Lecture 4: Vehicular Communication Architecture

Architectures, Protocols, Operation and Deployment

Prof. Sangyoung Park

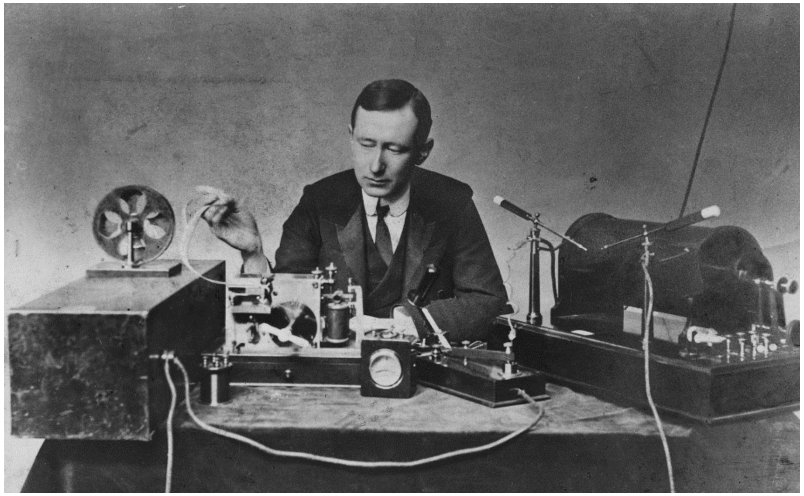
Module ”Vehicle-2-X: Communication and Control“

Contents

- Communication basics
- Protocols for vehicular communication architectures
- Architectures for vehicular communication architectures

Basics of Wireless Communication

- What is wireless communication?
  - Transfer of information or power between two or more points that are not connected by an electrical conductor
  - Most common wireless common wireless technologies use radio waves

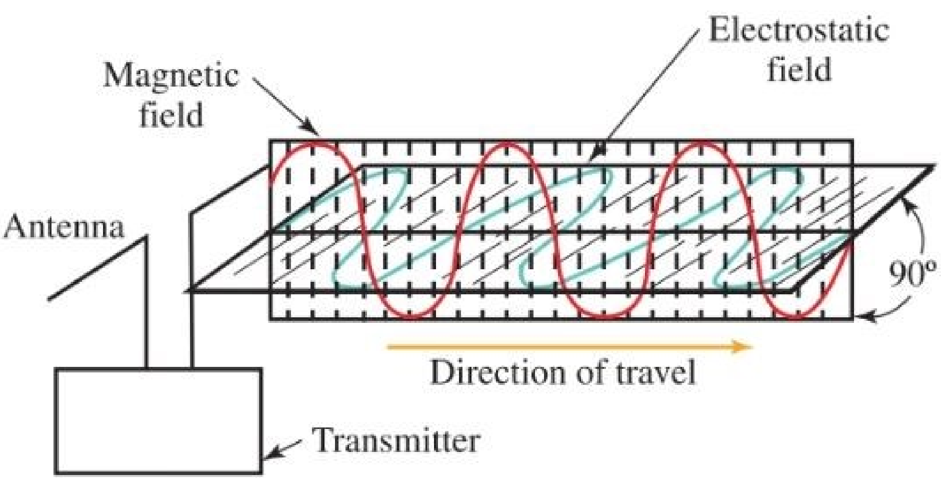


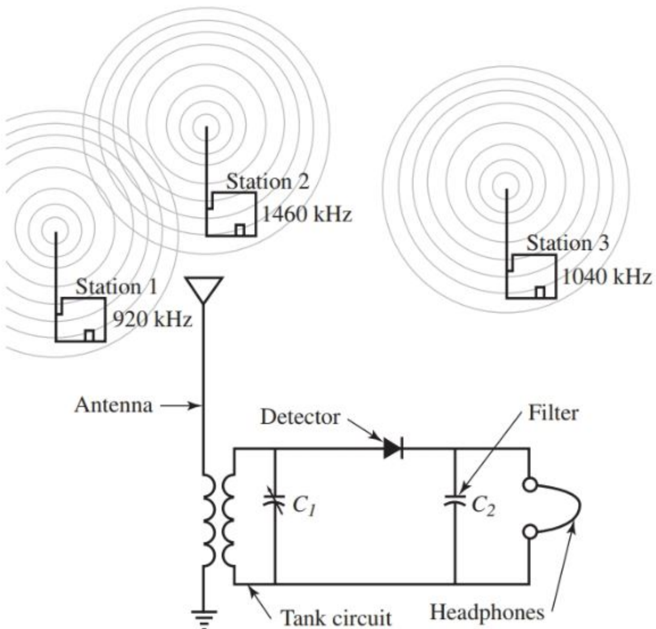
Marconi sending the first radio signal across the Atlantic

Source: Wikipedia

Basics of Wireless Communication

- Basics of Wireless Communication
  - Electromagnetic waves are generated around alternating currents (transmitter)
  - Electrical currents are generated when electromagnetic waves reach the antenna (receiver)

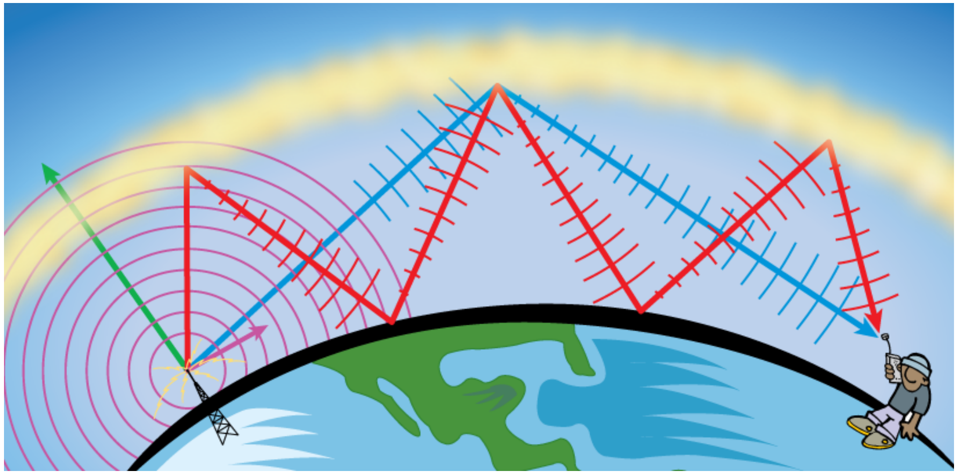




Source: http://electricalacademia.com/electronics/radio-transmitter-and-receiver-working-block-diagram/

