Revision of Lecture Nineteen

- Previous lecture has discussed various multiple access techniques

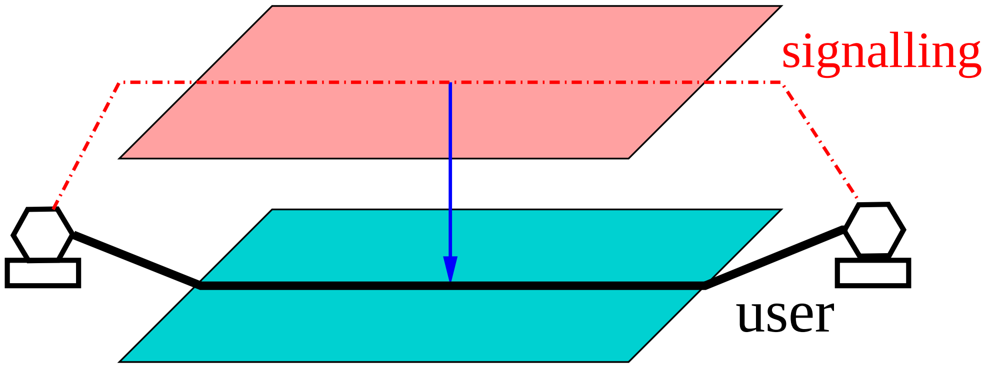
  Central issue is how to separate different users: FDMA, TDMA, CDMA, SDMA

- It also discusses channelisation spreading codes and CDMA technology

- This lecture we turn to **medium access control**, critical sublayer linking physical layer, PHY, and network layer

Signalling

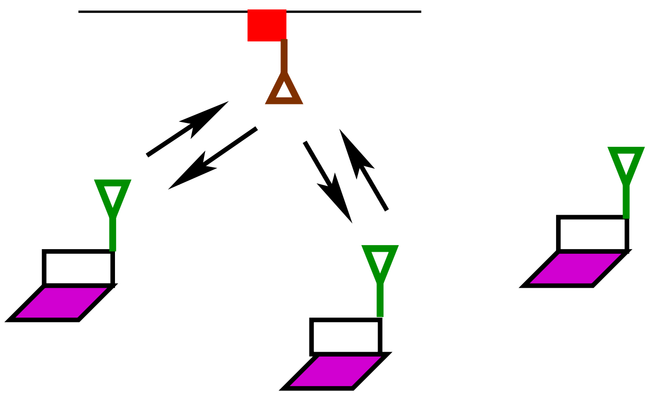
- In traditional fixed telephone network, the network is viewed as two planes, **user** and **signalling** planes, and a common channel signalling is adopted. Access to (a signalling channel in) the network is relatively simple

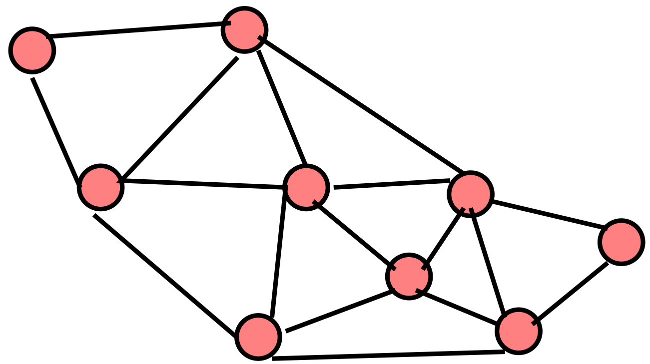


- In wireless mobile network, user connects to the network via **air interface**, and more sophisticated **protocol** is needed to resolve **multiple access** where several users compete to access a single (signalling) channel
  - GSM call set up: mobile has to reserve a slot in the dedicated control channel to set up a call and this request has to be made via the random access channel
  - In UTRAN, request for a control channel (signalling spreading code) is made via a similar random access channel
  - Packet radio: many users attempt to access the single channel randomly

Contention Algorithms

- Having **central access point**: communication between users (MS) via base
  - Down link: based → MS, base has control, can avoid **contention**
  - Uplink: MS → base, many users compete to access, multiple access interference





- No central access point, e.g. *Ad hoc* networks, contention problem

- Two categories of **contention protocols**
  - **Random access**: no coordination among users
  - **Scheduled access**: coordination among users

