COM-405: Mobile Networks

Lecture 7.0: Scheduling II
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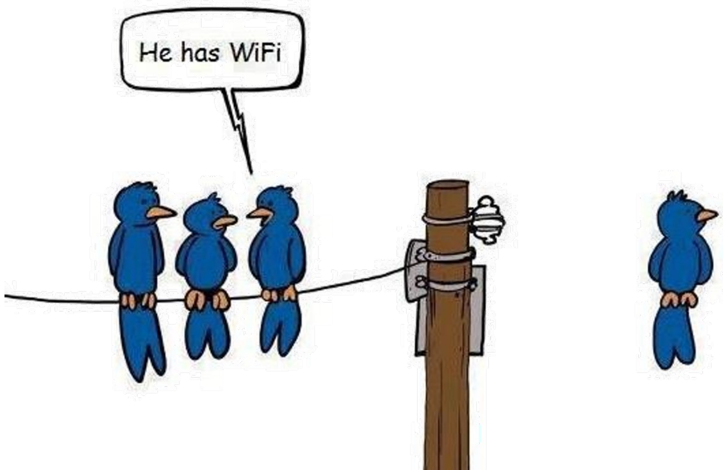
slides shamelessly stolen from Prof. JP Hubaux with minor modifications



Laboratory of SEnsing
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Round-Robin (RR) Scheduling

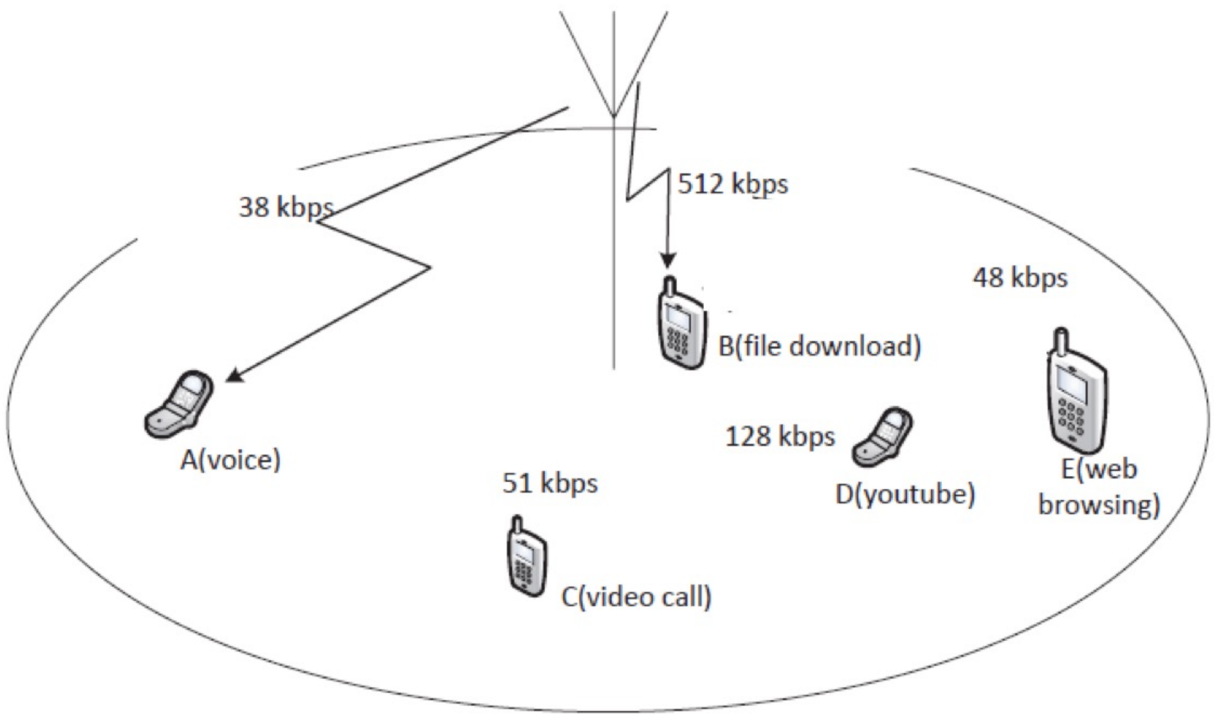
- Users are scheduled in a round robin, i.e. cyclic order
- i[t]: user scheduled at time t. RR scheduler:

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

- 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:

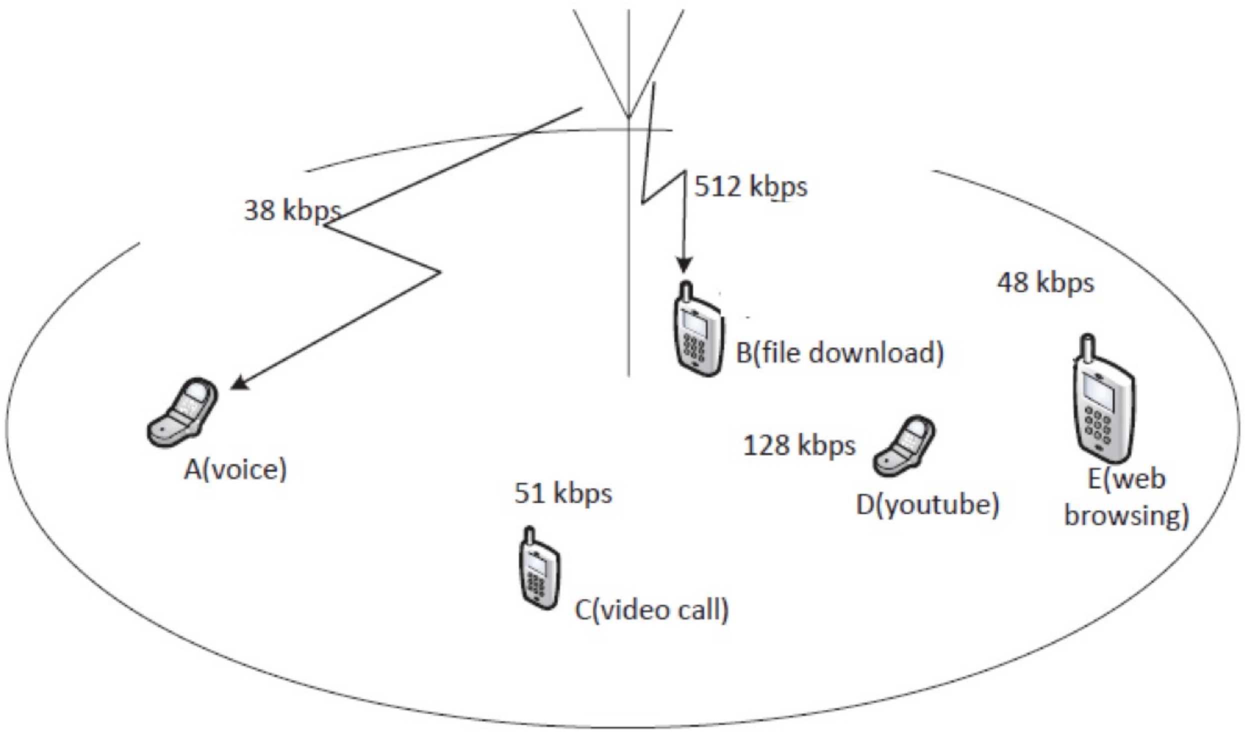
$$\widehat{r_i}[t] = B \log_2\left(1 + \frac{\Gamma_i[t]}{\theta}\right)$$

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



Proportional Fair Scheduling

- PF scheduling: balance the competing interests of network throughput and minimum service level
- Objective: maximize

$$\sum_{i=0}^{M-1} \ln S_i$$

- S_i: long-run throughput for user i can be predicted using

$$\widehat{S}_i[t] = \left(1 - \frac{1}{\tau}\right) S_i[t-1] + \frac{1}{\tau}\, \hat{r}_i[t] I(i)$$

where $\tau \gg 1$ is a constant defined by the scheduler.

