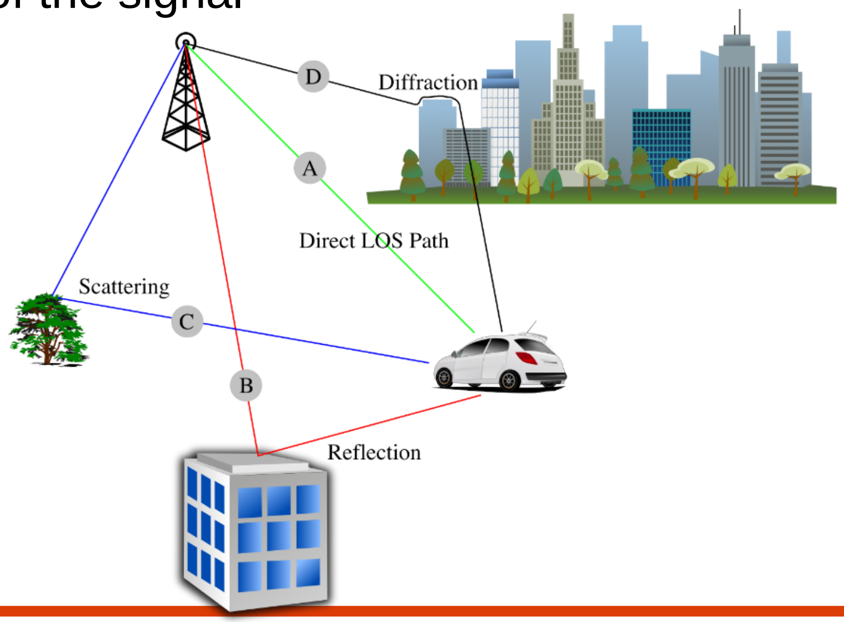
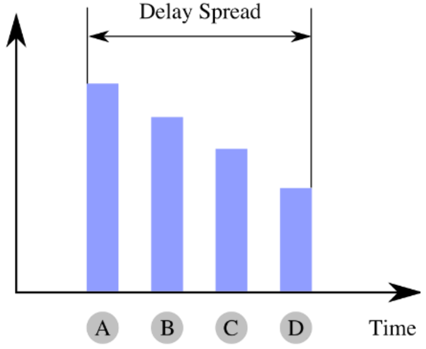
Doubling Time Parameters

- Doubling the time parameters may improve the **robustness** against the effects of mobility
  - Doubled **guard interval** reduces the **inter-symbol interference (ISI)** caused by multipath propagation
  - Robust to maximum **delay spreads**
    - Total elapsed time between the first (**direct line-of-sight path**) and **last** echo of the signal





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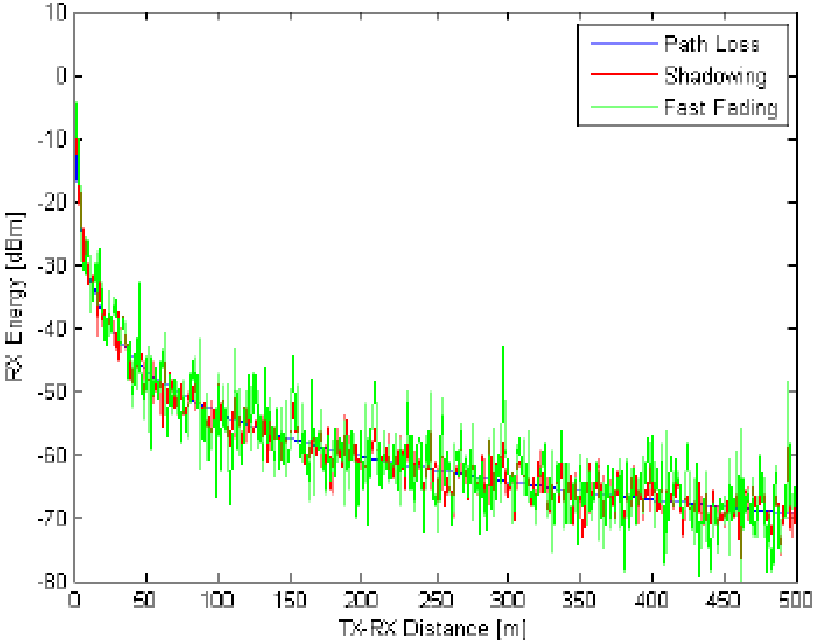
Multipath and Shadowing Effects

- BUT the increased **frame duration** makes the signal more sensitive against **fast-fading** effects
  - **Fast fading** originates due to effects of constructive and destructive interference patterns which is caused due to multipath
  - Effects particularly pronounced given the **small wavelength** (~5 cm at 5.9 GHz) and the high **relative velocities**



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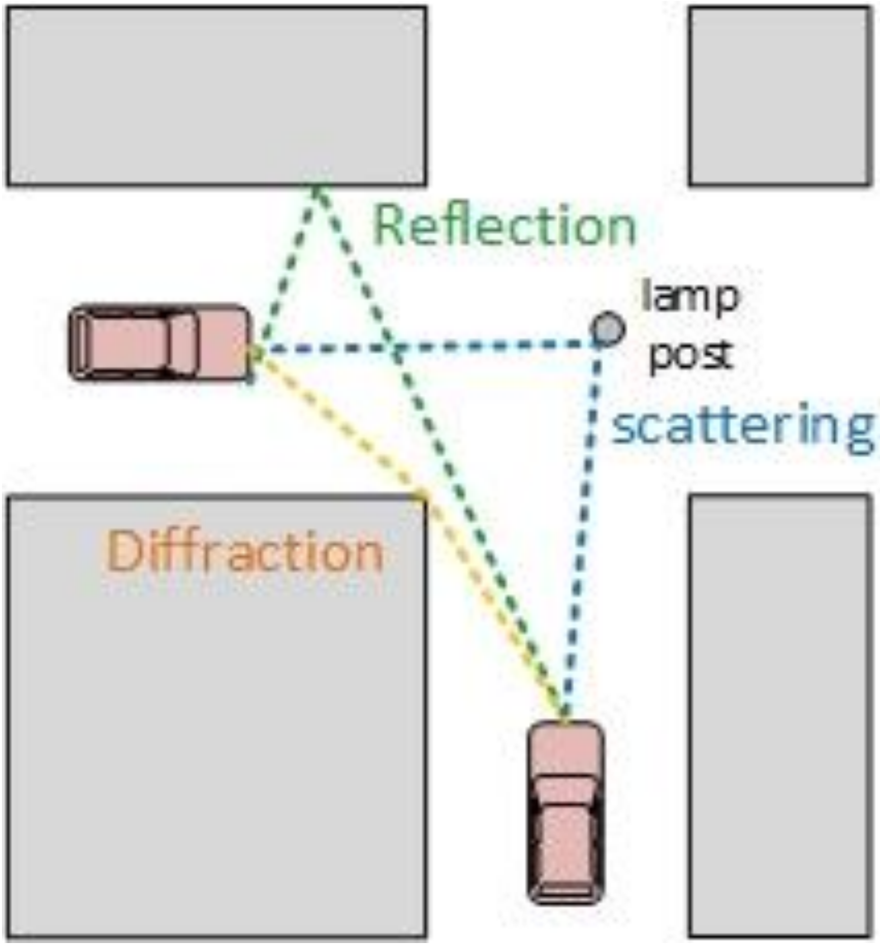
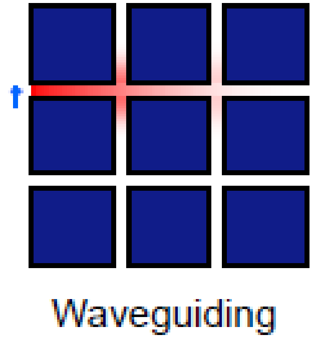
Propagation Characteristics

- **Reflection:** Occurs when a wave hits a smooth object that is larger than the wave itself
  - Wave may bounce in another direction (phase shift)
- **Diffraction:** Bending and spreading around of an signal when it encounters an obstruction
- **Scattering:** Occurs when a signals wavelength is larger than pieces of a medium → Wave is reflected into multiple directions
- **Wave guiding:** Signal propagation along street canyons

