The Public Option: A non-regulatory alternative to Network Neutrality

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Highlights

- A more realistic equilibrium model of content traffic, based on
  - User demand for content
  - System protocol/mechanism

- Game theoretic analysis on user utility under different ISP market structures:
  - Monopoly, Duopoly & Oligopoly

- Regulatory implications for all scenarios and the notion of a *Public Option*
Three-party model \((M, \mu, N)\)

- \(\mu\): capacity of a single access ISP
- \(M\): # of users of the ISP (# of active users)
- \(N\): set of all content providers (CPs)
- \(\lambda_i\): throughput rate of CP \(i \in N\)
User-side: 3 Demand Factors

- **Unconstrained throughput** $\hat{\theta}_i$
  - Upper-bound, achieved under unlimited capacity
  - E.g. 5Mbps for Netflix

- **Popularity of the content** $\alpha_i$
  - Google has a larger user base than other CPs.

- **Demand function of the content** $d_i(\theta_i)$
  - Percentage of users still being active under the achievable throughput $\theta_i \leq \hat{\theta}_i$
Unconstrained Throughput $\hat{\lambda}_i$

(Max) Throughput $\hat{\theta}_i(=7Kbps)$  User size $M(=10)$

Content unconstrained throughput

$\hat{\lambda}_i = \alpha_i M\hat{\theta}_i (=42Kbps)$

Content popularity

$\alpha_i (=60\%)$
Demand Function $d_i(\theta_i)$

demanding # of users $\alpha_i M d_i(\theta_i)$

achievable throughput $\tilde{\theta}_i$
Demand Function $d_i(\theta_i)$

- Assumption 1: $d_i(\theta_i)$ is continuous and non-decreasing in $\theta_i$ with $d_i(\tilde{\theta_i}) = 1$.
- More sensitive to throughput
- Throughput of CP $i$:

$$\lambda_i(\theta_i) = \alpha_i M d_i(\theta_i) \theta_i$$
Axiom 1 (Throughput upper-bound)

\[ \theta_i \leq \hat{\theta}_i \]

Axiom 2 (Work-conserving)

\[ \lambda_N = \sum_{i \in \mathcal{N}} \lambda_i = \min \left( \mu, \sum_{i \in \mathcal{N}} \hat{\lambda}_i \right) \]

Axiom 3 (Monotonicity)

\[ \theta_i(M, \mu_2, \mathcal{N}) \geq \theta_i(M, \mu_1, \mathcal{N}) \quad \forall \mu_2 \geq \mu_1 \]
Uniqueness of Rate Equilibrium

Theorem (Uniqueness): A system \((M, \mu, \mathcal{N})\) has a unique equilibrium \(\{\theta_i : i \in \mathcal{N}\}\) (and therefore \(\{\lambda_i : i \in \mathcal{N}\}\)) under Assumption 1 and Axiom 1, 2 and 3.

User demand: \(\{\theta_i\} \rightarrow \{d_i\}\)
Rate allocation: \(\mu, \{d_i\} \rightarrow \{\theta_i\}\)

\(\Rightarrow\) Rate equilibrium: \((\{\theta_i^*\}, \{d_i^*\})\)
**ISP Paid Prioritization**

**ISP Payoff:** 
\[ c \sum_{i \in \mathcal{P}} \lambda_i = c \lambda_p \]

<table>
<thead>
<tr>
<th>Capacity</th>
<th>Charge</th>
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<tbody>
<tr>
<td><strong>Premium Class</strong></td>
<td><strong>Ordinary Class</strong></td>
</tr>
<tr>
<td>((M, \kappa \mu, \mathcal{P}))</td>
<td>((M, (1 - \kappa)\mu, \emptyset))</td>
</tr>
<tr>
<td>(\kappa \mu)</td>
<td>((1 - \kappa)\mu)</td>
</tr>
<tr>
<td>($c/\text{unit traffic})</td>
<td>($0)</td>
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Monopolistic Analysis

- Players: monopoly ISP $I$ and the set of CPs $\mathcal{N}$

- A Two-stage Game Model $(M, \mu, \mathcal{N}, I)$
  - $1^{\text{st}}$ stage, ISP chooses $s_I = (\kappa, c)$ announces $s_I$.
  - $2^{\text{nd}}$ stage, CPs simultaneously choose service classes reach a joint decision $s_{\mathcal{N}} = (\mathcal{O}, \mathcal{P})$.