→ schedule the user with the highest $\dfrac{\hat{r}_i[t]}{S_i[t-1]}$

Proportional Fair Scheduling

- Meet the proportional fairness criterion:

Assuming s_i is the optimal value, for any other feasible value, the sum of proportional changes is non-positive, i.e.

$$\sum_i \frac{\hat{s}_i - s_i}{s_i} \leq 0$$

- Intuition: when the scheduling result is already proportionally fair, if scheduling is changed s.t. the throughput of a user is increased by a percentage, the cumulative decrease of the throughputs of other users will be higher
- In other words, any attempt of improvement somewhere will generate a higher damage elsewhere

Proportional Fair Scheduling

- Why proportional fair

Assume $\delta_i \ll s_i$

$$\sum_{i=0}^{M-1} \ln(s_i + \delta_i) = \sum_{i=0}^{M-1} \ln(s_i) + \sum_{i=0}^{M-1} \ln\left(1 + \frac{\delta_i}{s_i}\right)$$

$$\approx \sum_{i=0}^{M-1} \ln(s_i) + \sum_{i=0}^{M-1} \frac{\delta_i}{s_i}$$

but $\sum_i \frac{\delta_i}{s_i} \leq 0$

$$\leq \sum_{i=0}^{M-1} \ln(s_i)$$

Max-Min Scheduling

- Objective: maximize the minimum user throughput

$$\max \min_i S_i$$

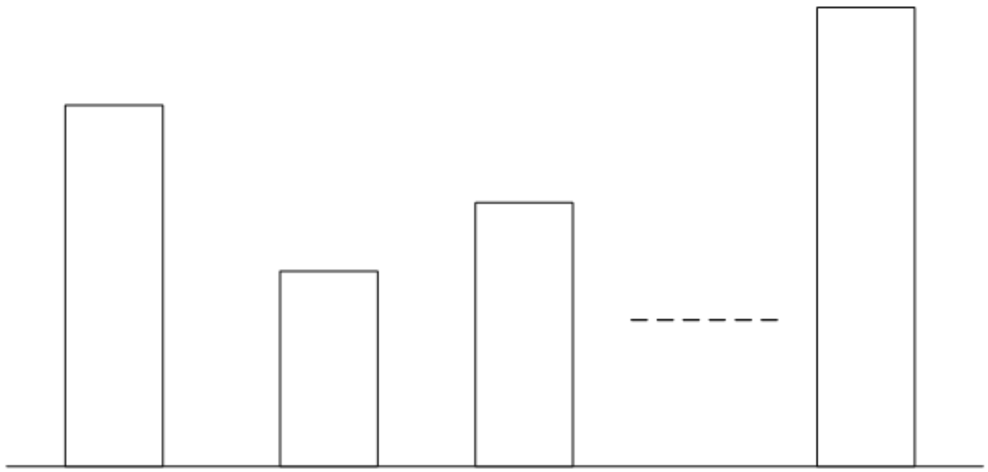
- A scheduling result is max-min fair if and only if a further increase of throughput of one user will result in the decrease of a user with a smaller throughput

$$\widehat{S_i}[t] = \left(1 - \frac{1}{\tau}\right) S_i[t-1] + \frac{1}{\tau}\, \widehat{r_i}[t] I(i)$$

- Schedule the user with the minimum $(1 - \frac{1}{\tau}) S_i[t-1]$, i.e. the one with the smallest throughput at time t-1.

Max-Min Scheduling

- M empty cylindrical buckets (users), all with the same radius but different heights.
- Allocate water



