1. What are the challenges faced by multiple access mechanism?

   - Shared medium: All stations share the same communication channel
   - No centralized control and uncoordinated channel access
   - Access to the channel by others cannot be blocked by a sender
   - Packet collisions may occur if more than two stations transmit at the same time

2. List three strategies used to coordinate a multiple channel access and briefly describe their functions

   - Static allocation: Channel capacity is divided among the stations. Each station's (frequency, time) is reserved
   - Dynamic assignment: No a priori allocation, before sending stations have to obtain permission to send
   - Random access: No a priori allocation, no coordination of/among stations

3. What are the advantages of using a static channel allocation?

   - A well-defined quality of service could be guaranteed
   - No further control of channel access is needed

4. What is the main task of MAC protocols?

   MAC protocols are responsible for regulating access to the shared communication medium by scheduling transmissions in time, frequency, space or/and unique codes to distinguish different users

5. List and describe three main categories of MAC protocols for wireless networks

   - Reservation-based: Static allocation or dynamic assignment of resources to stations
   - Random access: Stations compete for the channel using randomized procedures, no collision free allocation
   - Random with reservation: Stations compete using random access to obtain a dynamic assignment of resources

6. List and describe three main categories of MAC protocols for V2X networks

   - Contention-based: No predetermined schedule and vehicles are allow to access the channel randomly when they need to transmit, collisions may occur
   - Contention-free: Requires a predetermined channel access schedule. Each vehicle is allow to access the channel by a predetermined time slot, frequency band or code sequence
   - Hybrid: Combination of contention-based and contention-free to provide a high quality of service and therefore reduce the collision probability

7. List two requirements of MAC protocols imposed by the highly dynamic nature of V2X networks

   - Self-organizing: Scheduling of transmissions have to be performed in a distributed manner
   - Reactiveness: Management of allocated resources should be flexible and fast enough to let the protocol react timely to topology changes due to mobility

8. Explain how the pure ALOHA protocol works

   Whenever a station has a packet to send, it simply transmits the packet, if a collision occurs, it waits for a random period of time and re-sends it again

9. Derive the efficiency of pure ALOHA protocol

   The efficiency $E(p)$ is defined as the probability that any one of the N stations has a success (Transmission without collision)

$$E(p) = Np(1-p)^{2(N-1)}$$

10. Show that the maximum efficiency of pure ALOHA is 1/2e. Hint: $\lim_{N\to\infty}(1-\frac{1}{N})^N = 1/e$

    To determine the maximum efficiency $E_{\max}$, we have to find the p that maximizes the efficiency for a large number of stations $N \to \infty$

$$\frac{dE(p)}{dp} = 0 \implies \overbrace{N}^{f'}\overbrace{(1-p)^{2(N-1)}}^{g} - \overbrace{Np}^{f}\overbrace{2(N-1)(1-p)^{2(N-1)-1}}^{g'} = 0$$

$$N(1-p)^{2(N-1)-1}((1-p)-p2(N-1)) = 0$$

$$(1-p)-p2(N-1) = 0$$

$$p(1-2N)+1 = 0$$

$$p = \frac{1}{2N-1} \implies E_{\max} = \frac{N}{2N-1}\left(1-\frac{1}{2N-1}\right)^{2(N-1)}$$

$$\lim_{N\to\infty} E_{\max} = \lim_{N\to\infty} \frac{N}{2N-1}\left(1-\frac{1}{2N-1}\right)^{2(N-1)}$$

$$= \lim_{N\to\infty} \underbrace{\frac{N}{2N-1}}_{\frac{1}{2}} \frac{\overbrace{\left(1-\frac{1}{2N-1}\right)^{2N-1}}^{\lim_{N\to\infty}(1-\frac{1}{N})^N = 1/e}}{\underbrace{\left(1-\frac{1}{2N-1}\right)}_{1}}$$

$$= \frac{1}{2}\cdot\frac{1}{e}$$

11. A group of N vehicles shares a 6 Mbit/s pure ALOHA channel. Each vehicle generates at a constant rate of 800-byte packet every 100 msec. What is the maximum value of N?

