Bus Systems

Wireless Automotive Communication

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Wireless Automotive Communication

Learning objectives

- Understand principles of wireless networks
  - Understand differences to wired bus systems
- Understand specific challenges in automotive environments
  - Learn about solutions to these challenges

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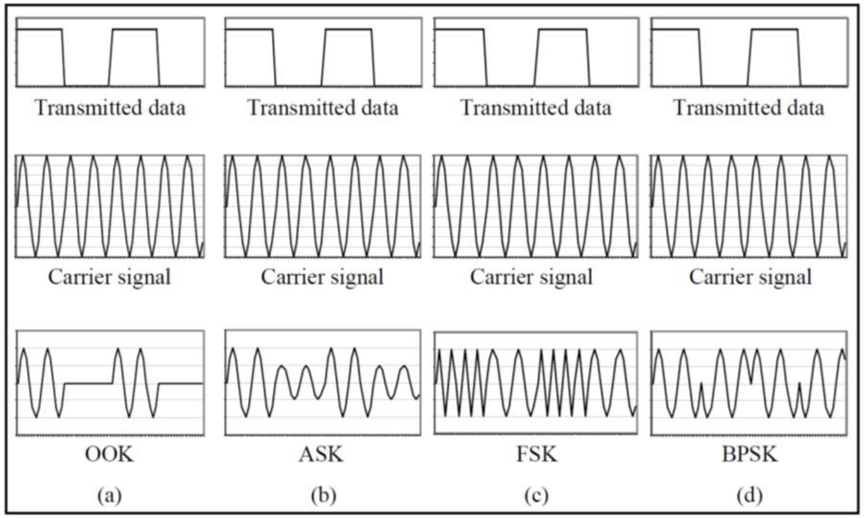
Wireless Networks – Modulation schemes

- Wireless networks modulate information on carrier waves
- Use OOK, ASK, FSK, BPSK, Quadrature (QPSK, QAM) modulation
- Usable modulation schemes depend on transmission range
  - Signal strength at receiver limits applicability of modulation schemes
- Need to consider:
  - Intended transmission range of wireless network
  - Permitted signal energy
  - Environment (signal fading, reflections)
  - Node movements



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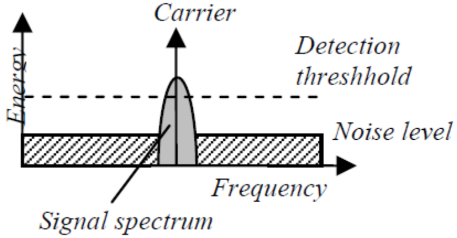
Wireless Networks – Modulation schemes

- The carrier frequency defines core frequency of a wireless transmission
  - Usually, many wireless transmissions share the same medium
  - Transmissions are therefore bandwidth constrained
- Depending on modulation scheme and frequency, a specific bandwidth in the frequency spectrum is required for the transmission
- The maximum transmitted signal energy is fixed by regulatory means (grey area)
  - If more bandwidth is required, the energy for each frequency decreases
  - Need to find tradeoff between stability and network throughput



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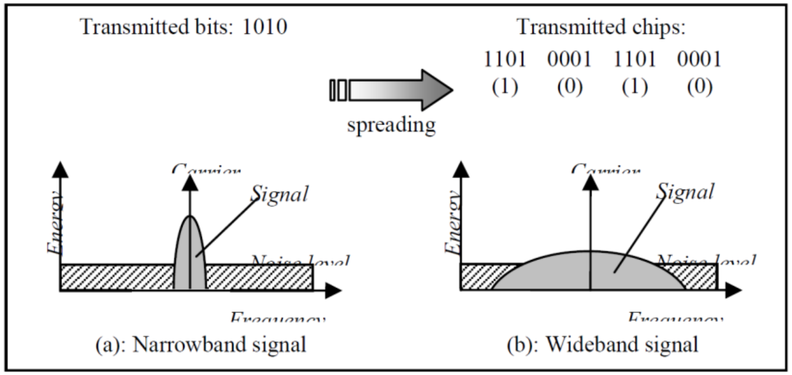
Wireless Networks – Signal Spreading

- Signal spreading turns narrow band signals into wideband signals
- Increases resistance to narrow interferences
  - Does not increase the amount of transmitted payload
  - Does not decrease the transmission range of a wireless network
  - Does decrease the physical carrier sensing range of a wireless network
    - Also useable to hide a signal in the ambient noise
- Achieved by multipling signal bits with longer chip sequences (e.g. 1→4, 4→16…)
  - Chip rate is >> than bit rate, signal requires much more bandwidth to transmit all chips
  - Signal is reconstructed at receiver by correlating received signal with known chip sequences
  - Signal strength is reconstructed correctly at receiver only when chip sequences are known



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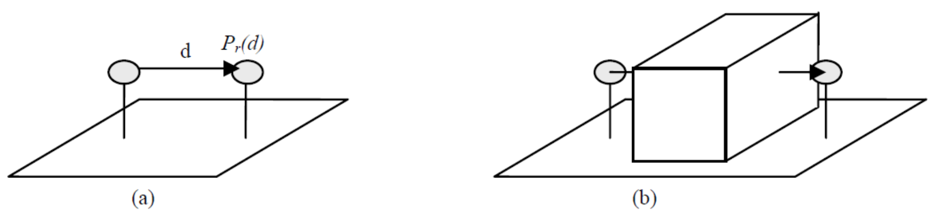
Wireless Networks – Signal Fading

- Wireless signal strength fades with increasing distance (long scale fading)
  - This effect is significant
  - Depends on environment, e.g. if a line of sight between sender and receiver is available
  - Higher frequency carriers are more affected by obstacles between senders and receivers



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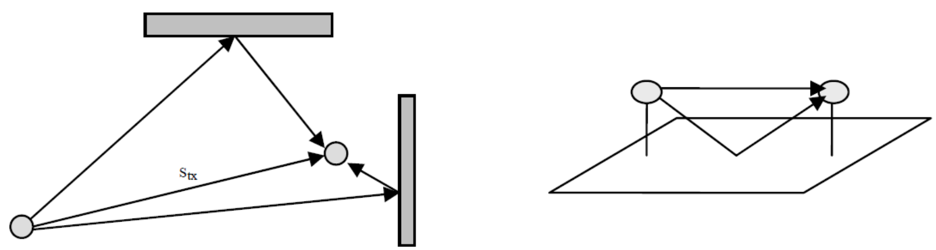
Wireless Networks – Signal Fading

- Signal strength also changes due to reflections (short scale fading)
  - This effect is significant, but not predictable
  - Overlapping of waves that arrive over multiple propagation paths
  - Propagation paths are created by reflections, and have different lengths