Max-Min Scheduling

- M empty cylindrical buckets (users), all with the same radius but different heights.
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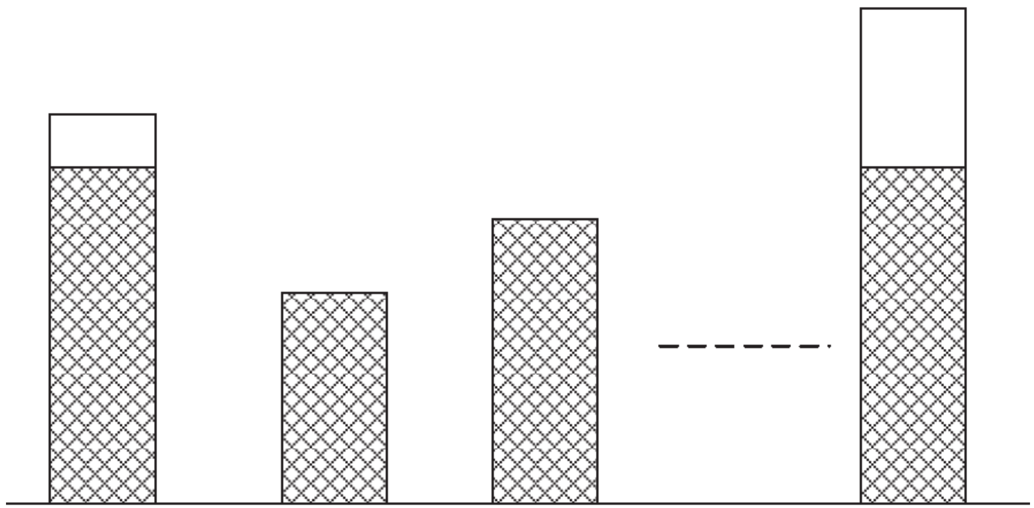
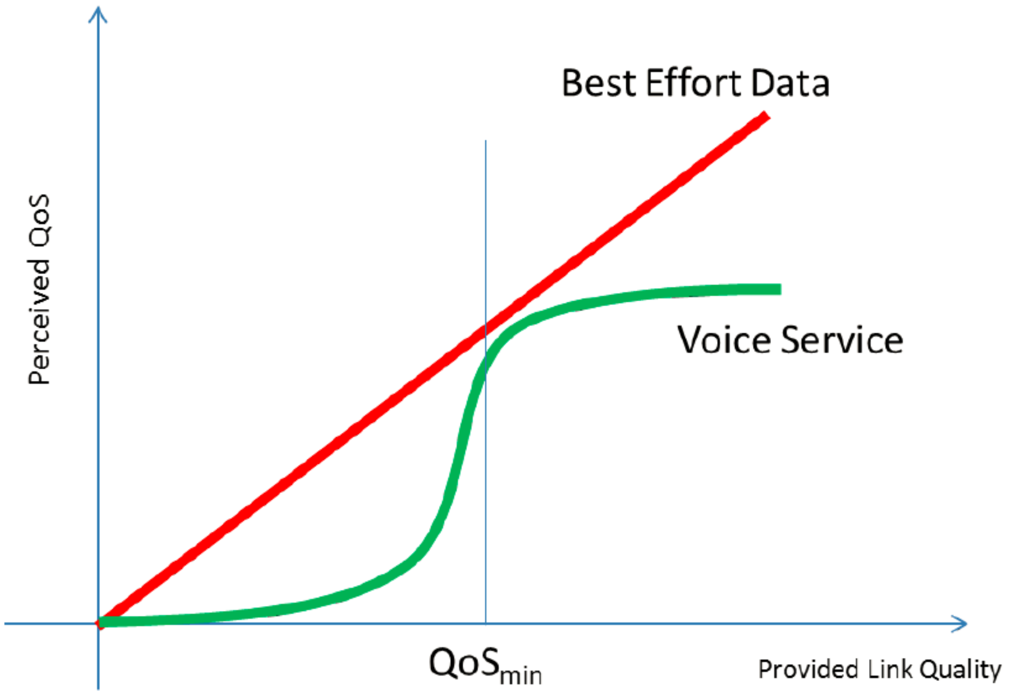


Can these schedulers deal with QoS?



