# Opportunistic Wireless Scheduling

Wireless Networking
Sunghyun Choi, Associate Professor
Multimedia & Wireless Networking Lab. (MWNL)
School of Electrical Engineering
Seoul National University

# Fairness Model for Networks

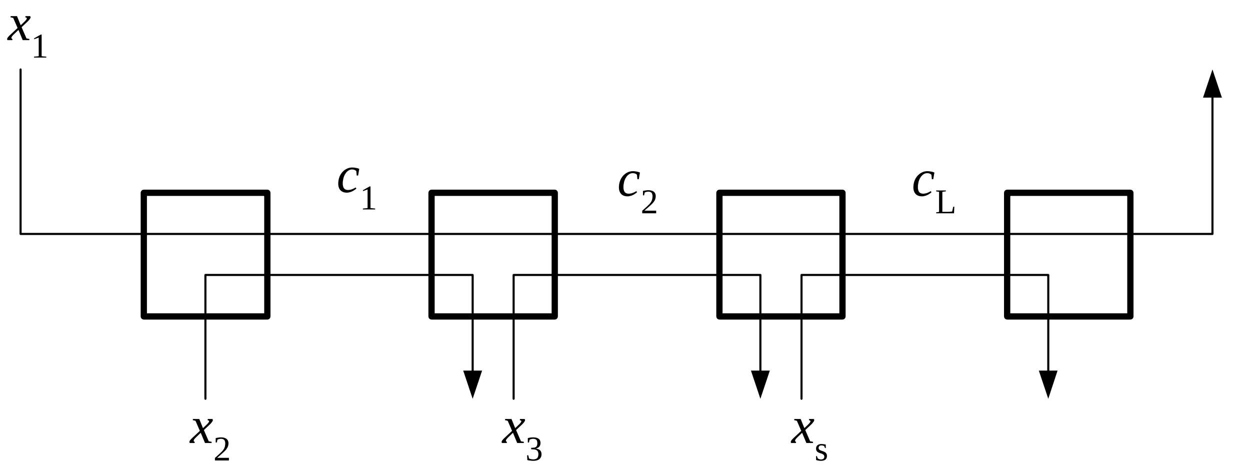
# Network model

source s=1,2,...,S $\quad x_s$ : allocated rate of source $s$

links l=1,2,...,L $\quad c_l$ : capacity of link $l$

$A_{l,s} \in \{0,1\}$ $\quad$ indicator for the source $s$ which flows on the link $l$

$$feasible\,allocation: \sum_{s=1}^{S} A_{l,s} x_s \le c_l,\ \forall l$$




Example of simple network model (parking-lot scenario)

# Max-min fairness

- Definition

A *feasible allocaion* $\mathbf{x} = [x_1, ..., x_S]$ is "max-min fair" if and only if
for any other feasible allocation $y = [y_1, ..., y_S]$,
if $y_s > x_s$, then there exist some $s'$ s.t. $x_{s'} \leq x_s$ and $y_{s'} \leq x_{s'}$

- The algorithm "progressive filling"

$step-1$: set $x_s = 0, \forall s$
$step-2$: grows all $x_s$ together at same pace
$step-3$: if some link $l$ saturated, $x_s$ stops growing for $s$ s.t. $A_{l,s} = 1$

# Proportional fairness

- Definition

An *allocaion* $\mathbf{x} = [x_1, ..., x_S]$ is "proportionally fair" if and only if for any other feasible allocation $y = [y_1, ..., y_S]$, we have

$$\sum_{s=1}^{S} \frac{y_s - x_s}{x_s} \leq 0$$

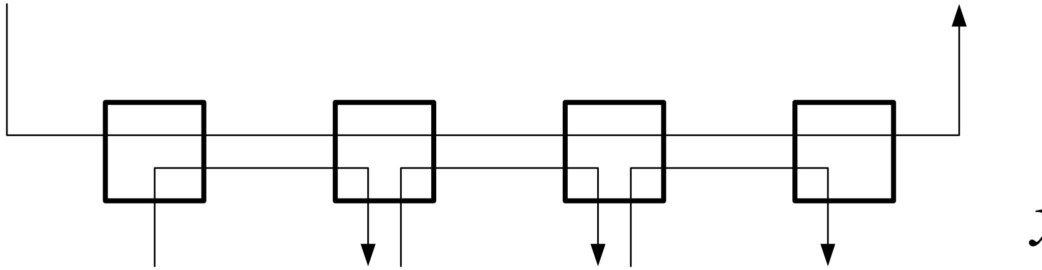
  - Any change in the allocation must have a negative average change
  - Max-min fair is not proportional fair
  - PF takes into consideration the usage of network resources

- Theorem

There exists *one unique PF allocation*.