- If no LOS exists → diffraction and scattering are primary means of reception





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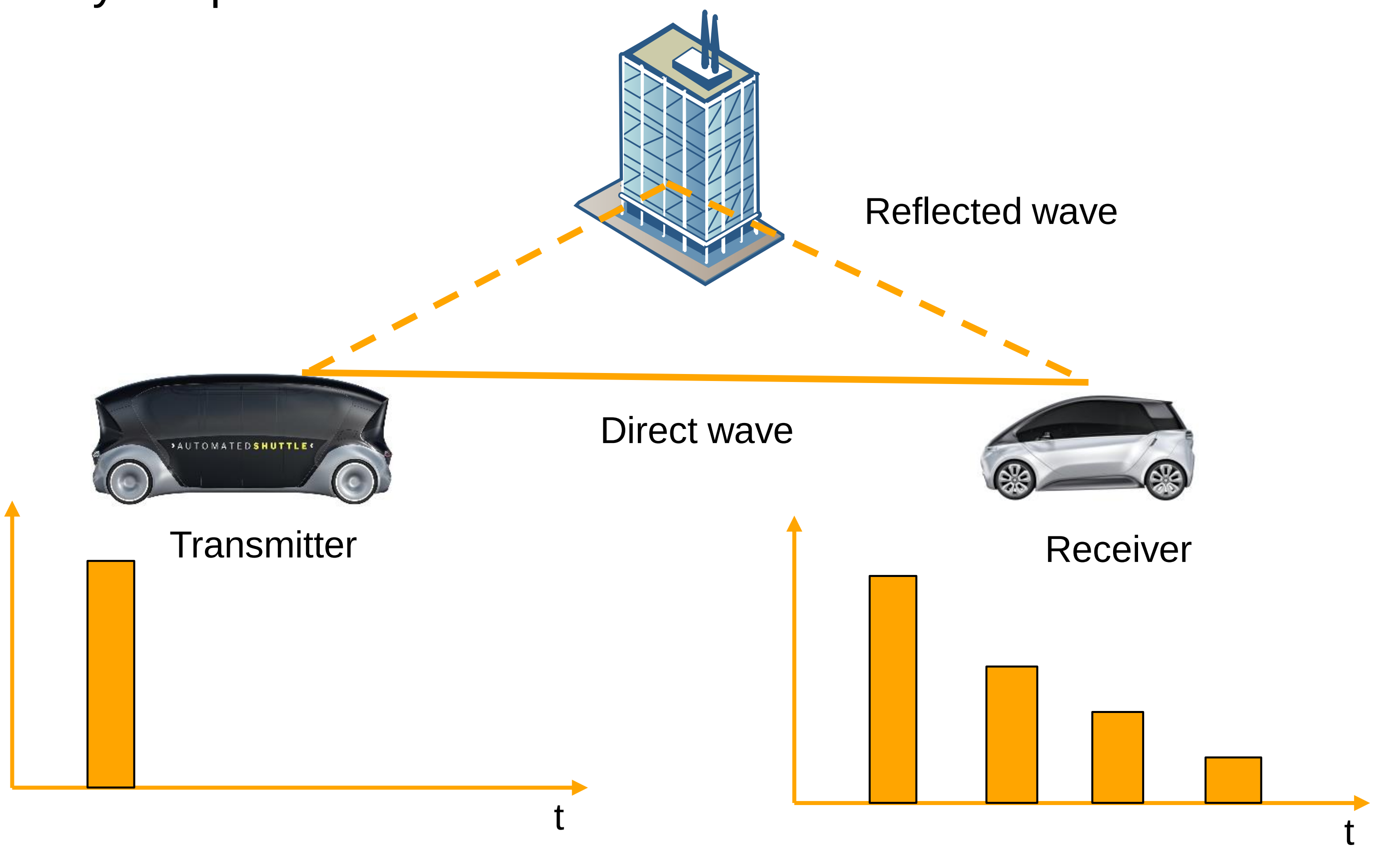
Multipath Propagation

- Multipath signals are **all time shifted** with respect to one another, as they travel different paths
  - Same signal arriving to the receiver through **different paths** and hence with different delays or phase shifts



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Delay Spread

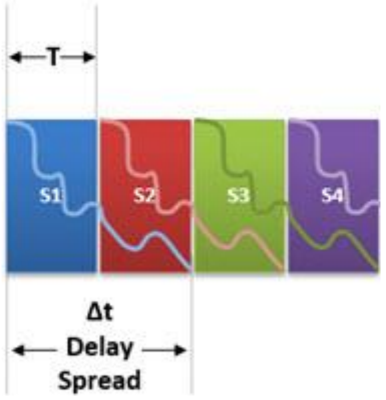
► Delay spread is the time between **first and last versions** of a signal

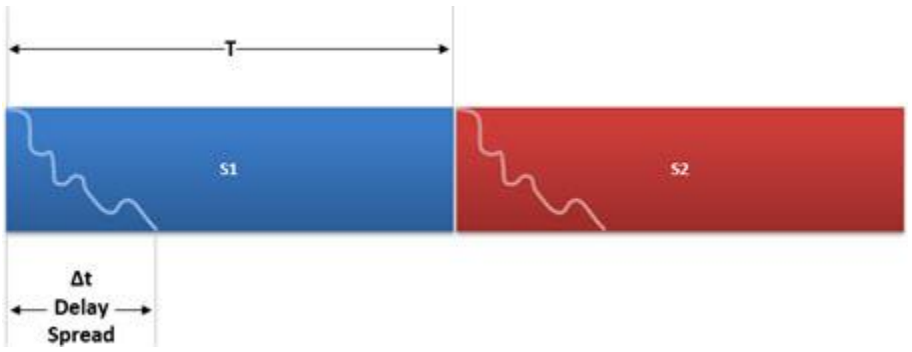
► Doubling guard interval reduces the inter-symbol interference (ISI) caused by multipath propagation

► (a) If the **symbol period T is very short** compared to the delay spread Δt the impact is **significant** (T << t)

► (b) if the **symbols length is extended**, most of symbols will **not suffer** the impact of ISI (T >> t)

► Increasing symbol length makes the physical layer **robust to maximum delay spreads**





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Typical Delay Spread Values

- ► Delay spread varies with the environment → 90% of delays introduced by multipath effect are lower than
  - ► Suburban: **0.6us**
  - ► Highway: **1.4us**
  - ► Rural: **1.5us**

- ► OFDM guard interval need to be longer than 1.5us
  - ► A channel width of 10MHz with **1.6us** is used for 802.11p
  - ► **8.5MHz** as a theoretical optimal channel width might **offers highest protection** again delay spread
    - ► Ease of implementation with 802.11a is a reasonable choice

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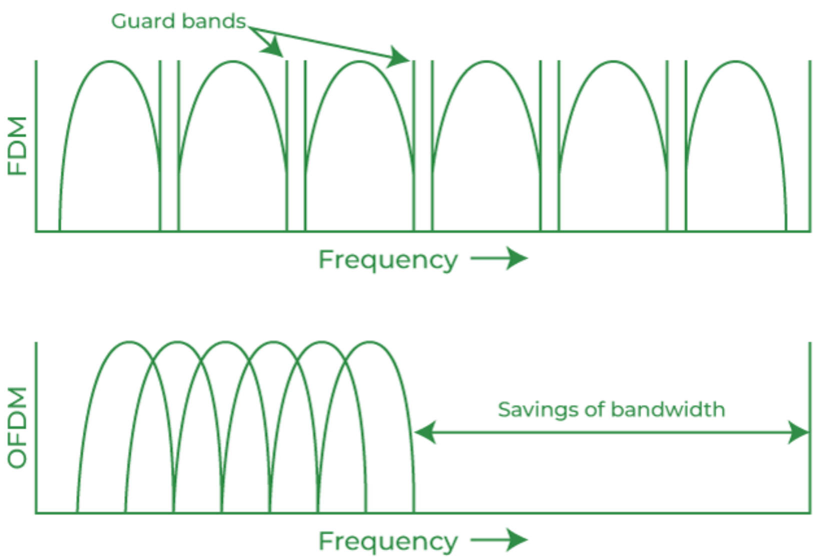
OFDM - Orthogonal Frequency-Division Multiplexing (1/3)

- ► IEEE 802.11p PHY adopts **OFDM** to combat inter-symbol interference and the preamble for signal detection, time synchronization, carrier frequency offset and channel estimation
- ► Frequency division multiplexing (FDM) scheme used as a digital multi-carrier modulation method
  - ► Use **multiple narrow-band subcarriers** instead of a **single wide-band carrier**