Max Utility Scheduling

- Previous schedulers do not consider QoS
- Utility-based scheduling
  - Utility quantifies the satisfaction of each user given the allocated resources
  - Model the QoS perception of users
  - Objective: maximize the sum utility of all users, i.e. total network satisfaction
- Utility functions: model how user perceives services

Max Utility Scheduling

$$\max \sum_{i=0}^{M-1} U_i(S_i)$$

- Different utility functions can be designed.
- In addition to QoS modeling, different utility functions can be designed to reflect fairness and efficiency.
- Max-throughput (highest efficiency):

$$U(S) = S$$

- Proportional fair:

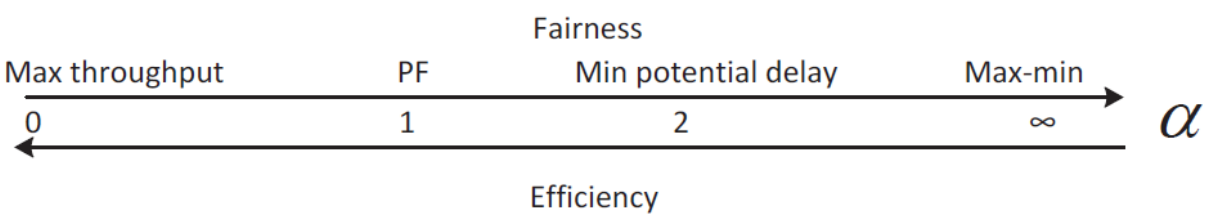
$$U(S) = \ln(S)$$

Max Utility Scheduling - Alpha Fair Utility

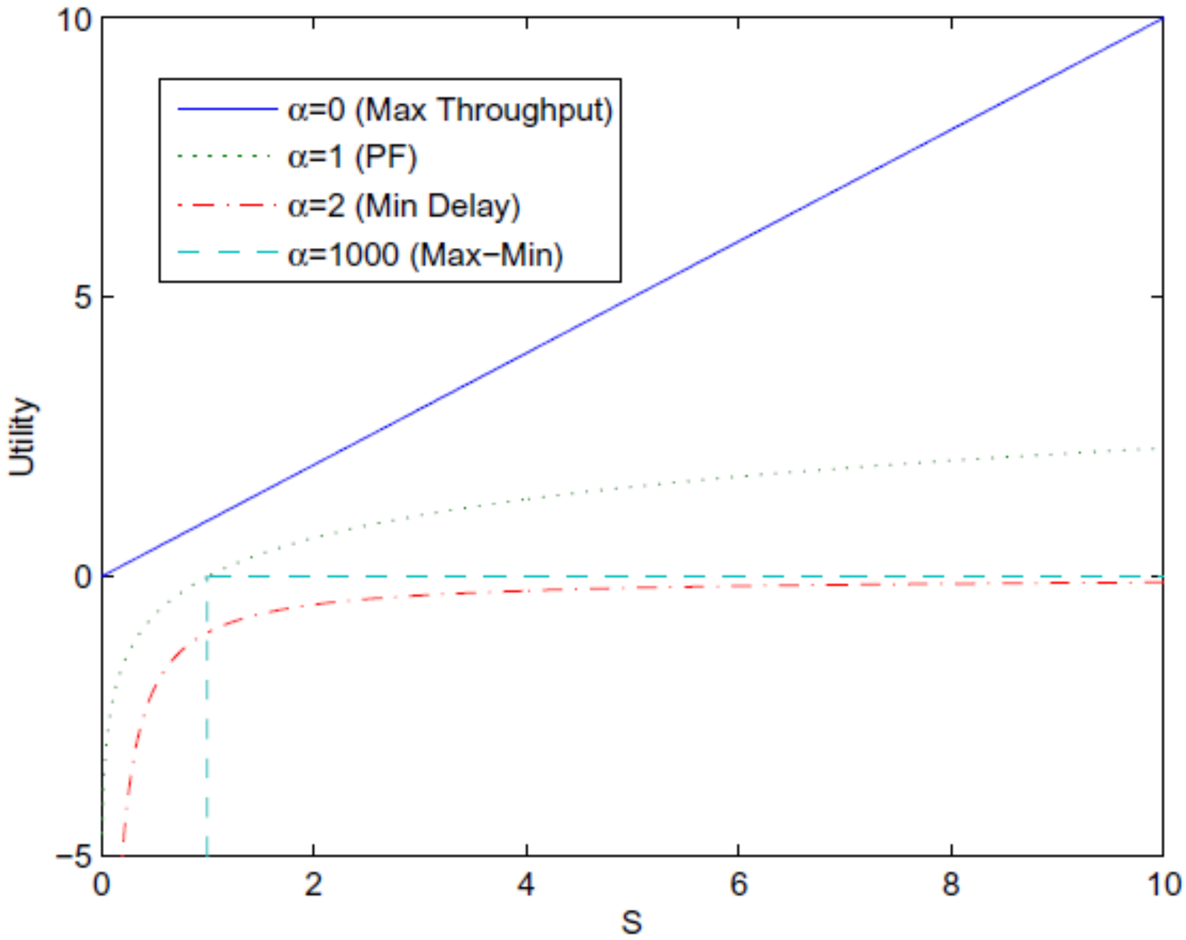
- More generic definition: α fair scheduling

