1. Enumerate the main changes on the physical layer to fulfill the V2X-requirements
    - Operation on an exclusive frequency band at 5.9 GHz
    - 10 MHz physical layer (PHY) mode with all timings doubled for greater robustness against multipath fading
2. List the main changes on the MAC layer
    - No synchronization, authentication and association as these procedures are very time sensitive
    - A new operation mode in the MAC layer: *outside-the-context of BSS* (OCB)
    - Enhanced Distributed Channel Access (EDCA) providing Quality of Service (QoS) that allows to prioritize safety messages
3. What is the motivation behind the operation mode *outside-the-context of BSS*?
    - 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
4. Explain briefly the advantages of doubling timing parameters on the physical layer
    - It ensures robustness against the effects of mobility as doubling the guard interval in time domain will reduce the inter-symbol interference (ISI) caused by multipath propagation
5. What is the main drawback of increasing a frame duration in time domain?
    - The increased frame duration makes the signal more sensitive against fast-fading effects
6. What is the delay spread?
    - Total elapsed time between the first (direct line-of-sight path) and last echo of a same signal
7. What is the source of fast fading?
    - Fast fading originates due to effects of constructive and destructive interference patterns which is caused due to multipath
8. List the four wave propagation characteristics specific to V2X communication
    - Reflection
    - Diffraction

- Scattering
- Wave guiding

9. When does scattering occur?

   - Scattering occurs when a signals wavelength is larger than pieces of a medium. The wave is reflected into multiple directions

10. What is multipath propagation?

    - Multipath propagation is the propagation phenomenon that happens when a same signal arrives at the receiver through different paths and hence with different delays or phase shifts

11. How does increasing the symbol length affect the communication performance?

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

12. What are the advantages of Orthogonal Frequency-Division Multiplexing (OFDM)?

    - Combats inter-symbol interference
    - Provides robustness against severe channel conditions such as multipath fading
    - Increases spectral efficiency as inter-carrier guard bands are not required

13. How does OFDM deals with subcarriers overlaps?

    - Subcarriers 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

14. What are the factors that cause inter-symbol interference (ISI)?

    See lecture slide 16

15. What is the role of the preamble?

    - A bit sequence used to notify receivers of the eminent arrival of a frame

16. What is the content of the physical layer convergence procedure (PLCP)

    - Provides details on frame length, modulation and coding rate

17. List the sequences during frame reception

    - See lecture slide 20

18. How does frame body capture effect works?

- See lecture slide 21

19. How does frame body capture effect reduces the impact of hidden terminal?

    - At least one frame (with stronger signal) originated by a hidden station would probably be successfully received even in an overlapping situation

20. What is a channel propagation model?

    - Mathematical representation of the effects of a communication channel through which wireless signals are propagated

21. Briefly provide two approaches for channel modeling

    - Deterministic
    - Stochastic

22. What is the difference between NLOS and OLOS?

    - 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
    - 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)

23. Briefly present the Two-Ray interference model

    - Deterministic channel model
    - A physically more accurate approximation of path loss considering the phase difference of two interfering rays: direct line of sight and reflected non line of sight path

24. Derive the phase difference as well as the angle of incidence of the Two-Ray interference model

    Solution: By considering the drawing on figure 1, we could derive the following

    - Length of the direct line-of-sight ray

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

    - Length of the ground-reflected ray

    $$d_{Ref,1} + d_{Ref,2} = \sqrt{(h_t + h_r)^2 + d^2}$$

    - Path-length difference between both waves

    $$\Delta d = d_{Ref,1} + d_{Ref,2} - d_{LOS} = \sqrt{(h_t + h_r)^2 + d^2} - \sqrt{(h_t - h_r)^2 + d^2}$$

