Lec16-mwf

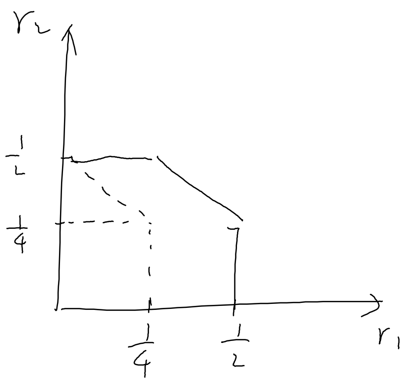
Thursday, February 8, 2018 11:24 AM

HW3 is on the web.

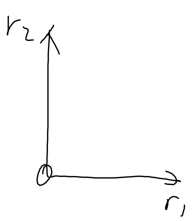
Example - 10min

Sunday, February 23, 2020 10:22 AM

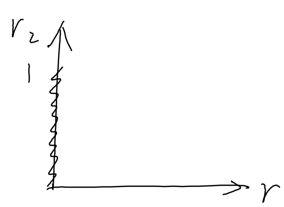
Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
State	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Arrivals 1	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	4
Service 1	0	0	1	0	0	0	1	1	0	0	1	0	0	0	1	0
Queue 1	0	0	0	0	4	4	3	2	2	2	1	1	1	1	0	4
Arrivals 2	3	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0
Service 2	0	1	0	1	0	1	0	0	0	1	0	1	0	1	0	1
Queue 2	3	2	2	1	1	0	0	0	0	0	3	2	2	1	1	0



Rate vector: (0.4, 0.3)

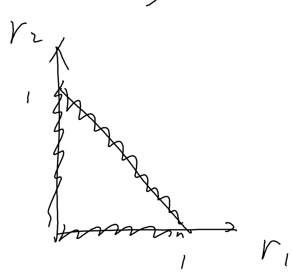


(0, 0)



(0, 1)

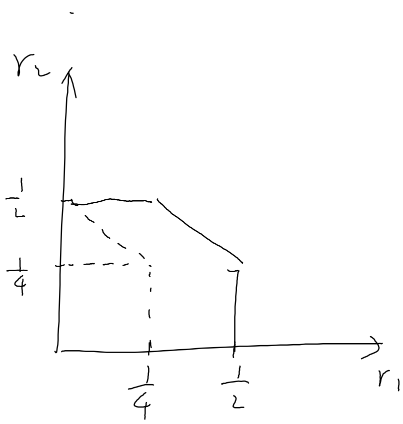
(1, 0)



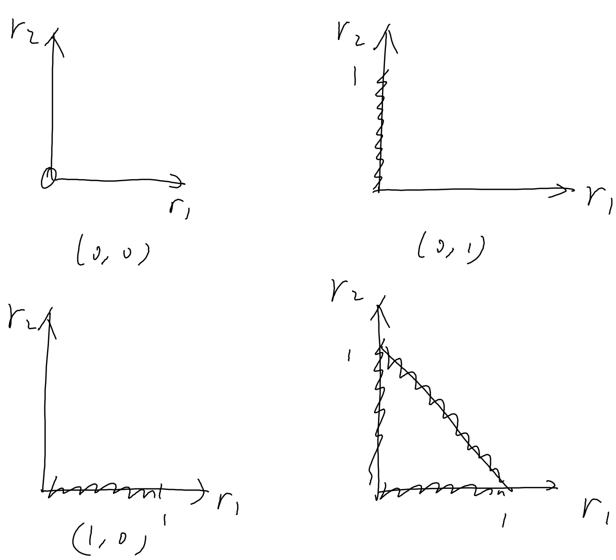
Example - handout

Sunday, February 23, 2020 10:22 AM

Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
State	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Arrivals 1	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	4
Service 1																
Queue 1																
Arrivals 2	3	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0
Service 2																
Queue 2																



Rate vector: (0.4, 0.3)



Implications - 15min

Tuesday, January 29, 2008 3:41 PM

(1) Cellular networks: a single cell.

Assume that BS can schedule one user at a time. — FDMA, TDMA, OFDM

The throughput-optimal scheme reduces to picking the user with the largest $q^l(t)\, r^l(t)$, where $r^l(t)$ is the rate available to user l, if it is scheduled. (Assume interference from other cells is fixed.)

If there are multiple channels/sub-carriers, then in each channel/sub-carriers, schedule the user with the largest

$$q^l(t)\, r^{l,c}(t)$$

where $r^{l,c}(t)$ is the rate available to user l if it is scheduled in channel c (Note that $r^{l,c}(t)$ could vary over c due to frequency-selective fading.)