$$U_\alpha(S) = \begin{cases} \frac{S^{1-\alpha}}{1-\alpha} & \alpha \geq 0 \text{ and } \neq 1 \\ \ln(S) & \alpha = 1. \end{cases}$$

- α measures how fair the scheduling result is
  - 0: Max throughput;
  - 1: Proportional fair;
  - 2: equivalent to minimizing $\sum_{i=0}^{M-1} \frac{1}{S_i}$
    - Minimize the total potential delay
  - Infinity: Most fair, max-min scheduler.



Alpha Fair Utility

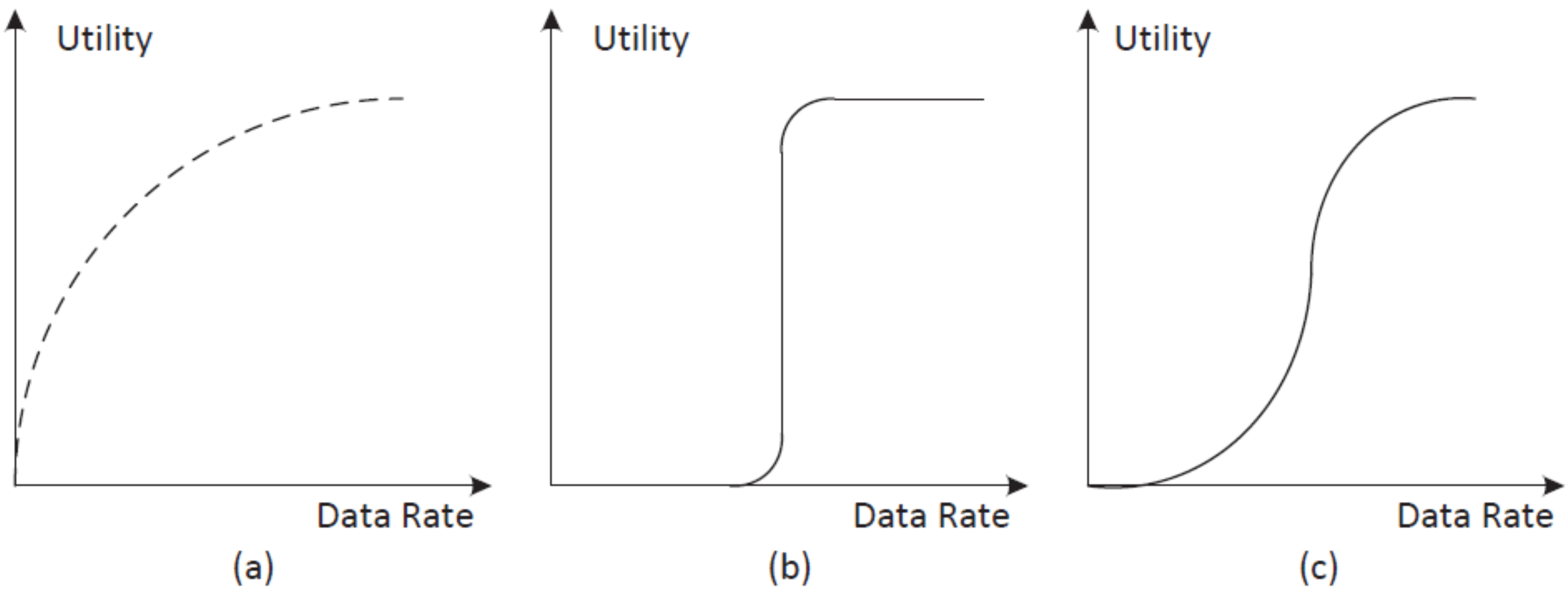


Resource

PF: proportional fairness

Utility Functions with QoS Consideration

- Determined based on traffic characteristics



- (a) best effort; (b) real time with tight delay requirement;
  (c) real time with loose delay requirement.