Basics of Wireless Communication

- How could Marconi send signals across such a distance? (England – New Foundland)
  - Ionosphere: Electrically charged gas particles (ionized) formed by radiation from the sun
  - Reflected or refracted at around 100 km altitude



Source: US National Weather Service

Basics of Wireless Communication

- But what about the signal attenuation?
  - You send a **powerful signal**!
  - Signals transmitted by new high-power station in England
  - 150 m, kite-supported antenna for reception

Transmitter Antenna

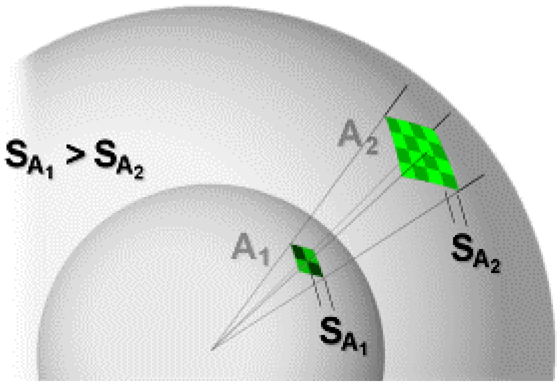
Source: Wikipedia

Basics of Wireless Communication

- How is range determined?
  - A transmitter should put **enough energy** into a **symbol** for the receiver to be able to **hear** it
- Symbol?
  - A radio signal that represents information
  - FSK (frequency shift keying)
    - Radio transmitting at frequency X: 1
    - Radio transmitting at frequency Y: 0
- Hearing
  - Receiver could hear and comprehend the message if „energy per symbol“ is large enough

Basics of Wireless Communication

- What lowers the „energy per symbol“?
  - Propagation loss
    - Spreading out of RF energy as the signal dissipates
    - Square of the distance in free-space
    - $\frac{P_r}{P_t} = D_t D_r \left(\frac{\lambda}{4\pi d}\right)^2$, D_t, and D_r are parameters related to the direction of antenna, λ is the wavelength, and d is the distance
  - Attenuation loss
    - Propagation through material other than air walls, etc.
  - Connector loss
  - Transmit antenna loss
  - Receiver antenna loss
    - Small antennas, etc.



Source: http://www.radartutorial.eu/01.basics/Free-Space%20Path%20Loss.en.html

Basics of Wireless Communication

- One easy thing to forget
  - One easy way to increase the energy per symbol is to reduce the data rate
  - If you use constant power consumption on the transmission side, half the data rate, then the energy per symbol will be twice
  - Hence, decreasing the data rate also effectively increases the range of wireless communication

	Outdoor Range		Indoor Range	
Mode	Meters	Feet	Meters	Feet
1 Mbps DSSS	550	1804	50	164
2 Mbps DSSS	388	1275	40	133
5.5 Mbps CCK	235	769	30	98
11 Mbps CCK	166	544	24	79
5.5 Mbps PBCC	351	1151	38	125
11 Mbps PBCC	248	814	31	101
6 Mbps OFDM	300	984	35	114
12 Mbps OFDM	211	693	28	92
18 Mbps OFDM	155	508	23	76
24 Mbps OFDM	103	339	18	60
36 Mbps OFDM	72	237	15	48
48 Mbps OFDM	45	146	11	36
54 Mbps OFDM	36	119	10	32

https://www.eetimes.com/document.asp?doc_id=1271995

Basics of Wireless Communication

- What other factors play a role in successful hearing?
  - Interference
  - Signal to noise ratio (SNR)

$$SNR = \frac{P_{signal}}{P_{noise}}$$

  - If noise is too large compared to the signal, the original signal cannot be reconstructed
- Decibels (dB)
  - Because many signals have a very wide dynamic range, signals are often expressed using the logarithmic decibel scale
  - $P_{signal,dB} = 10\log_{10}(P_{signal})$, $P_{noise,dB} = 10\log_{10}(P_{noise})$
  - Similarly signal to noise ratio can be defined,

$$SNR_{dB} = 10\log_{10}(SNR) = 10\log_{10}(\frac{P_{signal}}{P_{noise}})$$
$$= P_{signal,dB} - P_{noise,dB}$$