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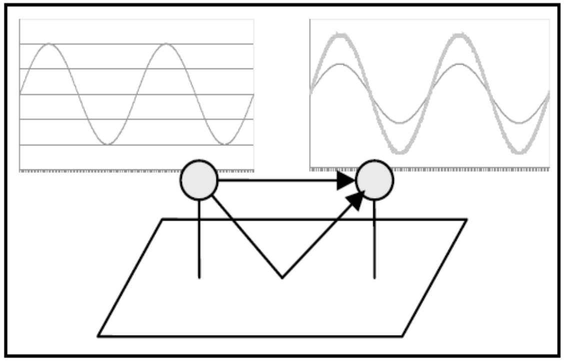
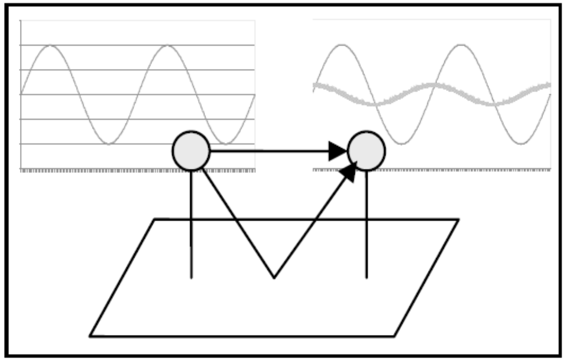
Wireless Networks – Signal Fading

- Signal strength also changes due to reflections (short scale fading)
  - Overlapping waves are received with different phases
    - This leads to positive (constructive) and negative (destructive) interferences



Constructive interference



Destructive interference

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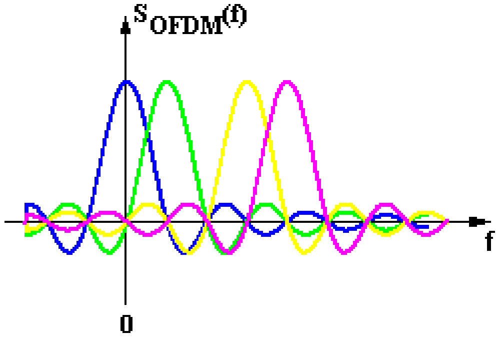
Wireless Networks – OFDM

- OFDM splits main carriers into (usually overlapping) sub carriers
  - Each carrier may use its own modulation scheme
    - Enables adaptation of transmission system to channel conditions
    - Enables adaptation of transmission system to needs of concurrently transmitted streams (WIMAX)
  - Data carriers transmit actual payload
  - Pilot carriers transmit fixed bit sequences to assess channel quality
  - OFDM generally enables better utilization of channel due to dynamic adaption to interferecnes in narrow frequency bands



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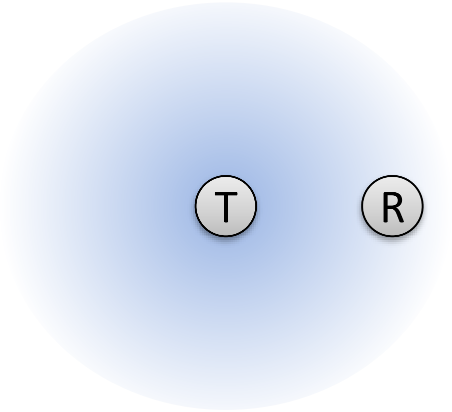
Wireless Networks – Radio communication

- Communication via radio waves over a shared medium (air)
  - When using wired media, all bus participants perceive the same medium state
  - A collision is visible after the electric waves did propagate through the medium

- For wireless media, this is not the case
  - Signal strength fades drastically with increasing distance
  - Sender and receiver nodes therefore perceive different states of the wireless medium
  - Signal strength has ist highest value at transmitter
  - Signal strength value at receiver is not known



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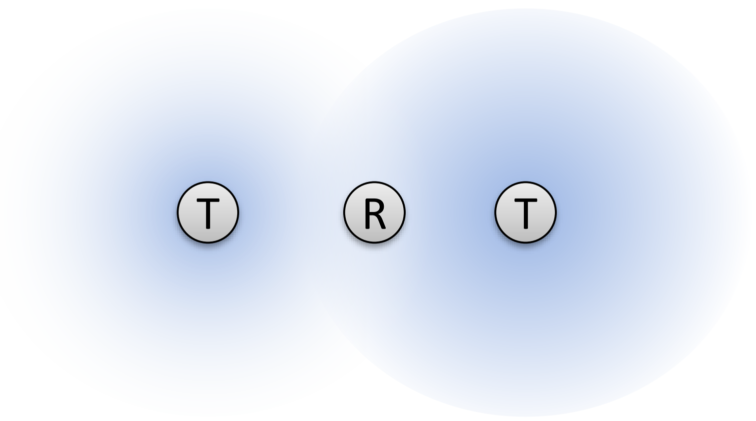
Wireless Networks – Collisions

- Collisions cannot be detected
  - Here, even if the transmitter would be sampling the medium while transmitting, would only receive its own signal due to its high signal strength
  - At the receiver node, two signals are received with same signal strength
  - This causes a collission (overlapping of waves)
  - This is detectable by the receiver, but by none of the transmitter nodes



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Wireless Networks – Collisions

- Collision detection or collision resolution schemes cannot be used
  - Wireless networks use instead CSMA/CA (Carrier Sense Multiple Access / Collision Avoidance)

- CSMA/CA basic steps
  - Check if medium is free or not
    - Based on energy level on medium (physical carrier sensing)
    - Based on virtual carrier sensing (see below)
  - If medium is free, wait for random time
    - Break synchronization with other senders
    - The random time might be dependent on message or node priority
  - Transmit frame
  - Wait for acknowledgement
  - Repeat if necessary

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Wireless Networks – Collisions

- Problems of wireless networks
  - Collisions are not fully prevented but only avoided to a degree
    - Nodes do not always receive each other, therefore a receiver could be in transmission range of other stations than sender
    - In this case, senders that do not see each other could send concurrently
  - Collisions are only detected due to missing acknowledgement frame
    - Significant chance that only ACK Frame was lost due to collision
    - Causes unwanted effects with ACK Frames sent by higher level protocols (e.g. TCP)
      - DATA (TCP) → ACK (MAC) → ACK (TCP) → ACK (MAC)
      - Chance is high that one of the three redundant ACK frames is lost instead of data frame

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Wireless Networks – MACA

- Carrier sensing in wireless networks is not as reliable as in wired networks
  - Wired networks: Signal level roughly everywhere the same after propagation delay has passed
    - Solved by defining minimum frame lengths
  - Wireless networks: Fading causes different signal levels at different nodes
    - Senders only sense their environment, not that of receiver(s)
    - Causes hidden terminal and exposed node problems

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Wireless Networks – MACA

- MACA adds virtual carrier sensing by implementing an RTS/CTS mechanism
  - Sender transmits RTS → Request to send. Sender indicates request to send, virtual carrier sensing mechanism (Network Allocation vector – NAV) of all nodes in transmission range of sender stores this request and reports „medium is busy“ for estinated transmission time to upper layers
  - Receiver transmits CTS → Clear to Send. NAV of all nodes in transmission range of receiver stores the transmission time that is enclosed in CTS frame and reports „medium is busy“ for estimated transmission time to upper layers

- Advantage:
  - Lowers the probability of colliding transmissions while transmitting payload
  - RTS/CTS frames higher priorized and significantly smaller than data frames

- Disadvantages
  - Requires additional transmission time
  - Introduces additional collision probabilities for RTS/CTS frames

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Wireless Networks – Differences to wired networks

- Shared communication media with bounded transmission range
  - Different nodes perceive different medium states
  - Collisions occur at receivers, not at transmitters
  - Nodes with sufficient space between each other may transmit conuccrently without noticing the other transmitting node

