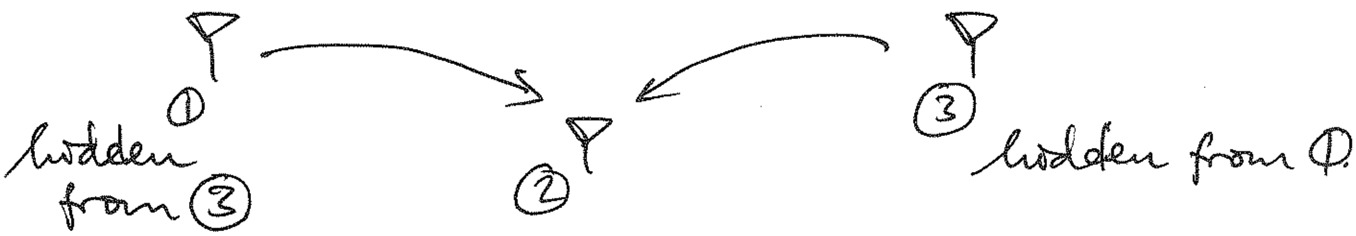
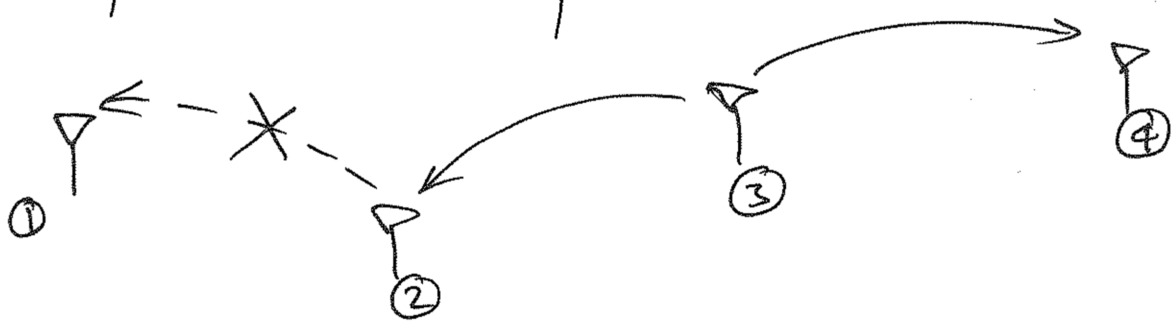
(out of range) of each other and hence are hidden from each other but can start transmission to a node in the middle at the same time.



- Exposed terminal problem:



Node 2 wants to transmit to node 1, and node 3 wants to transmit to node 4. These two transmission will not interfere with each other, but since node 2 senses node 3 using the channel it will refrain from transmission.

- Several techniques to avoid hidden terminal problem include 4-way handshake, busy-tone transmission.

+) Scheduling:

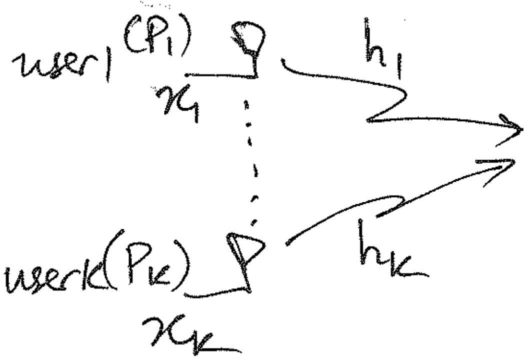
- Scheduling is used to assign users to different channels or time slot to reduce and avoid the collision in random access.

- Scheduling can be used with both continuous and bursty data.

- Even with scheduling, some form of random access is needed at the start to initiate access.

Packet-reservation multiple access: after initial random access, a user with successful transmission will continue to use the channel until done with the transmission.