It can be obtained by maximizing $J(\mathbf{x}) = \sum_s \ln(x_s)$ for feasible allocation

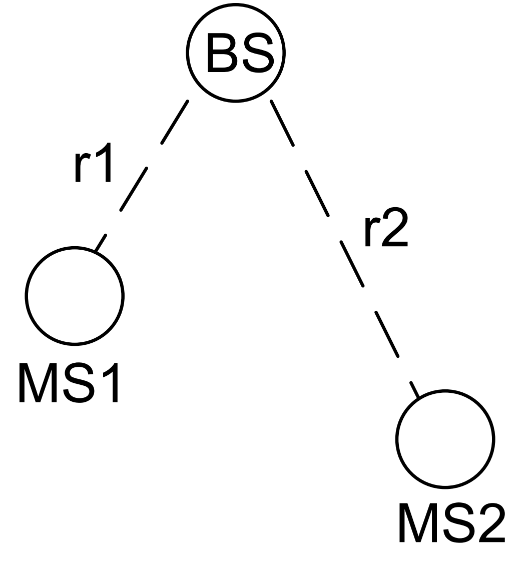
# Examples



- c1=c2=c3=1
- Max-min fair
  - x1=x2=x3=x4=1/2
- PF
  - x1=1/4 & x2=x3=x4=3/4
- For single-hop flows
  - Max-min = PF

# Wireless Single-hop Case

- Max-min ≠ proportional due to
  - Location-dependent channel
  - Time-varying channel
- Example
  - Time-invariant & TDM-based
  - Time-share ratio a1, a2
    - Max-min:
      a1=r2/(r1+r2), a2=r1/(r1+r2)
    - PF: a1=a2=1/2
      PF = resource usage fair
      = temporal fairness