- Medium access control
  - Medium access control protocols must support this
  - CSMA/CA – Avoid collisions (but does neither detect nor prevent them)
    - Collisions are only detected by absence of acknowledgement frame
    - This frame is transmitted in addition to ACK frames of higher level protocols
    - The same data transmission therefore might be protected by redundant ACK frames
  - MACA – virtual carrier sensing to prevent hidden and exposed node problems
    - Not feasible for networks with dynamically changing topologies

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Wireless Networks – Channel access mechanisms

- Disctributed Coordination Function (DCF)
  - Implements CSMA/CA
  - Use of MACA (RTS/CTS) is optional but must be understood

- Point Coordination Function
  - Transmissions are polled through centralized Master
  - Split in Contention-Free and Contention Period
  - Enables very fine grained (soft) Real-Time communication
  - Only rarely implemented in practice

- We focus on the DCF

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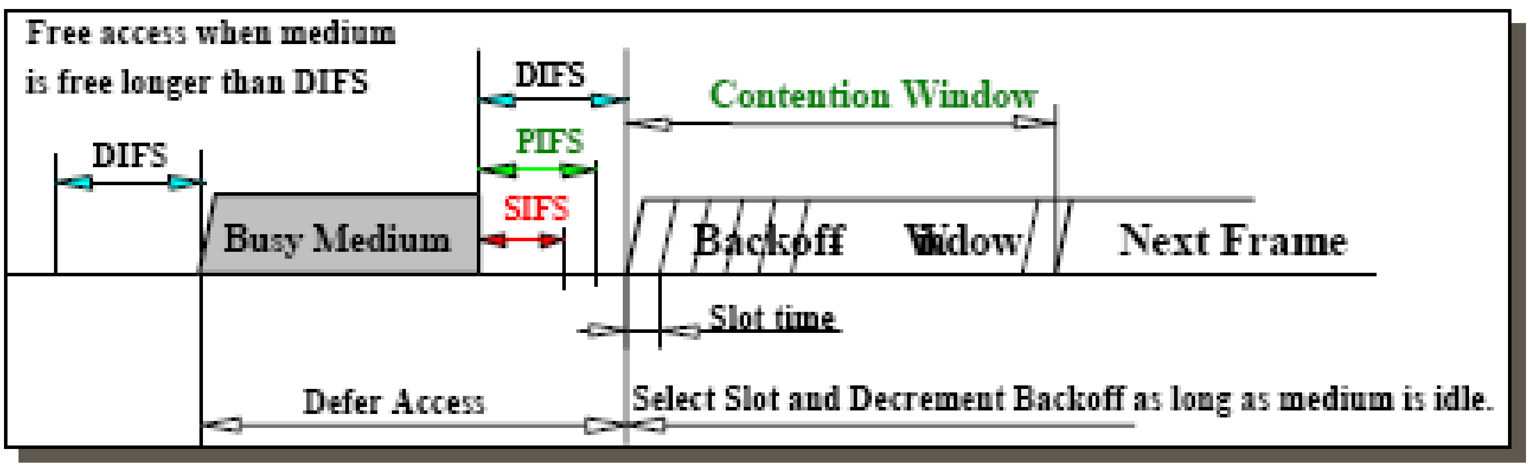
Wireless Networks – DCF

- Disctributed Coordination Function (DCF)
  - Implements CSMA/CA
  - Use of MACA (RTS/CTS) is optional but must be understood

- Basic approach (again)
  - Select random value out of contention window
  - Wait for medium to become idle
  - Wait for random contention window counter or backoff period counter to become zero
  - Start transmission
  - If transmission failed:
    - Stop transmission attempt if this was the 16th consecutive failure
    - Otherwise:
      - Increment contention window size
      - Select random backoff period duration from new window
      - Continue at step 2 (Wait for medium to become idle)

Wireless Networks – DCF

- Medium is divided into slots
  - A slot is a time duration of a fixed length as defined by 802.11 standard
  - Slots are the atomic time intervals of 802.11 networks
  - A slot is sensed to be idle or busy based on physical and virtual carrier sensing
  - A slot is only idle if both physical and virtual carrier sensing report this slot to be idle



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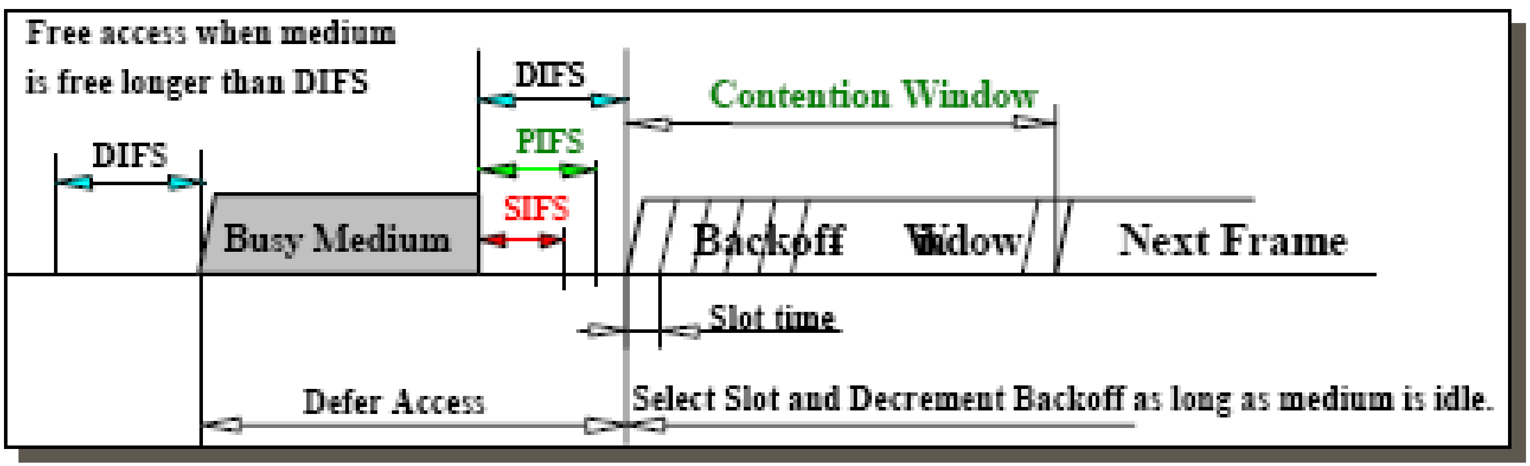
Wireless Networks – DCF

- Medium is considered to be IDLE after Inter Frame Space (IFS) has passed
  - Length of inter frame spacing depends on type of transmitted data
  - Regular data transmissions are protected by DIFS (distributed inter frame spacing)
  - DIFS is a multiple of a fixed slot time
  - Nodes need to wait for DIFS + Random contention window before starting a transmission



