COM-405: Mobile Networks

Lecture 6.1: Scheduling I

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slides shamelessly stolen from Prof. JP Hubaux with minor modifications

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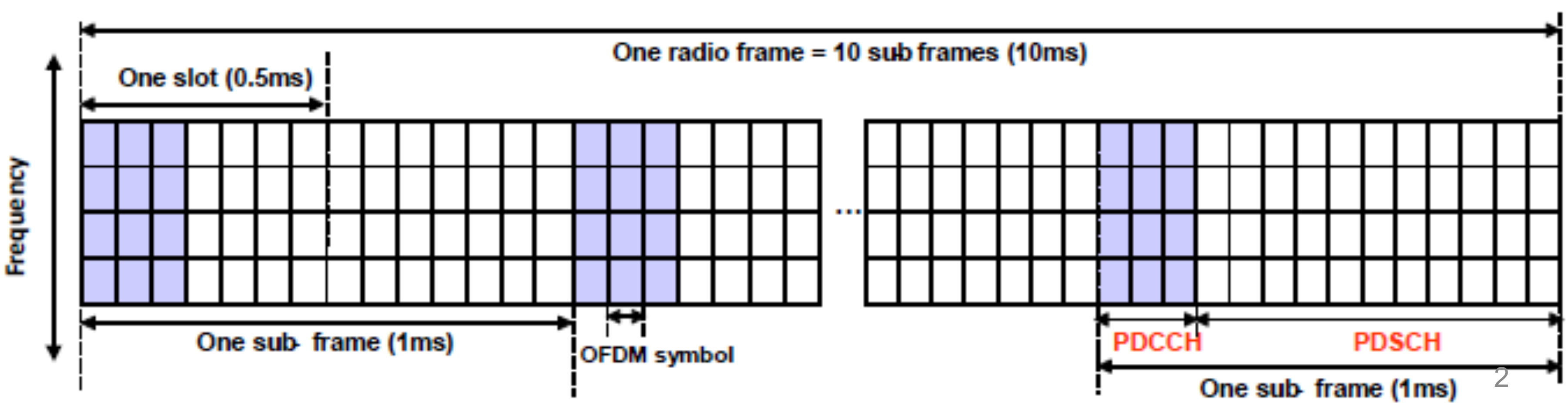
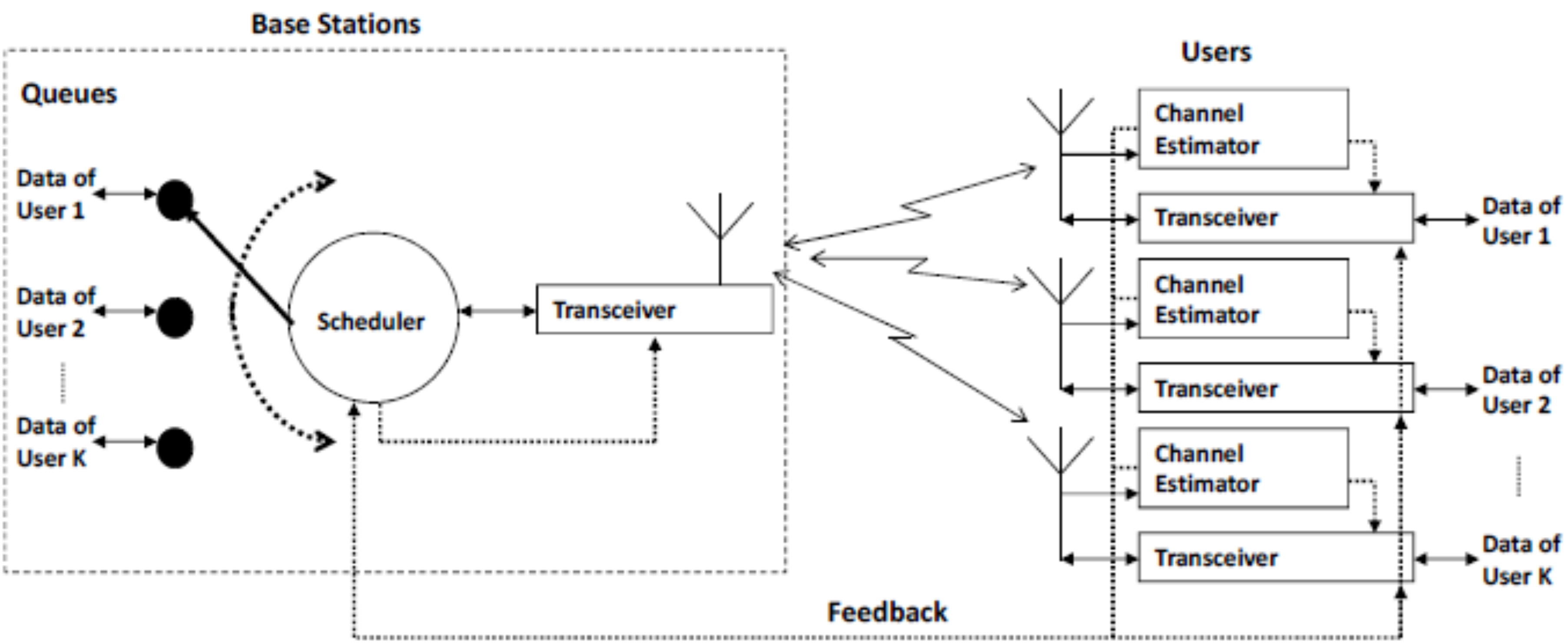
A Reservation-based Protocol

- Physical Downlink Control Channel (PDCCH): conveys control information for each user.
- Physical Downlink Shared Channel (PDSCH): multiplex the data of all terminals:
  - Each user will transmit on a unique set of Orthogonal Frequency Division Multiplexing (OFDM) symbols and frequency blocks.
- Reservation phase: PDCCH. Data phase: PDSCH.



