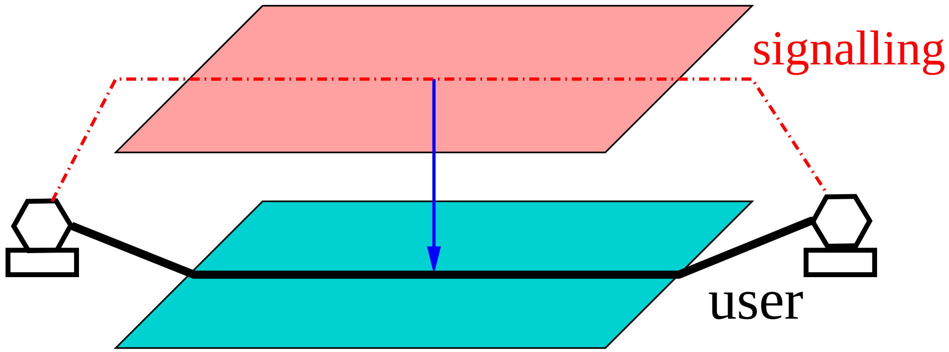
Revision of Previous Two Lectures

- Lecture Twenty-One has discussed duplexing protocols and various multiple access techniques
  - Central issue is how to separate different users: FDMA, TDMA, CDMA, SDMA
  - and how to separate transmitting and receiving (forward and reverse channels): FDD, TDD, SDD
  - It also discusses channelisation spreading codes and CDMA technology
- Lecture Twenty-Two has detailed DS-CDMA systems
  - Uplink system model and multiuser detection
  - Downlink system model and single user detection
- This lecture we turn to **medium access control**, critical sublayer linking physical layer, PHY, and network layer

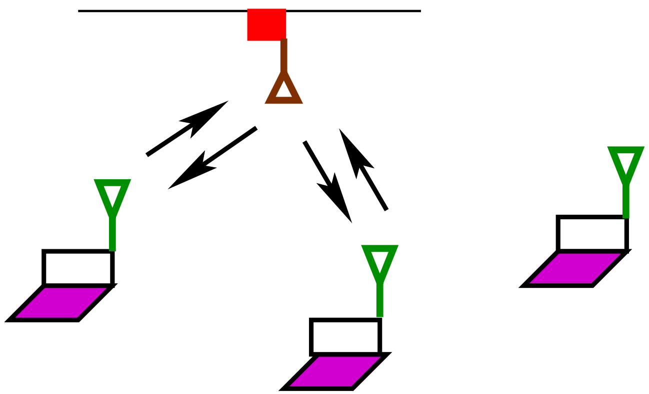
Signalling

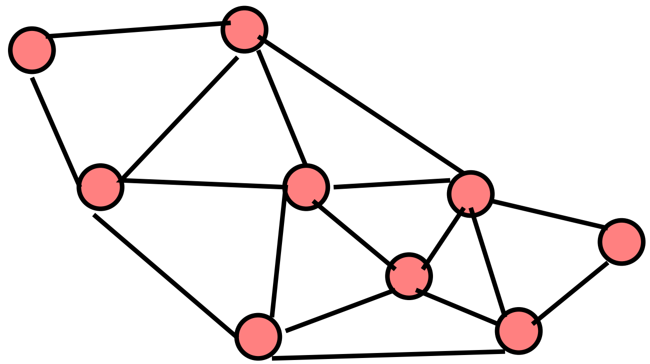


- In traditional fixed telephone network, the network is viewed as two planes
  - **User** and **signalling** planes
  - Common channel signalling is adopted
  - Access to (a signalling channel in) the network is relatively simple
- In mobile network, user connects to network via **air interface** and needs more sophisticated **protocol** 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
- Signalling overhead: different layers' protocols add their signallings
  - IPv6 packet: signalling overhead counts to 50% of packet
  - In mobile networks, total network signalling overhead counts to 95% of what are transmitted in whole network, i.e. only 5% are actually users' data

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, causing multiple access interference, and requiring protocols to resolve contention





- No central access point, e.g. *Ad hoc* networks, many users compete to access, and having contention problem

- Two categories of **contention protocols**
  - **Random access**: no coordination among users
  - **Scheduled access**: coordination among users, e.g. taking turns to access