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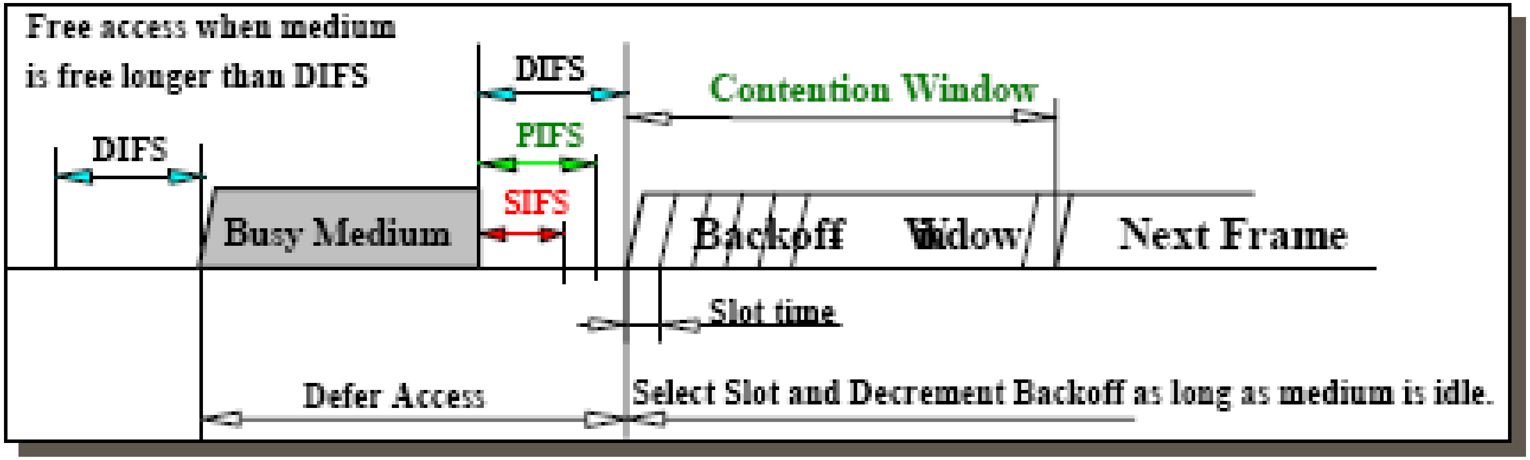
Wireless Networks – DCF

- Without additional measures, all nodes with waiting transmissions would start trnansitting at the same time after medium is considered to be idle. CSMA/CA avoids this: Nodes select a random value (slot counter) from contention window interval [CWMin, CWMax], this value defines the numbers of slots that a transmittier must wait prior to transmitting
  - Nodes count down this value in every idle slot, count down is paused if medium is busy
  - Pause applies for physical and/or virtual carrier sensing
  - Nodes wait again for a DIFS idle period after the end of a transmission before they continue with counting down the slot counter



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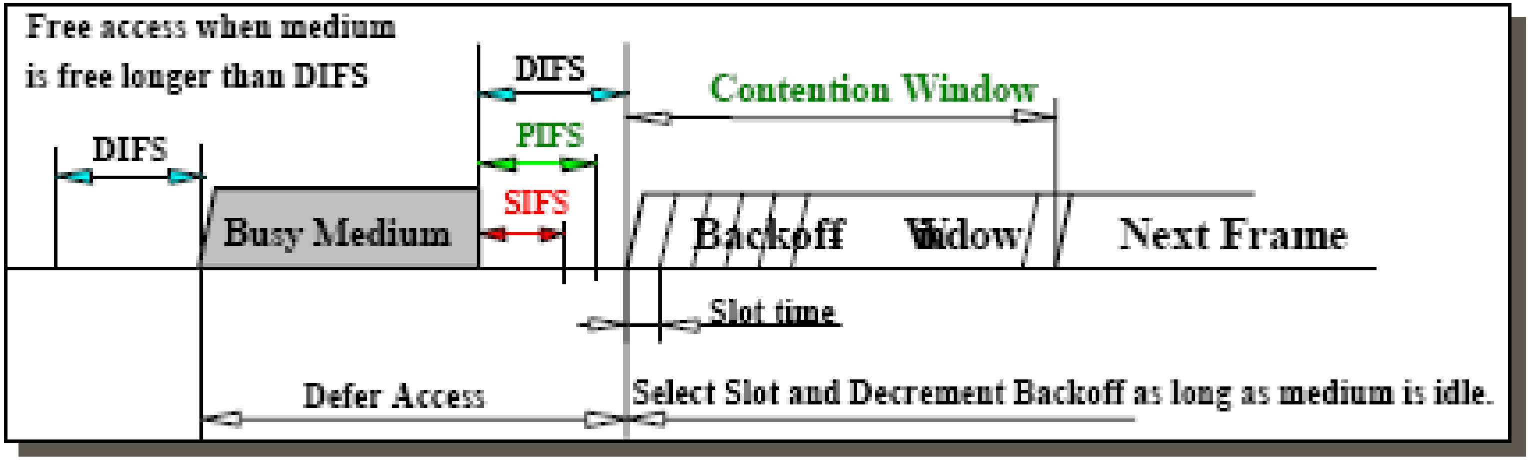
Wireless Networks – DCF

- Transmission
  - Transmission of regular frames starts as soon as DIFS + Slot counter has passed
- Frame priorization
  - CTS/ACK frames are transmitted with higher priority
  - They are always transmitted with SIFS instead of DIFS and no additional contention
  - Take precedence among all other waiting frames, because those will first wait for a longer DIFS



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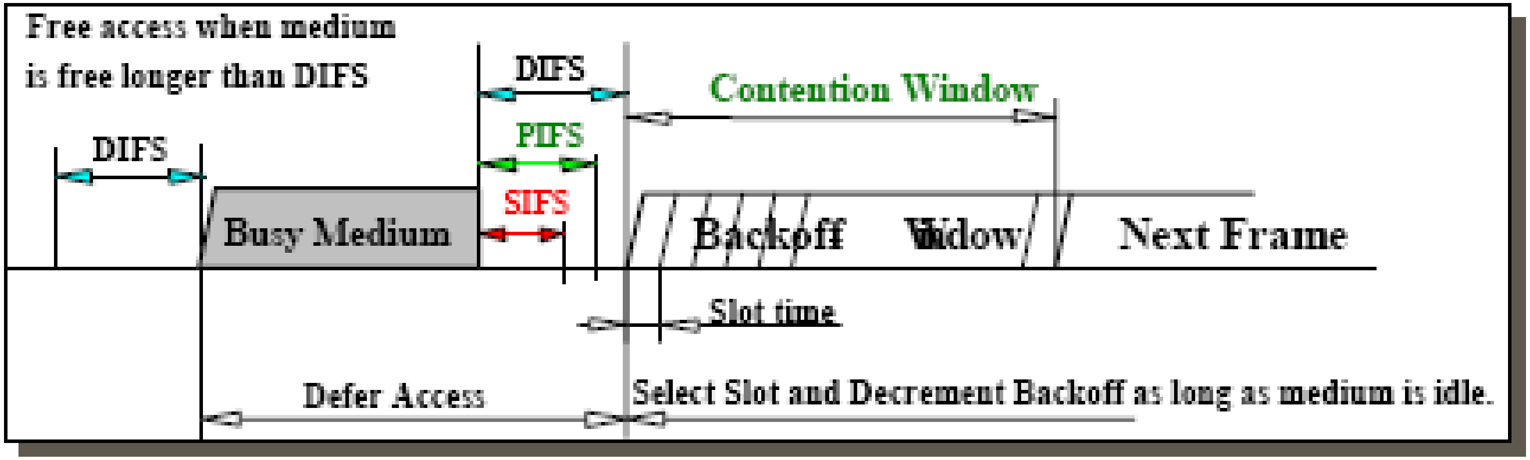
Wireless Networks – DCF