Role of Scheduling

- Reservation phase:
  - Estimate channel $\longrightarrow$ Feedback $\longrightarrow$ Scheduling

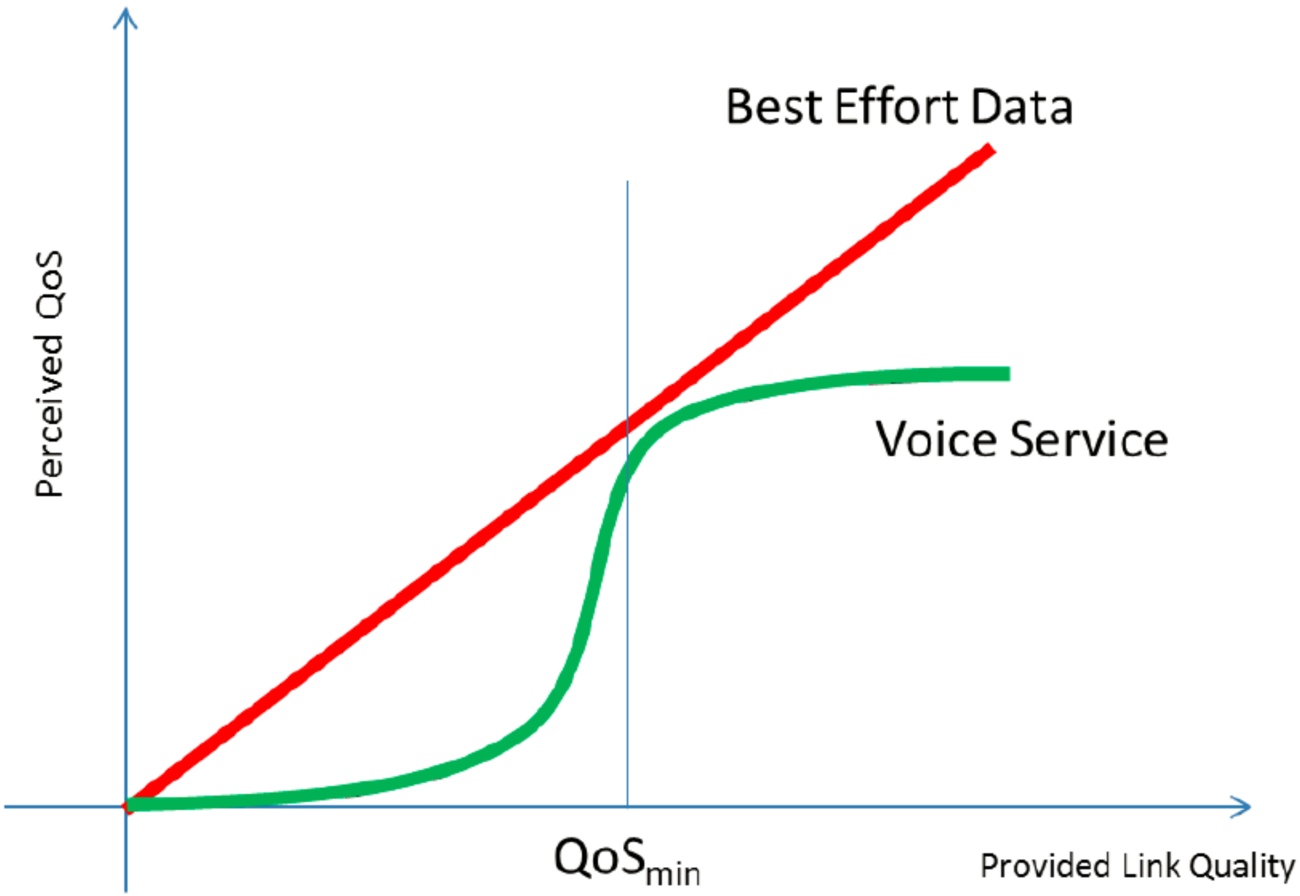


Issues in Wireless Scheduling

- Need to support mixed classes of traffic with different characteristics:

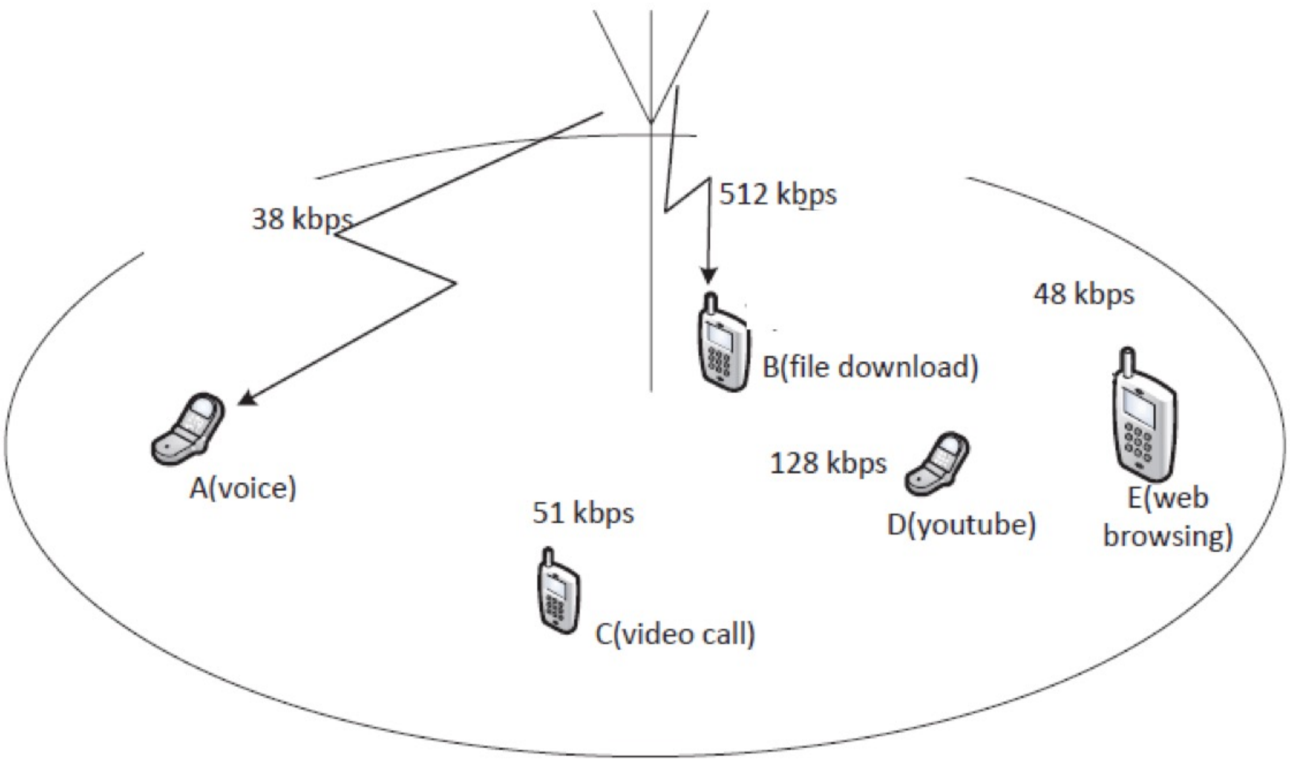
Traffic class	Characteristics	Example
Conversational	Preserve time relation (variation) between information entities of the stream. Conversational pattern (stringent and low delay)	voice
Streaming	Preserve time relation (variation) between information entities of the stream.	streaming video
Interactive	Request response pattern. Preserve payload content	web browsing
Background	Destination is not expecting the data within a certain time. Preserve payload content	emails

Perceived QoS



Issues in Wireless Scheduling

- Need to be flexible in allocating network resources
  - Achieved using scheduling algorithms



Note: In modern cellular networks, bitrates can be much higher than those in the picture

Issues in Wireless Scheduling

- Channel variation
  - Shadowing, fading, noise, interference, and user mobility
  - Unstable, error-prone, and hard to predict
  - Capacity of each link varies significantly in different time periods and locations
- Even if the scheduler knows QoS requirements
  - Difficult to estimate the amount of resources needed
  - An adaptive procedure is needed to assure QoS, taking into account the requirements and channel variations

Uplink capacity with M users

- In general, when there are M uplink users, the sum of the data rates is bounded by (from Shannon–Hartley theorem):

$$\sum_{i=1}^{M} r_i \leq B \log_2\left(1 + \frac{\sum_i P_i |h_i|^2}{N}\right)$$

where:

- B is the frequency bandwidth
- P_i is the transmission power of user i
- h_i is the channel of user i
- N is the noise power = $N_0 B$ where N_0 is the noise spectral density