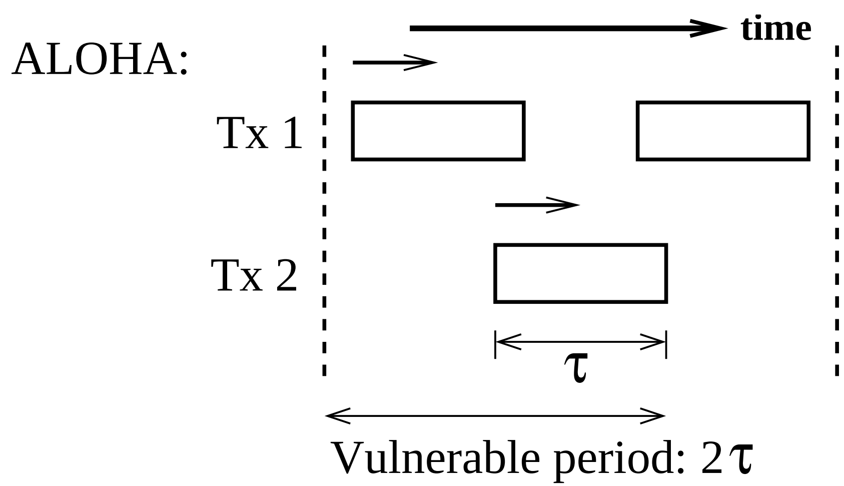
Packet Radio

- Based on random access: transmission of a user is done by bursts of data (packets)
  - 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 (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 $1 - p$

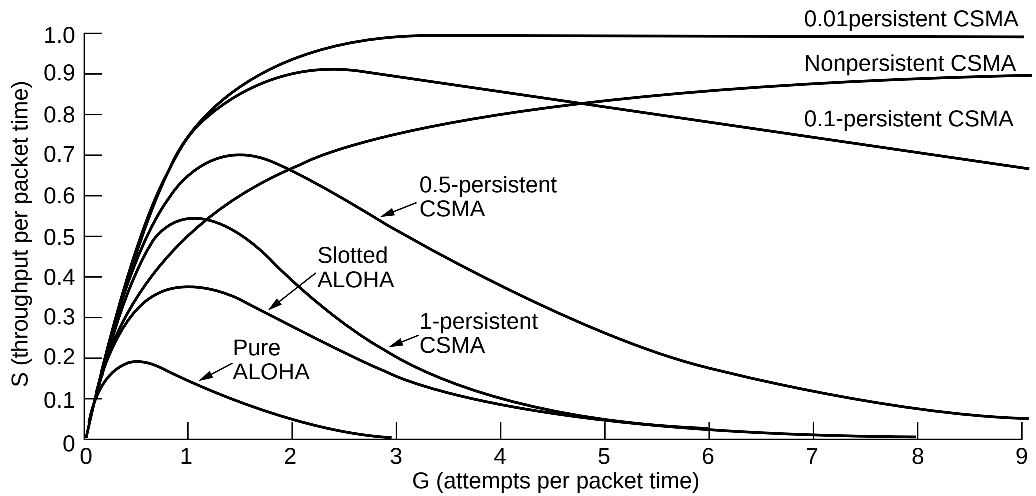
- **Detection delay** is determined by receiver hardware: a small detection time means that a user can detect a free channel rapidly

- **Propagation delay** is critical to performance

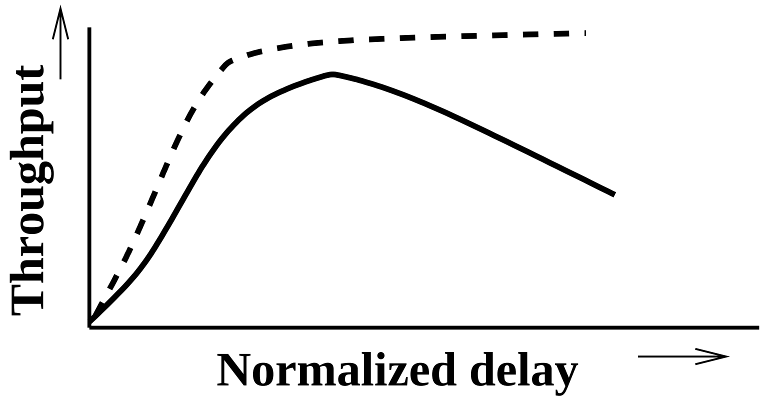
  - A small propagation delay means that as soon as a user launches a packet, others knows quickly and will defer to transmit, thus reducing collisions