- Shorter PIFS and SIFS are used to give priority to management frames
  - Stations transmitting these frames wait for shorter time and therefore transmit first
  - SIFS is used before transmission of Acknowledgement and CTS frames
  - PIFS is used to implement PCF



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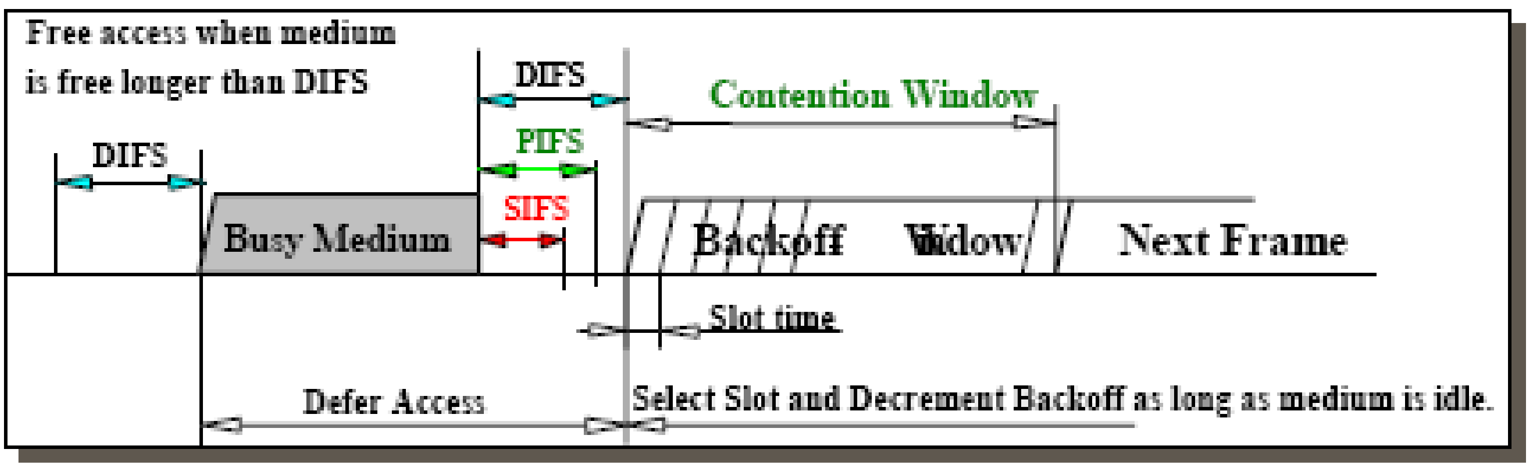
Wireless Networks – DCF

- By assigning different IFS and CWMIN/CWMAX values to frame types, a priorization may be realized
    - Does not provide hard real-time guarantees but enables priorization of mean transmission delays
    - EDCF implements such a mechanism (Standardized in 802.11e)



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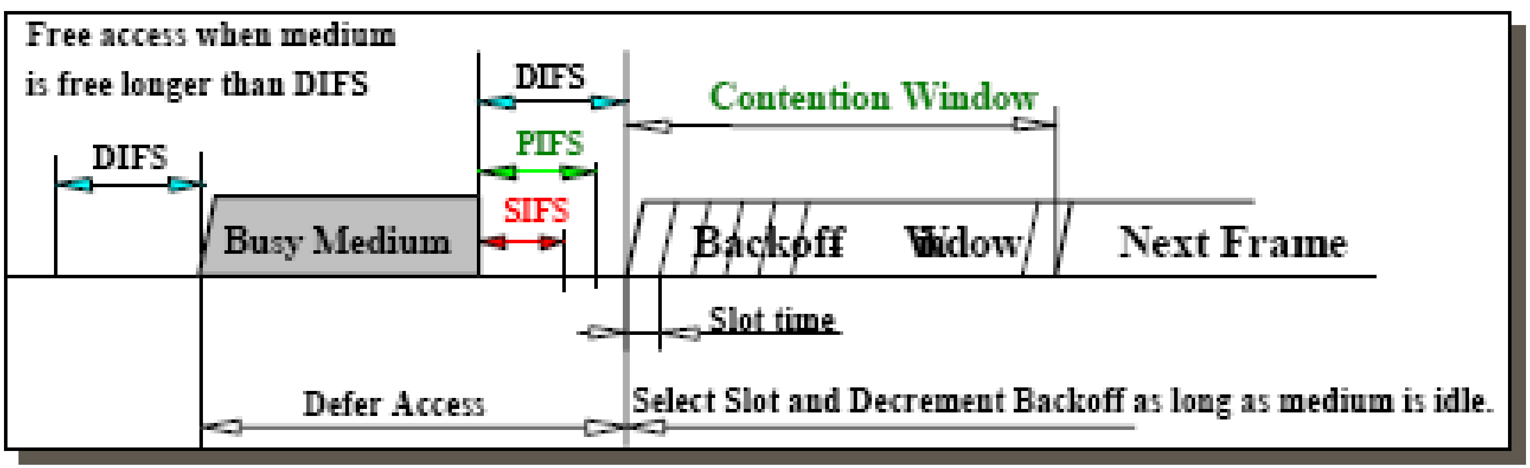
Wireless Networks – DCF and EDCF

- Nodes that need to re-transmit an information due to a missing ACK frame
  - Increment contention window to select next slot counter out of a bigger value range
    - → Less probability for two nodes selcting the same value in high traffic networks
    - → Repeated collisions cause longer backoff periods to be selected
    - → Transmission is cancelled after 16 consecutive failures



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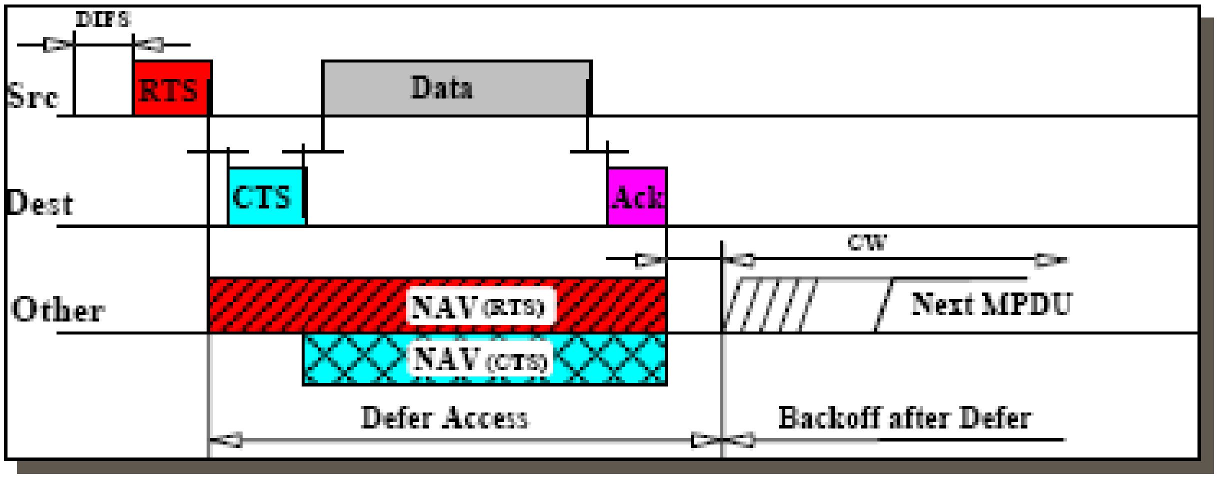
Wireless Networks – Example – DCF using RTS/CTS