    With pure ALOHA the maximum usable bandwidth is 0.18×6 Mbit/s = 1.08 Mbit/s
    Each vehicle requires $\frac{800 \times 8}{100\text{ms}} = 64$ kbit/s, so $N = \frac{1080 \text{ kbit/s}}{64 \text{ kbit/s}} \approx 16$

12. How does the slotted ALOHA protocol work?

    When the station has a fresh packet to send, it waits until the beginning of the next slot and transmits the entire packet in the slot. Time is divided into slots of fixed size

13. Derive the efficiency of slotted ALOHA protocol

    See lecture slide 17

14. Show that the maximum efficiency of slotted ALOHA is 1/e. Hint: $\lim_{N\to\infty}(1-\frac{1}{N})^N = 1/e$

    See lecture slide 18

15. A small slotted ALOHA system has N customers, each of whom has a probability $p = \frac{1}{N}$ of transmitting during any slot (both new and retransmission). What is the channel throughput as a function of N? Evaluate this expression numerically for $N = 2, 4, 10, 100, 200$ and $N \to \infty$

    - With slotted ALOHA a packet transmission succeed in a slot when only one customer attempt to use it and the others not $\implies S = Np(1-p)^{N-1} = (1-\frac{1}{N})^{N-1}$ as throughput
    - for $N = 2, 4, 10, 100, 200 \implies S = 0.5, 0.42, 0.38, 0.36, 0.36$

16. List three reservation-based MAC Protocols

    TDMA, FDMA, CDMA

17. Explain how the time division multiple access (TDMA) works

    The channel is divided into rounds of n time slots each. Different time slots are assigned to different stations within a round

18. What are the main limitations of TDMA?

    - A station is limited to an average rate even when it is the only station with packets to send
    - Receiver has to synchronize precisely

19. How does the frequency division multiple access (FDMA) work?

    The channel is divided into different frequencies. Each frequency is assigned to one of the stations

20. What are the main limitations of FDMA?

- A station has a limited bandwidth even when it is the only station with packets to send
- Guard bands between individual frequency bands are needed

21. What is the cause of frequency shifts in V2X networks?

    Frequency shifts are caused by the unpredictable Doppler shift of the signal spectrum due to the user mobility. A guard band between adjacent channels must be added.

22. Give a brief comparison between TDMA and FDMA

    FDMA is simple to implement and no time synchronization is needed as for TDMA

23. How does the code division multiple access (CDMA) work?

    Different codes are assigned to different stations. Each station uses its unique code to encode the data bits it sends

24. Give a main limitation of CDMA

    All signals have to arrive at a receiver with roughly the same power level

25. How does the closed-loop power control is used in CDMA work?

    Closed-loop power control is used to control the transmission power: Feedback on how much their transmit power should be is continuously provided to transmitting stations over a dedicated channel. So that all signals arrive at a receiver with roughly the same power level

26. Give an example highlighting the CDMA coding

    See lecture slide 25

27. How does the carrier sense multiple access (CSMA) work?

    When the physical layer observes no activities on it, a station then waits a random back-off time chosen from the interval [0,CW]; CW is decremented as the medium is idle; whenever the countdown reaches zero, the frame is immediately transmitted

28. How are priorities of different frame types modeled in IEEE 802.11p?

    See lecture slide 31

29. Consider a V2X network consisting of two stations A and B having each one single packet to send which belongs to access categories AC_VO and AC_VI, respectively. After the busy channel becomes clear, station A and B draw a CW of 3 and 1, respectively. Calculate the channel access time observed by both stations. Assume a time slot $T_{slot} = 13\mu s$. Both stations are within the same communication range.

    Channel access time: $T_{CA} = T_{AIFS} + CW \times T_{slot}$

    - Station A (AC_VO, $T_{AIFS} = 58\mu s$, CW=3): $T_{CA} = 58\mu s + 3 \times 13\mu s = 97\mu s$

- Station B (AC_VI, $T_{AIFS} = 71\mu s$, CW=1): $T_{CA} = 71\mu s + 1 \times 13\mu s = 84\mu s$

Although station A has a transmit queue with the highest priority AC, station B will access the channel first

30. Why does the CW is doubled after each packet/ACK collision in unicast transmissions?

    It provides a greater spread of simultaneous transmission attempts during high utilization periods

31. Why does the CW never be doubled in broadcast transmissions?

    Due to the lack of ACKs

32. Explain the hidden- and exposed terminal problem

    See lecture slides 33 and 35

33. How is the hidden terminal problem solved in unicast transmission?

    To prevent the hidden terminal problem, Request-to-send (RTS) and Clear-to-send (CTS) control packets is used to notify all stations in the network about an upcoming transmission