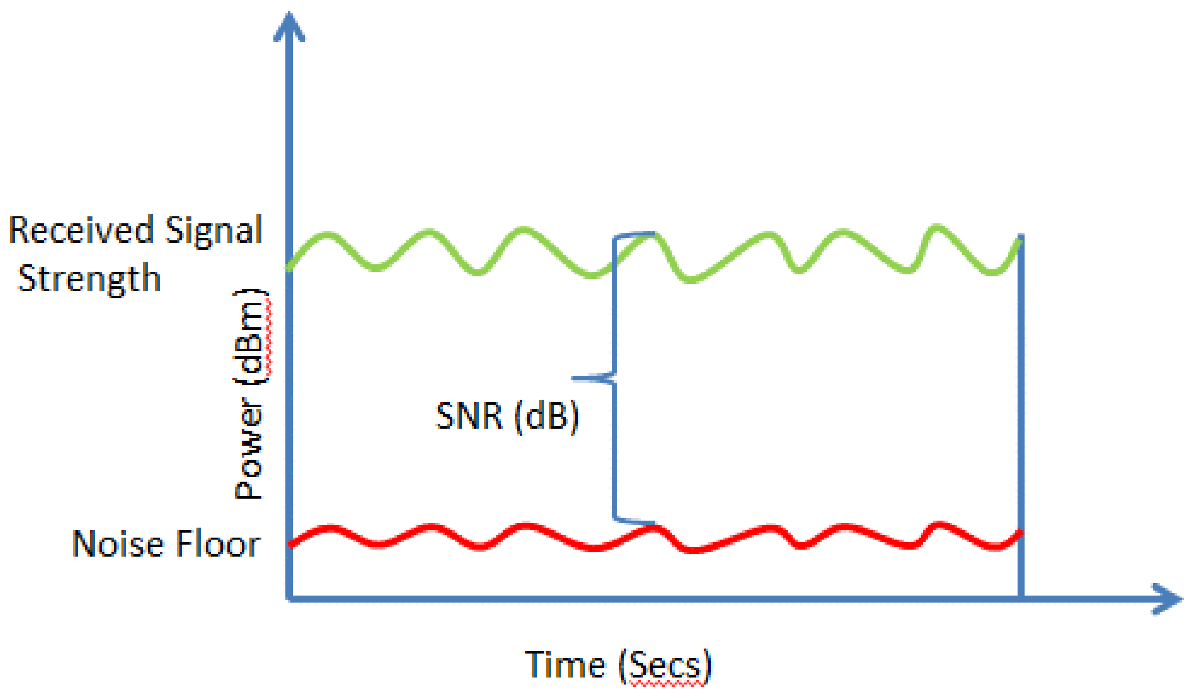
Basics of Wireless Communication

- What are the typical signal strengths?
  - Often described in terms of dB with reference to milliwatt (mW): dBm

Power level	Power	Notes
80 dBm	100 kW	Transmission power of FM radio station (50 km range)
62 dBm	1,588 W	Maximum legal power of US HAM
60 dBm	**?? W**	Microwave RF power
27 dBm	500 mW	Typicall cellular phone transmission power
23 dBm	200 mW	IEEE 802.11n wireless LAN 40 MHz-wide in 5 GHz
15 dBm	32 mW	Typical wireless LAN transmission in laptops
4 dBm	2.5 mW	Bluetoothe class 2 radio, 10 m range
-174 dBm	0.178 fW	Typical received signal power from a GPS satellite
-∞ dBm	0 W	Zero power

Basics of Wireless Communication

- What is the SNR in dB if a receiver gets a signal of -75 dB and the noise floor is measured at -90 dBm?



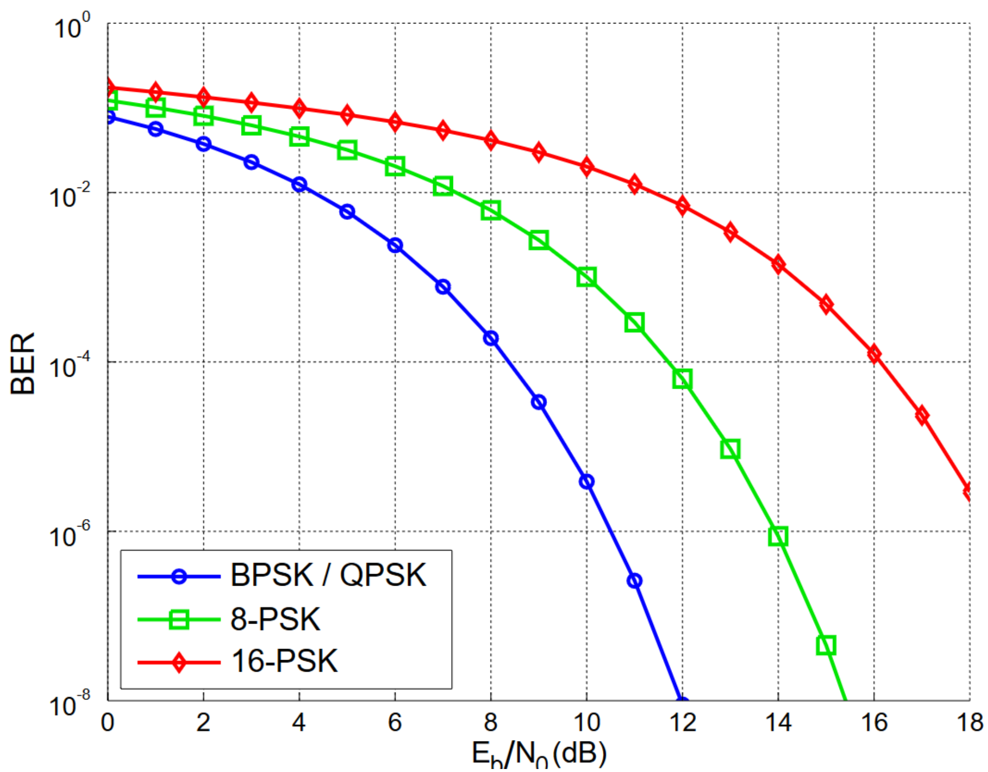
Source: https://documentation.meraki.com/MR/WiFi_Basics_and_Best_Practices/Signal-to-Noise_Ratio_(SNR)_and_Wireless_Signal_Strength

Basics of Wireless Communication

- SNR impacts performance
- SNR of an access point (AP) signal, measured at the user device, decreases as range to the user increases
- SNR decreases when there are RF interference from microwave ovens and cordless phones increases the noise level
- Laptop access to a 802.11b/g access point
  - > 40 dB SNR: excellent signal 5 bars: very fast
  - 25 dB to 40 dB SNR: very good signal (3-4 bars): very fast
  - 15 dB to 25 dB SNR: low signal (2 bars): usually fast
  - 10 dB to 15 dB SNR: very low signal (1 bar): mostly slow
  - 5 dB to 10 dB SNR: no signal

