Scheduling mobile users in Cellular Networks

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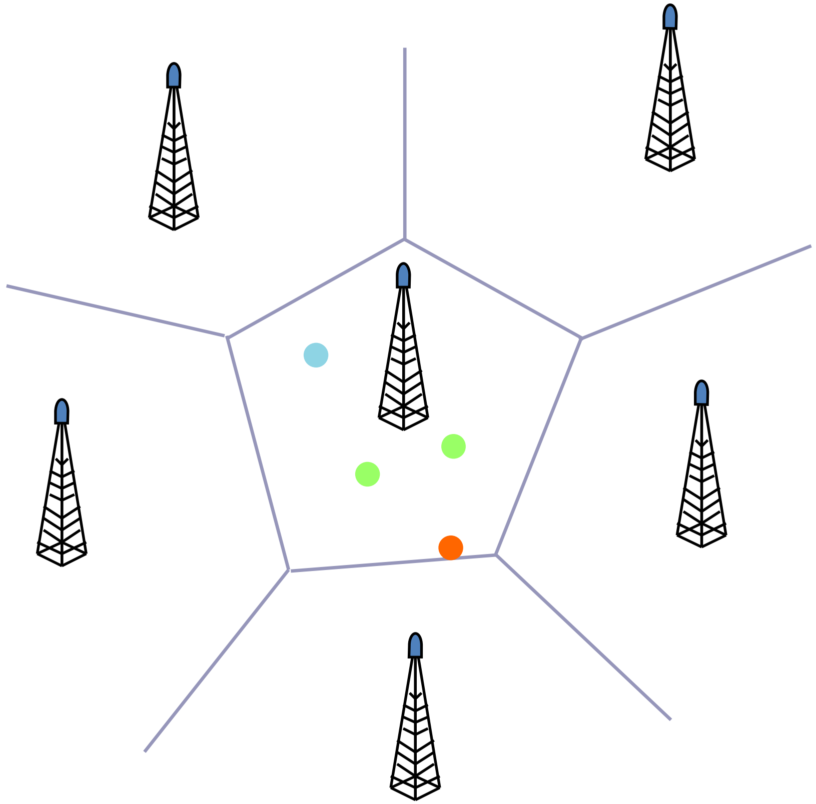
Cellular data networks



data transfers

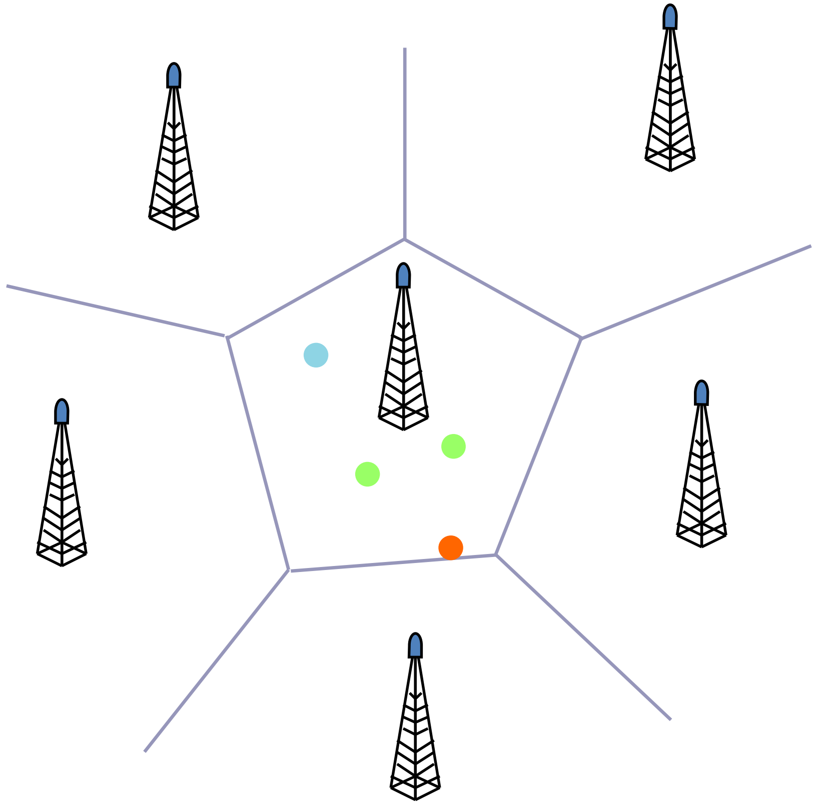
feasible rate:

- user location
- fading

scheduling:

- opportunistic
- proportional fair

Cellular data networks

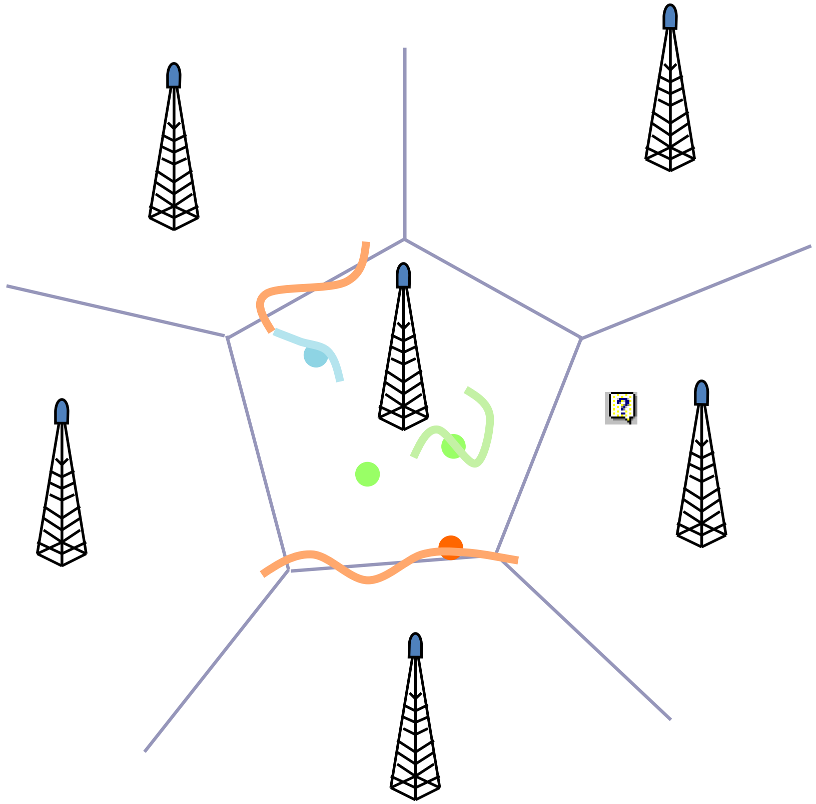


performance at flow level?

flow-level stability

flow response time

Cellular data networks



performance at flow level?

flow-level stability

flow response time

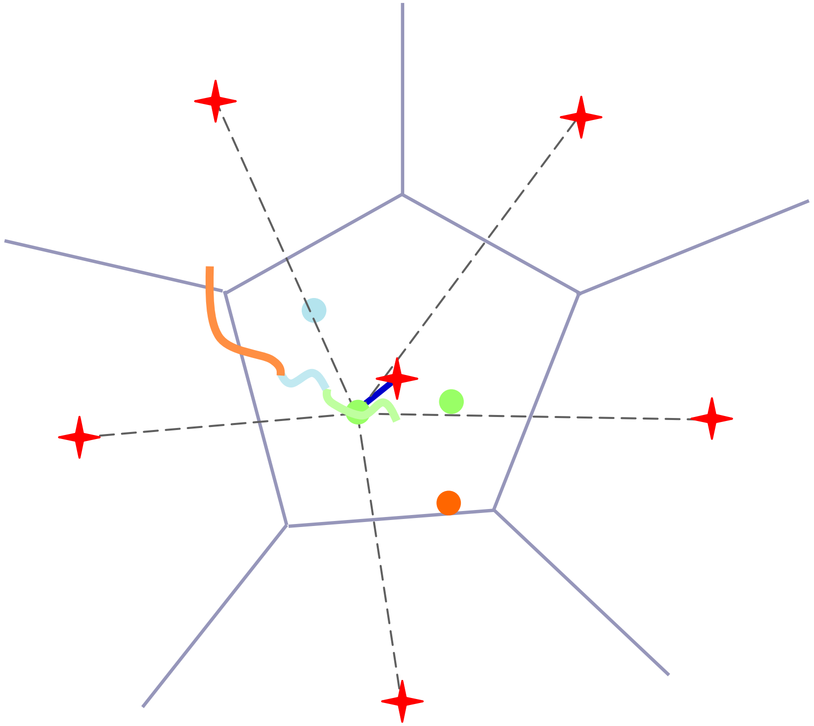
user mobility

Is proportional-fair still the best?