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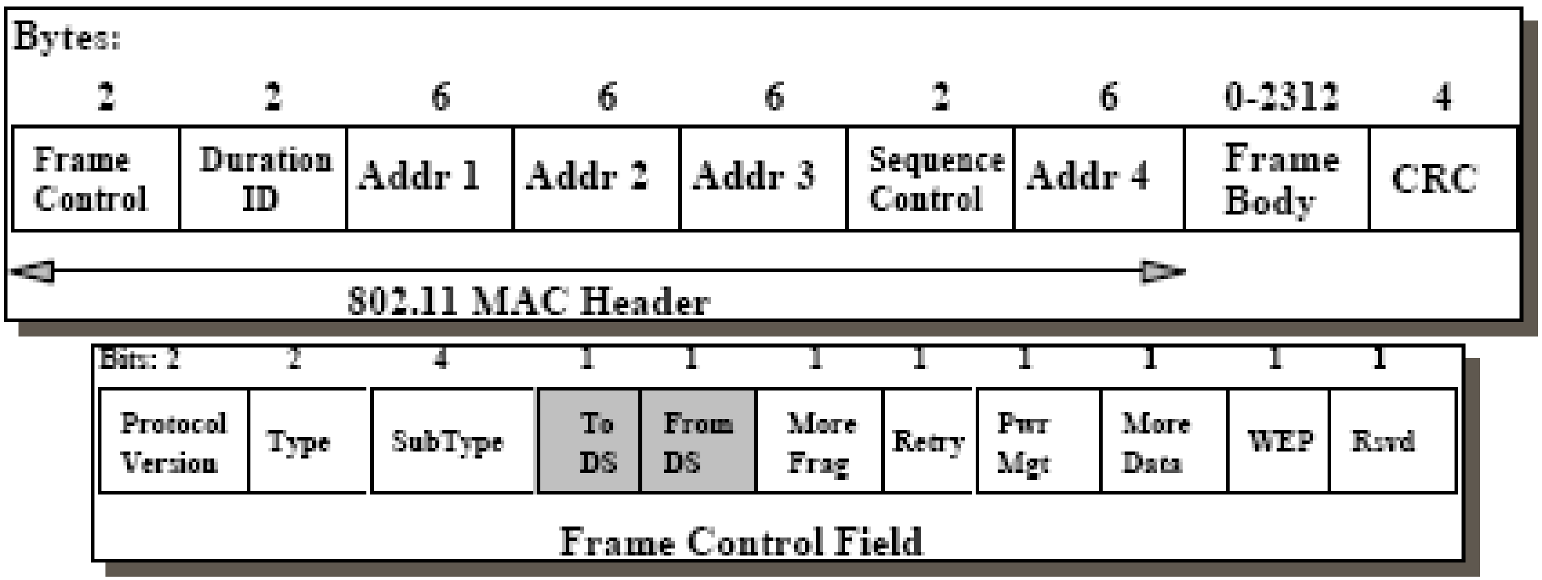
Wireless Networks – DCF and EDCF

- Discussion
  - DCF and EDCF reuire huge overhead for frame transmission
  - Due to slot times and synchronization times of physical transceivers
  - E.g., an ACK message (1 bit payload) could take 60µs to transmit completely
    - This is sufficient to transmit 3240 bits at 54 Mbps
  - Frame overhead in wireless networks is generally high →One aims for larger frames

Wireless Networks – Frame format

- The header of an 802.11 frame differs slightly depending on the frame type



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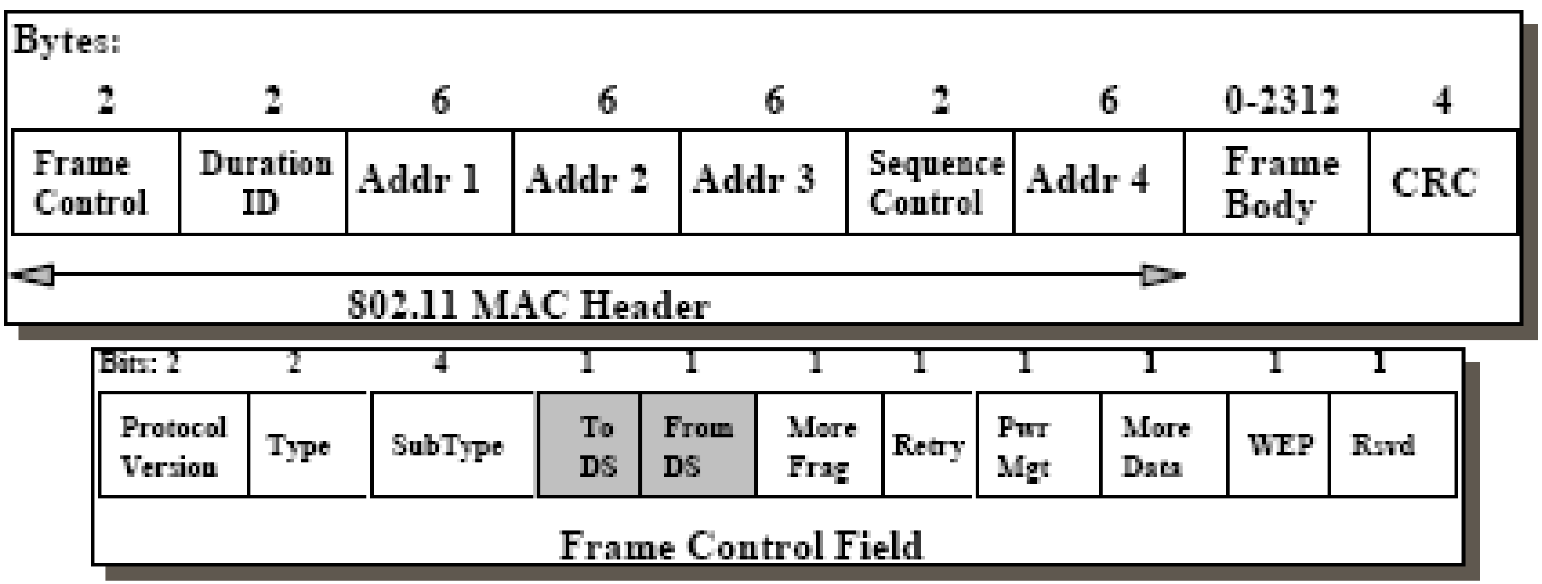
Wireless Networks – Frame format

- The header of an 802.11 frame differs slightly depending on the frame type
  - Protocol version, type & subtype of frame
  - Frame control field (see next slides)
  - Source and destination addresses (see next slides)
  - Sequence control field: Sequence number to filter duplicates caused by dropped Ack frames



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Wireless Networks – Frame format

- 802.11 – Frame control field
  - Protocol Version: two bits representing the protocol version. Currently used protocol version is zero. Other values are reserved for future use.
  - Type: two bits identifying the type of WLAN frame. Control, Data and Management are various frame types defined in IEEE 802.11.
  - Sub Type: Four bits providing additional differentiation between frames. Type and Sub type together to identify the exact frame.
  - ToDS and FromDS: Each is one bit in size. They indicate whether a data frame is headed for a distribution system. Control and management frames set these values to zero. All the data frames will have one of these bits set. However communication within an IBSS network always set these bits to zero.
  - More Fragments: The More Fragments bit is set when a packet is divided into multiple frames for transmission. Every frame except the last frame of a packet will have this bit set.