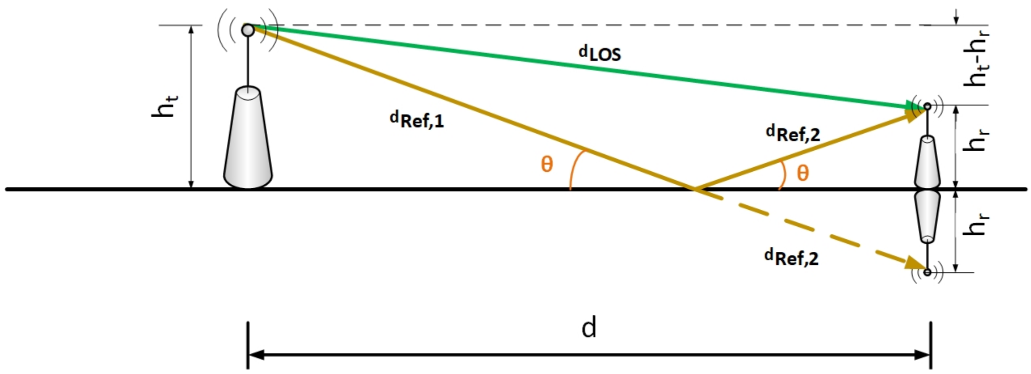

Figure 1: Simplification of the Two-Ray interference model

- Phase difference between the waves is $\Delta\phi = \frac{2\pi\Delta d}{\lambda}$
- Angle of incidence is the angle between the direct and the reflected ray

$$\sin\theta = \frac{h_t + h_r}{d_{Ref,1} + d_{Ref,2}} = \frac{h_t + h_r}{\sqrt{(h_t + h_r)^2 + d^2}}$$

$$\cos\theta = \frac{d}{d_{Ref,1} + d_{Ref,2}} = \frac{d}{\sqrt{(h_t + h_r)^2 + d^2}}$$

25. What is the motivation of providing an approximation of Two-Ray interference model?
    - Enable fast simulation but with the best level of accuracy
26. Briefly present the 3D Ray-optical channel model
    - Deterministic channel modelling approaches using 3D ray-optical algorithms
    - Each ray is modelled individually considering wave reflection, diffraction and scattering
27. What are the limitations of 3D Ray-optical channel model?
    - High computational efforts required
    - Couldn't ensure real time or near real time simulation
28. Briefly present the log-normal channel model
    - Uses a normal distribution with a fixed variance to distribute reception power
    - For every individual transmission the received power is then drawn from a distribution
    - Considers additional factors (shadowing) that contribute to path loss such as obstacles, which shield a receiver from all or part of the radiated power

29. Consider the following vehicular network topology shown in Figure 2 where vehicles B, C and D broadcast their frames with a transmission power $P_t = 23$ dBm at the frequency $f = 5.9$ GHz. For the path loss calculation between stations, assume a free space channel model with a path loss exponent of $\alpha = 2.0$.