$$Th_1 = a_1 r_1 \ \& \ Th_2 = (1-a_1) r_2$$

$$\Rightarrow \quad a_{1,PF} = \arg\max_{a_1} Th_1 \times Th_2$$

$$= \arg\max_{a_1} a_1 \cdot (1-a_1) r_1 r_2 = \frac{1}{2}$$

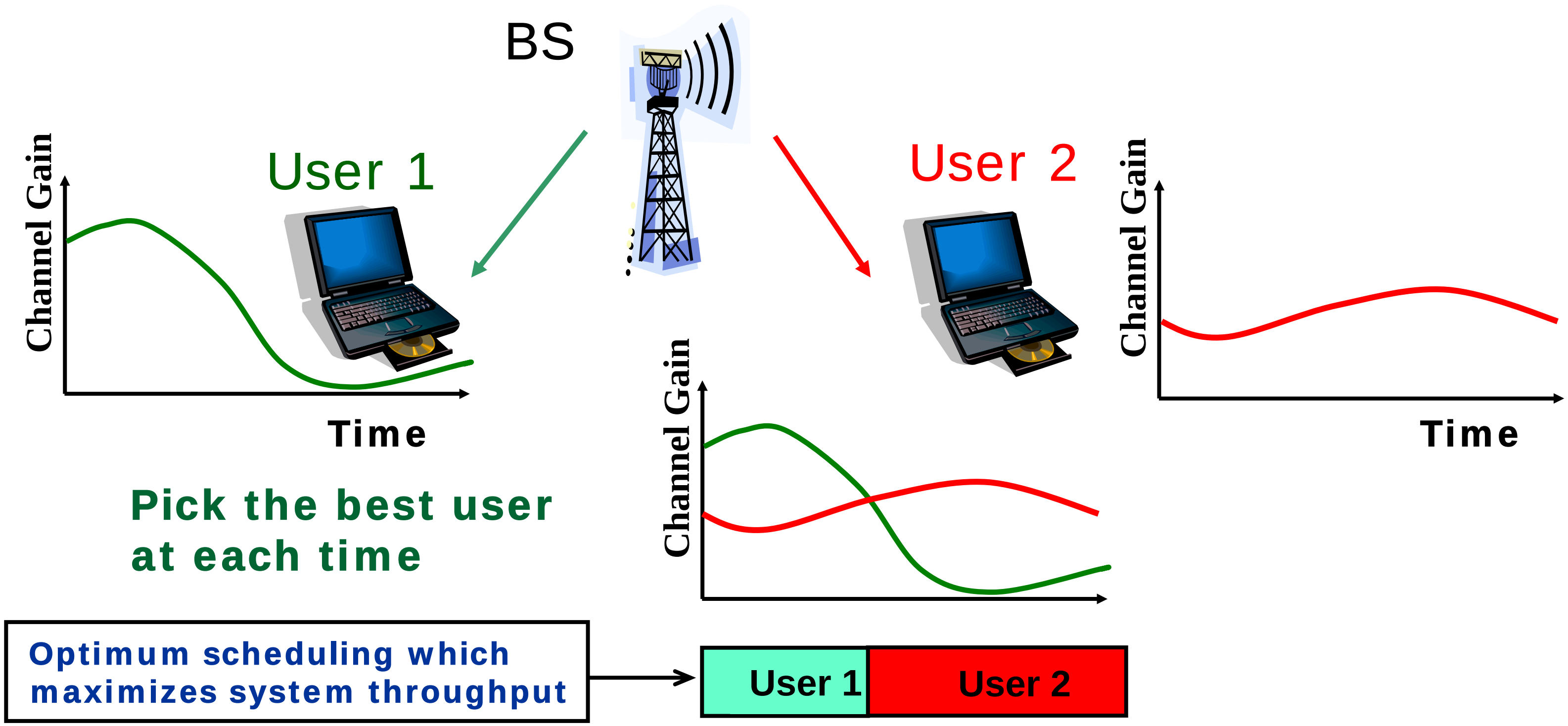
$$a_{1,max-min} = \frac{r_2}{r_1 + r_2}$$

# Packet Scheduling

# Scheduling Issues

- FIFO vs. WFQ
  - WFQ provides weighted share of bandwidth to each flow
- Throughput fairness vs. temporal fairness
  - They become different in wireless network with AMC
- Opportunistic scheduling
  - Channel gain for a user fluctuates over time
  - Multi-user diversity (MUD) possible