Basics of Wireless Communication

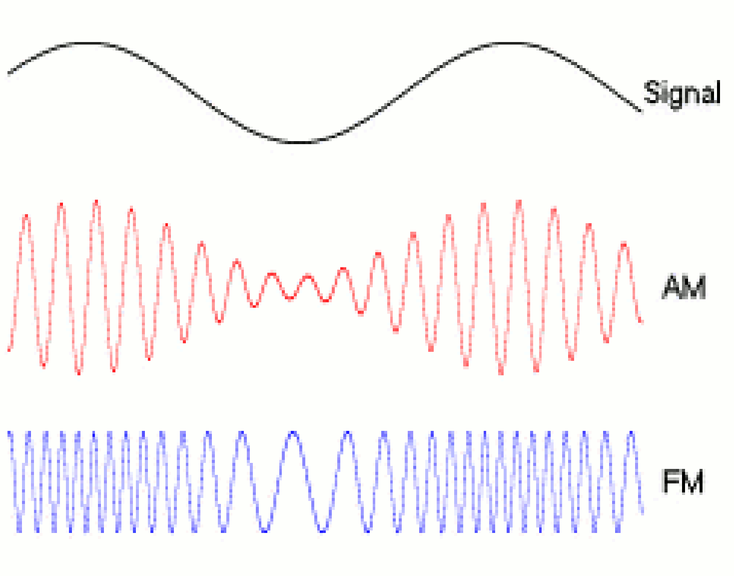
- Why is the data rate slower for lower SNR?
  - E_b/N_o: Energy per bit to noise power spectral density ratio
    - Signal power divided by the user bit rate
  - Bit error rate (BER) increases according to decreasing E_b/N_o
    - You have to retransmit if there is a bit error



Source: wikipedia

Basics of Wireless Communication

- What is modulation?
  - Process of varying one or more properties of a periodic waveform, called the *carrier signal* with a modulating signal that typically contains information to be transmitted
- Analog Modulation
  - Amplitude modulation (AM)
  - Frequency modulation (FM)

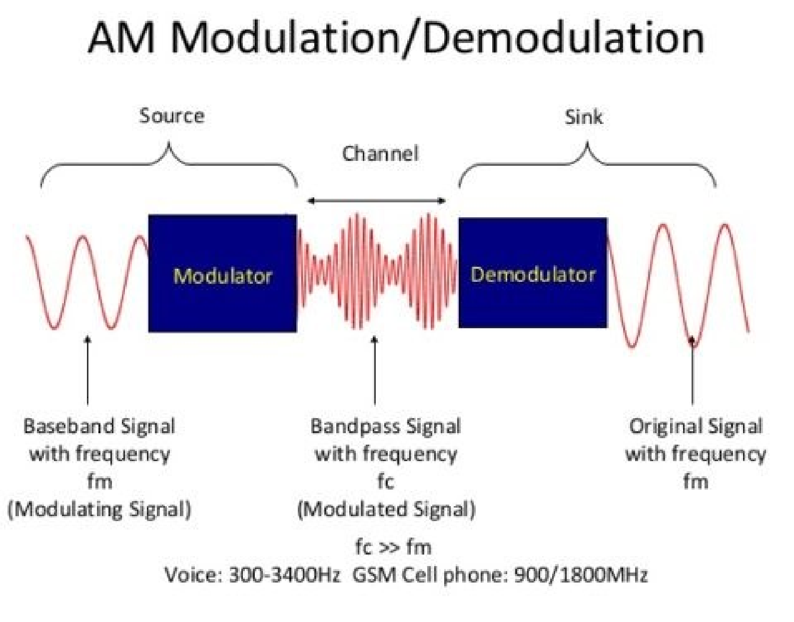


Source: wikipedia

Basics of Wireless Communication

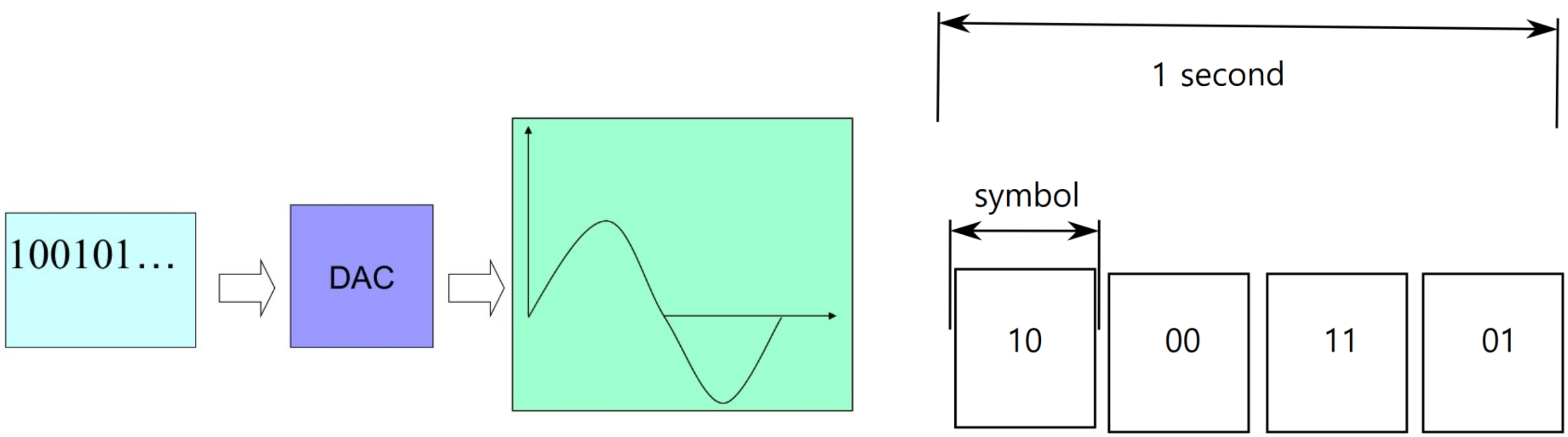
- Why do you need a carrier signal?
  - You need oscillation to send something over the wireless channel
    - How would you send a flat signal over a wireless channel?
  - Several carrier waves of different frequencies can transmit at the same time without interference

- Modulation and demodulation?