Uplink capacity with two users

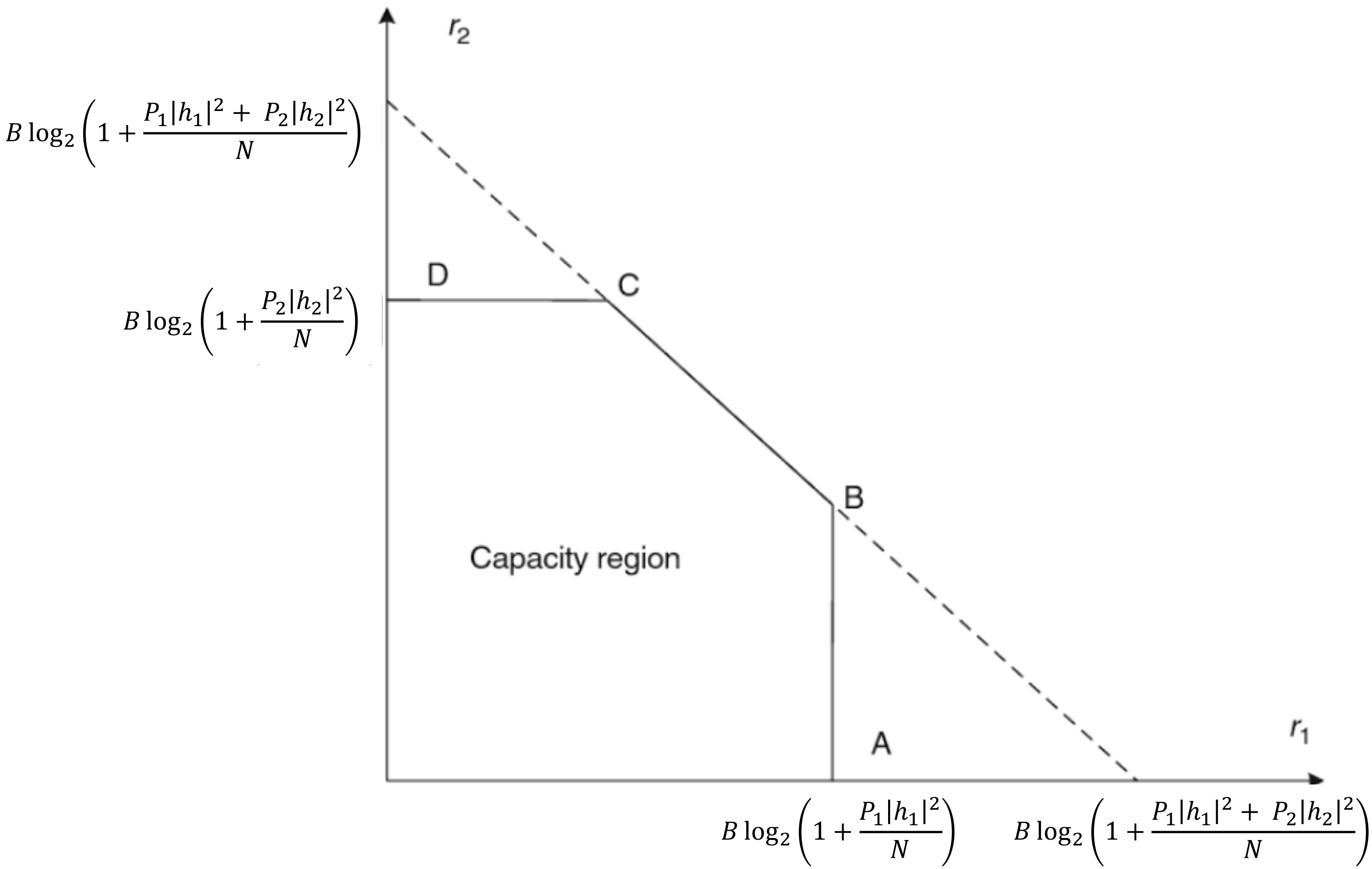
- Consider the uplink transmission with two users whose channels are static. The capacity region is the set of all rates (r_1, r_2) that satisfy the following three constraints:

$$r_1 \le B \log_2\left(1 + \frac{P_1|h_1|^2}{N}\right)$$

$$r_2 \le B \log_2\left(1 + \frac{P_2|h_2|^2}{N}\right)$$

$$r_1 + r_2 \le B \log_2\left(1 + \frac{P_1|h_1|^2 + P_2|h_2|^2}{N}\right)$$

Uplink capacity with two users



Uplink capacity with three users

- With three users, the capacity region is the set of all rates (r_1, r_2, r_3) that satisfy the following constraints:

$$r_1 \leq B \log_2\left(1 + \frac{P_1|h_1|^2}{N}\right)$$

$$r_2 \leq B \log_2\left(1 + \frac{P_2|h_2|^2}{N}\right)$$

$$r_3 \leq B \log_2\left(1 + \frac{P_3|h_3|^2}{N}\right)$$

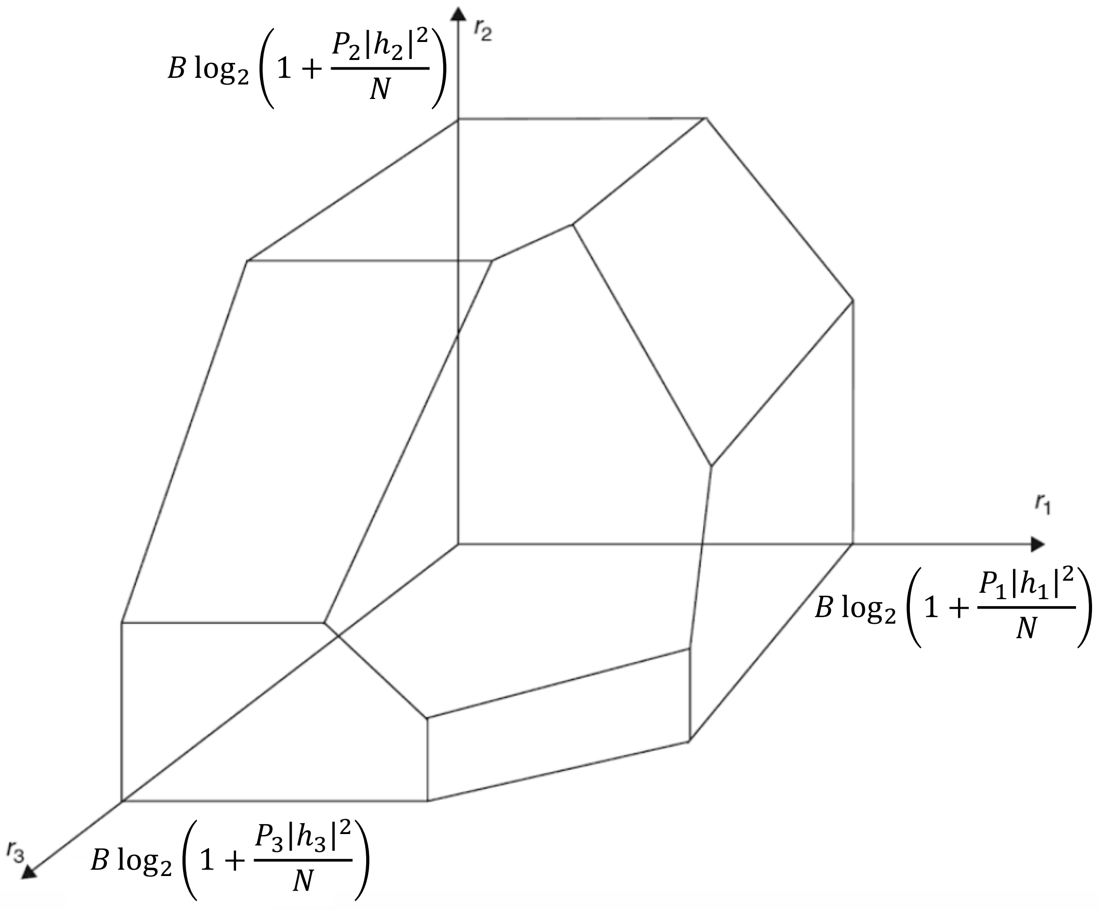
$$r_1 + r_2 \leq B \log_2\left(1 + \frac{P_1|h_1|^2 + P_2|h_2|^2}{N}\right)$$