Packet Radio

- It is based on random access. Transmission is done by bursts of data (packets) and collision from simultaneous transmissions of multiple transmitters is detected by base station, who sends out ACK or NACK accordingly
- ACK: has received the packet from a particular user, and NACK: the previous packet was not received correctly. Note the perfect feedback employed
- Performance: throughput S (packets/s) which defines the average number of packets successfully transmitted per unit time, and average delay D (s) experienced by a packet
- Define the vulnerable time as the time interval during which packets are susceptible to collisions with other users' transmissions, and assume constant packet length τ (s) and fixed channel rate

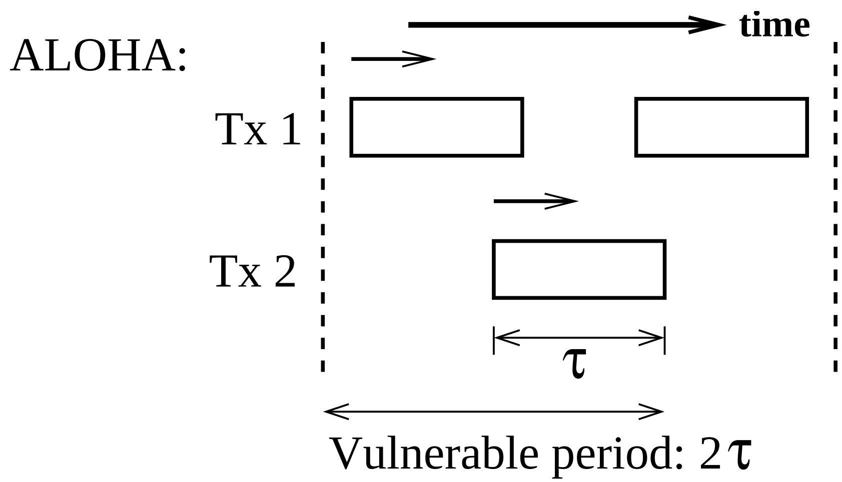
Packets transmission is Poisson distribution with mean arrival rate λ (packets/s)

Normalised channel traffic or average number of old and new packets submitted per packet time is

$$G = \lambda\tau \quad \text{(unit in Erlang)}$$

The throughput is then given by

$$S = G \times \text{Prob(no collision)}$$



ALOHA Class

- ALOHA: also called pure ALOHA. Whenever a user has a packet to send, it simply transmits the packet and waits for ACK. If collision occurs (arrival of an NACK), it waits for a random period of time and retransmits the packet again
- Slotted ALOHA: time is divided into slots of equal length greater or equal to the packet duration τ, and packet transmission can only start at beginning of a time slot
- Probability that a packet does not suffer from a collision is given by

$$P_0 = \begin{cases} e^{-2G}, & \text{ALOHA} \\ e^{-G}, & \text{slotted ALOHA} \end{cases}$$

The throughput/packet time is then

$$S = \begin{cases} G \cdot e^{-2G}, & \text{ALOHA} \\ G \cdot e^{-G}, & \text{slotted ALOHA} \end{cases}$$

- Maximum throughput of ALOHA:

$$\frac{dS}{dG} = e^{-2G} - 2Ge^{-2G} = 0 \Rightarrow G_{\max} = \frac{1}{2} \Rightarrow S_{\max} = \frac{1}{2}e^{-1} = 0.1839$$

Maximum throughput of slotted ALOHA:

$$\frac{dS}{dG} = e^{-G} - Ge^{-G} = 0 \Rightarrow G_{\max} = 1 \Rightarrow S_{\max} = e^{-1} = 0.3679$$

Carrier Sense Multiple Access

- A user wishing to transmit first listens to the medium to see if another transmission is in progress (carrier sense)