Source: http://hamradioindia.com/articles/modulation-demodulation/

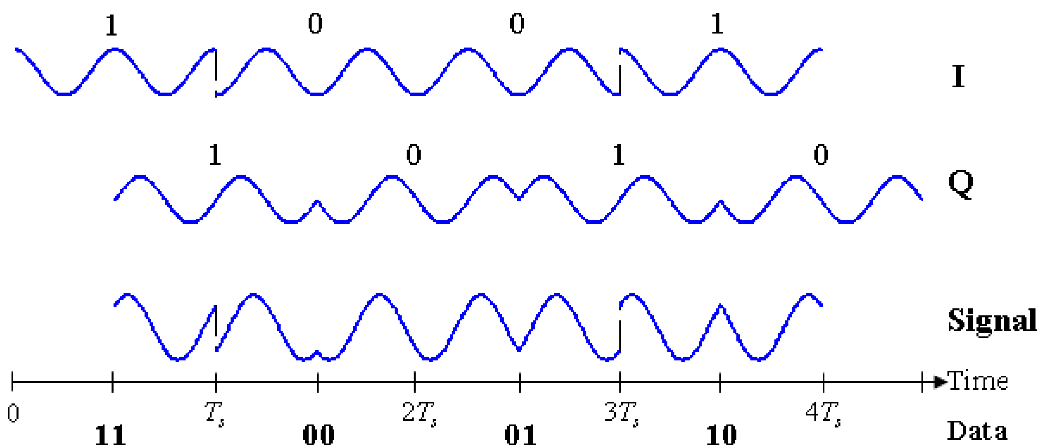
- Digital modulation
  - Modulation: digital-to-analog conversion
  - Demodulation: analog-to-digital conversion
  - Analog "symbols" are assigned to each digital bits
    - Four symbols are representing 10, 00, 11, 01
    - For example, musical tones can be a "symbol"
    - 4 symbols/sec = 8 bits/sec



Source: S. Nazin, "Digital to Analog Conversion"

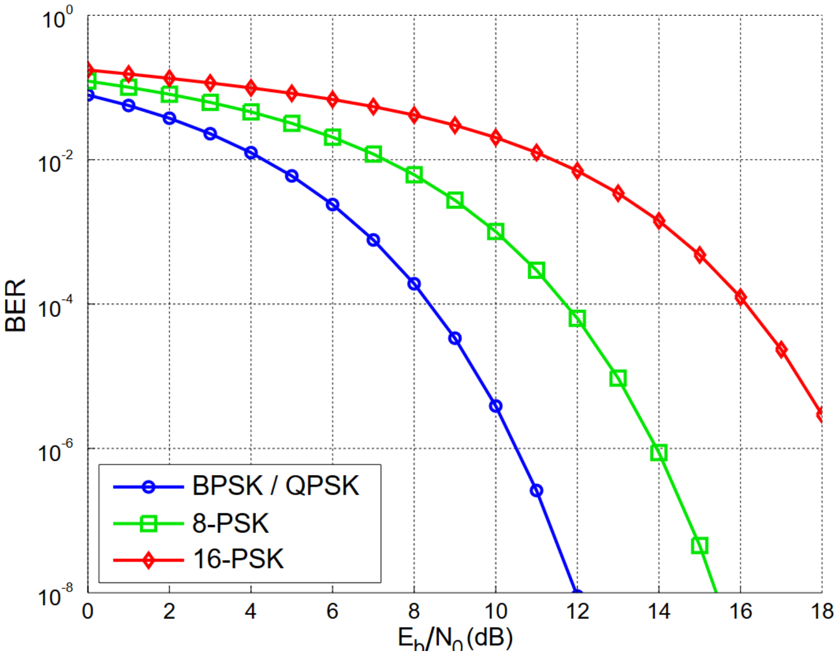
Basics of Wireless Communication

- Digital modulation types
  - PSK (phase shift keying)
    - different phases are used
  - FSK (frequency shift keying)
    - different frequencies are used
  - ASK (amplitude shift keying)
    - different amplitudes are used
  - QAM (quadrature amplitude modulation)
    - at least two phases and two amplitudes are used



Basics of Wireless Communication

- So what were BPSK and QPSK?
- BPSK with binary (two) symbols
- QPSK with four symbols, etc
- Why is the BER lower for BPSK?
  - The more elaboerated manner you divide the phases, the error of detecting symbols in a wrong way increases

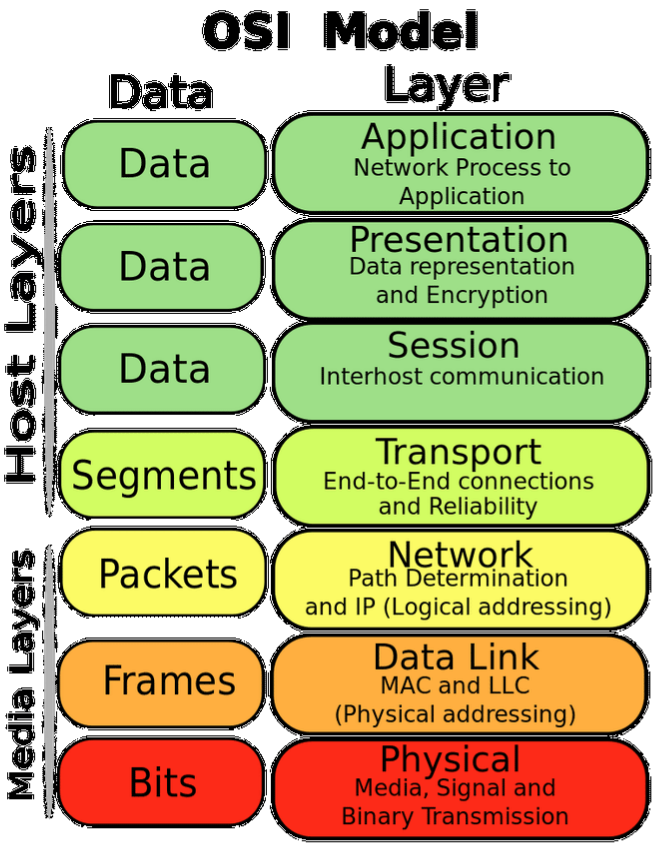


Basics of Wireless Communication

- What happens if there is a bit error?
- You can apply error coding and trying to figure out what the original bit was
- You can retransmit the data bits
- But these sorts of tasks maybe be handled at different abstraction layers