CSMA (continue)

- A random contention algorithm is characterised by its statistics:
  - Average throughput $S(G)$ and average delay $D(G)$ as well as their variances as functions of network load G
- For CSMA, (a) throughput versus load, and (b) trade-off throughput versus delay



(a)



(b)

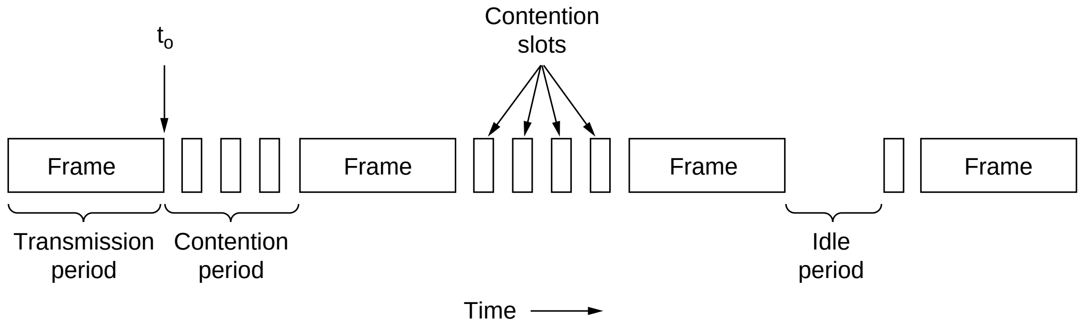
  - Method performs very well for small p in terms of S at high load G
  - However, for smaller p, users must wait longer (larger delay) to attempt transmission
  - Hence, characteristics of dashed curve in (b) is preferred
- Better performance can be achieved if user continues to listen to medium while transmitting and stops transmission immediately if collision is detected
  - This leads to 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

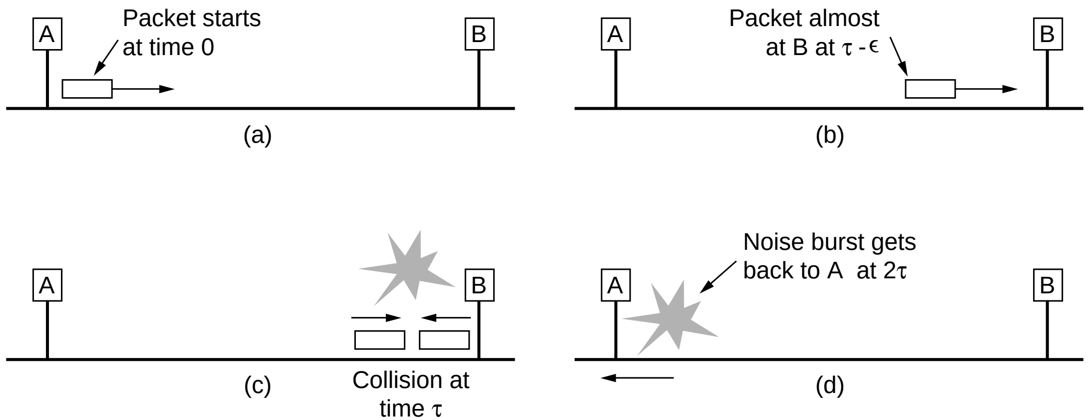
  Let τ be end-to-end (two farthest users) propagation time



- 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 $\tau = 25.6\ \mu$s: Frame length 64 bytes $\Rightarrow U = 0.27$, and frame length 1024 bytes $\Rightarrow U = 0.85$