- Suitable for TDMA or OFDM systems
- What if the BS can adjust power?

(2) What if the BS uses some sort of CDMA scheme?

$\Rightarrow$ more than one user can be scheduled at the same time.

Let us focus on the downlink.

Assume that rate is a linear function of SINR

$$r_l(t) = B \frac{P_l g_l}{\sum_{k \neq l} P_k \cdot g_l + N_l}$$

where P_l is the transmitting power for user l, and g_l is the propagation gain to user l.

Assume that the BS has a total power constraint.

$$\sum_l P_l \le P_{max}$$

The throughput-optimal policy then corresponds to:

$$\underset{\vec{p}:\ \sum_l P_l \le P_{max}}{\arg\max} \underbrace{\sum_l \rho^l \cdot \frac{P_l g_l}{\sum_{k \neq l} P_k g_l + N_0}}_{= f(\vec{p})}$$

It turns out that the solution to this optimization problem is of the following form: the BS will transmit to one user at the maximum power.

To see this, suppose there exist two users l & k, and the BS transmits to these two users at the same time, i.e.,

$$P_l > 0$$
$$P_k > 0$$

Let $P_0 = P_l + P_k$, Let $P_l = x$, $P_k = P_0 - x$

then write $f(\vec{P})$ as a function of x

$$f(x) = f(\cdots \underset{\underset{P_l}{\uparrow}}{x}, \cdots \underset{\underset{P_k}{\uparrow}}{P_0 - x}, \cdots)$$

It turns out that it is a convex function of $P_l = x$. To see this, note that $f(x) = f(P_l)$ has three kinds of terms:

ⓐ $h \neq l$, $h \neq k$,

$$q^h \cdot \frac{P_h g_h}{\sum_{k \neq h} P_k g_h + N_0}$$ is independent of P_l (since $P_l + P_k = P_0$)

ⓑ $$q^l \cdot \frac{P_l g_l}{\sum_{h \neq l,k} P_h \cdot g_l + (P_0 - P_l) g_l + N_0}$$

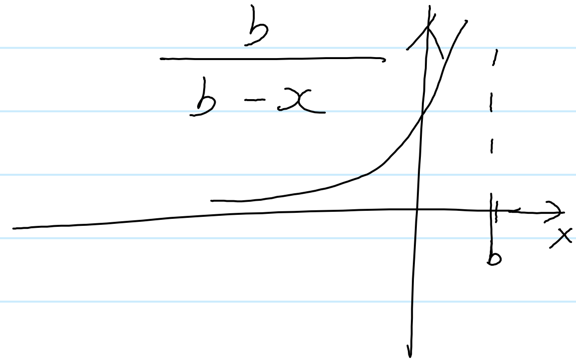
$$= q^l \left[-1 + \frac{\sum_{h \neq l,k} P_h g_l + P_0 g_l + N_0}{\sum P_h g_l + (P_0 - P_l) g_l + N_0} \right]$$

$$= \gamma^l \left[-1 + \frac{\cdots}{\sum_{h\neq l,k} P_h \delta_l + (P_0 - P_l)\delta_l + N_0} \right]$$

Simplified argument:

$$\frac{ax}{b-ax}$$

$$= -1 + \frac{b}{b-ax}$$



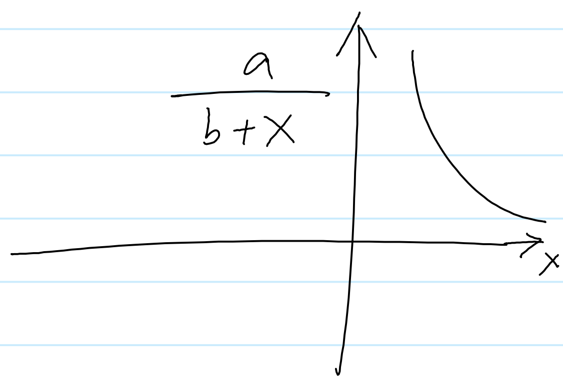
(c) $$\gamma^k \cdot \frac{(P_0 - P_l)\delta_K}{\sum_{h\neq l,k} P_h \delta_K + P_l \delta_K + N_0}$$

$$= \gamma^k \left[-1 + \frac{\sum_{h\neq l,k} P_h \delta_K + P_0 \delta_K + N_0}{\sum_{h\neq l,k} P_h \delta_K + P_l \delta_K + N_0} \right]$$

Simplified argument

$$\frac{b-ax}{c+ax}$$

$$= -1 + \frac{b+c}{c+ax}$$



Hence, $f(x) = f(P_l)$ is larger either at $P_l = 0$, $P_k = P_0$ or $P_l = P_0$, $P_k = 0$

$\Rightarrow$ BS only transmits to one user.