# Opportunistic Scheduling




**NEW CONCEPT**

***Need quick scheduling and variable size frames to better adapt channel conditions***

# cdma2000 1xEV-DO

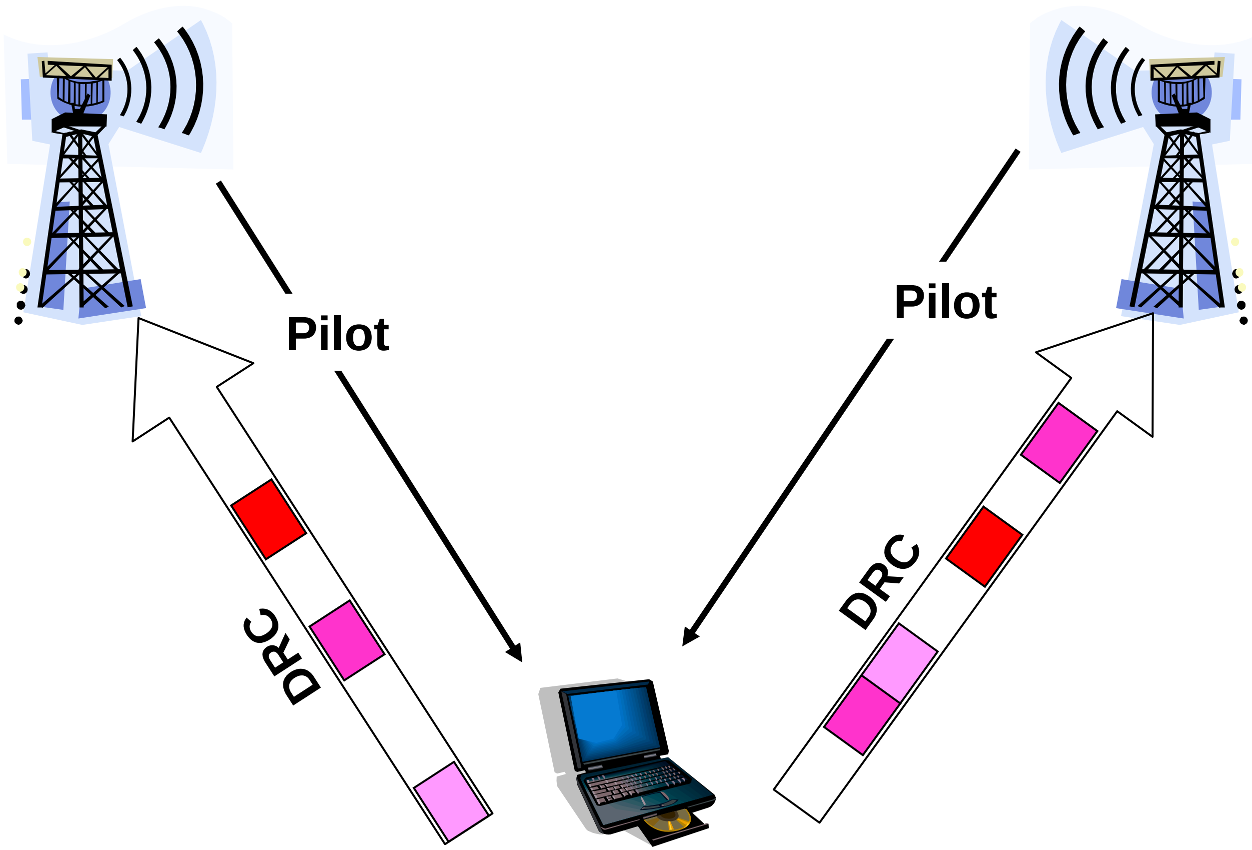
Note: this is used for June (SKT) and Fimm (KTF) today

# EV-DO: Multiple Tx Rates

HARQ(CC)