WDMA LAN

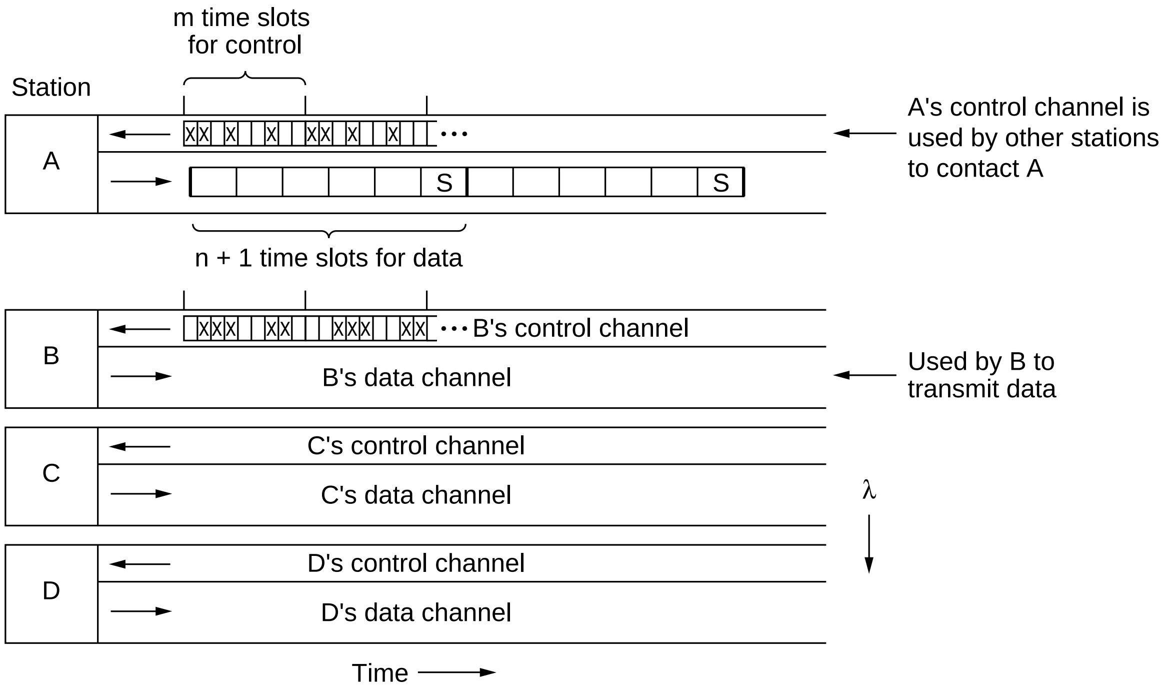
- Wavelength division multiple access for optic communications is similar to FDMA. In this kind of fiber optics LANs, a channel is a wavelength band

- 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

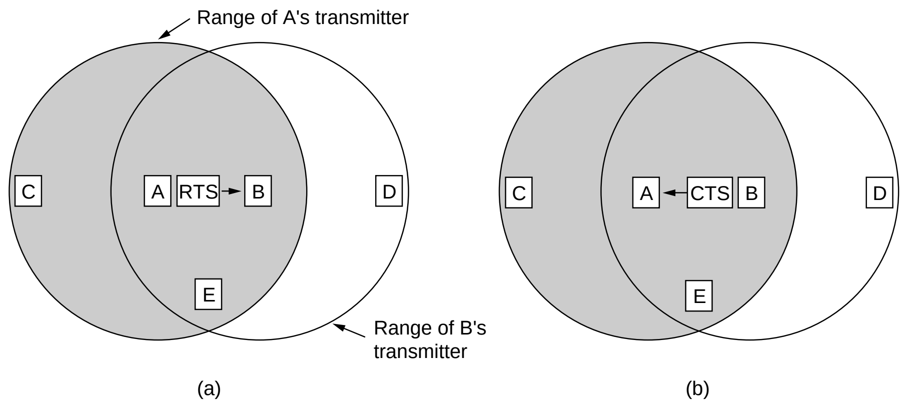
- Multiple access with collision avoidance (MACA): sense activity around intended receiver. Consider that A is trying to communicate with B:

  A transmits a Request to Send (RTS) to B

  B answers with a Clear to Send (CTS)

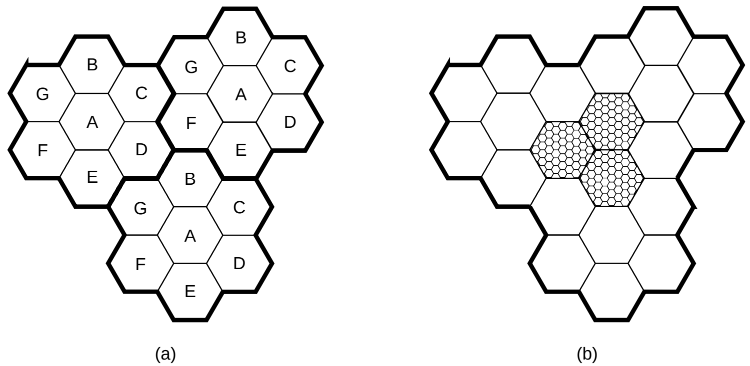
  C can hear the RTS from A but not the CTS from B, and it can freely transmit

