Fair Congestion Pricing

Soheila Aalami
Department of Civil Engineering

Negative Effects of Congestion

- **Delays ⇒** Late arrivals for work, meetings, ….
- **Inability to forecast travel time ⇒** allocating more time to travel "just in case"
- **Wasted fuel ⇒** increasing air pollution + carbon dioxide emissions
- **Stressed and frustrated motorists ⇒** encouraging road rage + reduced health
- **Emergencies ⇒** interrupts the movement of emergency vehicles
- **Higher chance of collisions**

Congestion Pricing

What is Congestion Pricing?

- A dynamic pricing strategy designed to regulate traffic demand by charging the prices without increasing supply.

Benefits of Congestion Pricing

- Handles the increased demand for travel while meeting the sustainability goals of our cities
  - Influencing choice of residential and business location
  - Reduction in trip lengths and use of private vehicles
- Less congestion without a need to build more infrastructure
- Reduces environmental impacts associated with the use of road systems

Fairness in Congestion Pricing

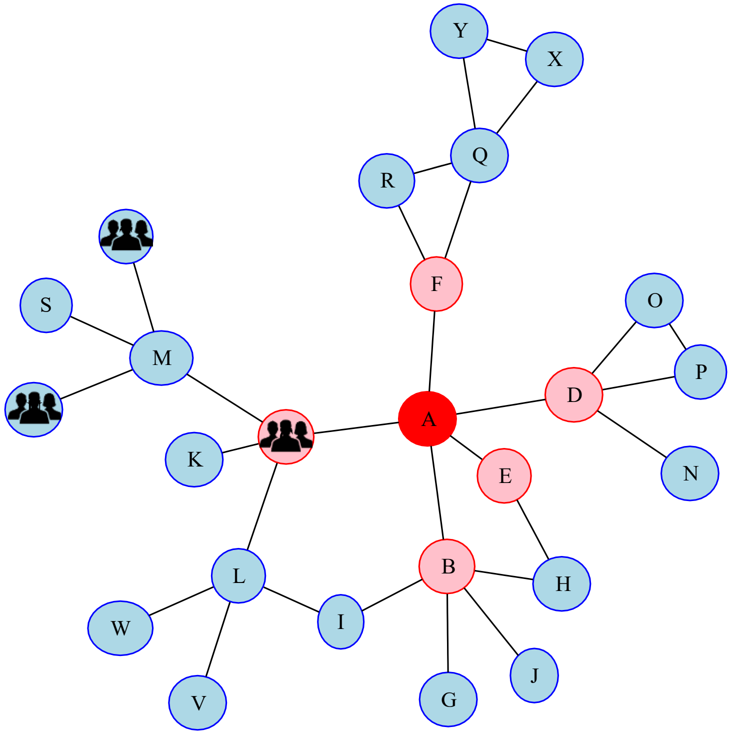
Example Objectives

- Give fairer access to drivers from communities far from downtown
- Given an advantage to communities with no access to public transit to use personal vehicles

Problem Modeling

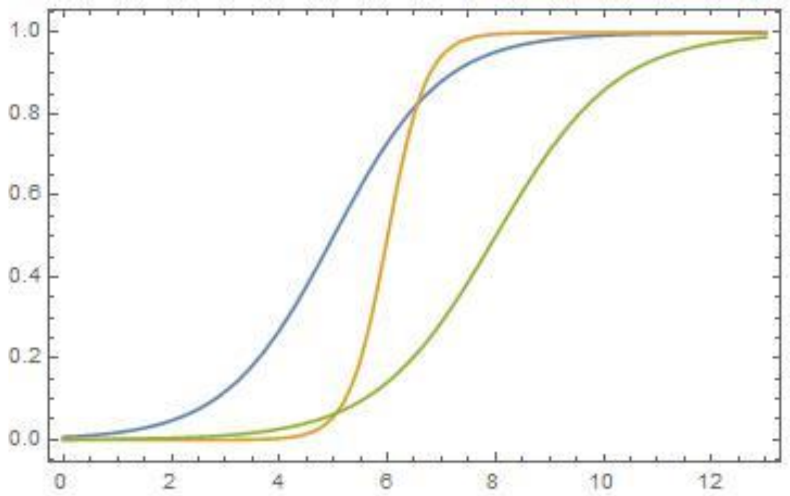
ASSUMPTIONS

- A set of communities with known demand
- A transportation network connects the communities
- A set of links in which each link has a specified capacity
- Each community has a utility function U(x)



Utility Functions of Communities

1. Utility is always non-negative.
2. $U_i(\cdot)$ is a non-decreasing function of flow
3. It is bounded



Objective: to guide traffic to the routes, in such a way that allocated flows and prices to communities and links are utility max–min fair.

Fairness

- Fairness is a debatable topic

- There are many different definitions for fairness
  - Equal allocation
  - **Max-Min fairness**
  - Proportional fairness

Solution Algorithm

A distributed utility based flow control algorithm

- A **link algorithm** is deployed at each link to update the link price depending on the severity of link Congestion.
- A **community algorithm** is implemented at each community edge to adapt the flow rate based on the announced prices.
- Both link algorithm and community algorithm are iterative.
- At time t + 1,
  - Each link l updates its link price according to: $$p_l(t+1) = \left[p_l(t) + \gamma(x^l(t) - c_l)\right]^+$$
  - For each community, we use the following first-order Lagrangian algorithm to update its its path flow:

$$x_{s,i}(t+1) = \left[x_{s,i}(t) + \gamma\left(\frac{1}{U_s(x_s(t))} + \alpha_s(t) - \beta_s(t) - p^r_{s,i}(t)\right)\right]^+$$

Algorithm 1. Distributed max–min fair algorithm

- **Link l's algorithm:**

At time t = 1,2, ..., each link l:

1. Aggregates flow rates $x_{s,i}(t)$ for all paths $R_{s,i}$ that contain link l.

2. Computes a new link price $p_l(t+1) = [p_l(t) + \gamma(x^l(t) - c_l)]^+$

3. Communicates the new price $p_l(t+1)$ to all communities whose path $R_{s,i}$ contains link l.

- **Communities' algorithm:**

At time t = 1,2, … each community:

1.Receives from the network the path prices $p^r_{s,i}(t) = \max_{l \in R_{s,i}} p_l(t)$

for all its paths $R_{s,i}, i = 1, 2, \ldots, n_s$

2. Updates the path rate $x_{s,i}(t+1)$ ind community rate $x_s(t+1)$ using

3. Computes new lower bound and upper bound price $\alpha(t+1)$ and $\beta(t+1)$ for the next step

4. Communicates the new flow rate $x_{s,i}(t+1)$ to all the links which are contained in paths $R_{s,i}$

Ideas for Future Work

- Considering proportional fairness instead of max-min fairness
- Considering utility function for individual drivers instead of communities

Thank you!