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Wireless Networks – Frame format

- The header of an 802.11 frame differs slightly depending on the frame type
  - Retry: Sometimes frames require retransmission, and for this there is a Retry bit which is set to one when a frame is resent. This aids in the elimination of duplicate frames.
  - Power Management: This bit indicates the power management state of the sender after the completion of a frame exchange. Access points are required to manage the connection and will never set the power saver bit.
  - More Data: The More Data bit is used to buffer frames received in a distributed system. The access point uses this bit to facilitate stations in power saver mode. It indicates that at least one frame is available and addresses all stations connected.
  - WEP: The WEP bit is modified after processing a frame. It is toggled to one after a frame has been decrypted or if no encryption is set it will have already been one.
  - Order: This bit is only set when the "strict ordering" delivery method is employed. Frames and fragments are not always sent in order as it causes a transmission performance penalty

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Wireless Networks – Addresses

- The address fields are interpreted differently based on To/From DS bits in frame control field

To DS	From DS	Address 1	Address 2	Address 3	Address 4
0	0	DA	SA	BSSID	N/A
0	1	DA	BSSID	SA	N/A
1	0	BSSID	SA	DA	N/A
1	1	RA	TA	DA	SA

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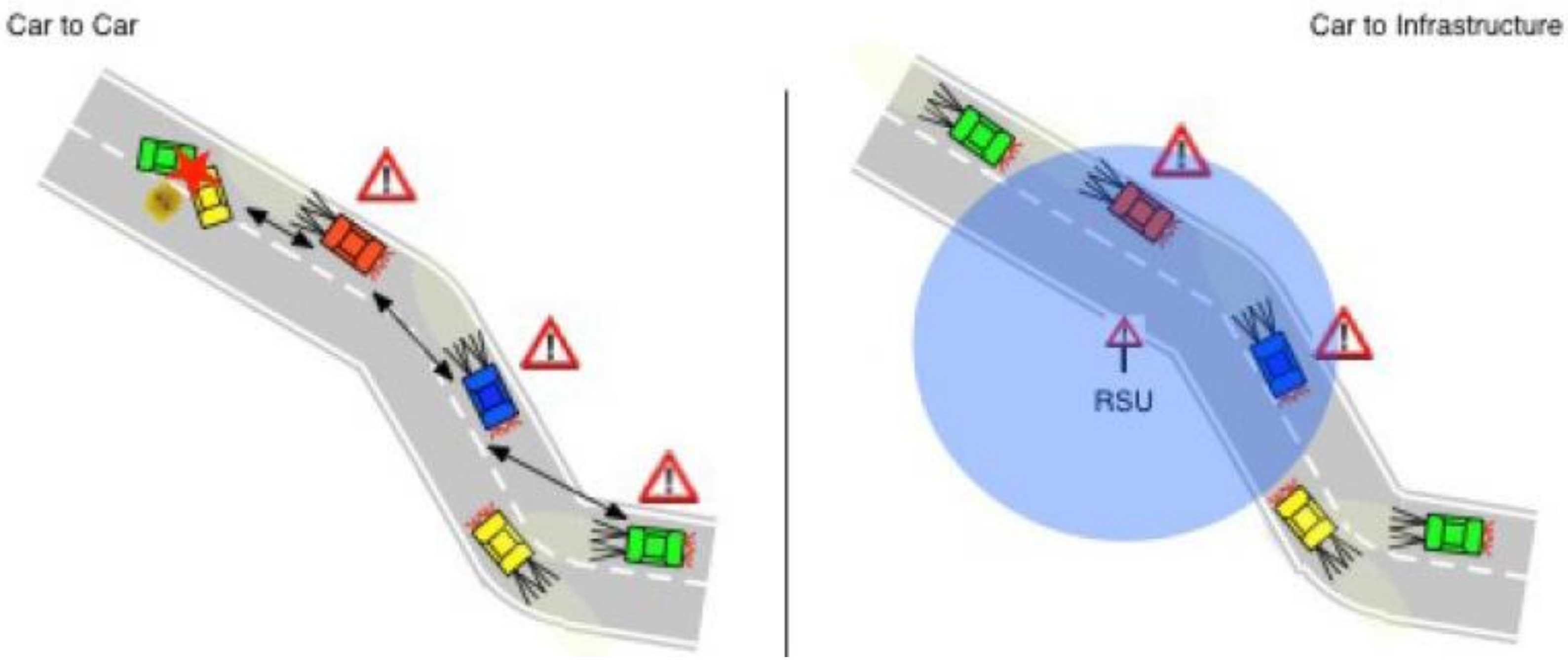
Wireless Networks – Types of Automotive Applications



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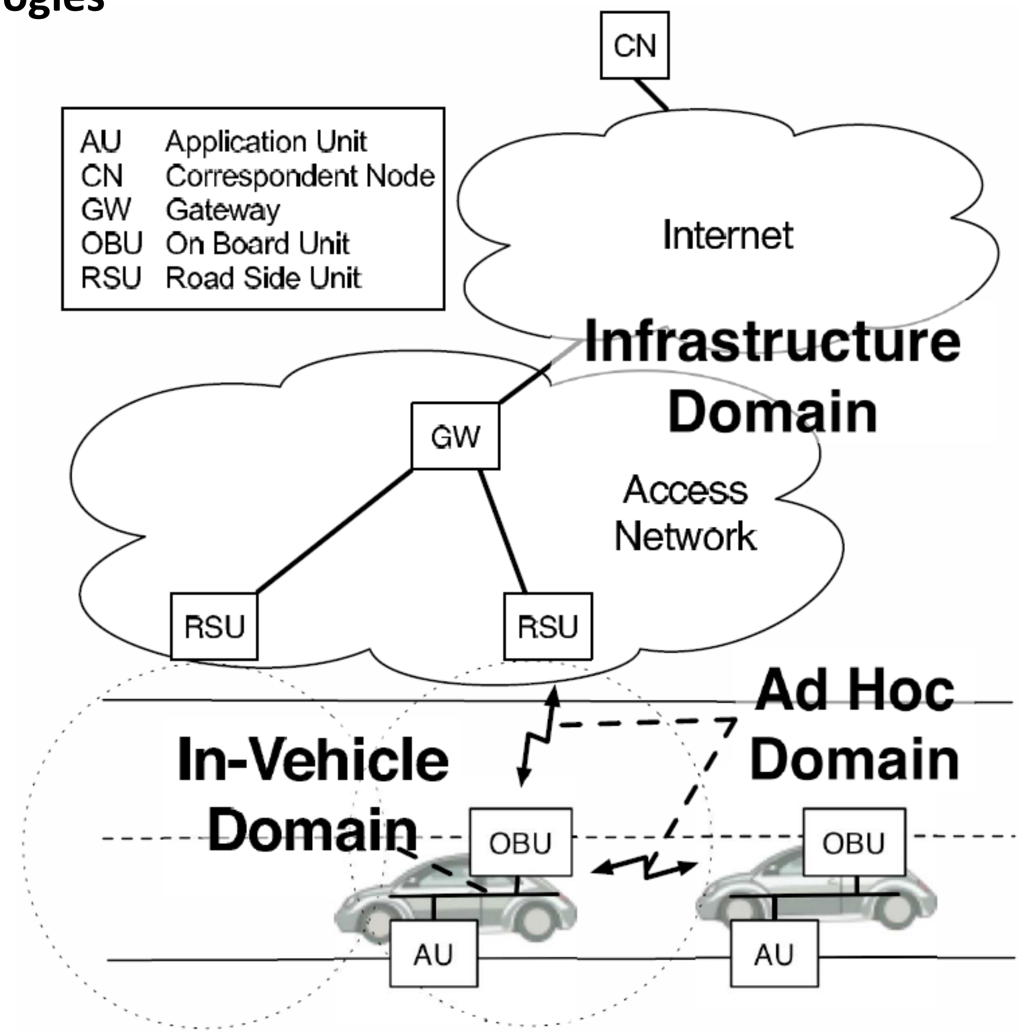
Wireless Networks – Network topologies



