+) Multiple access techniques:

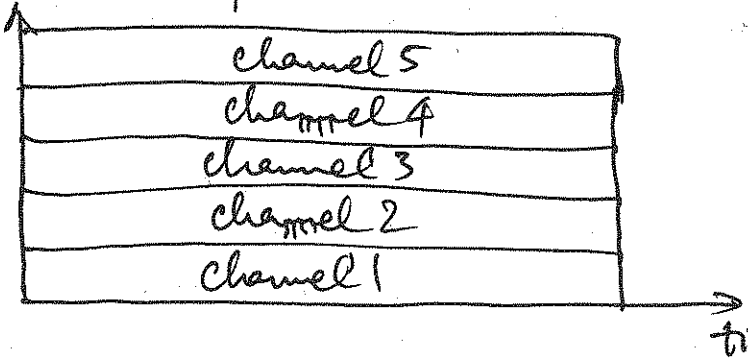
- Note that multiple access techniques refer to the way of allocating resources among users and apply to both UL & DL. This is different from the "multiple access channel" which is a model for the uplink (UL).

- Multiple access usually refers to the approach when dedicated resources are allocated to users. It is used primarily for continuous applications such as voice and video.

The other approach is called random access, usually applied to applications that don't require dedicated channels.

- Common multiple access strategies:
  - FDMA: Frequency division multiple access
  - TDMA: Time division multiple access
  - CDMA: Code division multiple access.
  - SDMA: Space division multiple access.
  - Hybrid techniques such as in OFDMA.

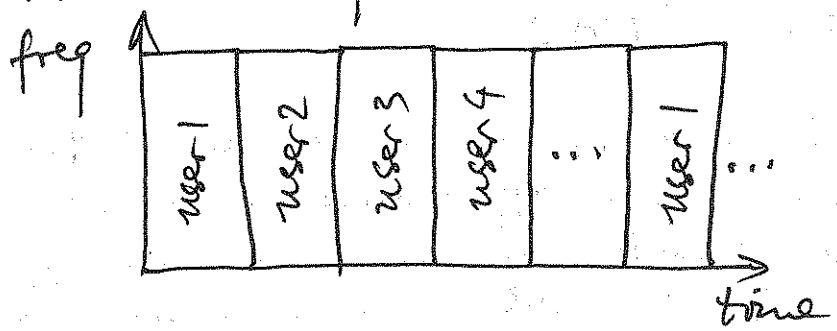
- FDMA technique:



- FDMA is used in 1G analog systems.

- FDMA usually implies non-overlapping (sub)channels for different users. The channels usually have guard bands to reduce ICI due to Doppler and filters, hardware

- TDMA technique:

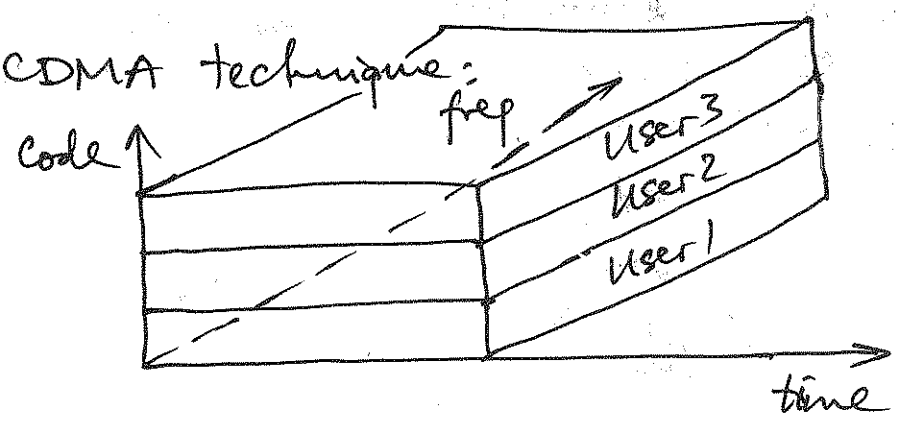


- Each user is assigned a slice of time and occupies the whole system bandwidth.