$\Rightarrow$ CDMA is effectively not used!

In general, for an ad-hoc network, if CDMA is used and the rate is a linear function of the SINR, then the throughput-optimal schedule will correspond to the following:

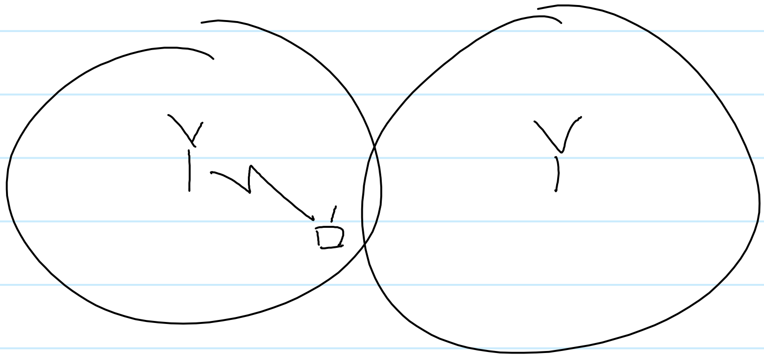
Each node either transmits to one receiver at its maximum power, or does not transmit to any receivers at all.

The receiver may still receive from multiple transmitters.

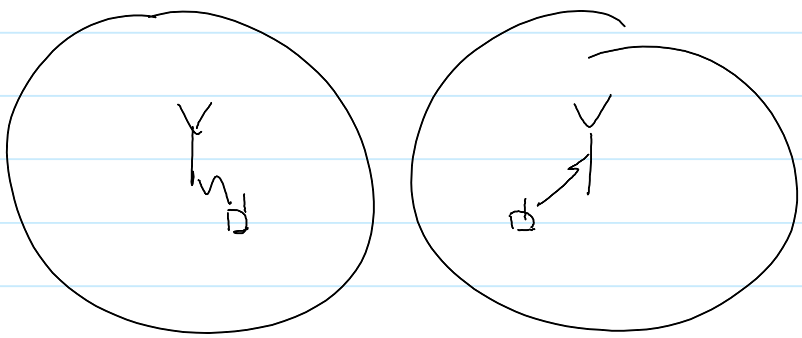
40 - Further, determining the set of active transmitters may still be NP-hard.

- How about MIMO?

- How about multiple cells?



Far user



Near users.

CDMA - handout

Thursday, February 20, 2020 12:06 PM

The throughput-optimal policy then corresponds to:

$$\underset{\vec{p}:\ \sum_h p_h \le P_{max}}{\arg\max} \sum_h \rho^h \cdot \underbrace{\frac{p_h g_h}{\sum_{k \ne h} p_k g_h + N_0}}_{= f(\vec{p})}$$

It turns out that the solution to this optimization problem is of the following form: the BS will transmit to one user at the maximum power.

To see this, suppose there exist two users l & k, and the BS transmits to these two users at the same time, i.e.,

$$p_l > 0$$
$$p_k > 0$$

Let $p_0 = p_l + p_k$, Let $p_l = x$, $p_k = p_0 - x$

then write $f(\vec{p})$ as a function of x

$$f(x) = f(\cdots\ \underset{p_l}{x},\ \cdots\ \underset{p_k}{p_0 - x},\ \cdots)$$

It turns out that it is a convex

function of $P_l = x$. To see this, note that $f(x) = f(P_l)$ has three kinds of terms:

ⓐ $h \neq l,\ h \neq k,$

$$\rho^h \cdot \frac{P_h g_h}{\sum_{k \neq h} P_k g_h + N_0}$$ is independent of P_l (since $P_l + P_k = P_0$)

ⓑ $$\rho^l \cdot \frac{x\, g_l}{\sum_{h \neq l,k} P_h \cdot g_l + (P_0 - x) g_l + N_0}$$

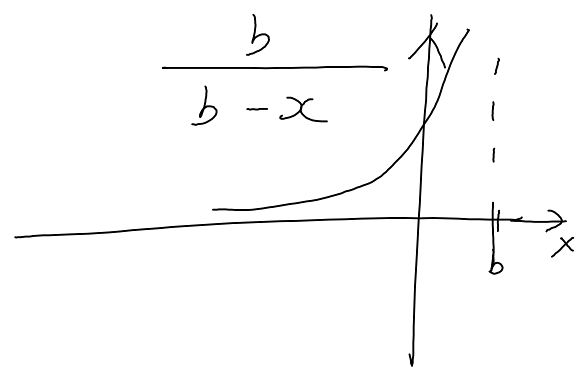
$$= \rho^l \left[-1 + \frac{\sum_{h \neq l,k} P_h g_l + P_0 g_l + N_0}{\sum_{h \neq l,k} P_h g_l + (P_0 - x) g_l + N_0} \right]$$