Agenda

- traffic, capacity
- fairness framework
- impact of mobility
- can we find a better scheduler?

Model



state of a user
(location)

class of a user
(path)

flow generation
ρ (Poisson)

user movement
(stat. ergodic Markov)

file transfers
(exponential)

C_i: mean feasible rate in state i

capacity: maximum traffic intensity s.t. system is stable

α-fairness

- objective: to solve: $$\max \sum_u \frac{T_u^{1-\alpha}}{1-\alpha}$$

- PF: $\alpha \to 1$, max-min: $\alpha \to \infty$, max-thru: $\alpha = 0$, etc.

- gradient algorithm:

$$\arg\max_u C_u(t) \times T_u^{-\alpha}(t)$$

- each BS schedules its users independently of other BSs.

Mo-Walrand'00

Capacity

- rate region:

$$\mathcal{R}^\alpha = r \in \mathbb{R}_+^K : \exists \theta \in \mathbb{R}_+^K, \forall k, r_k < \sum_n \frac{\theta_k A_{k,n}^\alpha}{\sum_{l=1}^K \theta_l B_{l,n}^\alpha}$$

$$A_{k,n}^\alpha = \sum_{i \in \mathcal{I}^n} \pi_{i,k} C_i^{1/\alpha}$$

$$B_{k,n}^\alpha = \sum_{i \in \mathcal{I}^n} \pi_{i,k} C_i^{(1-\alpha)/\alpha}$$

Theorem: *the network is stable iff* $\rho = (\rho_1, \ldots, \rho_K) \in \mathcal{R}^\alpha$.

Capacity

$$\mathcal{R}^\alpha = r \in \mathbb{R}_+^K : \exists \theta \in \mathbb{R}_+^K, \forall k, r_k < \sum_n \frac{\theta_k A_{k,n}^\alpha}{\sum_{l=1}^K \theta_l B_{l,n}^\alpha}$$

- sketch of proof:
- sufficient condition through fluid limits*
  - spatial homogenization – assume that in the limit the number of users is distributed as π
- necessary condition: consider $\rho \notin \mathcal{R}^\alpha$

define γ: $\gamma \times \rho \in \mathcal{R}^\alpha. \quad \gamma < 1, \quad \gamma \times \rho \in \partial\mathcal{R}_\alpha$

can find θ such that for all *k*,

$$\rho_k > \sum_n \frac{\theta_k A_{k,n}^\alpha}{\sum_{l=1}^K \theta_l B_{l,n}^\alpha}$$

*Simatos-Tibi 09

Capacity

$$\mathcal{R}^\alpha = r \in \mathbb{R}_+^K : \exists \theta \in \mathbb{R}_+^K, \forall k, r_k < \sum_n \frac{\theta_k A_{k,n}^\alpha}{\sum_{l=1}^K \theta_l B_{l,n}^\alpha}$$

- interpretation:

$\theta_k / \sum_l \theta_l$ is the proportion of class-*k* users

$$\sum_n \frac{\theta_k A_{k,n}^\alpha}{\sum_{l=1}^K \theta_l B_{l,n}^\alpha}$$

service rate of class-*k* users in cell *n*

depends on α !