- TDMA system requires tight time synchronization and often has guard periods (time intervals) to ease synchronization requirement and compensates for errors and multipaths.

- TDMA is used in 2G systems (GSM, IS-136). The broadband technique is single carrier with equalization.

- CDMA technique:



- All users occupy the whole system bandwidth at the same time.
- Users are separated by using orthogonal codes on the downlink.
Uplink usually uses non-orthogonal code to relax

the synchronization requirement, but creates multiple access interference (MAI).

- Power control is used in uplink to ensure the received SNR of different users are approximately the same. This power control is to compensate for the near-far effect so that no one user's signal will swamp another user's signal.

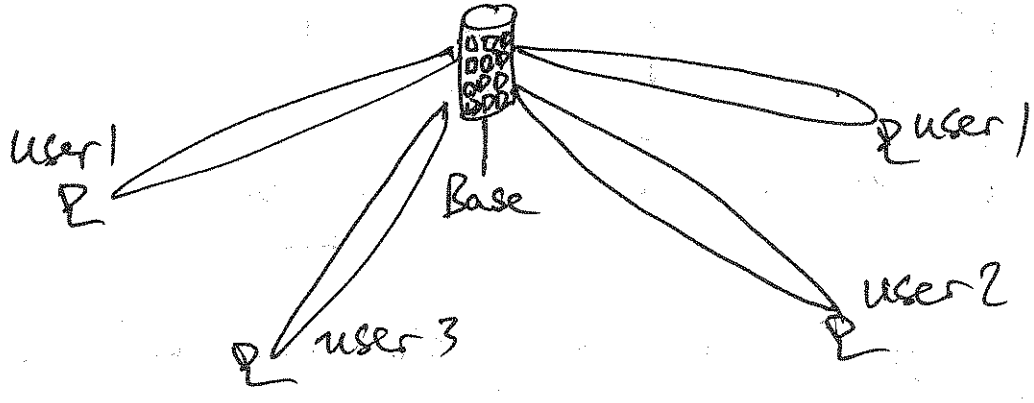
This power control results in significant overhead because of frequent feedback required.

- CDMA is used in 3G systems.

- Space-division multiple access - SDMA techniques:

- SDMA can be used when there are multiple antennas at the base station.

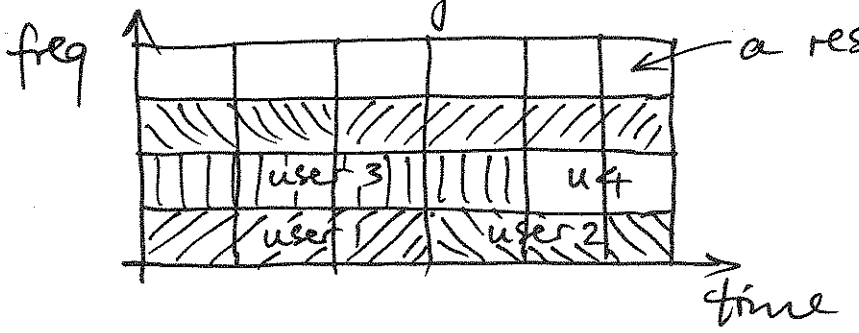
- The idea is to use directional antennas or beamforming from an array of antennas to direct non-overlapping beams to different users



- SDMA via beamforming requires tracking of user's channel (or location) at the base transmitter.
- SDMA is promissory with massive MIMO for 5G.

- Hybrid techniques: OFDMA.

- OFDMA is a hybrid between FDMA and TDMA.



- Resources in both time and frequency are divided into resource blocks.

- Each user can occupy a number of resource blocks which usually are non-overlapping. But some standards also allow users to overlap in resource blocks.

- Very tight time and frequency synchronization is required, as well as a complex scheduling system to assign resource blocks to users. The overhead is high.

- The goal is to make as an efficient use of resources as possible and to push the data rates.

- OFDMA is used in 4G systems (LTE).