OSI Model

- Open Systems Interconnection Model (OSI Model)
  - Conceptual model that characterizes and standardizes the communication functions of a telecommunication or computing system
  - Lower layers are closer to physical world and hardware
  - Upper layers are closer to software
- Physical layer: Everything we discussed
- Data link layer: MAC, Ethernet
- Network layer: IP
- Transport layer: TCP, UDP
- Session layer
- Presentation layer: SSL, SSH, IMAP, FTP
- Application layer: HTTP, DNS



Wireless Network Protocols

- IEEE802.11
  - WLAN computer communication in various frequencies
  - Created and maintained by IEEE
  - Set of media access control (MAC) and physical layer

Wireless Network Protocols

- 802.11 physical layer (PHY)
  - Interface between the MAC and the wireless media where frames are transmitted and received
- PHY provides an interface to exchange frames with the upper MAC layer for transmission and reception of data
- PHY uses signal carrier and spread spectrum modulation to transmit data frames over the media
- PHY provides a carrier sense indication back to the MAC to verify activity on the media

Wireless Network Protocols

- 802.11 – Frame formats (layer 2)
  - MAC header: contains control information including „retry“ bits
    - Retry bits ensure duplicate packets are handled
  - Payload (actual data)
  - Frame check sequence (FCS): error detecting codes – adds redundancy

2	2	6	6	6	0 or 2	6	0 or 2	0 or 4	variable length	4
Frame Control	Duration /ID	Address 1	Address 2	Address 3	Sequence Control	Address 4	QoS Control	HT Control	Frame Body	FCS

Wireless Network Protocols

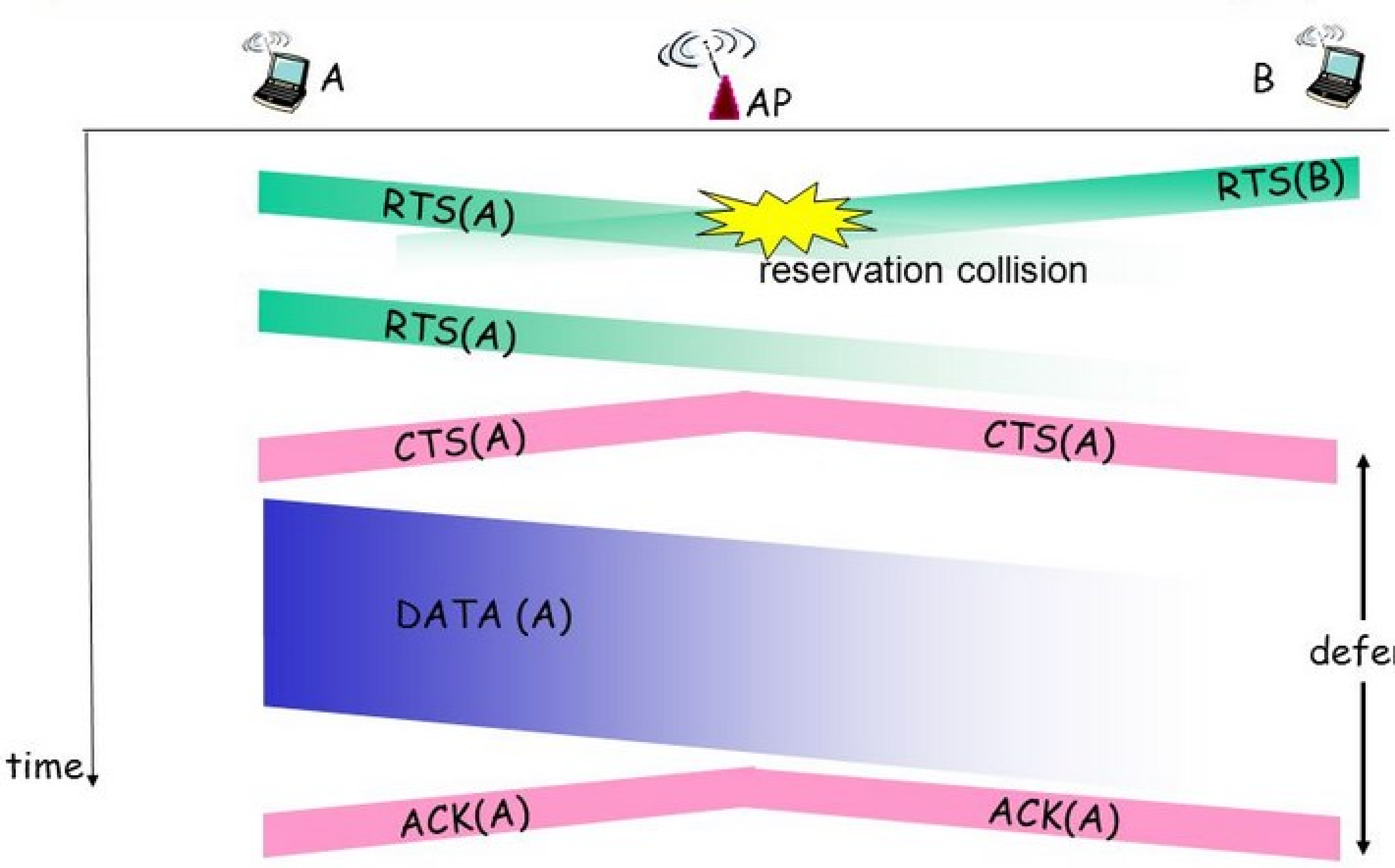
- 802.11 Media Access Control
  - How is access to the media controlled?
- Asynchronous, best-effort, connectionless delivery of MAC layer data
- There is no guarantee that the frames will be delivered successfully
- 802.11 MAC utilizes carrier-sense multiple access with collision avoidance (CSMA/CA)
- Security is provided by wireless equivalent privacy (WEP), which is an encryption service for data delivered on WLAN