Impact of fairness index α

- the smaller the fairness index the larger the capacity

$$\text{If } \alpha' \geq \alpha, \text{ then } \mathcal{R}_{\alpha'} \subseteq \mathcal{R}_{\alpha}$$

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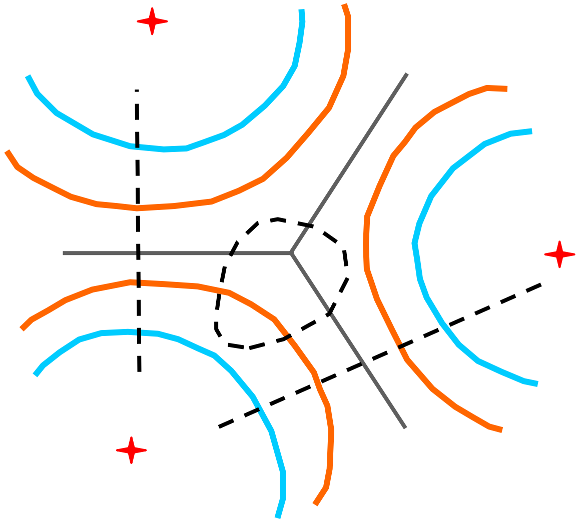
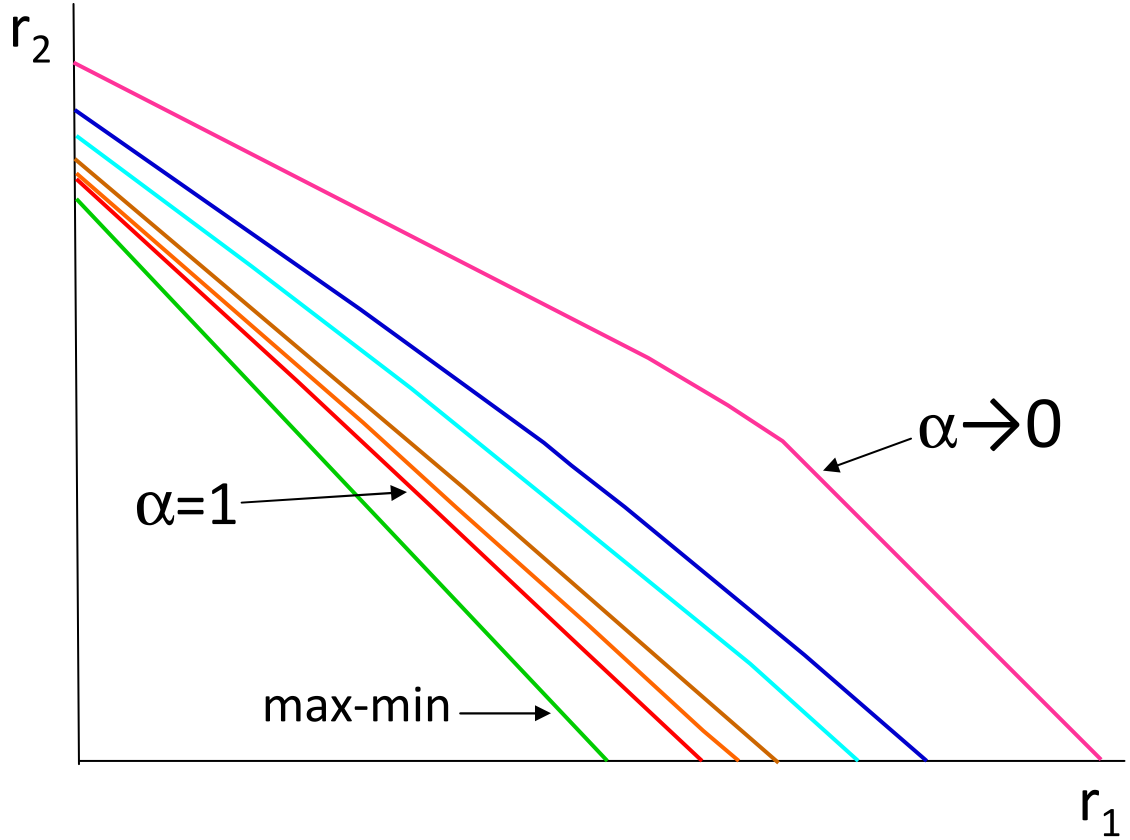




Impact of mobility

- no dependence of α in the absence of mobility:

$$\mathcal{R}^{\text{no}} = \{r \in \mathbb{R}_+^K : \forall n, \sum_k \sum_{i \in \mathcal{I}^n} \pi_{i,k} r_k / C_i < 1\}$$

- under any given α-scheduler, capacity increases with mobility:

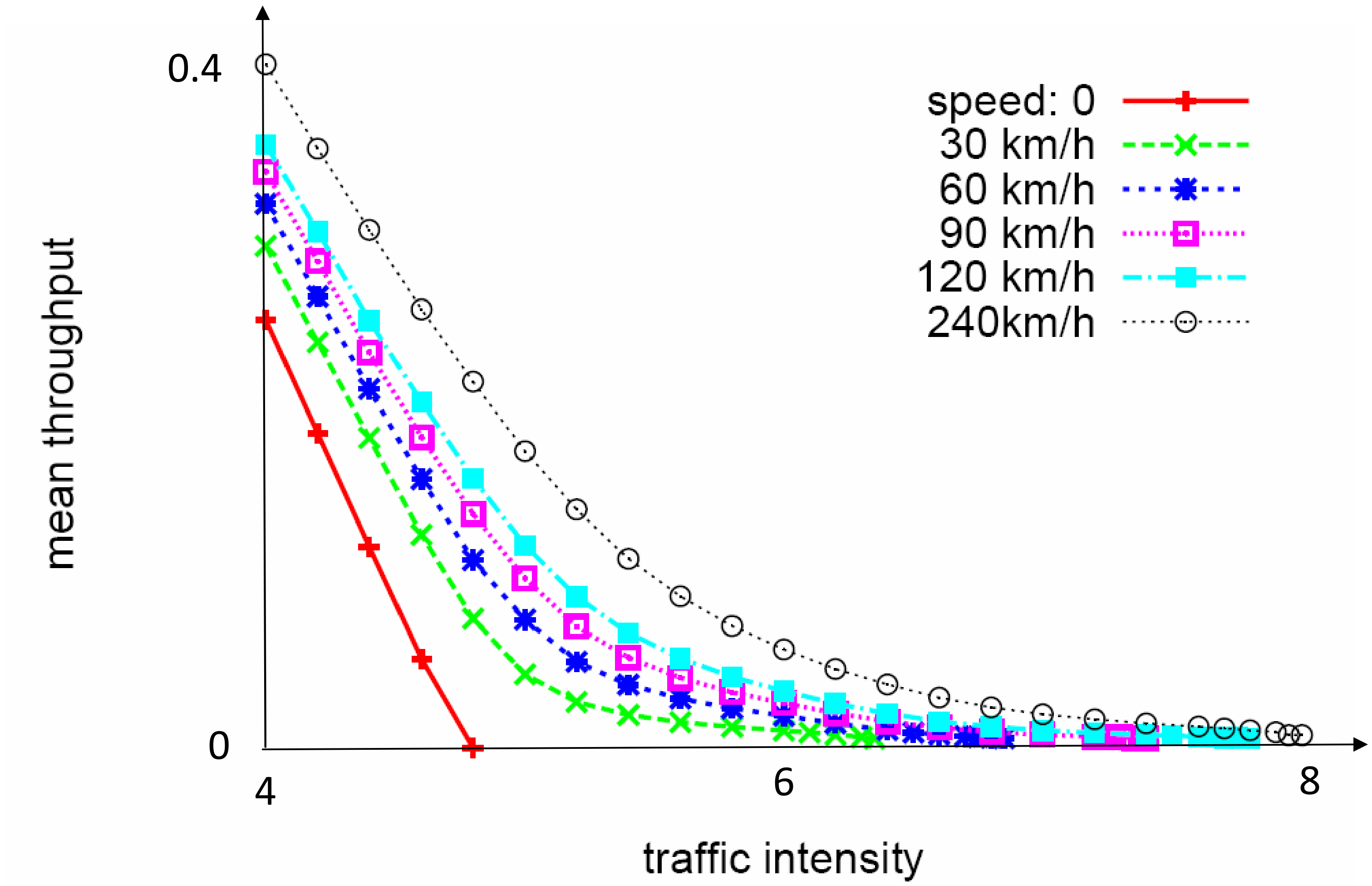
For any $\alpha > 0$ $\quad \mathcal{R}^{\text{no}} \subseteq \mathcal{R}^{\alpha}$