+) <u>Uplink capacity</u>: The multiple access channel



$$y = \sum_{j=1}^{K} h_j x_j + n.$$

The capacity is a K-tuple rate region specified by:

$$\sum_{j \in S} R_j \leq \log_2\left(1 + \frac{1}{\sigma_n^2} \sum_{j \in S} |h_j|^2 P_j\right)$$

$$\forall S \subseteq \{1, 2, \ldots, K\}.$$

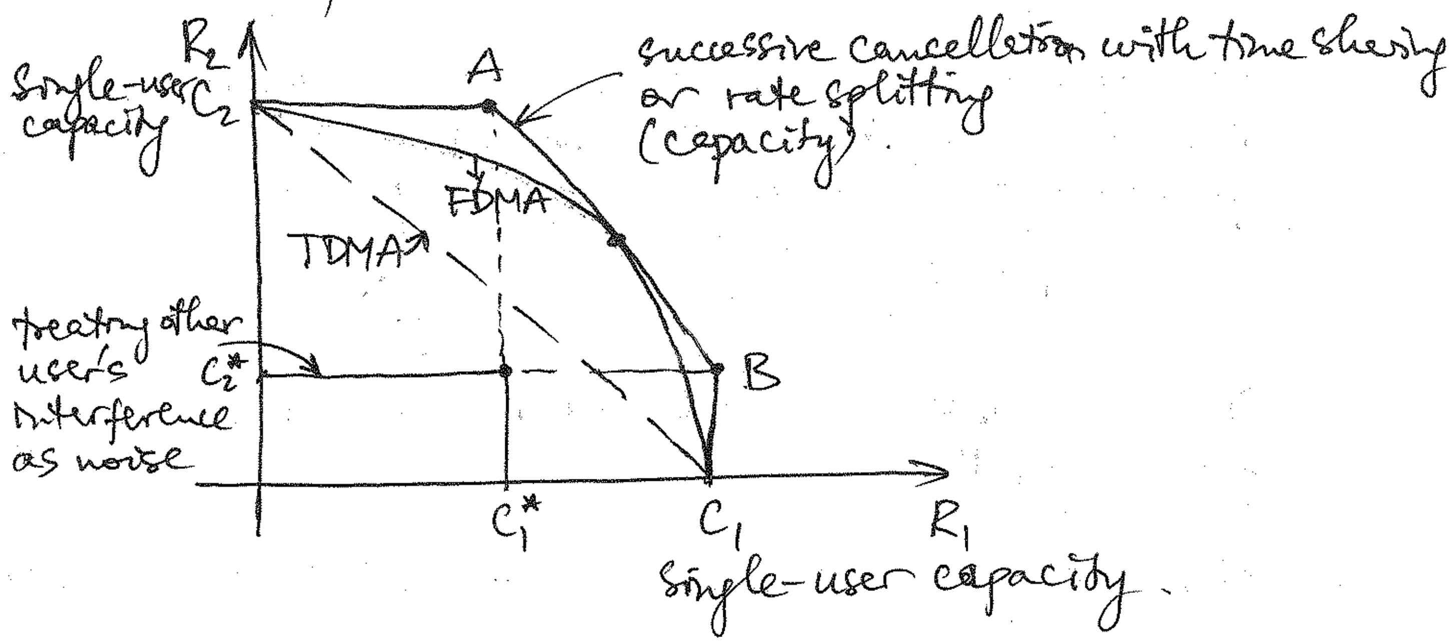
For 2 user channel this region is

$$R_1 \leq \log_2\left(1 + \frac{P_1}{\sigma_n^2} |h_1|^2\right)$$

$$R_2 \leq \log_2\left(1 + \frac{P_2}{\sigma_n^2} |h_2|^2\right)$$

$$R_1 + R_2 \leq \log_2\left(1 + \frac{P_1 |h_1|^2 + P_2 |h_2|^2}{\sigma_n^2}\right)$$

The total transmission rate from any subset of users is no larger than the rate as if all user in that subset acts as one (cooperate to become a "superuser" with multiple antennas)



- Successive cancellation: decode the signal of one user first, treating other user's signal as noise, then subtract the decoded signal and decode the other user.

The order of decoding matters:
- corner A: decode user 1 first, then user 2
- corner B: reverse (2 first then 1).

- Time sharing: switching between 2 (or multiple) options according to some proportion.

For example: decoding user 1 first for $\frac{1}{3}$ of the time and user 2 first for $\frac{2}{3}$ of the time will get us the rate point $\frac{1}{3}$ down the line AB.

- Rate splitting: Each user splits its data into multiple substreams and encodes each substream with a different rate such that the effective rate is similar to what is achieved by time sharing.