  If the channel is in use, it must wait. If the medium is idle, it may transmit

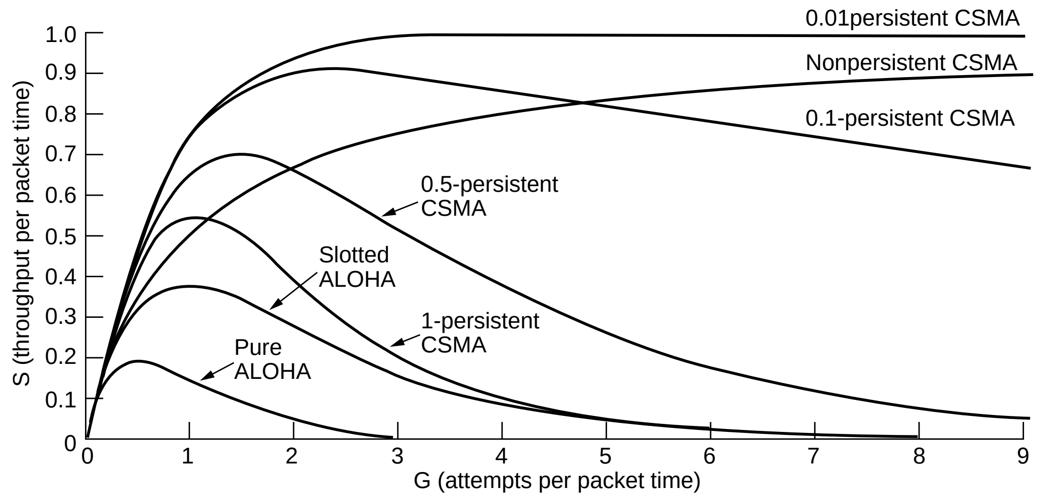
  - **1-persistent**: a user keeps listening to see if channel is free and, as soon as the channel is idle, it transmits
  - **Nonpersistent**: when the channel is busy, it waits for a random period of time before trying to listen again. This is less greedy
  - **p-persistent**: for slotted systems. When the channel is free during current slot, it transmits with probability p and defers until next slot with probability $1 - p$

- Detection delay is determined by receiver hardware: a small detection time means that a user can detect a free channel rapidly

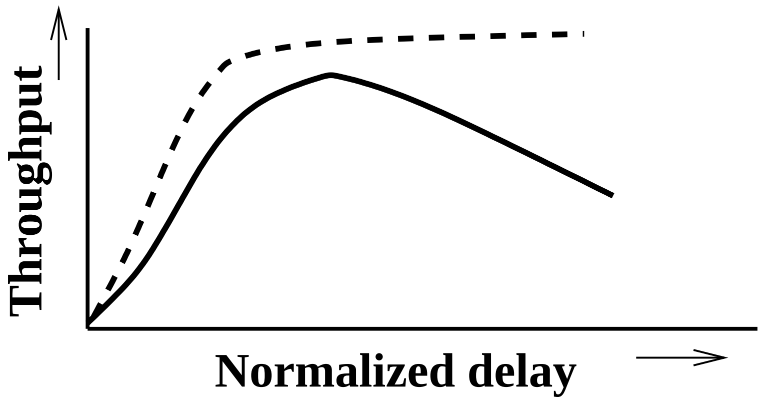
- Propagation delay is critical to performance: a small propagation delay means that as soon as a user launches a packet, others knows quickly and will defer to transmit, thus reducing collisions

CSMA (continue)

- Throughput versus load: For CSMA with small p, the method performs very well in terms of throughput at high load. However, for smaller p, users must wait longer (larger delay) to attempt transmission



- Trade-off throughput versus delay: Characteristics of dashed curve is preferred



- A random contention algorithm is characterised by its statistics: means and variances of throughput and delay

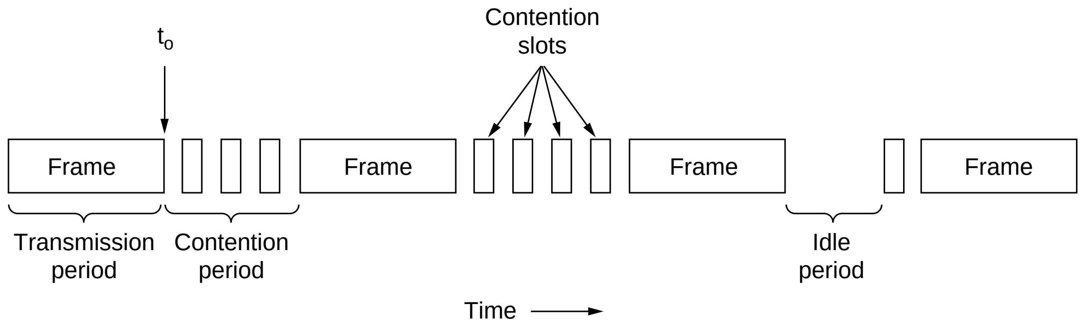
Better performance can be achieved if user continues to listen to medium while transmitting and stops transmission immediately if collision is detected ⇒ CSMA with collision detection