show $\quad \mathcal{R}^{\text{no}} \subseteq \mathcal{R}^{\text{max-min}}$

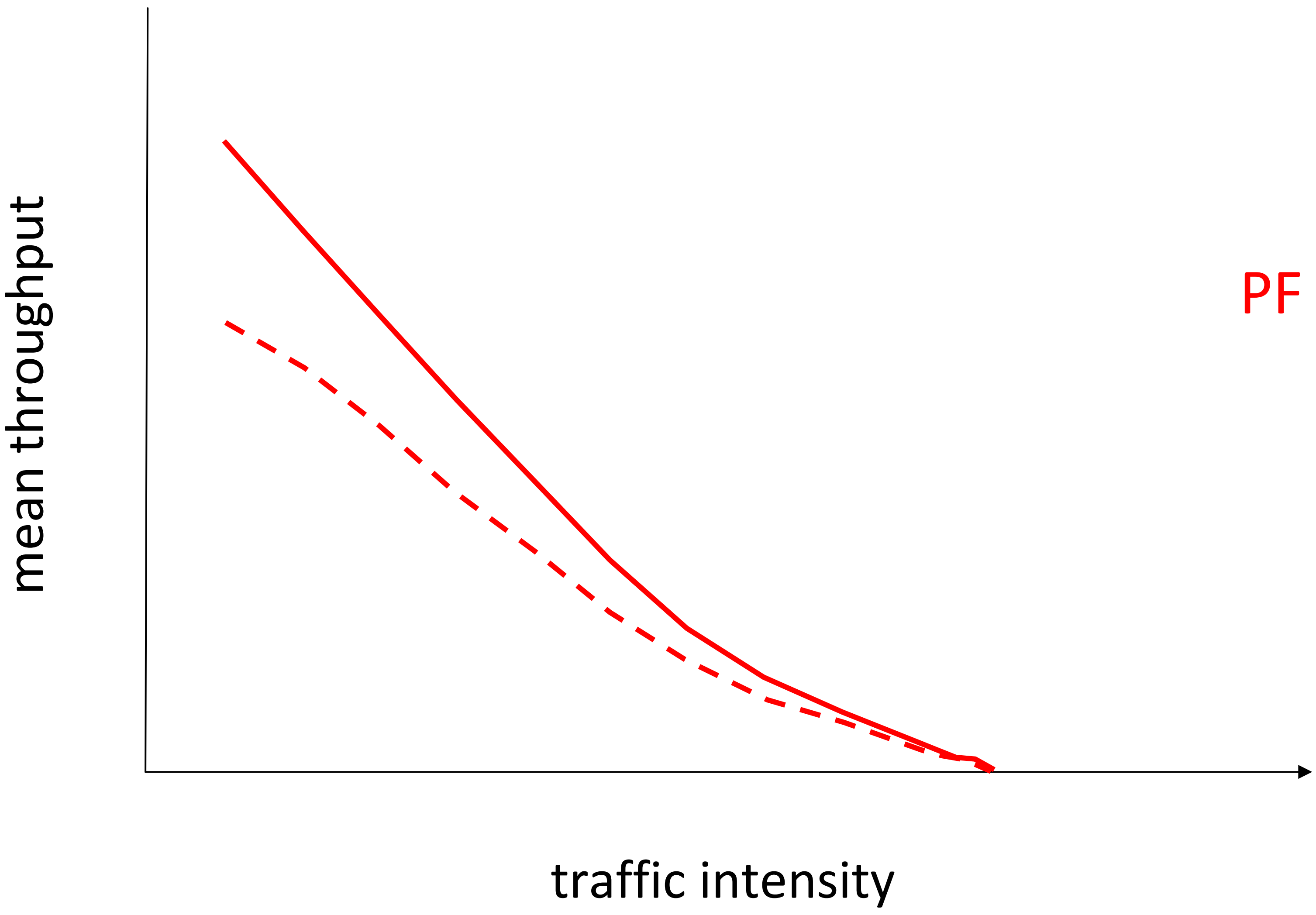
Impact of mobility

- stability region increases with *any* mobility
- in reality, the mean response time may be too high for values of traffic intensity below the capacity limit
- mean flow response time: exact analysis difficult, but it may be possible to have bounds
- here we show simulation results

Impact of mobility



what about fairness?