  D hears only CTS from B, and must keep silent



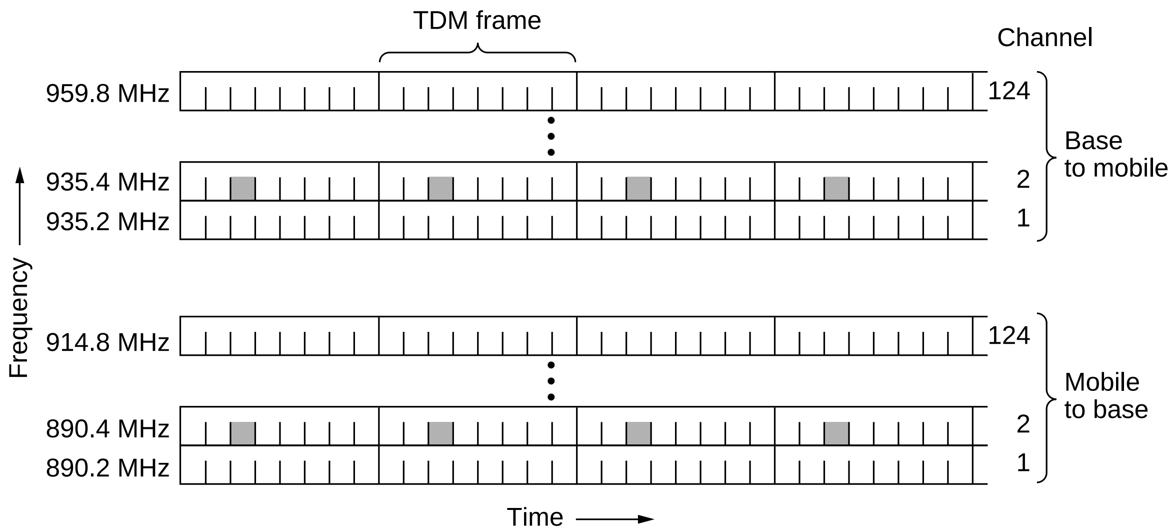
Cellular Network: User Channels

- 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

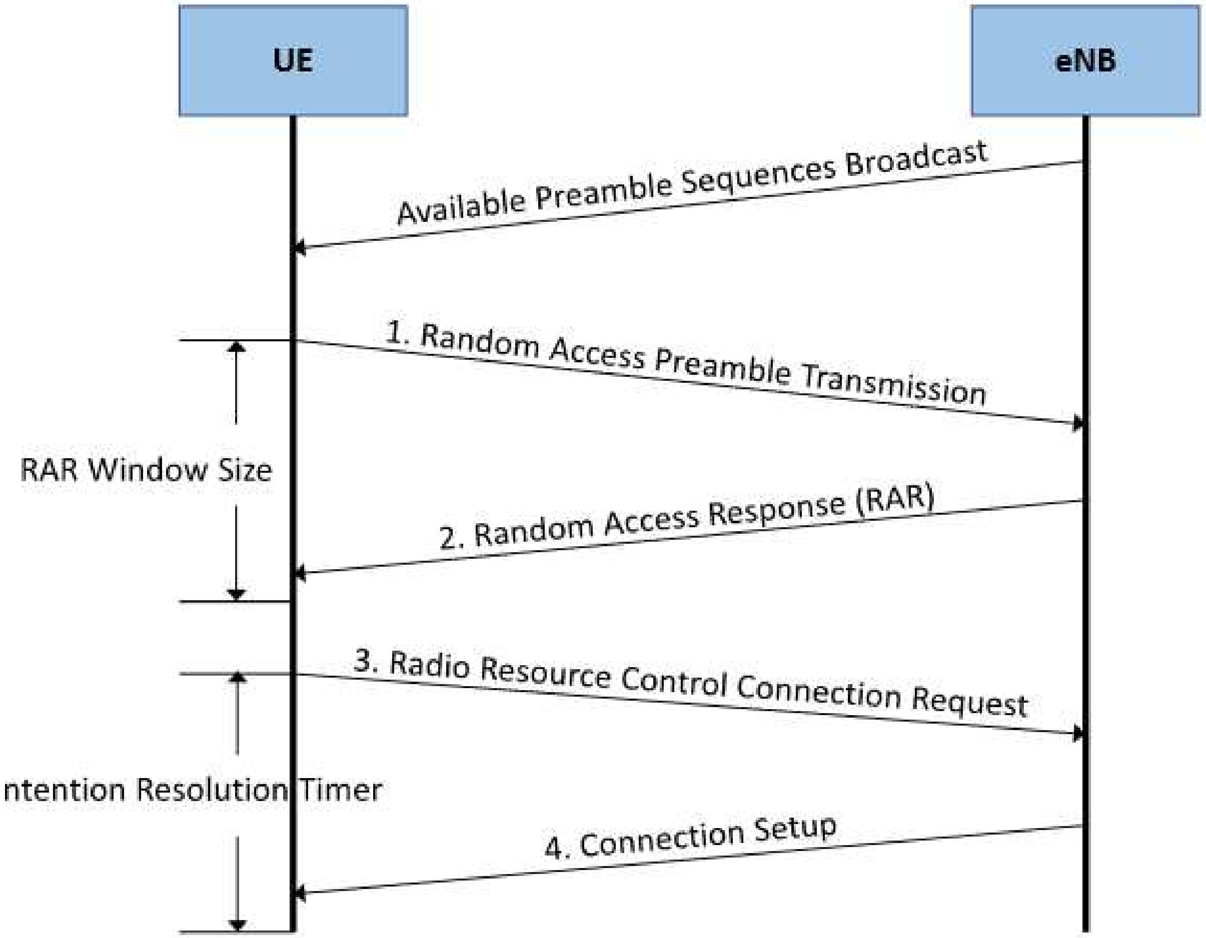


Cellular Network: Control Channels

- In a cellular network, each cell is assigned with a set of user channels, and it also has a set of control channels, and GSM's 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)

4G Access

- Similar to 2G and 3G, UE accesses 4G network with **grant-based** multiple access scheme: 4-step handshake via physical random access channel (PRACH)



4G Access (Continue)

1. UE randomly chooses and transmits a **preamble** from the set to BS who estimates transmission time of UE from detected preamble

2. For each detected preamble, BS sends **RA response** (RAR) with information of resource allocated to UE and timing advance for synchronization