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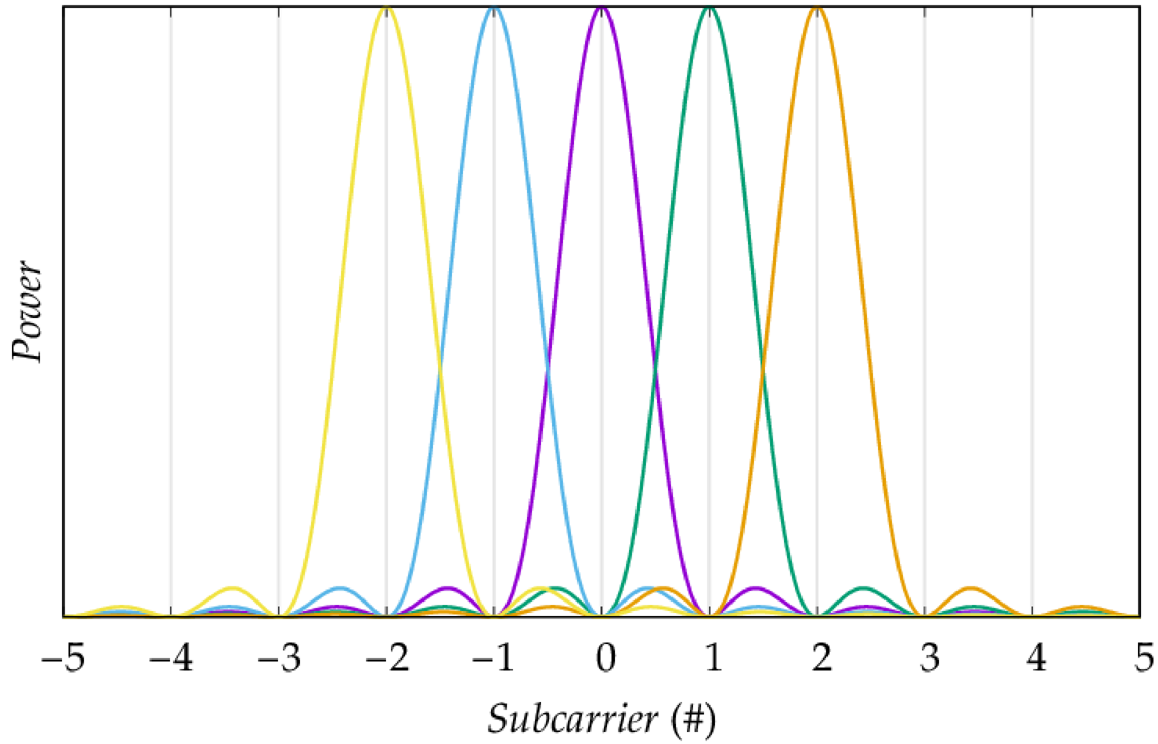
OFDM - Orthogonal Frequency-Division Multiplexing (2/3)

- It copes with severe channel conditions
  - **Multipath fading**
- Subcarrier signals are **orthogonal** to one another
  - Inter-carrier **guard bands** are not **required**
  - Spectra of the individual subcarriers **overlap**
    - They do not interfere at the **center frequencies** of other subcarriers
    - Contributions of each subcarrier are **zero** at multiples of the subcarrier spacing, i.e., the center frequencies of adjacent subcarriers



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OFDM - Orthogonal Frequency-Division Multiplexing (3/3)

- Some drawbacks
  - Need for a **guard period** between successive OFDM symbols
    - Duration of the guard period is chosen with regard to the **delay-spread** of the channel
    - It ensures that an OFDM symbol does not leak into the useful symbol time of the successive symbol, which would introduce **inter-symbol interference** and degrade performance
  - High Peak-to-Average Power Ratio (PAPR)
    - Contributions of the subcarriers occasionally add up, leading to peaks that can easily drive the **power amplifier into saturation**

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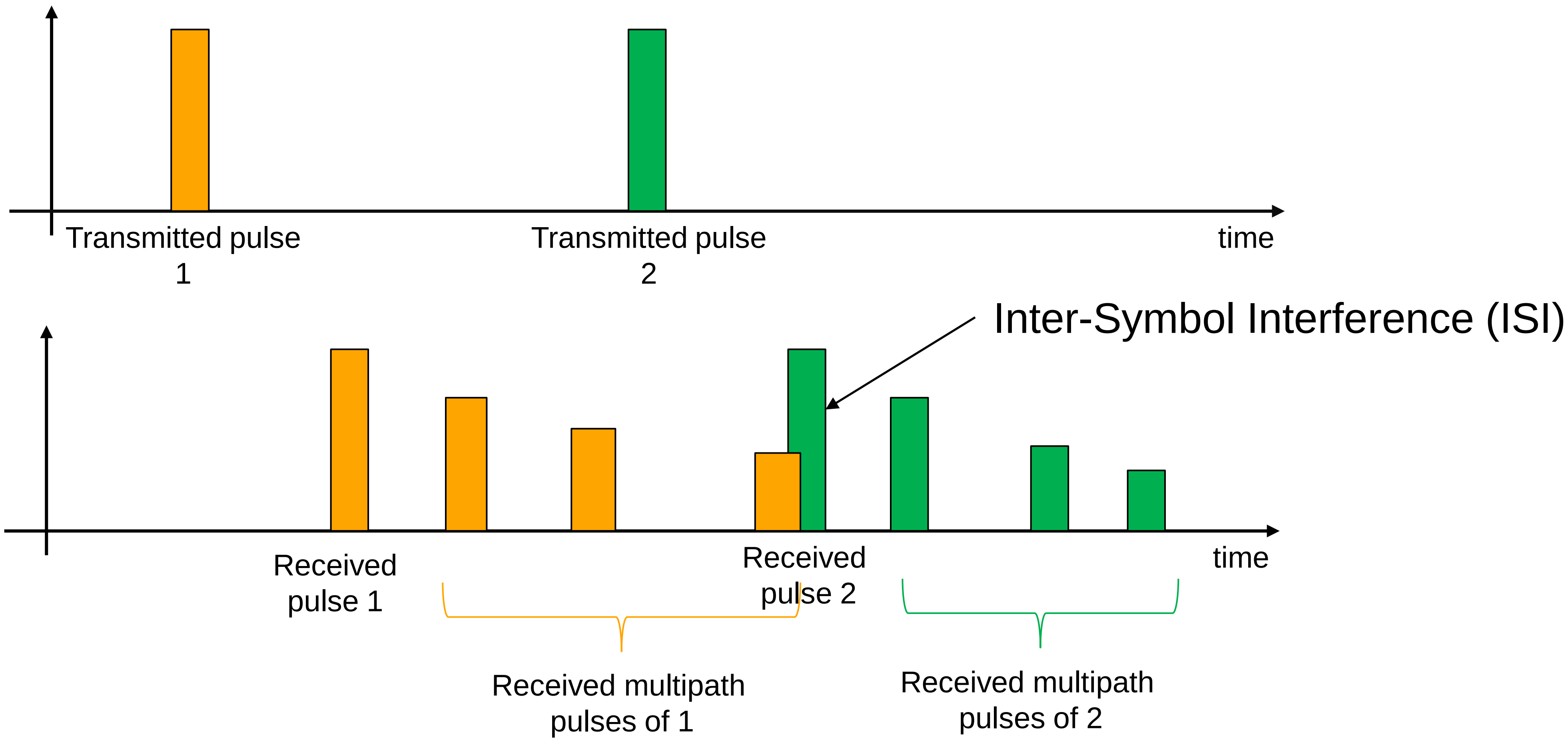
Inter-Symbol Interference

- ▶ Multipath may add **constructively** or **destructively**
- ▶ Delay spread is the time between **first and last versions** of a signal