CSMA/CA

- Carrier-sense multiple access with collision avoidance (CSMA/CA)
- CSMA/CA is a protocol that operates in the data link layer
- Steps
  - **Carrier sense:** Prior to transmitting, a node first listens to the shared medium
  - **Collision avoidance:** if another node was heard, the node waits for a period of time (usually random) for the node to stop transmitting before listening again for a free communications channel
  - **RTS/CTS Handshake (optional):** request to send (RTS) packet is sent to the receiver, and the receiver responds with a clear to send (CTS) packet
  - **Transmission**: the node awaits receipt of an acknowledgement packet from the acess point to indicate the packet was received and error-checked correctly

Collisions

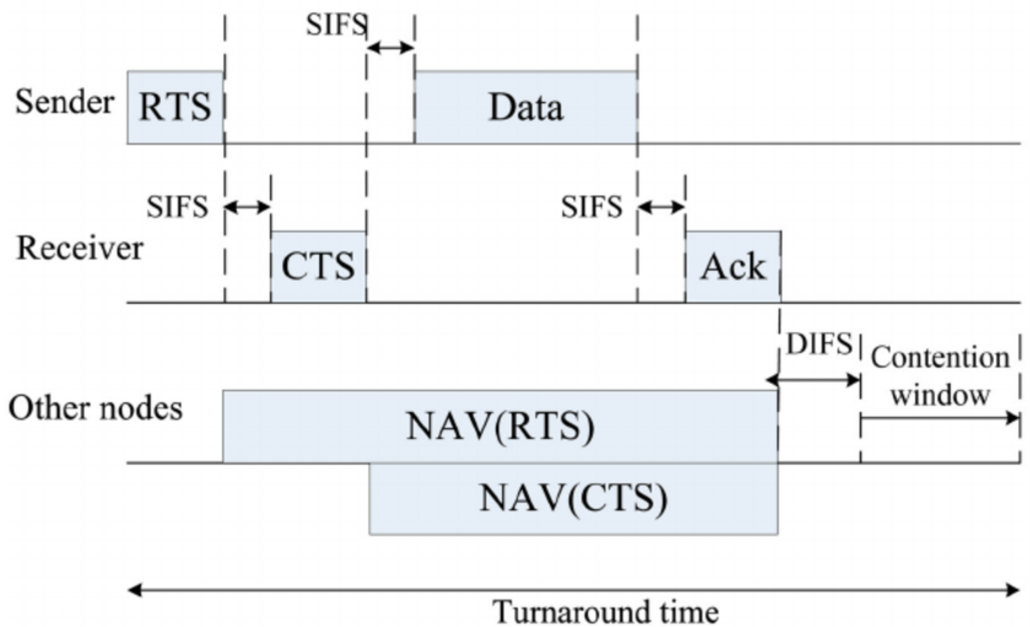
- Collision occurs when two nodes tries to access the same medium at the same time



Source:

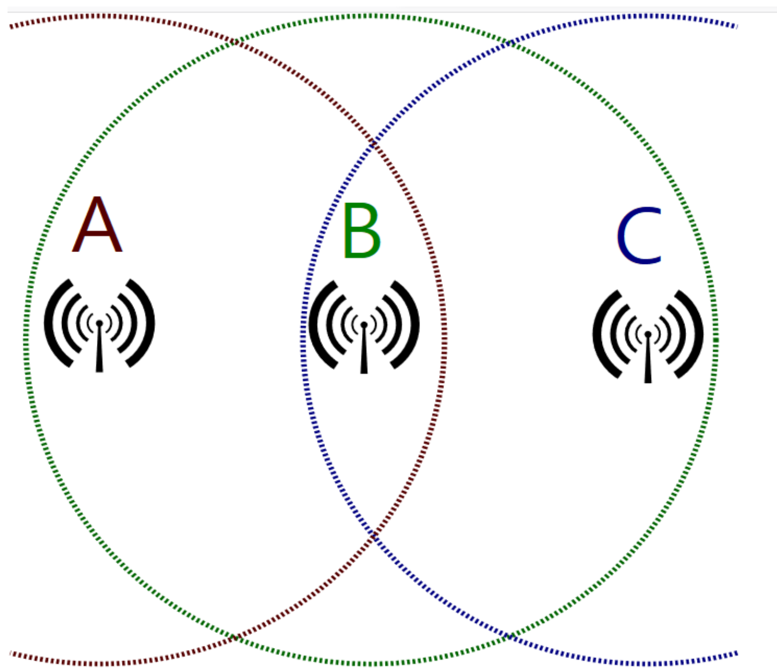
CSMA/CA

- CSMA/CA time graphs



CSMA/CA

- But why doesn‘t it guarantee successful delivery?
- Hidden node problem
  - If node A wants to send something to node B while node C is sending something, it cannot be sensed and there will be collision at node B