Scheduling in OFDMA Systems

- OFDMA: Orthogonal Frequency-Division Multiple Access
- One more dimension of resources
  - Subcarrier allocation

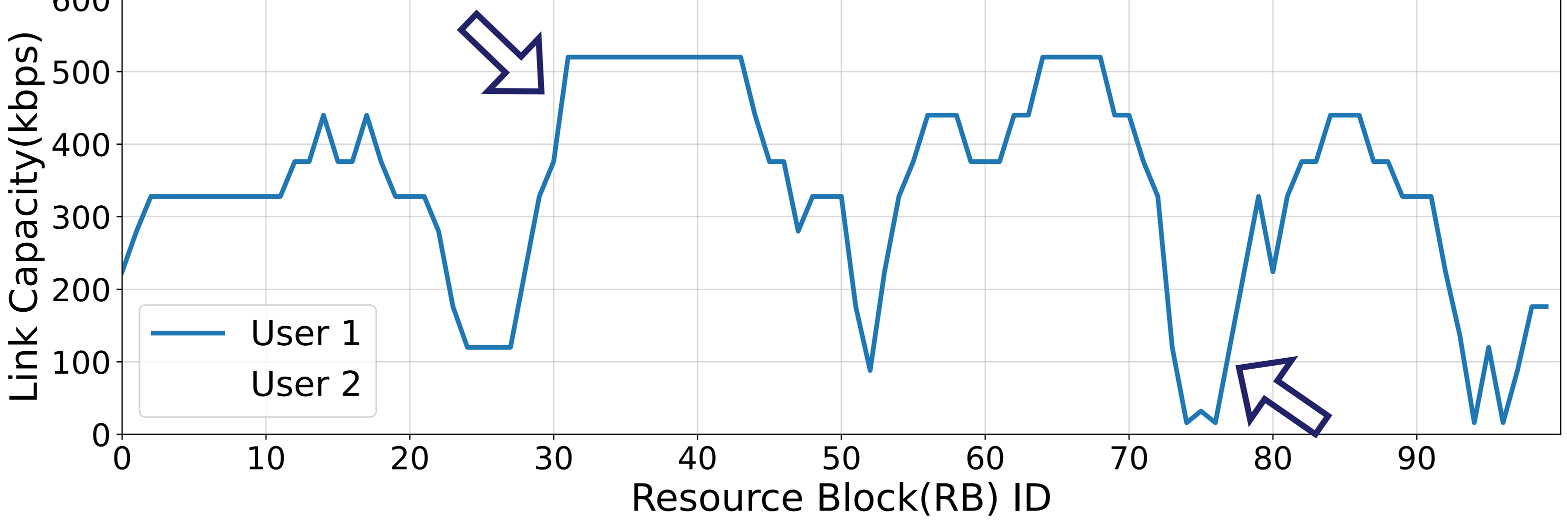
- Different users experience, independent wireless channels and their subcarriers may experience substantially different channel gains because of the frequency selectivity in the channels.

- Theoretically it is possible to set the data rate for each sub-carrier based on its channel quality and power allocated.

Scheduling in OFDMA Systems

- Subcarriers in deep fading for one user might not be used by this user as sending bits on these subcarriers costs too much power
  - They might be in good conditions on channels of other users → can be used by them instead
- Scheduling of subcarriers in an adaptive way based on the instantaneous channel qualities
- OFDMA systems typically use adaptive subcarrier assignment, power allocation, modulation and coding to exploit the diversity in multiple users and frequency to improve the network performance

Scheduling in OFDMA Systems



Scheduling in OFDMA Systems