- Outcome: set $\mathcal{P}$ of CPs shares capacity $\kappa \mu$ and set $\mathcal{O}$ of CPs share capacity $(1 - \kappa)\mu$. 
Utilities (Surplus)

- **ISP Surplus:** \( IS = c \sum_{i \in P} \lambda_i = c \lambda_P \);

- **Consumer Surplus:** \( CS = \sum_{i \in N} \phi_i \lambda_i \)
  - \( \phi_i \): per unit traffic value to the users

- **Content Provider:**
  - \( v_i \): per unit traffic profit of CP \( i \)
  
  \[ u_i(\lambda_i) = \begin{cases} 
  v_i \lambda_i & \text{if } i \in \mathcal{O}, \\
  (v_i - c)\lambda_i & \text{if } i \in \mathcal{P}.
  \end{cases} \]
Type of Content

Profitability of CP $v_i$

Value to users $\phi_i$
Monopolistic Analysis

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Theorem: Given a fixed charge $c$, strategy $s_I = (\kappa, c)$ is dominated by $s'_I = (1, c)$.

The monopoly ISP has incentive to allocate all capacity for the premium service class.
Utility Comparison: $\Phi$ vs $\Psi$
Regulatory Implications

- Ordinary service can be made “damaged goods”, which hurts the user utility.

- Implication: ISP should not be allowed to use non-work-conserving policies ($\kappa$ cannot be too large).

- Should we allow the ISP to charge an arbitrarily high price $c$?
High price $c$ is good when

\[ \text{Profitability of CP } v_i \]

\[ \text{Value to users } \phi_i \]
High price $c$ is bad when

Value to users $\phi_i$

Profitability of CP $v_i$
Oligopolistic Analysis

- A Two-stage Game Model \((M, \mu, \mathcal{N}, \mathcal{I})\)
  - 1\(^{\text{st}}\) stage: for each ISP \(I \in \mathcal{I}\) chooses \(s_I = (\kappa_I, c_I)\) simultaneously.
  - 2\(^{\text{nd}}\) stage: at each ISP \(I \in \mathcal{I}\), CPs choose service classes with \(s^I_N = (O_I, P_I)\)

- Difference with monopolistic scenarios:
  - Users move among ISPs until the per user surplus \(\Phi_I\) is the same, which determines the market share of the ISPs
  - ISPs try to maximize their market share.
Duopolistic Analysis

ISP I with $s_I = (\kappa, c)$

ISP J with $s_J = (0, 0)$

Public Option
Duopolistic Analysis: Results

- Theorem: In the duopolistic game, where an ISP $J$ is a Public Option, i.e. $s_J = (0, 0)$, if $s_I$ maximizes the non-neutral ISP $I$’s market share, $s_I$ also maximizes user utility.

- Regulatory implication for monopoly cases:
Oligopolistic Analysis: Results

- Theorem: Under any strategy profile $s_{-I}$, if $s_I$ is a best-response to $s_{-I}$ that maximizes market share, then $s_I$ is an $\epsilon$-best-response for the per user utility $\Phi$.

- The Nash equilibrium of market share is an $\epsilon$-Nash equilibrium of user utility.

- Oligopolistic scenarios:
Regulatory Preference

ISP market structure

Oligopoly

Monopoly

User Utility

Hands Off the Internet

Public Option

Network Neutrality
Senator, what do you think about the public option?..