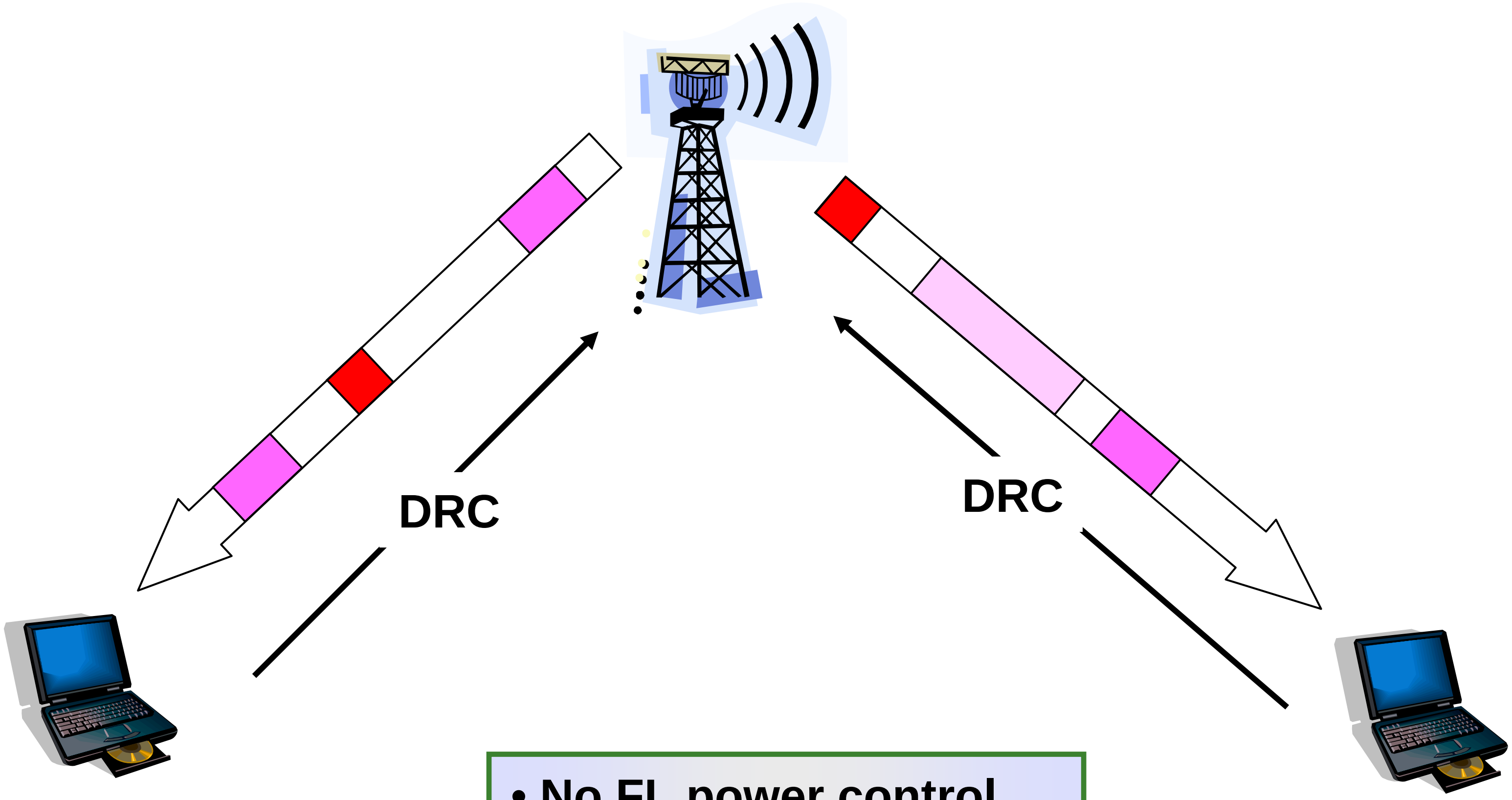
| Complete Packet Type | Nominal Data Rate (kbps) | Nominal Packet Length (slots) | Packet Size (bits) |
|---|---|---|---|
| 38K | 38.4 | 16 | 1024 |
| 76K | 76.8 | 8 | 1024 |
| 153K | 153.6 | 4 | 1024 |
| 307K-2S | 307.2 | 2 | 1024 |
| 307K-4S | 307.2 | 4 | 2048 |
| 614K-1S | 614.4 | 1 | 1024 |
| 614K-2S | 614.4 | 2 | 2048 |
| 921K | 921.6 | 2 | 3072 |
| 1.2M-1S | 1,228.8 | 1 | 2048 |
| 1.2M-2S | 1,228.8 | 2 | 4096 |
| 1.8M | 1,843.2 | 1 | 3072 |
| 2.4M | 2,457.6 | 1 | 4096 |