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Wireless Networks – Automotive Challenges

- Nodes move at higher speeds → Frequency shift due to doppler effect
  - Requires modification of physical layer

- Connections between cars not moving in same direction and between cars and infrastructre will not last long
  - RTS/CTS handshake only makes sense for cars driving in the same direction
  - Why?

Wireless Networks – Automotive physical layer

- Modified version of 802.11a physical layer
  - Re-definition of physical layer properties to cope with node speed, transmission range and doppler effects
  - Definition of agreed frequency bands

- Re-definition of physical layer properties

Parameters	IEEE 802.11a	IEEE 802.11p half clocked mode	Changes
Bit rate (Mbit/s)	6, 9, 12, 18, 24, 36, 48, 54	3, 4.5, 6, 9, 12, 18, 24, 27	Half
Modulation mode	BPSK, QPSK, 16QAM, 64QAM	BPSK, QPSK, 16QAM, 64QAM	No change
Code rate	1/2, 2/3, 3/4	1/2, 2/3, 3/4	No change
Number of subcarriers	52	52	No change
Symbol duration	4 µs	8 µs	Double
Guard time	0.8 µs	1.6 µs	Double
FFT period	3.2 µs	6.4 µs	Double
Preamble duration	16 µs	32 µs	Double
Subcarrier spacing	0.3125 MHz	0.15625 MHz	Half

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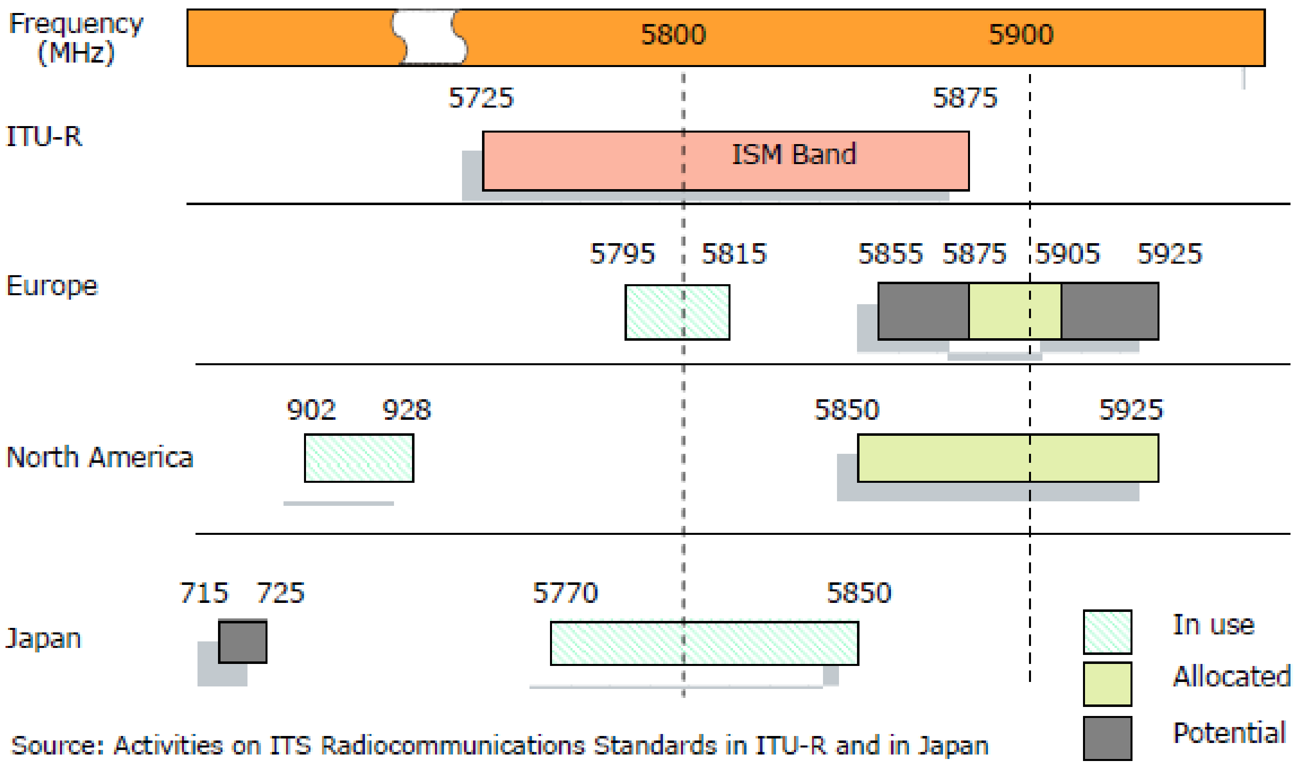
Wireless Networks – Agreed frequency bands

General ISM band is not feasible for automotive applications



Source: Activities on ITS Radiocommunications Standards in ITU-R and in Japan

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Wireless Networks – Automotive physical layer

- Channels
  - 802.11 networks use channels to support concurrent transmissions on adjacent or overlapping networks
  - Separated frequency bands
    - Requires network nodes to scan channels for networks, which are identified by their SSID
    - Requires too much time in automotive domain
  - Therefore: Fixed channel/service allocation
    - One default channel for „C2C“ (Car2Car) communications
  - Configuration of TCP/IP stack requires significant overhead
    - Negotiation of IP adresses
    - Definition of IP addresses and port numbers
    - Therefore, implementation of alternate WAVE communication stack

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Wireless Networks – Discussion

- How do wireless network differ from wired networks?
- What are the specific challenges of automotive wireless networks?
- Why is the use of TCP not advised together with 802.11 wireless networks?
- Why is it not simply possible to implement CAN or Flexray arbitration schemes in wireless networks?