CSMA with Collision Detection

- A user wishes to transmit:
  1. Listens to see if the channel is free. If the channel is idle, it transmits. If the channel is busy, it keeps listening until the channel is free, then transmits immediately (1-persistent)
  2. During the transmission, it keeps listening to detect collision. If a collision is detected, it stops transmitting immediately, and waits a random period of time before goes back to step **1**.
- States of CSMA/CD:

  transmission period, contention period and idle period

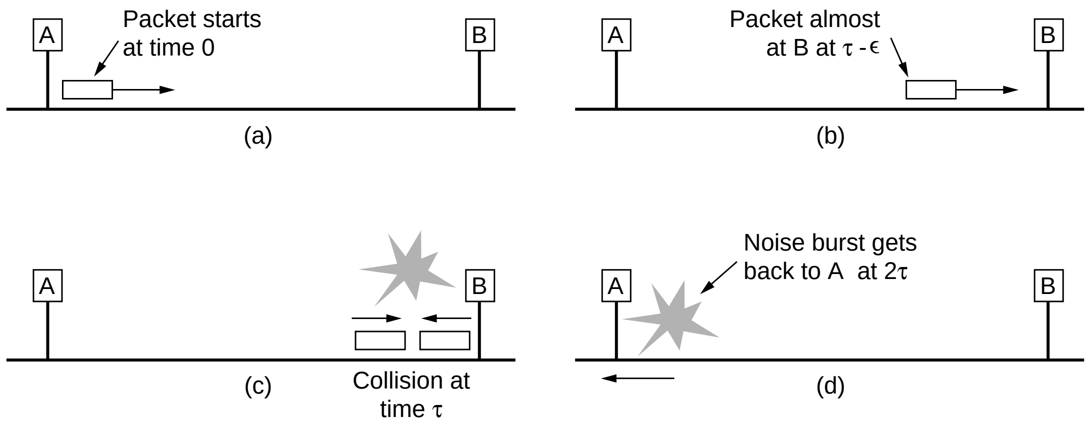
  Let τ be end-to-end (two farthest users) propagation time



- Worst case time to detect collision is 2τ:

  Frames should be long enough to allow collision detection prior to the end of transmission, otherwise CSMA/CD degrades to CSMA

  Binary exponential backoff is used: when repeatedly facing collisions, mean value of random delay is doubled



CSMA with CD Performance

- Let R be data rate (bps), d be link distance (m), V be propagation velocity (m/s), and L average frame (packet) length (bits). The link parameter is defined as:

$$a = \frac{\text{propagation time}}{\text{frame time}} = \frac{R\,d}{L\,V}$$

- Maximum possible utilisation of the channel is expressed as the ratio of throughput to capacity
- View time in "slots", with slot length 2τ and $\tau = \frac{d}{V}$. Recall CSMA/CD model: transmission, contention and idle periods. Under heavy load assumption $\longrightarrow$ no idle time
- Let T_t be average transmission interval and T_c be average contention interval. The maximum utilisation or efficiency is given by

$$U = \frac{T_t}{T_t + T_c}$$

- Since $T_t = \frac{1}{2a} \times 2\tau$ and it can be shown $T_c = e \times 2\tau$,