# C/I Measurement



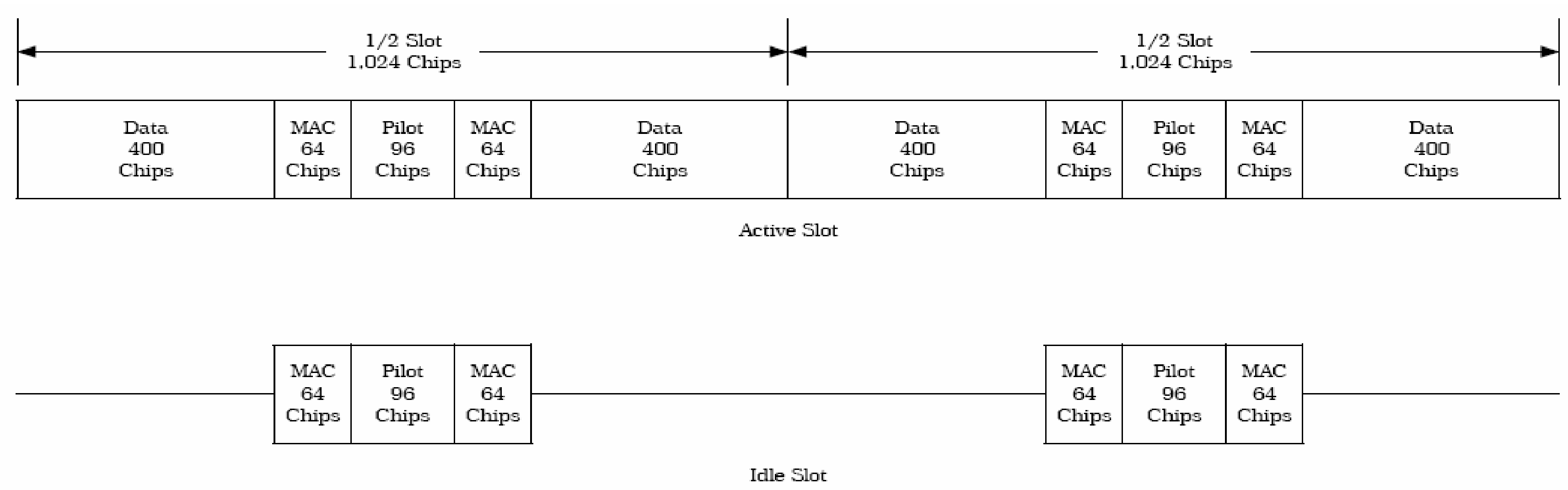

- MS measures the C/I from all the active BS→ determines the best sector and the supportable FL data rates → send the info through DRC channel.
- MS knows the available FL TX power → can decide rate based on only C/I.
- DRC: Data Rate Control

# Scheduling




- No FL power control
- No FL soft handoff

# EV-DO: FL Slot Structure



# Proportional Fair Queuing (PFQ)

- Packet for user *i* is transmitted if

$$i = \arg\max_j \left( \frac{DRC_j(t)}{R_j(t)} \right)$$

where $DRC_j(t)$ is the current DRC, i.e., requested rate, from user *j* at time slot *t*, and $R_j(t)$ is the average rate (or throughput) of user *j* at time slot *t*.