- For uplink, FDMA achieves the capacity at one special point when the bandwidth division between users is proportional to their received signal power:

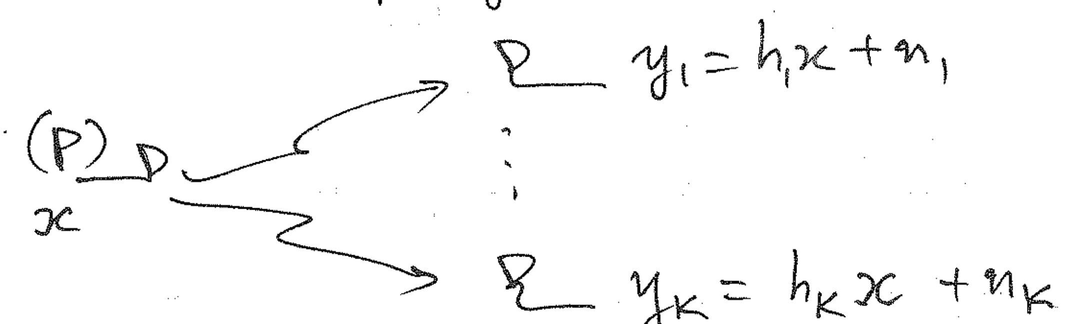
$$\frac{W_1}{W_2} = \frac{|h_1|^2 P_1}{|h_2|^2 P_2}.$$

- TDMA achieves the time-sharing line between single user capacity points.

TDMA with power control achieves the same as FDMA.

	α	$1-\alpha$	
	user 1	user 2	time
power	P_1	P_2	TDMA
	P_1/α	$P_2/1-\alpha$	TDMA w/power control

+) Downlink capacity: the broadcast channel



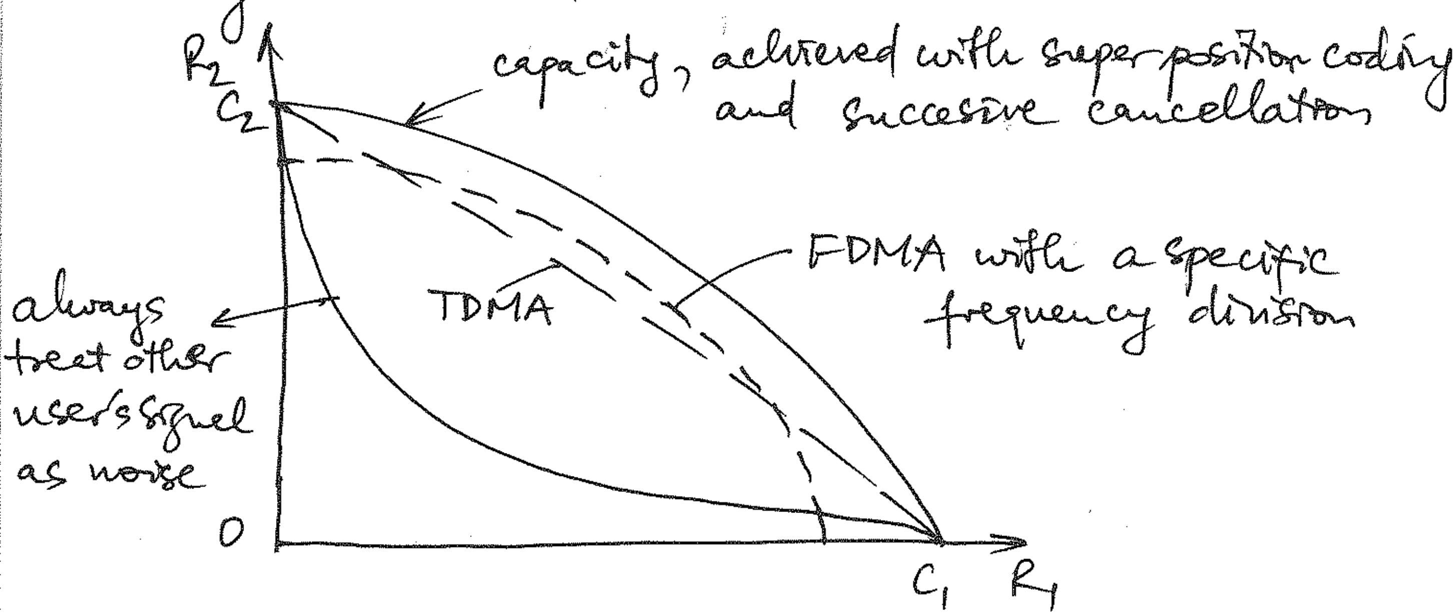
The transmitter has to apportionate the total power among the signals for different users.