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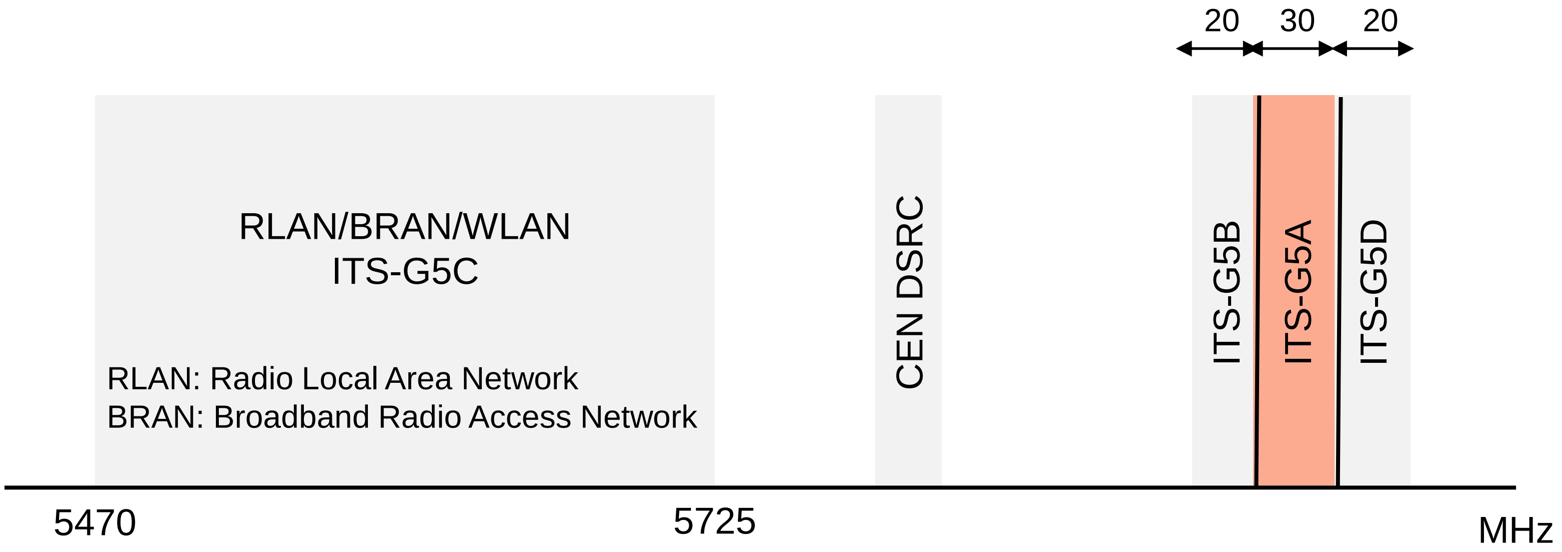
V2X Channel Allocation

- Channel allocation in the 5 GHz range
  - **ITS-G5A**: ITS road safety related applications
  - **ITS-G5B**: ITS non-safety applications
  - **ITS-G5C**: RLAN, BRAN, WLAN
  - **ITS-G5D**: Future ITS applications
  - **CEN DSRC**: Electronic toll collection



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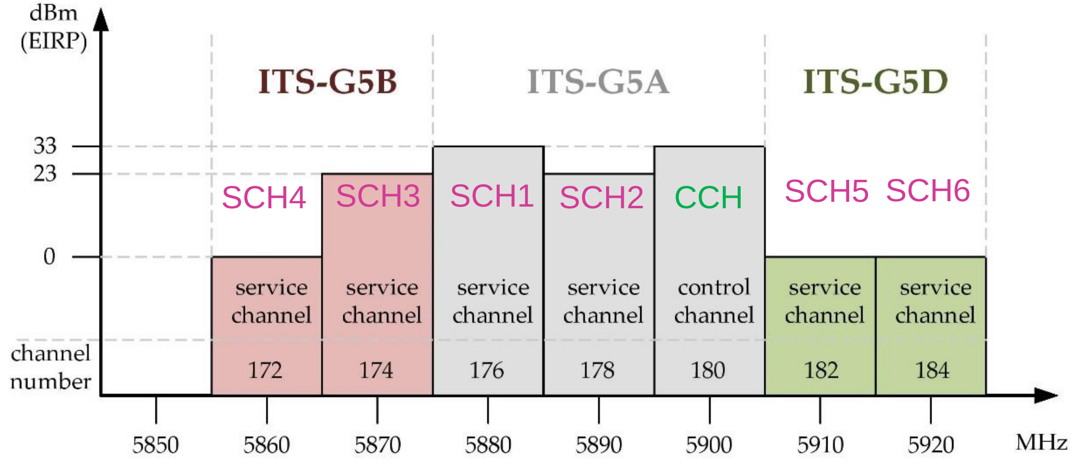
Channel Allocation

- Control Channel (CCH) is placed **at lower bound** of the frequency range
  - Benefit from less interference sources from nearby channels
    - Lowest part of the range is used as guard-band
- Control Channel is followed by SCH2, rather than SCH1
  - Nodes are allowed to transmit only at 23 dBm rather than 33 dBm
  - **Limit adjacent-channel interference**

	Channel type	Centre frequency	Channel number	Default data rate	Tx Power limit (EIRP)
ITS-G5A	CCH	5900 MHz	180	6 Mbit/s	33 dBm
	SCH2	5890 MHz	178	12 Mbit/s	23 dBm
	SCH1	5880 MHz	176	6 Mbit/s	33 dBm
ITS-G5B	SCH3	5870 MHz	174	6 Mbit/s	23 dBm
	SCH4	5860 MHz	172	6 Mbit/s	0 dBm
ITS-G5D	SCH5	5910 MHz	182	6 Mbit/s	0 dBm
ITS-G5D	SCH6	5920 MHz	184	6 Mbit/s	0 dBm



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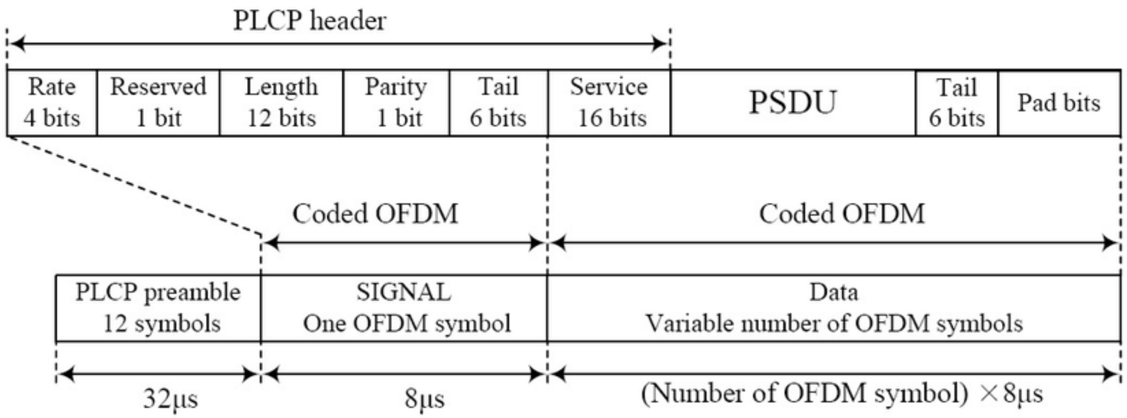
Frame Reception

- ► A sender may select **any modulation** and coding rate to transmit a frame
- ► To successfully receive a frame, a receiver needs to know whether the signal detected corresponds to a frame or just noise
  - ► Frame duration length, modulation rate and coding rate should be known
- ► Every frame starts with know **bit sequence** called **preamble**
  - ► Use to notify receivers of the eminent arrival of a frame
- ► The preamble is followed by the **physical layer convergence procedure (PLCP)**
  - ► Contains details on frame payload: frame length, modulation and coding rate



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Frame Reception Sequence

- ► When a radio is listening for incoming frames, it continuously looks for the **known pattern of the preamble** by demodulating the received signal
- ► Upon detection of the preamble, the receiver attempts to **decode the PLCP header**
- ► Upon success, the receiver demodulates incoming waveforms according to the **frame modulation, coding and duration** indicated in the PLCP header
- ► Raw bits are then passed to the **MAC layer** where a cyclic redundancy check (CRC) determined whether the frame is successfully received

- ► A receiver might be able to successfully **receive** and **decode preamble** and **PLCP header** but fails to receive the **frame body** (depends on signal quality)
- ► When a radio is **already receiving a frame**, it is not able to receive another **incoming frame**
  - ► It would treat the preamble of the new incoming frame as **part of the frame** being demodulated