$$U = \frac{1}{1 + 5.44a}$$

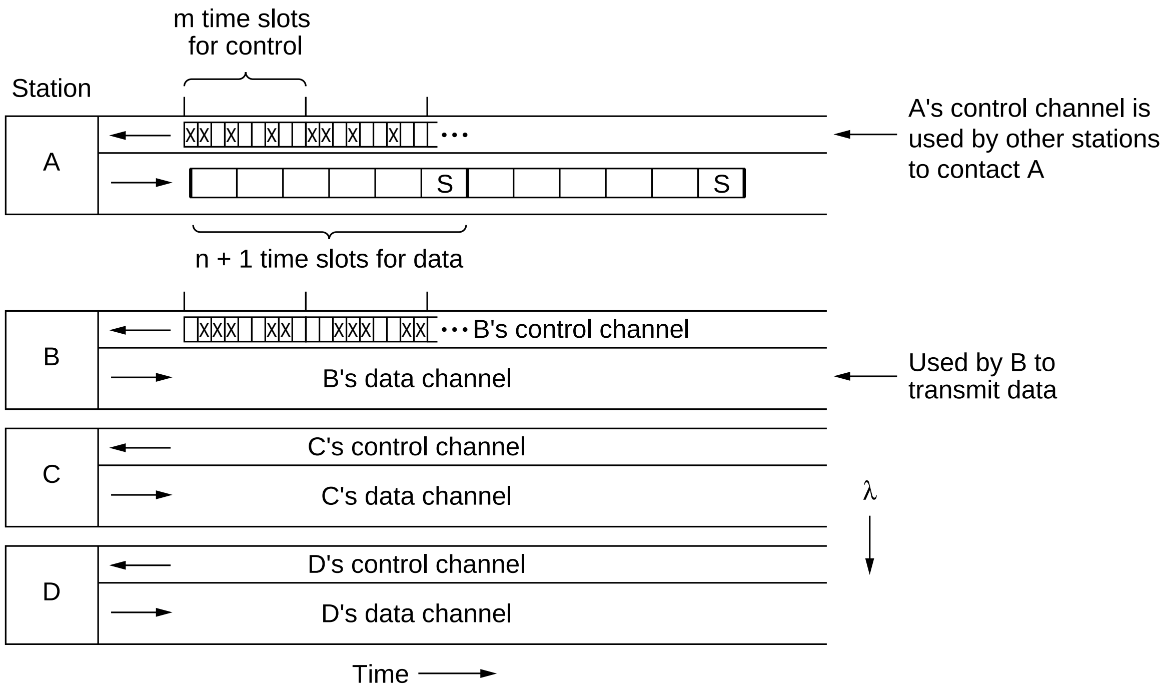
- **Example**. Guided media $V = 2 \times 10^8$ (m/s), 10 Mbps LANs (Ethernet) with $\tau = 25.6$ μs: Frame length 64 bytes $\Rightarrow U = 0.27$, and frame length 1024 bytes $\Rightarrow U = 0.85$

WDMA LAN

- Wavelength division multiple access for optic communications is similar to FDMA. In this kind of fiber optics LANs, a channel is a wavelength band
- A user gets two channels: control and data. A channel has fixed time slots, and data channel's last slot contains information on free slots in its control channel
- B communicates with A:

  To contact A, B reads status slot in A's data channel to see A has any control slots unused; then makes Tx request in a free slot in A's control channel

  If A accepts Tx request, B can send data on a specific slot of its own data channel and tell A where to pick up



Wireless LAN

- Wireless LANs use packet radio with short range, and typically there is a single channel covering the entire bandwidth (a few Mbps). CSMA would not work because:

  Hidden station problem: when A is transmitting to B, if C senses the medium, it will falsely conclude that it can transmit, as it cannot hear A

  Exposed station problem: when B is transmitting to A, if C senses medium, it hears an ongoing transmission and falsely concludes that it may not transmit to D, but in fact it can safely do so

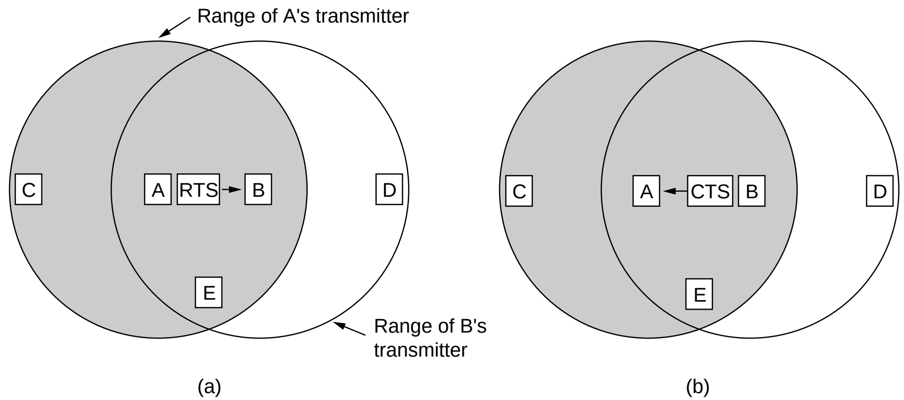
- Multiple access with collision avoidance (MACA): sense activity around intended receiver. Consider that A is trying to communicate with B:

  A transmits a Request to Send (RTS) to B

  B answers with a Clear to Send (CTS)

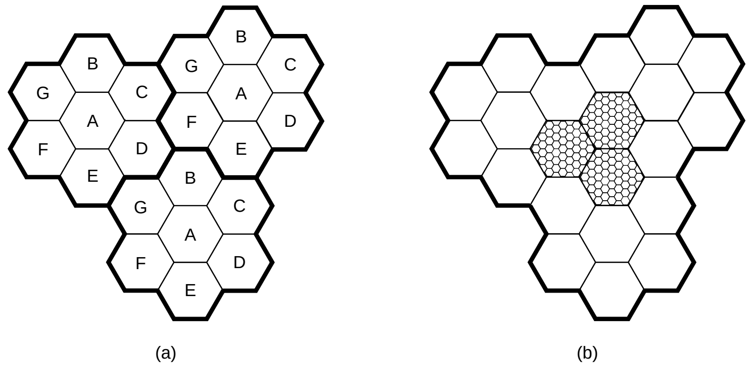
  C can hear the RTS from A but not the CTS from B, and it can freely transmit

  D hears only CTS from B, and must keep silent



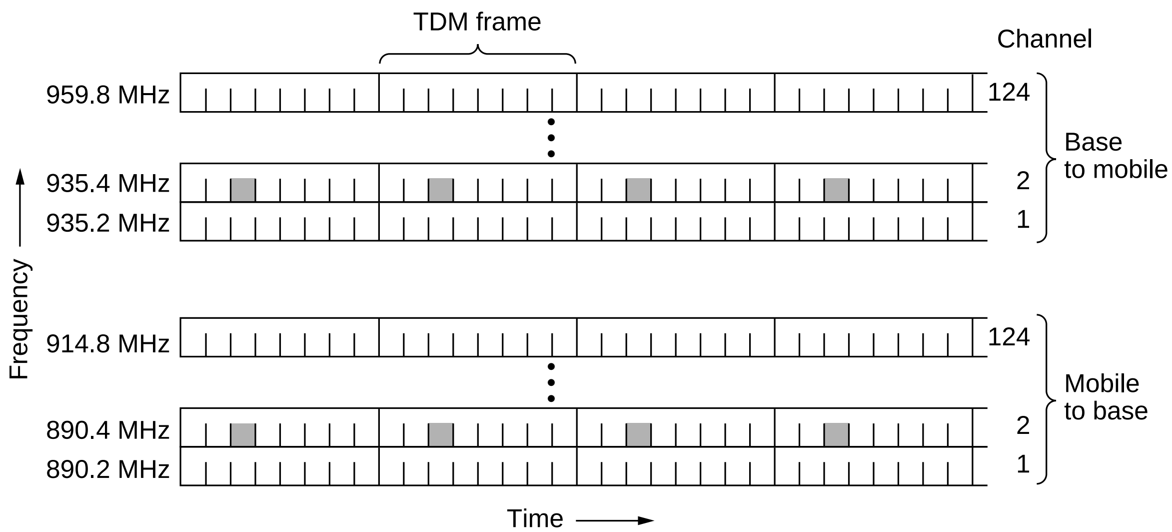
Digital Cellular Radio

- The concepts of cells and frequency reuse are fundamental to cellular radio. A cell maintains a set of frequency slots (channels). Two cells separated by a sufficiently long distance may use the same set of frequency slots (co-channels). This greatly improves bandwidth efficiency



- **GSM**: global systems for mobile communications uses a mixture of FDMA and TDMA technologies

GSM has 124 downlink channels and 124 uplink channels (FDM) per cell. Each such channel has a frequency band of 200 kHz and can support 8 separate users (TDM). Theoretically, there are $8 \times 124 = 992$ fully duplex (downlink/uplink) channels per cell, but many of them may not be used for avoiding co-channel interference with neighboring cells