The capacity region for 2 user contains all rate point (R_1, R_2) satisfying:

$$R_1 = \log\left(1 + \frac{\alpha P|h_1|^2}{\sigma_n^2}\right)$$

$$R_2 = \log\left(1 + \frac{(1-\alpha)P|h_2|^2}{\sigma_n^2 + \alpha P|h_1|^2}\right)$$

assuming $|h_1| > |h_2|$.

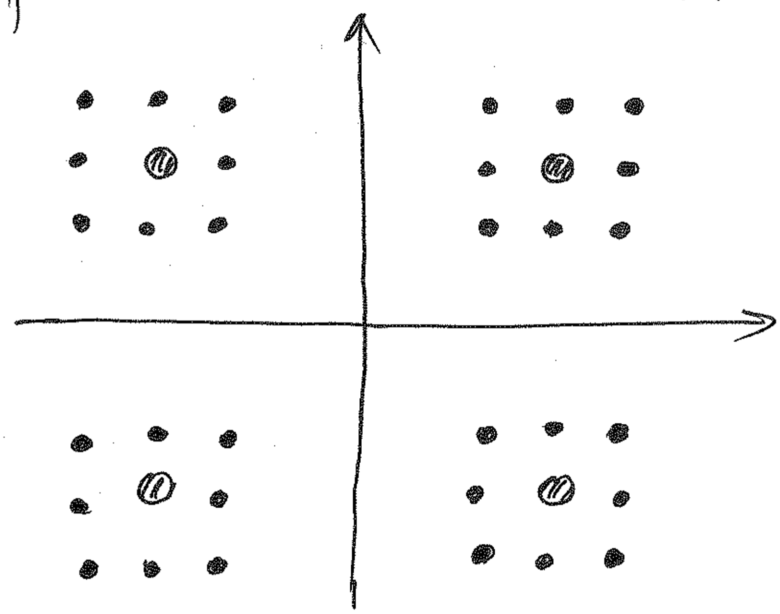


The difference among different techniques is more pronounced when the channel gain (or received SNR) is highly asymmetric. The difference diminishes as the channel gain becomes equal.

- Superposition coding: A multi-resolution (or multi-level) coding technique that embeds the code for one user within the code for another user.

The user with the stronger channel can then see both levels of codes, whereas the user with the weaker channel can only see the outside (coarser) level.

Example of a 2-level superposition of a 32-QAM on top of a QPSK constellation.



Here user 2 (with weaker channel) can only see which quadrant the transmit signal is in.

User 1 with stronger channel can also decode the quadrant, then it can distinguish the points inside each quadrant.

The signal transmitted from the base comes from the 32_QAM constellation.
The rate of user 2 is 2 bps (QPSK)
The rate of user 1 is 3 bps (8_QAM).

- For a given bandwidth B:

Assuming noise power spectral density is $\frac{N_0}{2}$.

Then the rate regions of different multiple access schemes are:

TDMA:

$$C_{TD} = \bigcup_{0 \le \alpha \le 1} \begin{cases} R_1 = \alpha B \log\left(1 + \frac{P|h_1|^2}{N_0 B}\right) \\ R_2 = (1-\alpha) B \log\left(1 + \frac{P|h_2|^2}{N_0 B}\right) \end{cases}$$

FDMA:

$$C_{FD} = \bigcup_{\substack{0 \le \alpha \le 1 \\ B_1 + B_2 = B}} \begin{cases} R_1 = B_1 \log\left(1 + \frac{\alpha P|h_1|^2}{N_0 B_1}\right) \\ R_2 = B_2 \log\left(1 + \frac{(1-\alpha) P|h_2|^2}{N_0 B_2}\right) \end{cases}$$