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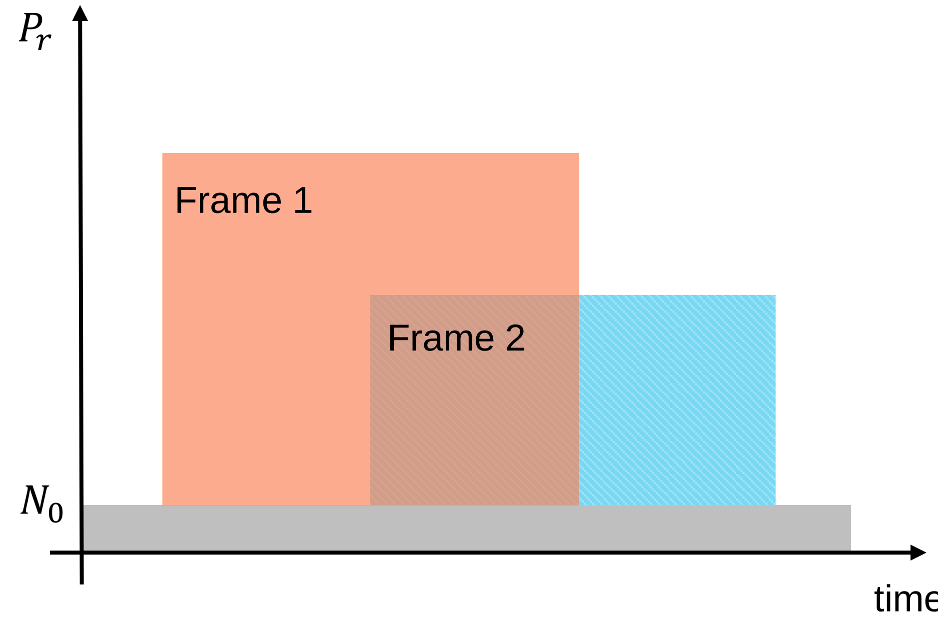
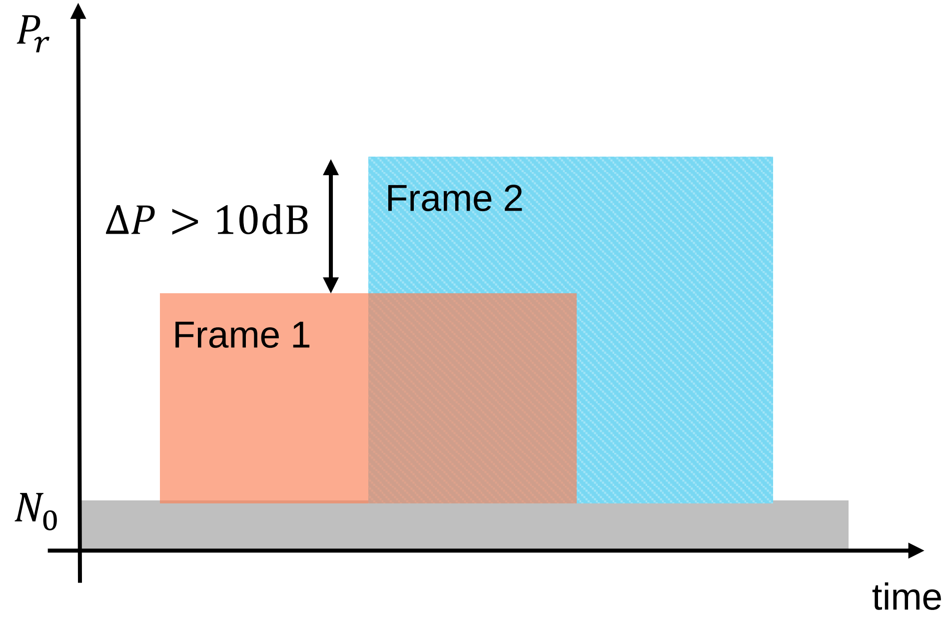
Frame Body Capture Effect

- Robust process for **decoding the preamble and PLCP header**
  - If a new frame arrives when a radio is still receiving the frame preamble and PLCP header of an earlier frame
    - The radio may choose **to lock onto the new frame** if it has sufficiently higher power than the earlier
    - It is also possible to capture a new incoming frame during the frame body reception
  - When a **sudden sharp (e.g. greater than 10dB)** is detected, the receiver assumes the arrival of a new frame with **a stronger signal**
    - Previous frame is then **abandoned** and preamble and PLPC of the new incoming frame is attempted to be decoded





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Frame Body Capture Effect

- Incoming frames associated with **stronger signal** are **preferred** over other others
  - They are likely originated by **nearby stations**

- Suitable for V2X enabling a cooperative awareness
  - Vehicles may preferred messages from **closer vehicles** over message from vehicles that are **further away**
  - Nearby vehicles will more likely impose **immediate risks** than faraway vehicles

- **Frame body capture** can also reduced the negative **impact of hidden terminal effects**

Lecture 5
Wireless Channel

► Wireless channel is a **medium** used to transmit data wirelessly from the transmitter antenna to the receiver antenna

Lecture 5
Channel Modeling

- ► Channel propagation model is a **mathematical representation** of the **effects** of a communication channel through which wireless signals are propagated
- ► Channel propagation models are used for **simulation** and **system testing**
- ► Channel propagation model is modeled **analytically** or **empirically** by real world measurements

- ► Two main approaches to model the channel
  - ► **Deterministic**
  - ► **Stochastic**

Lecture 5
Path Loss Model

- Knowledge of the propagation channel is essential for V2X communication systems
  - Required for the evaluation of interference and scalability analysis

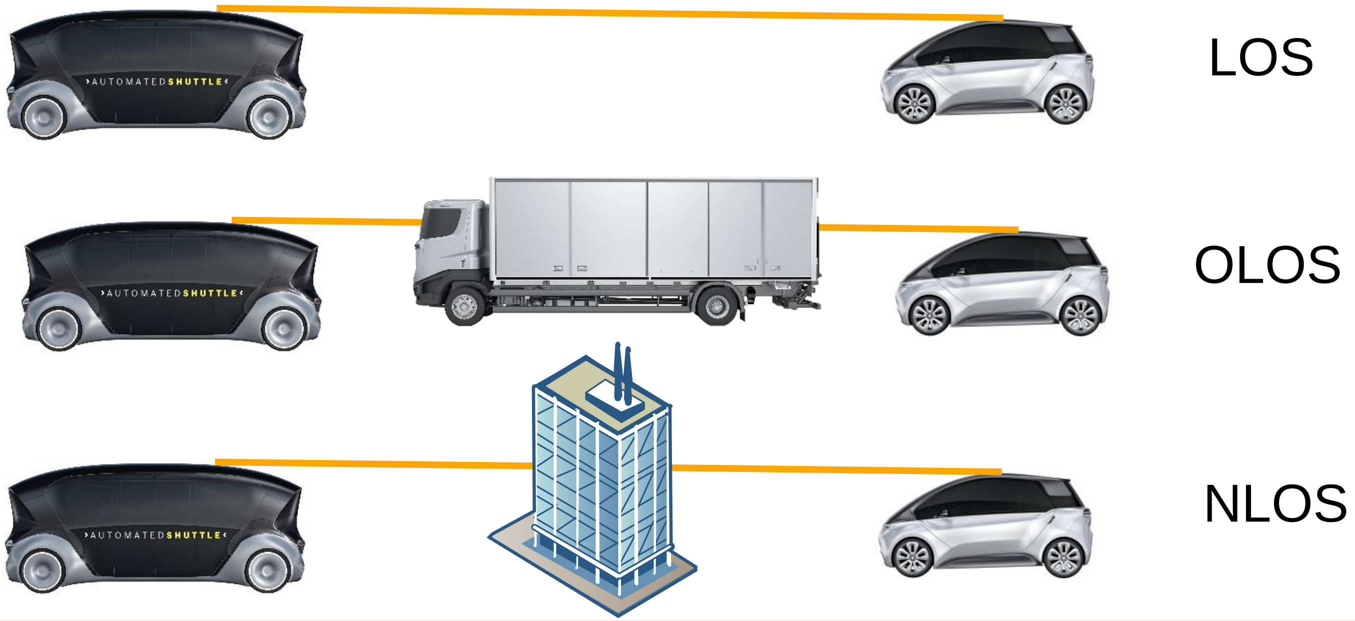
- **Received** power depends on **transmit** power, antenna gains and number of potential **loss terms**

$$P_r = P_t + G_t + G_r - \sum_x L_x \text{ in dB}$$

- How to derive the **path loss terms** $\sum_x L_x$?