Simplified argument:

$$\frac{ax}{b - ax}$$

$$= -1 + \frac{b}{b - ax}$$

$$\frac{b}{b - x}$$



ⓒ $$\rho^k \cdot \frac{(P_0 - x) g_K}{\sum_{h \neq l,k} P_h g_K + x\, g_K + N_0}$$

$$= \rho^k \left[-1 + \frac{\sum_{h \neq l,k} P_h g_K + P_0 g_K + N_0}{\sum_{h \neq l,k} P_h g_K + x\, g_K + N_0} \right]$$

Simplified argument

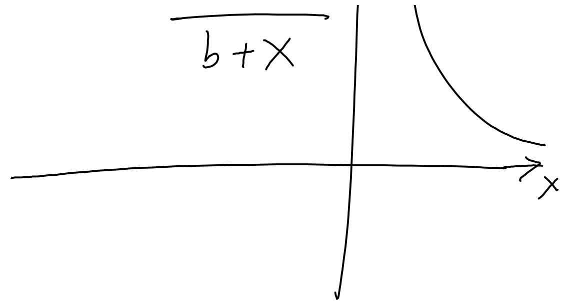
$$\frac{b - ax}{}$$

$$\frac{a}{b + X}$$

$$\frac{b - ax}{c + ax}$$

$$= -1 + \frac{b+c}{c+ax}$$

$b + x$



Hence, $f(x) = f(P_l)$ is larger either

at $P_l = 0$, $P_k = P_0$ or $P_l = P_0$, $P_k = 0$

$\Rightarrow$ BS only transmits to one user.

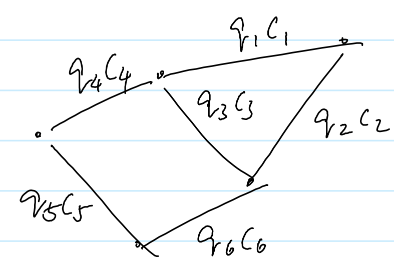
$\Rightarrow$ CDMA is effectively not used in the downlink.

More Implications - 10min

Tuesday, January 29, 2008 4:07 PM

② Node-exclusive interference model (1-hop interference)

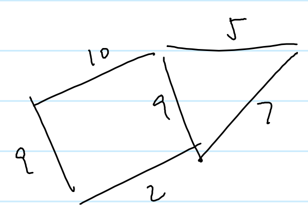
Assume that each link has a fixed capacity c_l if there is no interference



Each set of non-interfering links corresponds to a matching.

The throughput-optimal policy corresponds to computing the maximum-weighted-matching.

- complexity $O(N^3)$
- non-trivial to compute



An active area of research has been to find simpler distributed scheduling algorithms

- with lower complexity
- may only support a reduced capacity region

③ Two-hop interference model

— throughput-optimal policy is in general NP-hard

Critique - 5min

Sunday, January 27, 2008 11:13 AM

1. What if $K(t)$ is unknown

2. Delay is not captured, and could be large for some throughput-optimal schemes

3. no hop-by-hop dynamics

4. Complexity.

5. Other policies may also be throughput-optimal.

5

Complexity of Max-Weight Policy

Potential Solutions:

- Solve the max-weight decision approximately
- Apply max-weight only to part of the decisions that can solved by low complexity
  - e.g., only inside a single cell
  - Channel assignment chosen before-hand.
- Delegate the more complex decisions at a longer time-scale.

Cross layer design - 10min

Thursday, January 31, 2008 2:21 PM

So far we have focused on the MAC scheduling problem.

The capacity region problem is not the only one of interest.

<u>Routing</u>

- How to find good paths for each flows?
  - fully use available capacity
  - avoid hot-spots.
- Often, using a single-path cannot achieve the best performance (e.g. throughput)

  ⇒ multiple paths for a single flow.

<u>Rate Control</u>

- Suppose the rate vector $\vec{x}$ is not given
- Rather, the users can adapt their rates
  - the rates must lie within

the capacity-region
- congestion control
- as large as possible

- fairness

Energy Conservation:

- The throughput-optimal scheduling algorithm can stabilize the system for $\vec{x} \in \Omega$

- But it may not lead to the smallest energy consumption

Often these problems are closeot tied to the capacity region of the network.

Best to design the solution jointly considering these functionalities together with MAC / scheduling

→ "Cross-layer Design"