   - If UE not receive RAR within waiting window or gets RAR with no information about its request, postpones access to next RACH opportunity

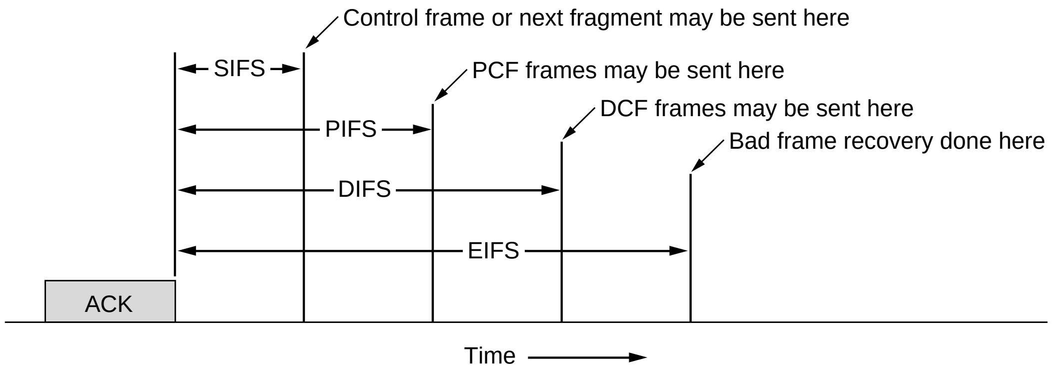
3. Successful UE makes radio resource control (RRC) **connection request** to BS via physical UL share channel

4. BS sends information of allocated resources to all UE that have gained access

- **Grant based** access introduces latency and access overhead, and is suitable for long data transmissions with relatively low number of devices
- For mMTC in 5G and beyond, there are massive devices and data packages are short. Grant-based access is inefficient, and we are currently develop **grant-free** multiple access schemes

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 $\longrightarrow$ 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



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 cellular network, e.g. GSM to 4G
- IEEE 802.11 WLAN MAC