+) Random access techniques:

- Random access is more suitable for applications that generate data in burst at random and hence do not require dedicated resource as in multiple access.

- Random access techniques are based on packetized data or packet radio.

- User data is formated into packets of N bits, which can include error correction/detection and control bits.

- If packets from different users overlap in time, then a collision occur and often both packets are lost (cannot be decoded succesfully).

- All users share the same channel bandwidth and transmit their data over this bandwidth without additional signaling to separate simultaneous transmissions

- Several common random access strategies are: ALOHA, slotted ALOHA, and CSMA

+) Pure ALOHA:

- This is the first random access protocol decised by Abramson to communicate over radio among the islands in Hawaii.

- In pure ALOHA, packets are transmitted as soon as they are formed.

- If packets overlap in time, collision occurs and the packets must be resend at a "later" time.

- Assume that a user sends packets (both new and old - repeated after a collision) according to a Poisson process at rate λ packets per unit time.

For a Poisson process, the probability that the number of packets arrivals during time period $[0, t]$ is equal to k is

$$Pr(X = k) = \frac{(\lambda t)^k}{k!} e^{-\lambda t}$$

The traffic load during a duration τ is $L = \lambda\tau$. L is unitless. Here τ is the transmission time of a packet which is related to the data rate as $\tau = \frac{N}{R}$. (N = packet length, R = data rate).

Thus in pure ALOHA, for no collision to occur during a packet transmission time of τ, there must be no other packets during the time window $[-\tau, \tau]$.

The probability of no collision is

$$Pr(X = 0) = e^{-\lambda 2\tau} = e^{-2L}$$

The corresponding throughput is

$$T = L \cdot e^{-2L} \quad \text{(frame or packet per packet time)}$$

The maximum throughput is only 0.18. That is ALOHA is only at most 18% of what a single user transmitting continuously would achieve.

- A part of the reason for low efficiency in ALOHA is because each user transmits packets as soon as they are formed (asynchronized)

By synchronizing users such that packets are aligned in time helps reduce the collision rate.

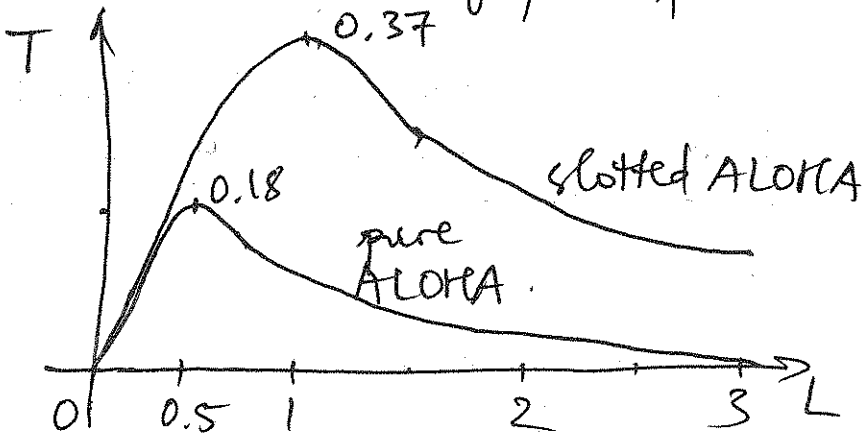
+) Slotted ALOHA: User can only transmit a packet at the beginning of a time slot.

No collision occurs if during the slotted time $[0, t]$ no other packets are transmitted.

The throughput is

$$T = L \cdot e^{-L} \quad \text{(packets per packet time)}.$$

The maximum throughput of slotted ALOHA is 0.37.



+) Carrier-sense multiple access: (CSMA).

- Users sense the channel and backoff for a random period of time if the channel is busy.

- CSMA works well when all users can detect each other's transmission with small propagation delay. It is used in wired LAN's Ethernet protocols.

- For wireless transmissions, there can be hidden terminal problem and exposed terminal problems.

- Hidden terminal problem: two nodes are too far