GSM Control Channels

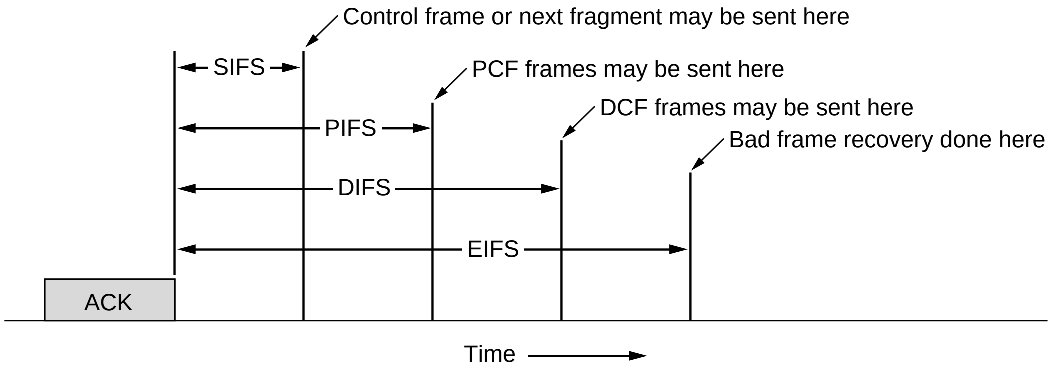
- **Broadcast control channel**: continuously broadcasts the base identity and the channel status. By monitoring this channel, mobile knows which cell it is in

- **Dedicated control channel**: is for location updating, registration, and call setup. Through this channel, a base knows who are in its cell

- Common control channel: consists of three logic sub-channels
  - **Paging channel**: is used by the base to announce incoming calls. Mobile continuously monitors this channel to see any call for it
  - **Random access channel**: is used by mobile to request a slot on the dedicated control channel, for call setup
    The access to the random access channel is based on slotted ALOHA
  - **Access grant channel**: is used to announce the assigned slot (who is granted access to which slot of the dedicated control channel)

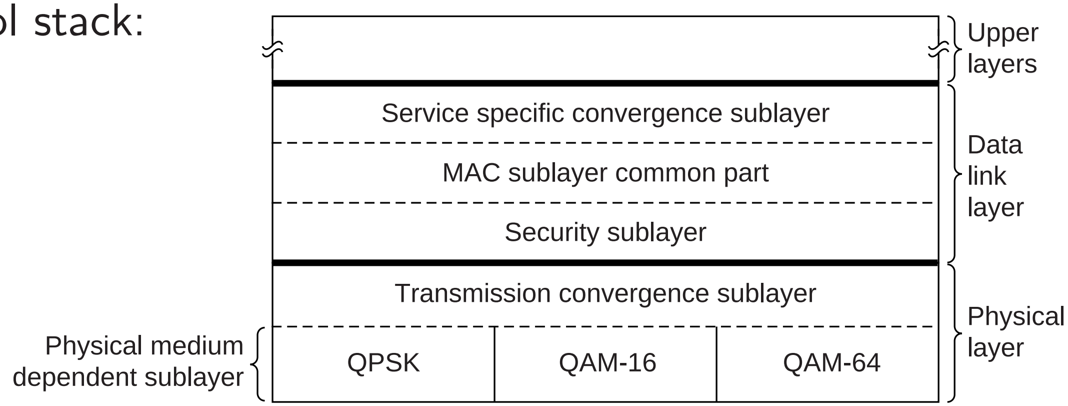
IEEE 802.11 Medium Access Control

- **WIFI** has two modes of operation: **distributed coordination function** with no central control (access point), and **point coordination function** with base station controlling activities in its cell
- For DCF, medium access control protocol is based on MACA (multiple access with collision avoidance)
  - To cope with noisy wireless channels, 802.11 allows frames to be fragmented into smaller pieces, each with its own checksum
  - Fragments are individually numbered and acknowledged using stop-and-wait
  - Once channel has been acquired using RTS and CTS, multiple fragments can be sent in row
- For PCF, base station polls users, asking them if they have frames to send and controls transmission order → no collision, a signed up user is guaranteed a certain fraction of bandwidth
  - Base periodically broadcasts a beacon frame, which contains system parameters, such as hopping frequencies and dwell times (for FHSS), clock synchronisation, etc., and it also invites new users to sign up for polling service
- 802.11 lets PCF and DCF to co-exist within a cell by carefully defining interframe time interval: after a frame has been sent, a certain dead time is required before any user may sent frame