$$R_j(t+1) = (1 - 1/t_c)R_j(t) + 1/t_c * Current\_Tx\_Rate\_of\_User\_j$$

# Some notes

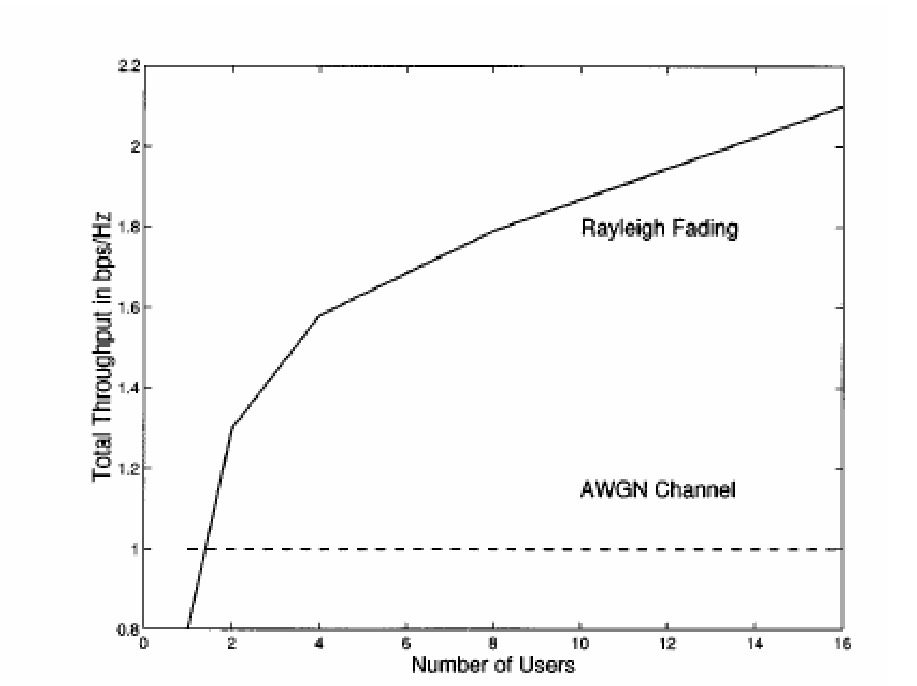
$\max \sum_i \log x_i$

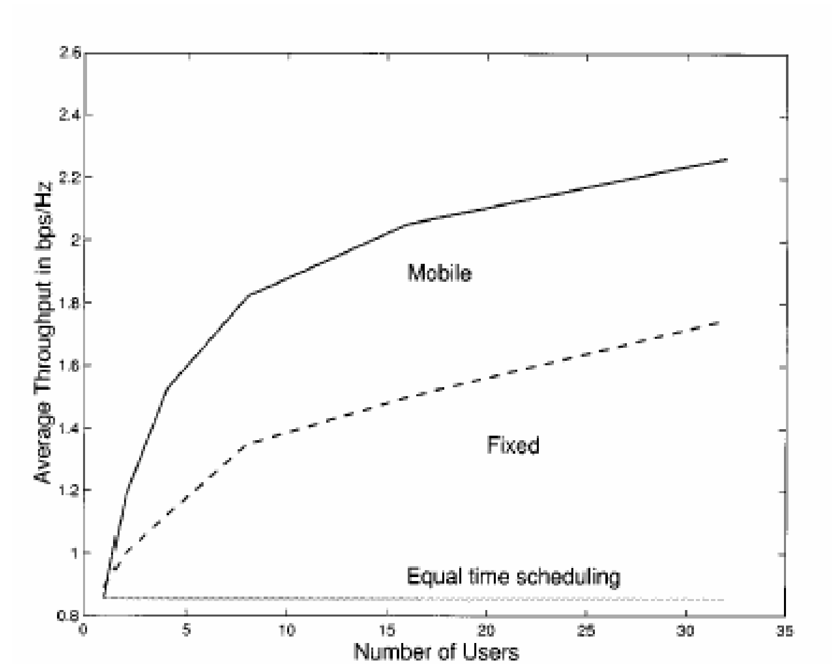
$\Rightarrow$ chose $\max \Delta \log x_i$

$\Rightarrow$ choose $\max \frac{\Delta x_i}{x_i}$

- PFQ achieves PF?
  - Think about the definition of PF.
- To achieve PF, $R_i(t)$ should be the received rate or throughput, NOT the average DRC!!!
- $t_c$ is related to the maximum amount of time for which an individual can be starved.

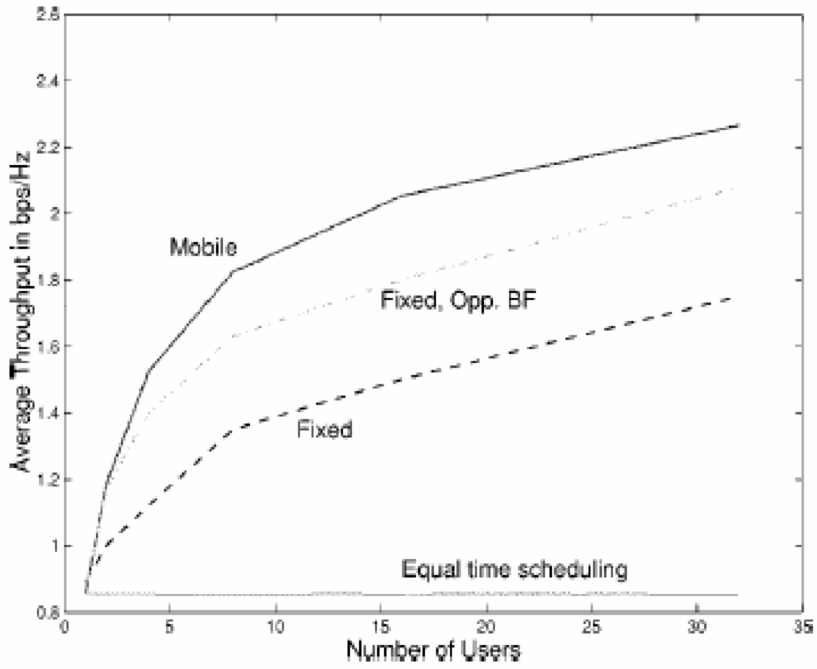
# Proportionally Fair Scheduling (Viswanath, Tse and R. Laroia,02)




Cf. Max C/R scheduling

# Opportunistic Beamforming (Viswanath, Tse and R. Laroia, 02)



# References


- A. Jalali, R. Padovani, and R. Pankaj, “Data throughput of CDMA-HDR a high efficiency-high data rate personal communication wireless system,” in Proc. VTC’2000.
- P. Viswanath, D. N. C Tse and R. Laroia, "Opportunistic Beamforming Using Dumb Antennas," IEEE Transactions on Information Theory , Vol. 48 (6), pp. 1277-1294, 2002.