Lecture 5
V2X Link Categories

- **Line-of-sight (LOS):** Situation where a line-of-sight between the TX and RX exists
- **Obstructed-line-of-sight (OLOS):** Situation where a line-of-sight between the TX and RX is obstructed partially by another object (dynamic blockages e.g. other vehicles)
- **Non-line-of-sight (NLOS):** Situation where the line-of-sight between the TX and RX is completely blocked by a larger object, e.g. a building



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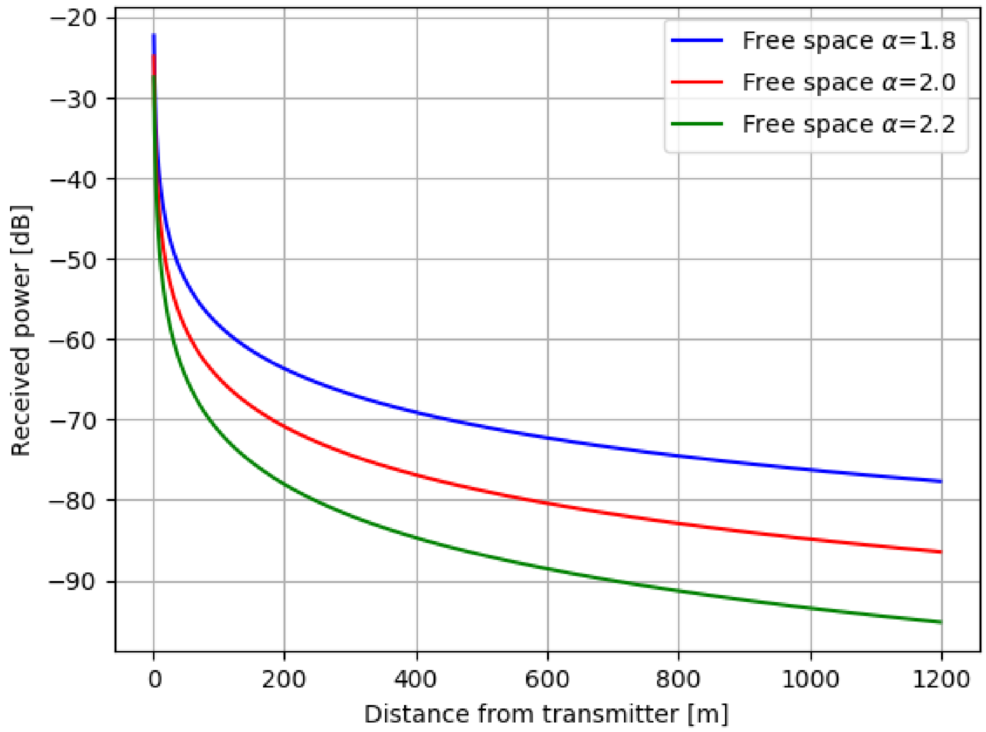
Free Space Model

- Path loss model computes the **average attenuation** of a signal in relation to the propagation **distance**
- **Free-space model** is the simplest deterministic path loss model known as Friis model
  - Consider only the distance and the wavelength **λ**
  - Path-loss exponent **α** for non-ideal channel conditions → **Environment-dependent**

$$L_{FS} = 10\log(16\pi^2 \frac{d^\alpha}{\lambda^\alpha})$$

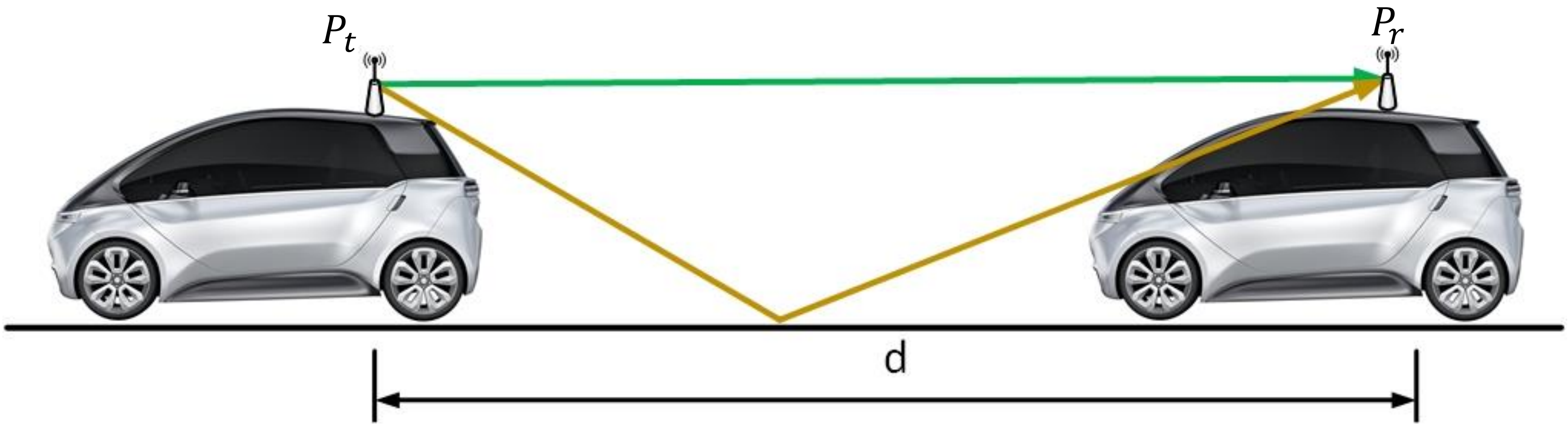


$$P_r = P_t + G_t + G_r - L_{FS} \text{ in dB}$$

Lecture 5

Two-Ray Interference Model (1/4)

- ► Deterministic channel model
- ► A **physically more accurate approximation** of path loss
  - ► **Phase difference** of two interfering rays: **direct** line-of-sight and **reflected** non-line-of-sight path
  - ► Received power $P_r = ?$



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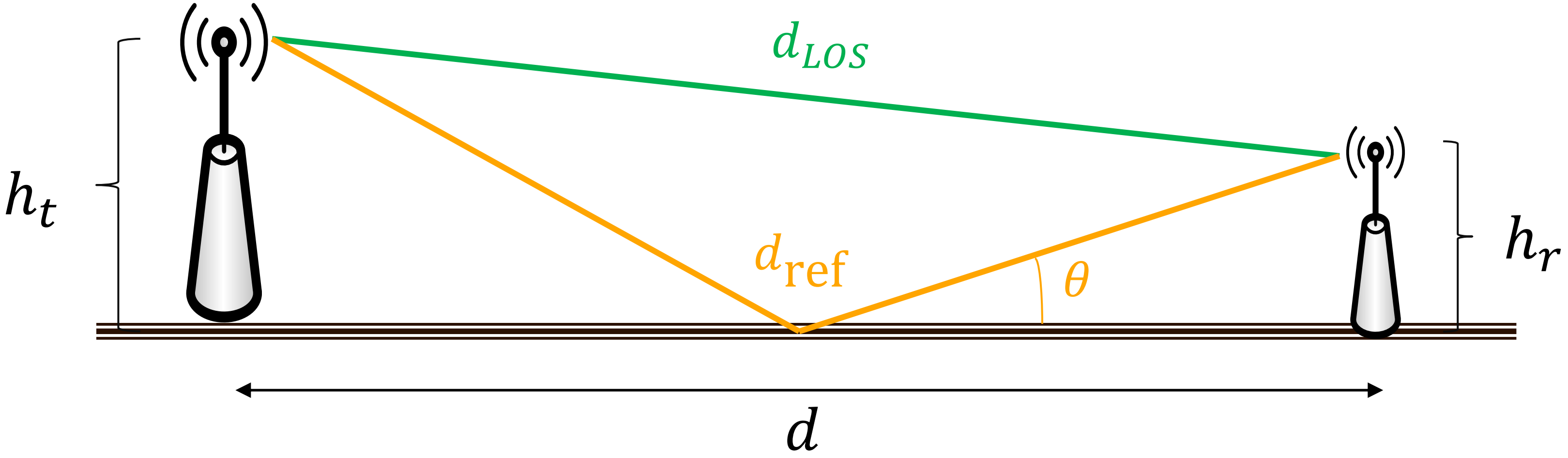
Two-Ray Interference Model (2/5)