Broadband Wireless

- IEEE 802.16 air interface for fixed broadband wireless access systems, also called wireless MAN, wireless local loop, or **WIMAX** has protocol stack:

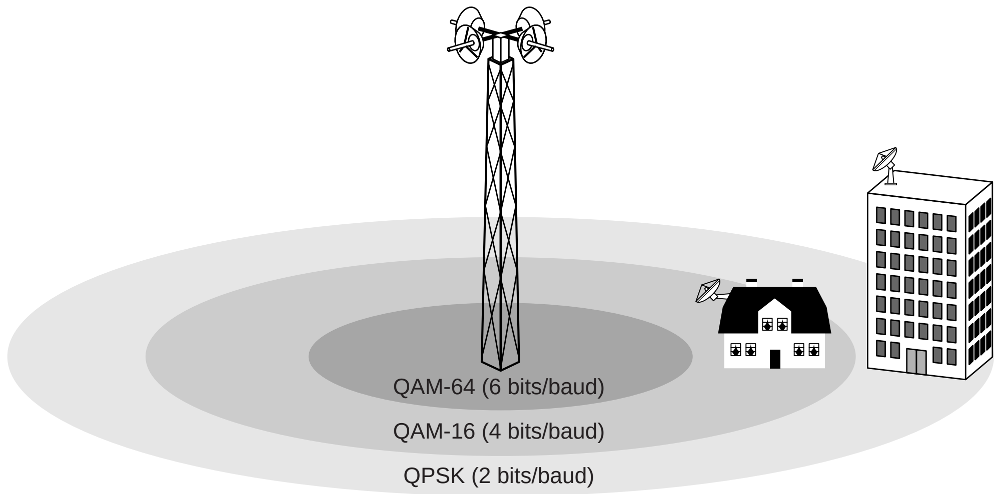


  It provides multimegabits wireless services for voice, Internet, movies on demand, etc.

- Physical layer operates in 10 to 66 GHz range, and base has multiple antennas, each pointing at a separate sector

  For close-in subscribers, 64QAM is used, so typical 25 MHz spectrum offers 150 Mbps; for medium-distance subscribers, 16QAM is used; and for distant subscribers QPSK is used

- Data link layer consists of three sublayers
  - Security sublayer manages encryption, decryption, and key management, crucial for privacy and security
  - Service-specific convergence replaces logical link control, providing seamlessly interface for network layer that may have both datagram protocols and ATM



802.16 MAC Sublayer Protocol

- 802.16 MAC sublayer is completely connection oriented to provide quality-of-service guarantees for telephony and multimedia, and MAC frames occupy an integral number of physical layer time slots

  Each frame is composed of subframes, and the first two are downstream and upstream maps
  - These two maps tell what is in which time slot and which time slots are free
  - Downstream map also contains system parameters to inform new users as they come on-line
- Downstream channel: base simply decides what to put in which subframe
- Upstream channel: there are competing subscribers and its allocation is tied to class of service
  - Constant bit rate: dedicate certain time slots to each connection and bandwidth is fixed through the connection, providing typical telephone channel service
  - Real-time variable bit rate: for compressed multimedia and other soft real-time applications in which bandwidth needed each instant may vary

    Base polls subscriber at fixed interval to ask how much bandwidth is needed this time
  - Non-real-time variable bit rate: for non-real-time heavy transmissions such as large file transfers

    Base polls subscribers often at non rigidly defined intervals to see who needs this service
  - Best-efforts: no polling and subscriber contends for bandwidth with others

    Requests for bandwidth are done in time slots marked in upstream map as available for contention. Successful request will be noted in next downstream map, and unsuccessful subscriber has to wait a random period of time before try again

Summary

- Basic concepts of contention: example of random access – packet radio, throughput and average delay, vulnerable time, Poisson distribution and mean arrival rate
- Contention algorithms: pure ALOHA, slotted ALOHA, CSMA (1-persistent, nonpersistent and p-persistent), trade-off between throughput and delay
- Contention algorithms: CSMA with CD, states, worst case detection time, link parameter, efficiency
- WDMA LANs: access protocol
- Wireless LANs: hidden and exposed station problems (why CSMA does not work), access protocol – MACA (key: sense intended receiver)
- Control channels and call set up in GSM
- IEEE 802.11 WLAN MAC, IEEE 802.16 broadband wireless MAC