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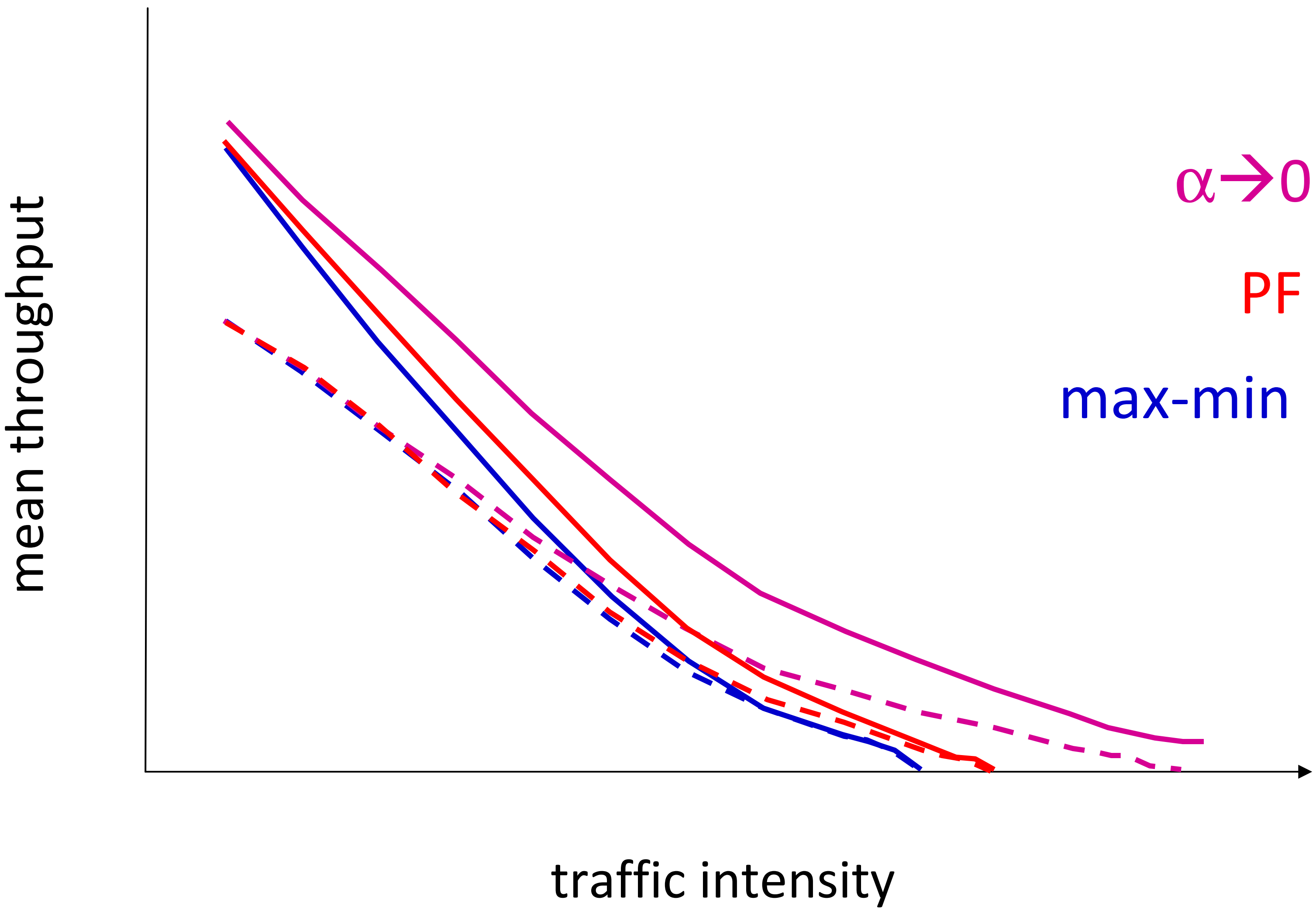

conclusion

- mobility is good!
  - increases capacity for any α-fair scheduler
- don't use PF for moving users, certainly not max-min
- towards adaptive schedulers
  - learn mobility, adapt scheduling
  - dynamically?

$\alpha \rightarrow 1$

$\alpha < 1$

thank you

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