$$r_1 + r_3 \leq B \log_2\left(1 + \frac{P_1|h_1|^2 + P_3|h_3|^2}{N}\right)$$

$$r_2 + r_3 \leq B \log_2\left(1 + \frac{P_2|h_2|^2 + P_3|h_3|^2}{N}\right)$$

$$r_1 + r_2 + r_3 \leq B \log_2\left(1 + \frac{P_1|h_1|^2 + P_2|h_2|^2 + P_3|h_3|^2}{N}\right)$$

Uplink capacity with three users



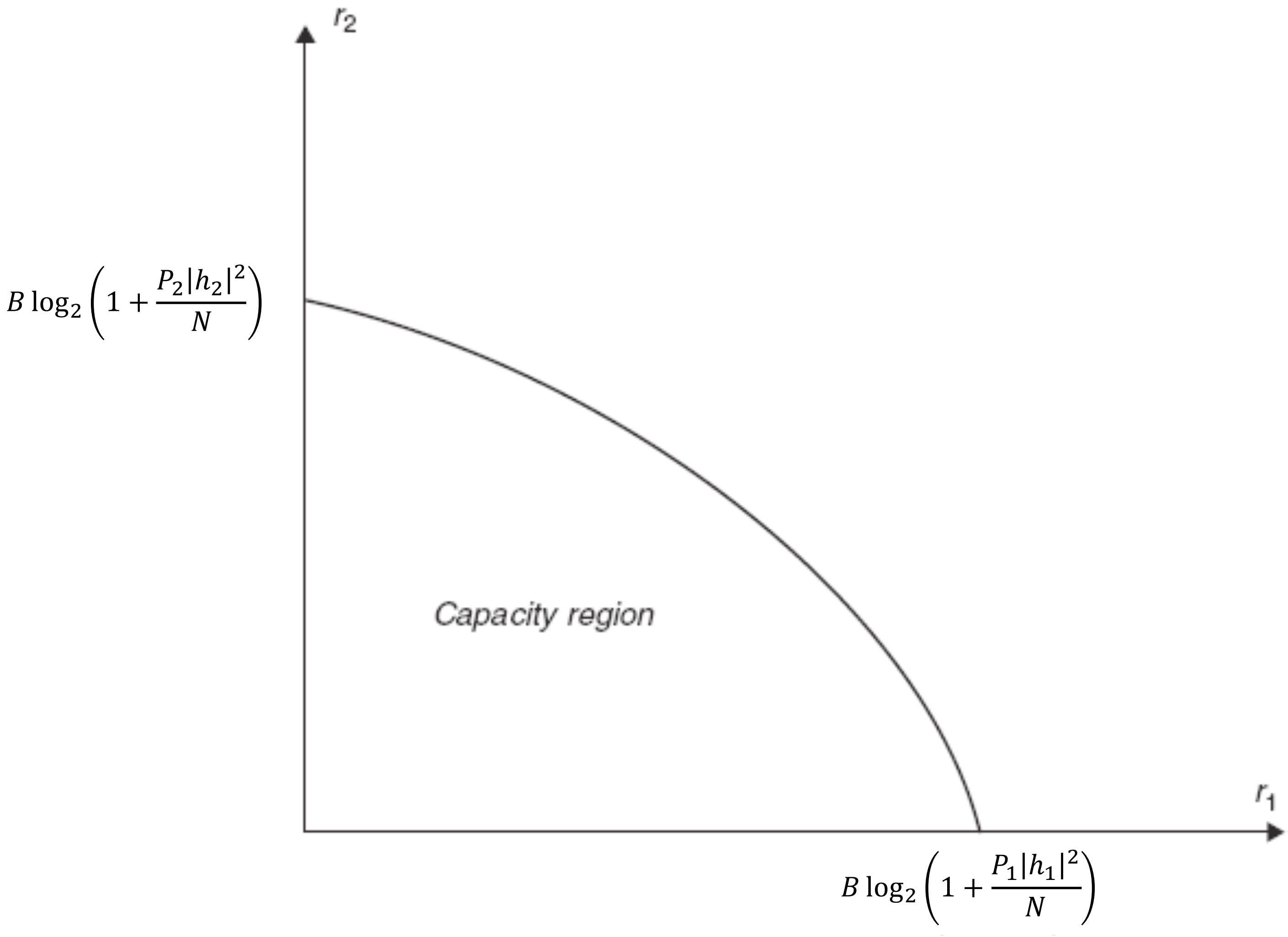
Downlink capacity with M users