► Radio signal reflected at the ground is also considered → more realistic



$$L_{TR} = 20\log(4\pi\frac{d}{\lambda}\left|1+\gamma e^{i\varphi}\right|)$$

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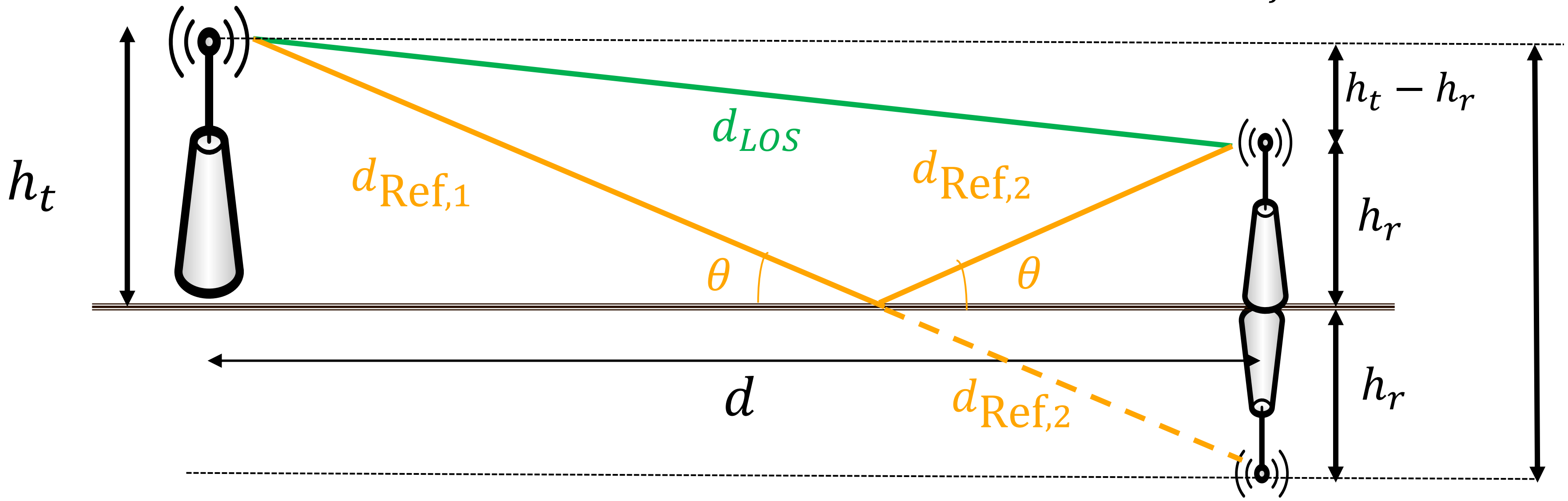
Two-Ray Interference Model (3/5)

$$\varphi = 2\pi \frac{d_{los} - d_{ref}}{\lambda}$$

$$d_{los} = \sqrt{d^2 + (h_t - h_r)^2}$$

$$d_{ref} = \sqrt{d^2 + (h_t + h_r)^2}$$



$$\sin\theta = \frac{h_t + h_r}{d_{ref}} \qquad \cos\theta = \frac{d}{d_{ref}}$$

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Two-Ray Interference Model (4/5)

$$\varphi = 2\pi \frac{d_{los} - d_{ref}}{\lambda}$$

$$d_{los} = \sqrt{d^2 + (h_t - h_r)^{\,2}}$$

$$d_{ref} = \sqrt{d^2 + (h_t + h_r)^{\,2}}$$

- **Phase difference** by the ray that is reflected from the ground compared to the direct path
- **Angle of incidence** θ

$$\sin\theta = \frac{h_t + h_r}{d_{ref}} \qquad \cos\theta = \frac{d}{d_{ref}}$$

- Reflection coefficient γ

$$\gamma = \frac{\sin\theta - \sqrt{\varepsilon_r - \cos\theta^2}}{\sin\theta + \sqrt{\varepsilon_r - \cos\theta^2}}$$

- **Path loss model** of two-ray interference model

$$L_{TR} = 20\log(4\pi \frac{d}{\lambda}\left|1 + \gamma e^{i\varphi}\,\right|)$$

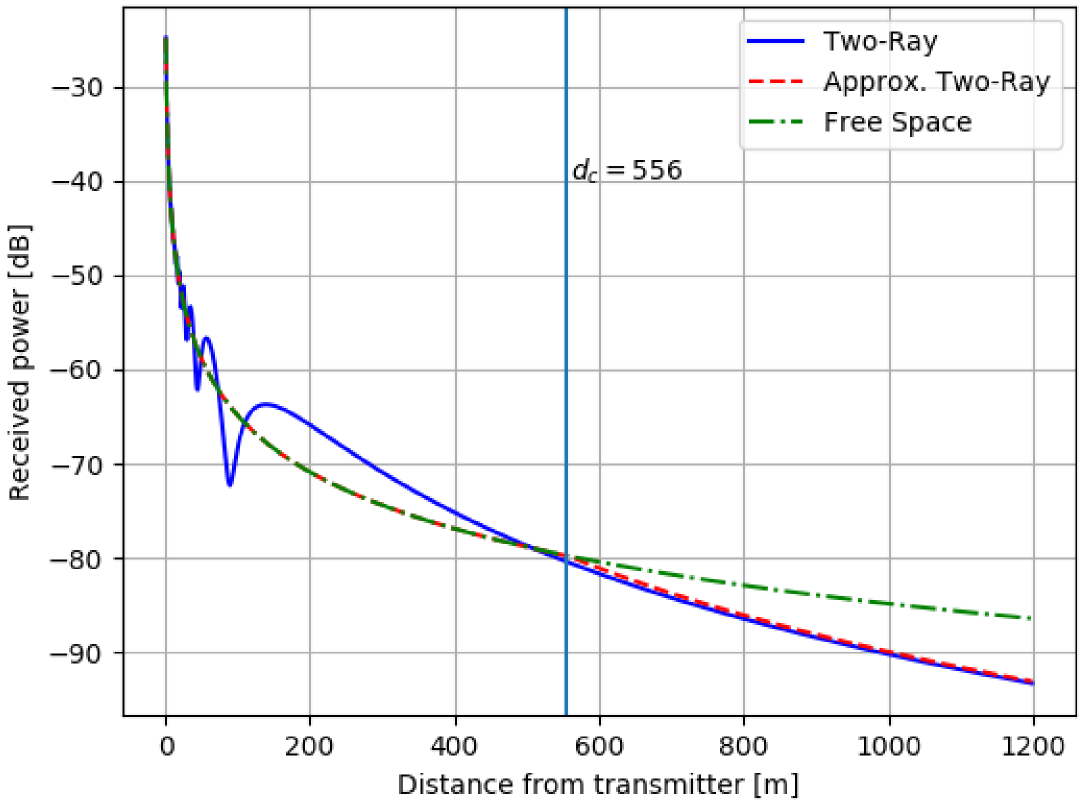
Lecture 5

Two-Ray Interference Model (5/5)

$$P_r = P_t + G_t + G_r - L_{TR} \text{ in dB}$$

- **Approximation** of two-ray interference model for **large distance**
  - To enable **fast simulation** but with the best level of accuracy

$$L_{TR,\text{far}} = 20\log(\frac{d^2}{h_t h_r})$$



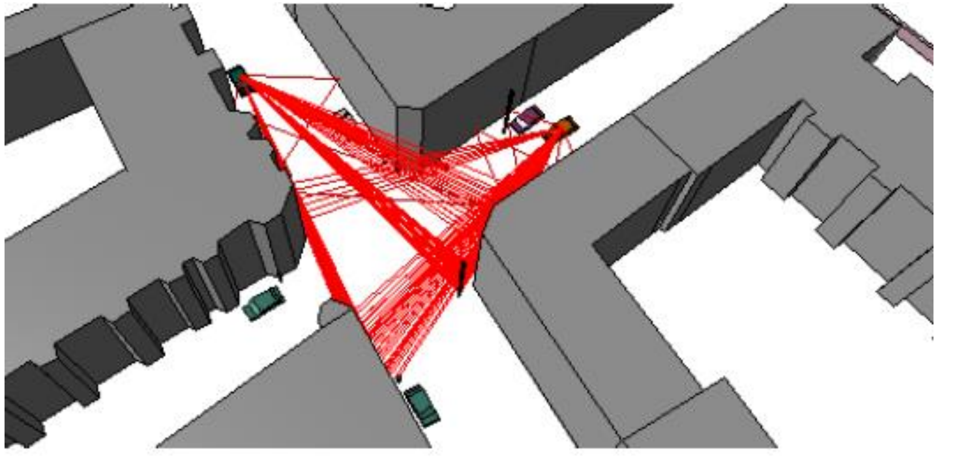
- Introducing a **cross-distance** $d_c = 4\pi \frac{h_t h_r}{\lambda}$
- Complete approximated two-ray interference model

$$L_{TR} = \begin{cases} L_{FS}\,, & d \le d_c \\ L_{TR,\text{far}}\,, & d > d_c \end{cases}$$