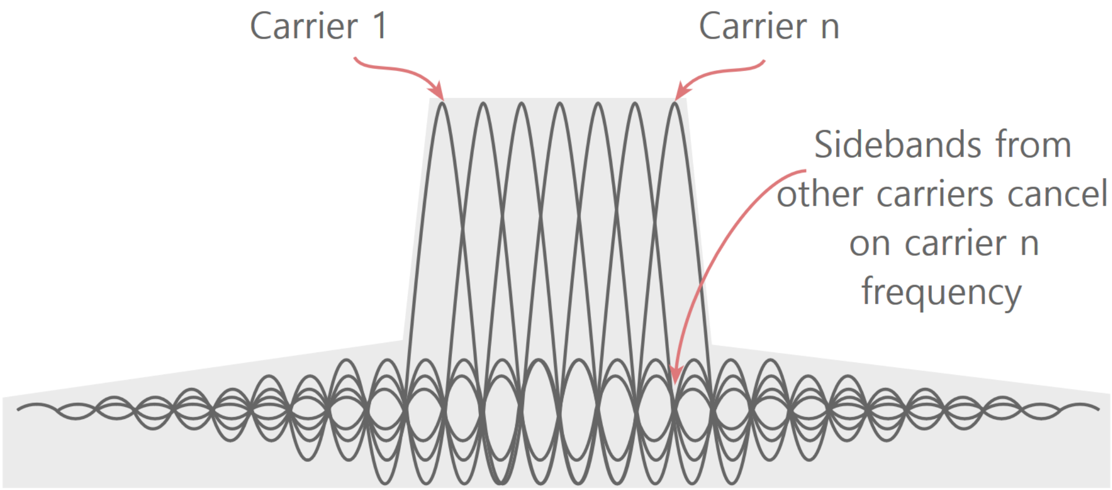


Wireless Network Protocols

- Amendments have been made
  - 802.11 legacy
    - Released in June 1997
    - Bitrate of 2 or 2 Mbit/sec
  - 802.11a (OFDM waveform)
    - Released in June 1999
    - Datarates of 1.5 to 54 Mbit/sec
    - Operates at 5 GHz frequency band and has less range
  - 802.11b (2000)
    - First widely accepted protocol
    - 11 Mbit/sec
    - 2.4 GHz range used – overlaps with microwave ovens, cordless phones, bluetooth – interference issues
  - 802.11g(2003)
    - OFDM based transmission scheme, 2.4 GHz band
    - 22 Mbit/sec or 54 Mbit/sec

OFDM

- Orthogonal frequency division multiplexing (OFDM)
  - Encodinig of digital data on ***multiple carrier frequencies***
  - Used in wireless networks and 4G mobile communications
  - Why is it called ***orthogonal***?
    - Because they channels are placed adjacent to each other with carefully set band gaps
    - Cancellation (see the common x-axis crossings) – no band gaps required to reduce inteference



List of WLAN Channels

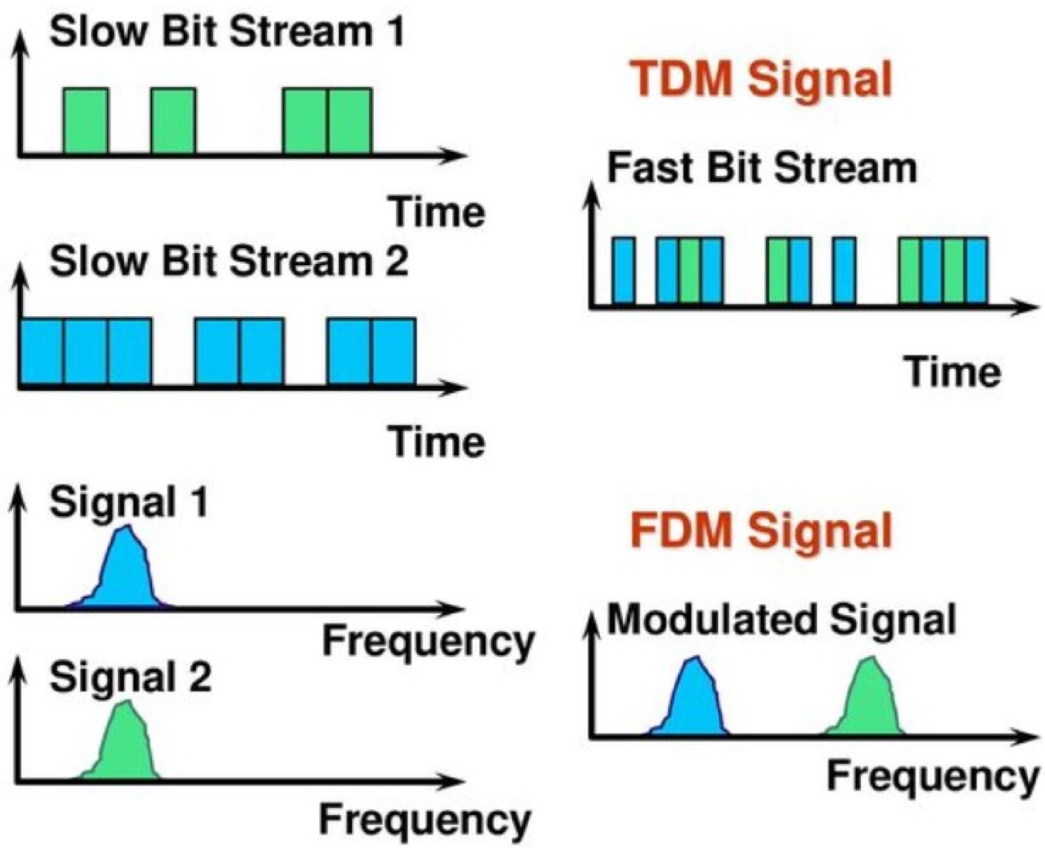
- Around 2.4 GHz (802.11b/g/n/ax)
  - Fourteen channels are designated in the 2.4 GHz range
  - Spaced 5 MHz apart
  - Does it mean only 14 devices can connect to an AP?
    - No
    - Multiple devices share single channel by dividing time

Channel	F_0 (MHz)	North America[6]	Japan [6]	Most of world[6][7][8][9][10][11][12][13]
1	2412	Yes	Yes	Yes
2	2417	Yes	Yes	Yes
3	2422	Yes	Yes	Yes
4	2427	Yes	Yes	Yes
5	2432	Yes	Yes	Yes
6	2437	Yes	Yes	Yes
7	2442	Yes	Yes	Yes
8	2447	Yes	Yes	Yes
9	2452	Yes	Yes	Yes
10	2457	Yes	Yes	Yes
11	2462	Yes	Yes	Yes
12	2467	No[B] except CAN	Yes	Yes
13	2472	No[B]	Yes	Yes
14	2484	No	**11b Only**[C]	No

Source: wikipedia

TDM vs FDM

- Time division multiplexing (TDM)
  - Sharing time on the same media
  - Need sync pulse
  - Interference is small
- Frequency division multiplexing (FDM)
  - Sharing frequency on the same media
  - Guard band needed to reduce interference
  - More complex circuit



Source: Sajid Awan, „Data over cable networks“

IEEE 802.11p

- IEEE 802.11p is an approved amendment to the IEEE 802.11 standard to add ***wireless access in vehicular environments*** (WAVE), published in 2010
- Data exchange between high-speed vehicles and between the vehicles and the roadside infrastructure (RSUs in the Vein example!)
- Licensed ITS (Intelligent Transportation Systems) band of 5.9 GHz (5.85 GHz – 5.925 GHz)