- In the downlink, the base station sends independent data streams to multiple users.
- Assuming $|h_1|^2 \leq |h_2|^2 \leq \cdots \leq |h_M|^2$, the capacity region is given by:

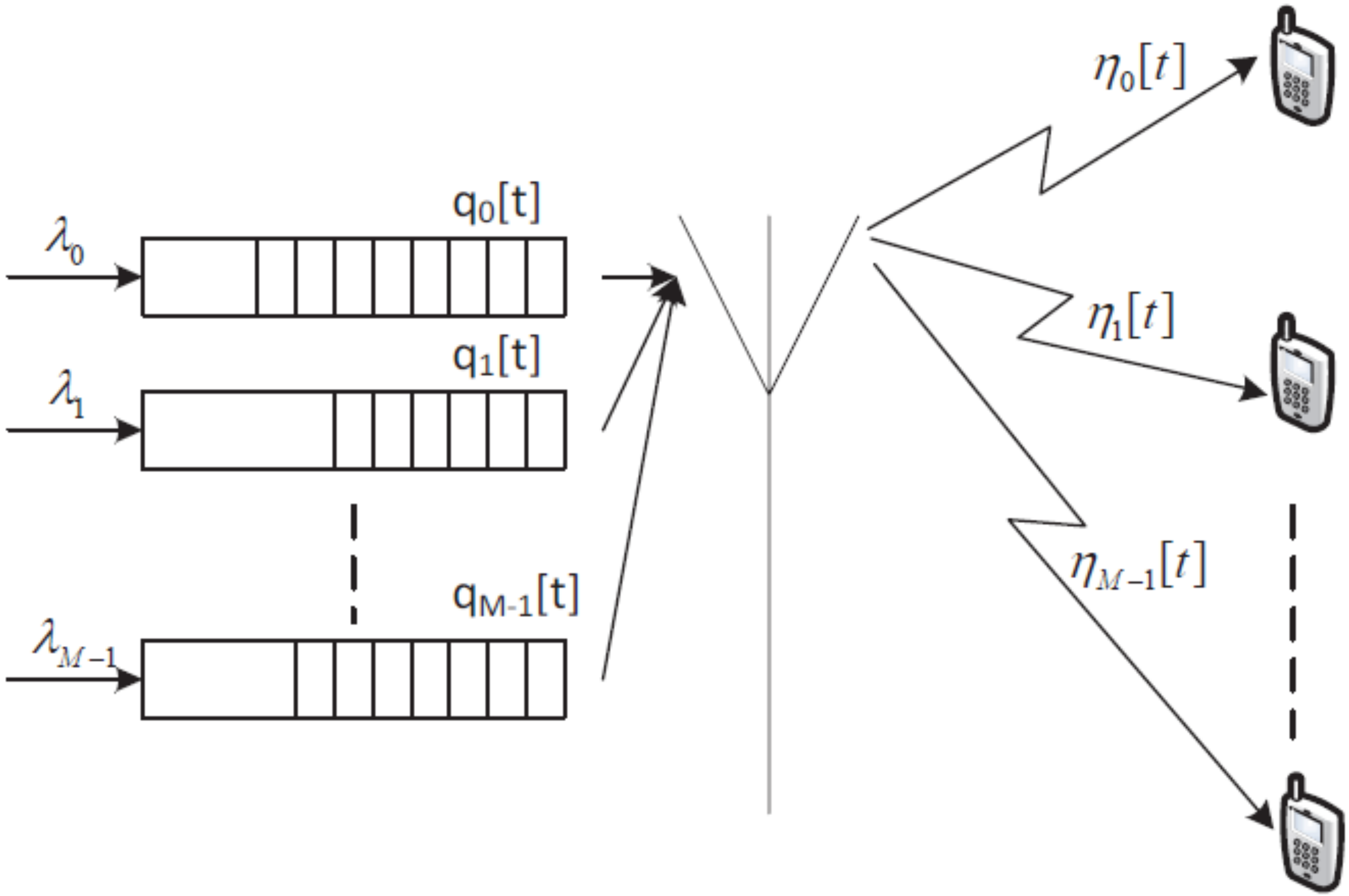
$$r_m \leq B \log_2\left(1 + \frac{P_m|h_m|^2}{\sum_{i=m+1}^{M} P_i|h_i|^2 + N}\right)$$

for all possible power allocations $\sum_m P_m = P_0$, where P_0 is the total transmission power of the base station.