Lecture 5

3D Ray-optical Channel Model

- Deterministic channel modeling approaches using **3D ray-optical algorithms**
- Direct path, **reflections** as well as **diffuse scattering** are taken into account
- All objects in the environment need to be modeled with **characteristics** (permittivity, conductivity and thickness)
- Each ray is **individually** evaluated
- Provides **accurate models** BUT requires high computational **efforts**



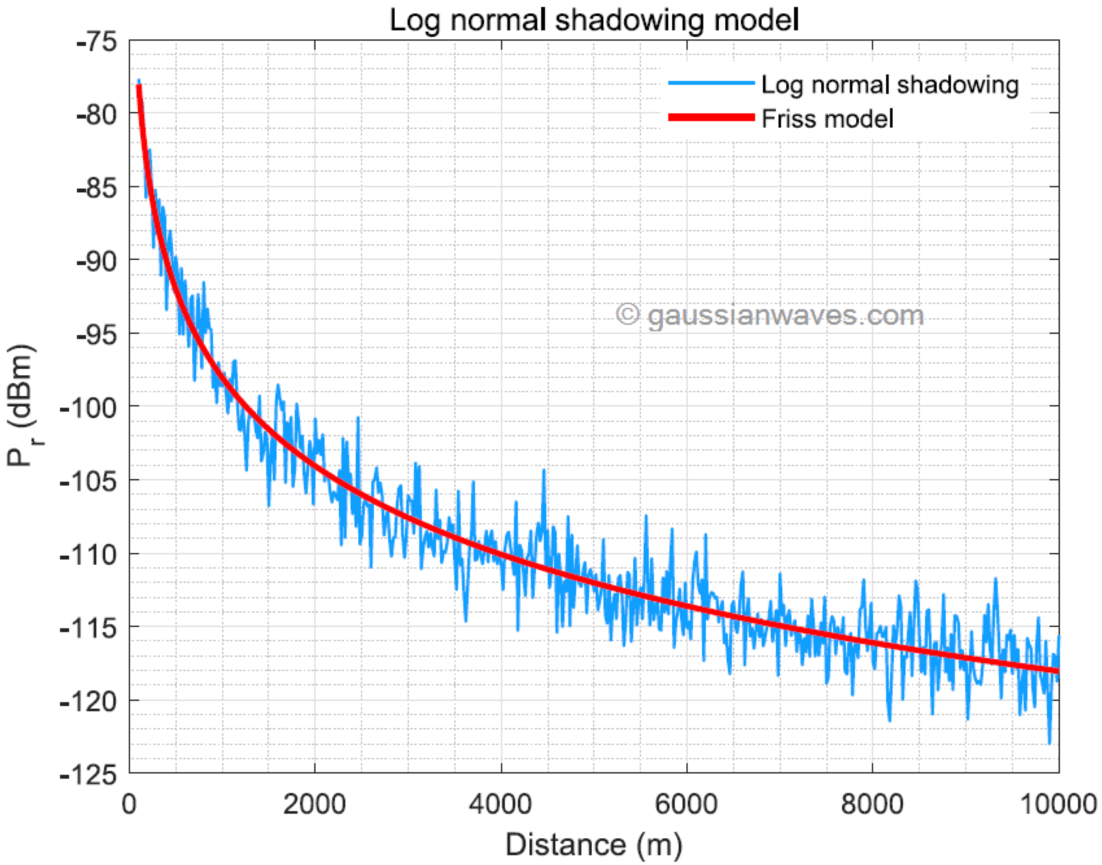
$$h(t) = \sum_{n=1}^{N} A_n \, \delta(t - \tau_n) \exp(-j\theta_n)$$

- Receive signal h(t) has N time-delayed impulses (rays), each of which is an attenuated and phase-shifted version of the original transmitted signal

Lecture 5

Log-Normal Shadowing Model (1/2)

- **Free space** and **two-ray interference** models do not include the critical fading effects found in a vehicular environment, i.e. shadowing or fading
- An extension of the free space model
- Encompasses random shadowing effects due to signal blockage by other vehicles, trees or building
- **Log-Normal Shadowing model** uses a normal distribution with variance σ to distribute reception power



$$P_r(d) = P_t + G_t + G_r - 10\alpha\log(d) + X_\sigma$$

- X_σ is a zero-mean Gaussian distributed random variable with standard deviation σ expressed in dB, used to emulate the shadowing effect

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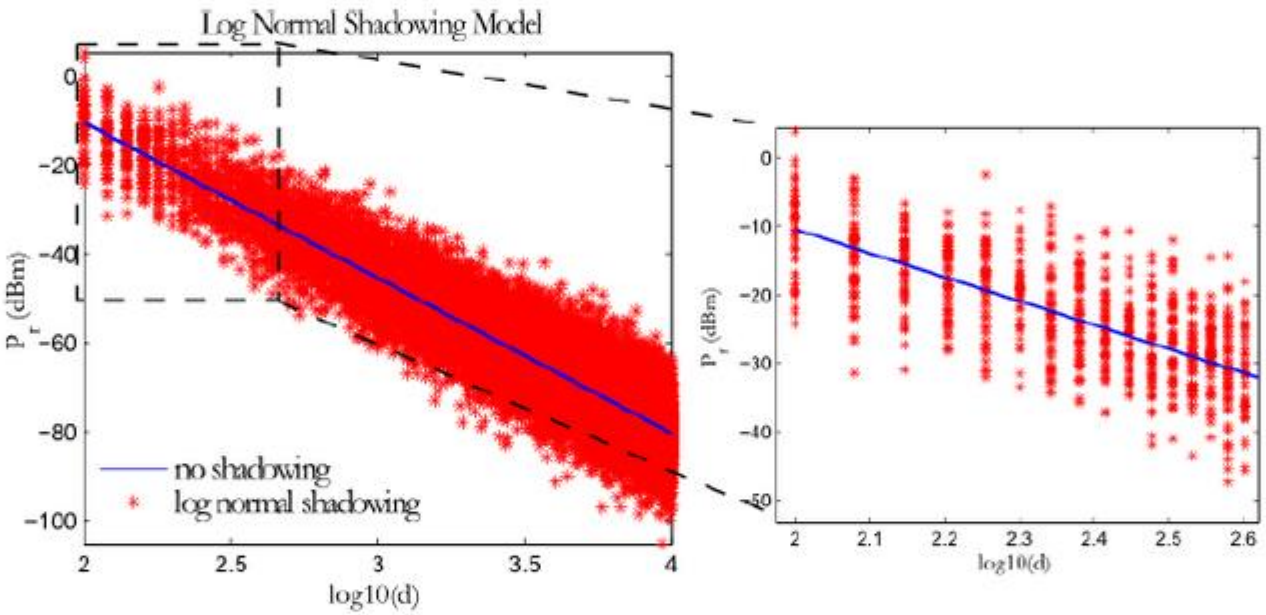
Log-Normal Shadowing Model (2/2)

- For every individual transmission the received power is then drawn from a **distribution**
  - With a certain probability two nodes close to each other cannot communicate
  - With a certain probability two nodes beyond the deterministic transmission range can communicate



$$P_r(d) = P_t + G_t + G_r - 10\alpha\log(d) + X_\sigma$$

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Nakagami Model

- Stochastic channel model
- It models situations used when scattered signals reach a receiver by multipath
- Reception power follows a **gamma distribution**

$$P_r(d, \mathrm{m}) = \mathrm{Gamma}(\mathrm{m}, \frac{\mathrm{P_{r,det}(d)}}{\mathrm{m}})$$

- Parameter m specifies the intensity of fading
- Distance dependence of the fading severity as a function of the distance between transmitter and receiver

$$\mathrm{m(d)} = 2.7\exp(-0.01(\mathrm{d}-1)) + 1$$

Lecture 5
Literature

► E.M. van Eenennaam: “A Survey of Propagation Models used in Vehicular Ad hoc Network (VANET) Research”

► C. Sommer et al.: “Simulation Tools and Techniques for Vehicular Communications and Applications”, 2015

► T. Abbas et al.: “A Measurement Based Shadow Fading Model for Vehicle-to-Vehicle Network Simulations”, 2015

► B. Bloessl, "A Physical Layer Experimentation Framework for Automotive WLAN," Dissertation, Department of Computer Science, Paderborn University, June 2018