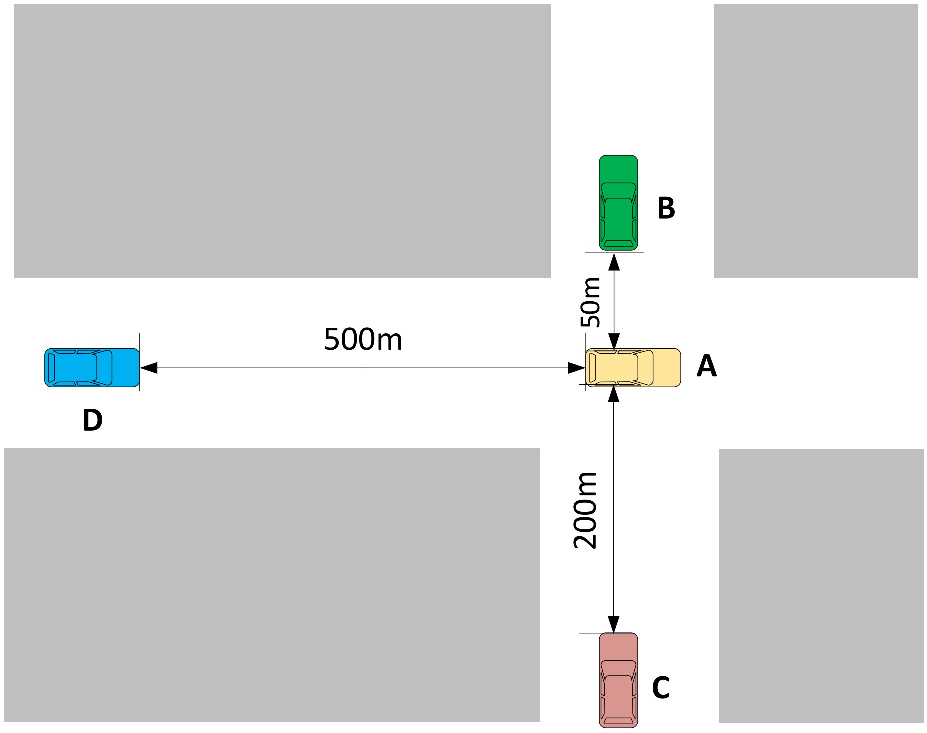

Figure 2: An intersection scenario

(a) The broadcasting vehicles transmit at different times without frame overlaps at any receiver. Calculate the received power $P_{r,B}$, $P_{r,C}$, and $P_{r,D}$ in dBm at the receiving vehicle A. Assume transmitter/receiver .antenna gain $G_t = G_r = 0$ dBi

- Received power

$$P_r = P_t + G_t + G_r - L_{FS}$$

where free space loss component L_{FS} is given as

$$L_{FS} = 10\log_{10}\left(4\pi\frac{d}{\lambda}\right)^2 = 20\log_{10}\left(4\pi\frac{d}{\lambda}\right) = 20\log_{10}\left(\frac{4\pi f}{c}\right) + 20\log_{10}(d)$$

$$\Longrightarrow P_{r,B} = -58.83 \text{ dBm}, \ P_{r,C} = -70.87 \text{ dBm, and } P_{r,D} = -78.83 \text{ dBm}$$

(b) Now assume that vehicles B and C transmit simultaneously their respective frames B and C which overlap at the receiving vehicle A.

i. Calculate the signal interference noise ratio (SINR) of each frame considering a noise power $N_0 = -100$ dBm
ii. How does the frame body capture help in such a situation?

- Signal interference noise ratio

$$SINR = \frac{P_r}{N_0 + \sum I}$$

where P_r is the power of the incoming signal of interest, I is the interference power of the other (interfering) signals in the network and N is some noise term.

Frame C is the interfering signal for frame B at the receiving vehicle A:

$$SINR_B(mW) = \frac{P_B(mW)}{N_0(mW) + P_C(mW)} = \frac{10^{P_{r,B}/10}}{10^{N_0/10} + 10^{P_{r,C}/10}} = \frac{1.3 \times 10^{-6}}{10^{-10} + 8.16 \times 10^{-8}} = 15.98\ mW$$

$$SINR_B(dBm) = 10 \log_{10}(15.98) = 12.3\ dBm$$

Likewise the frame B is the interfering signal for frame C:

$$SINR_C(mW) = \frac{P_C(mW)}{N_0(mW) + P_B(mW)} = \frac{10^{P_{r,C}/10}}{10^{N_0/10} + 10^{P_{r,B}/10}} = \frac{8.16 \times 10^{-8}}{10^{-10} + 1.3 \times 10^{-6}} = 0.0625\ mW$$

$$SINR_C(dBm) = 10 \log_{10}(0.0625) = -12.04\ dBm$$

- Although both frames B and C simultaneously arrive at the receiving vehicle A, the frame body capture enables the capability to capture the frame with stronger signal whenever the signal difference is greater than 10 dB

  $\Delta P_r = P_{r,B} - P_{r,C} = 12.04\ dB > 10\ dB \implies$ Frame B would successfully be decoded by vehicle A