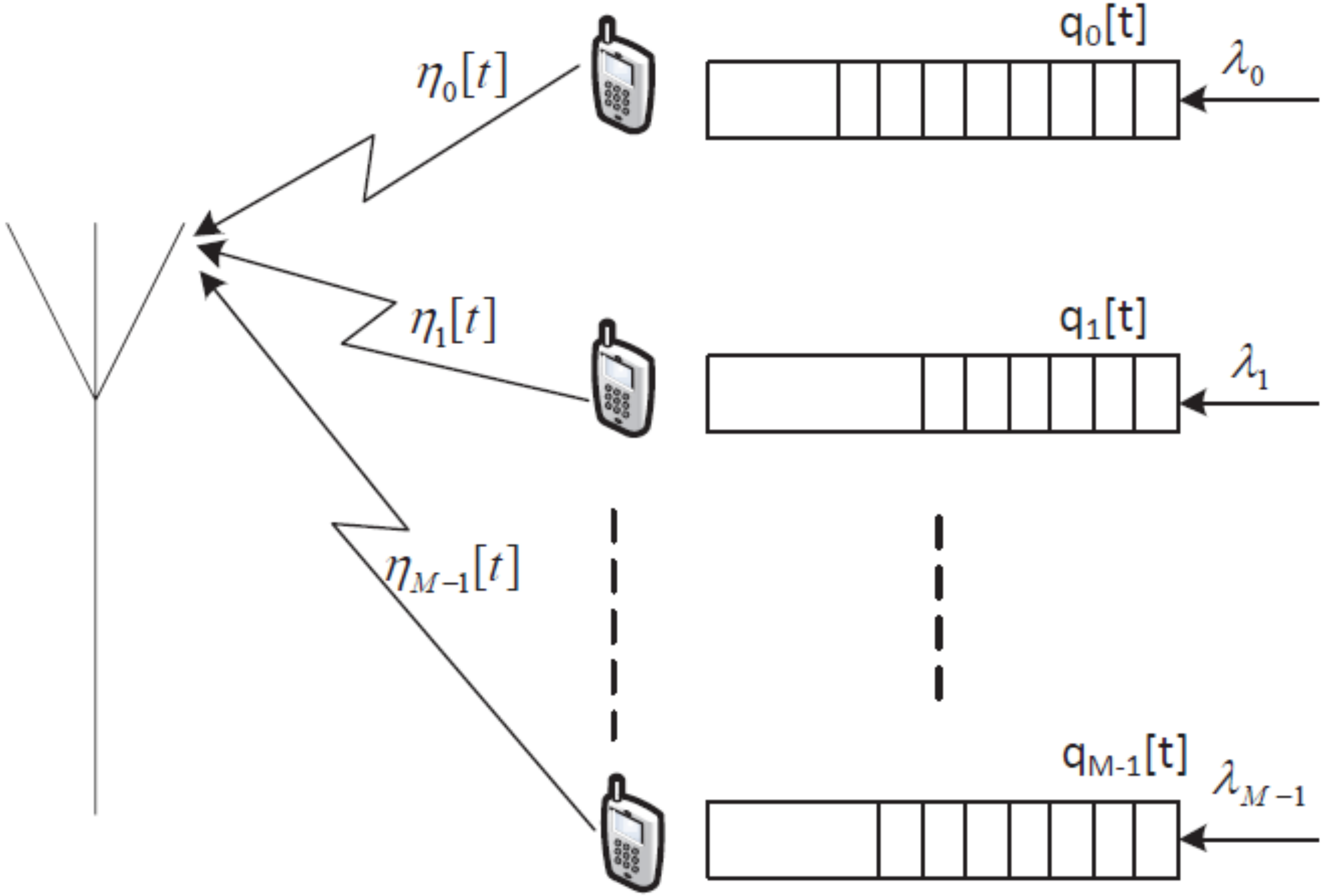
Downlink capacity with two users



Downlink Scheduling



Uplink Scheduling



Queue Modeling

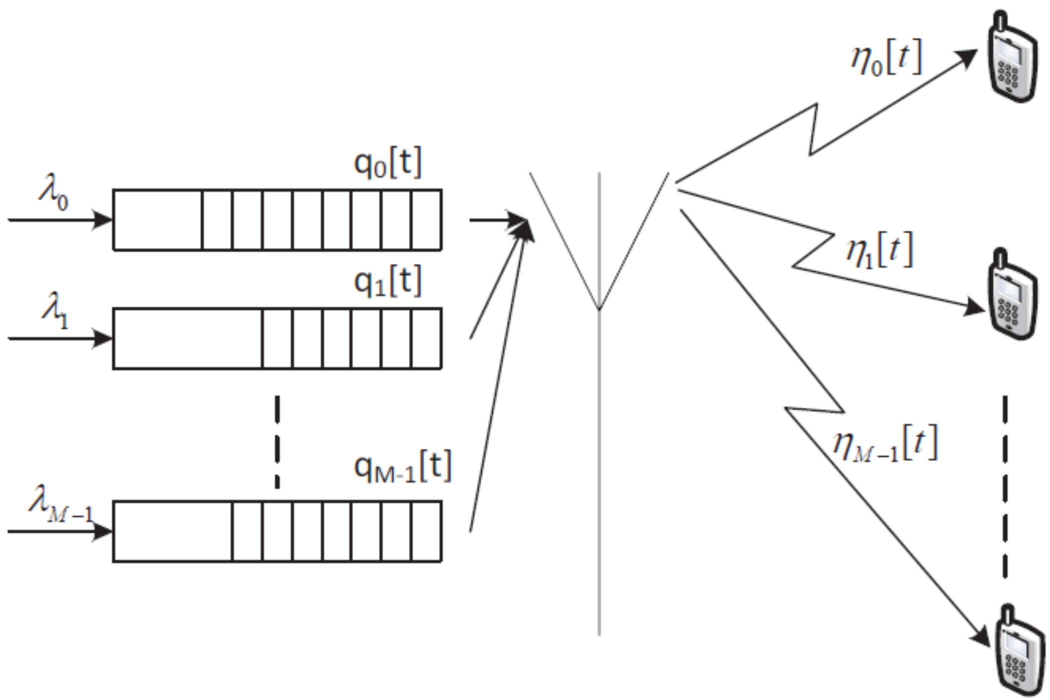
- At timeslot t, the queue of user i changes as follows:

$$q_i[t+1] = q_i[t] + \delta_i[t] - \eta_i[t]$$

Number of bits in the queue

Number of new bits arriving

Number of bits scheduled to transmit, determined by the scheduling algorithm



Round-Robin (RR) Scheduling

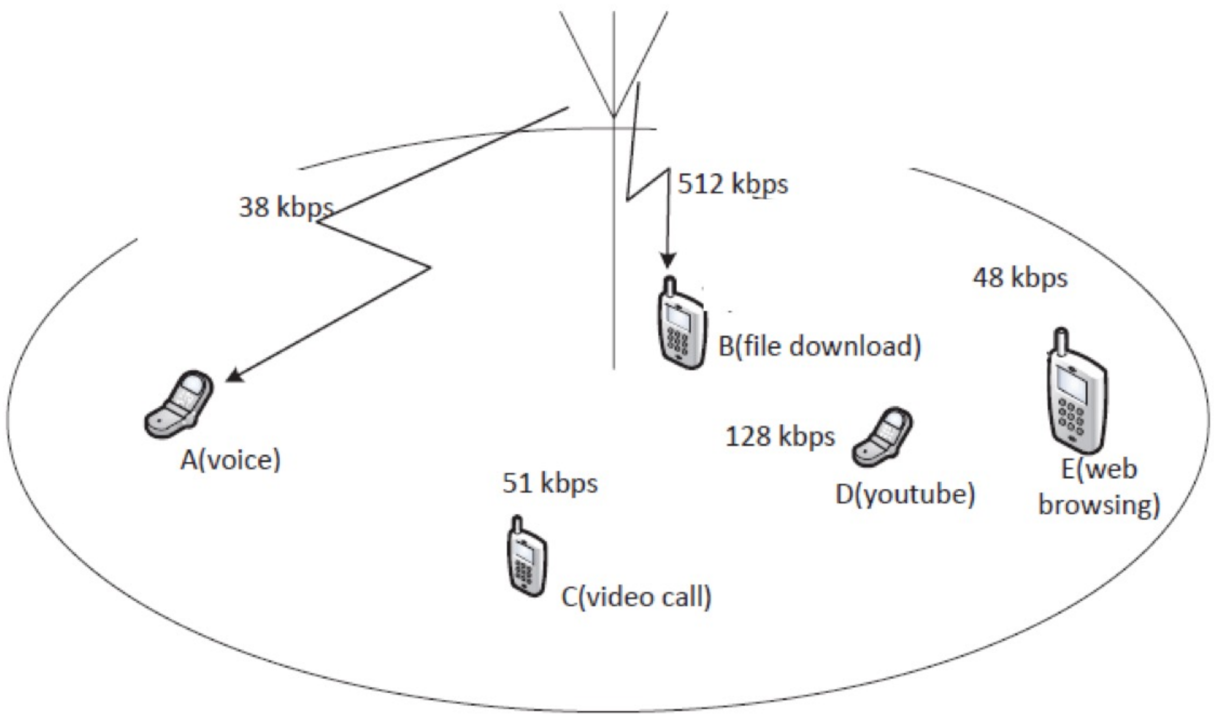
- Users are scheduled in a round robin, i.e. cyclic order
- i[t]: user scheduled at time t. RR scheduler:

$$i[t+1]=i[t]+1 \pmod{M-1}$$

- The algorithm is fair: all users are given the same amount of time resources

Round-Robin Scheduling

- Performance
  - All users are allocated the same amount of network resources
  - What is the throughput of all users in the following network?



Max Throughput Scheduling

- Objective: maximize total network throughput
- If user i is scheduled, the expected data rate is:

$$\widehat{r_i}[t] = \frac{\hat{\eta}_i[t]}{T}$$

Expected number of bits that can be successfully delivered

Slot length

- The total expected network throughput is

$$\hat{r}[t] = \sum_{i=0}^{M-1} \widehat{r_i}[t] I(i)$$

I(i): Scheduling indicator: 1 scheduled, 0 otherwise.

Max Throughput Scheduling

- Schedule the user with the highest expected data rate
  - one way of estimating $\widehat{r_i}[t]$ is:

$$\widehat{r_i}[t] = B \log_2\left(1 + \frac{\Gamma_i[t]}{\theta}\right)$$

where:

- B is the frequency bandwidth
- $\Gamma_i[t]$ is the signal-to-interference-plus-noise ratio (SINR) at time t given the allocated power.
- θ is the SINR gap that defines the gap between the channel capacity and a practical coding and modulation scheme

Max Throughput Scheduling

- Main drawbacks
  - Unfairness
  - Coverage limitation
  - Most users may never be served