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

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The Internet Landscape

- Internet Service Providers (ISPs)
  - Comcast
  - Time Warner Cable
  - SingTel

- Internet Content Providers (CPs)
  - Google
  - BitTorrent
  - Netflix

- Regulatory Authorities
  - Federal Communications Commission (FCC)
  - InfoComm Development Authority of Singapore (IDA)

- Users/Consumers
Network Neutrality (NN)
Paid Prioritization (PP)

Happier?
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 \((M, \mu, \mathcal{N})\)

- \(\mu\): capacity of a single access (eyeball) ISP
- \(M\): # of users of the ISP (# of active users)
- \(\mathcal{N}\): set of all content providers (CPs)
- \(\lambda_i\): throughput rate of CP \(i \in \mathcal{N}\)
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 $\alpha_iM d_i(\theta_i)$
Assumption 1: $d_i(\theta_i)$ is continuous and non-decreasing in $\theta_i$ with $d_i(\hat{\theta}_i) = 1$.

More sensitive to throughput

Throughput of CP $i$:

$$\lambda_i(\theta_i) = \alpha_i M d_i(\theta_i) \theta_i$$

Demanding # of users $\alpha_i M d_i(\theta_i)$
System Side: Rate Allocation

- 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)
  \[ \theta_i(M, \mu_2, \mathcal{N}) \geq \theta_i(M, \mu_1, \mathcal{N}) \forall \mu_2 \geq \mu_1 \]
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>Class</th>
<th>Capacity</th>
<th>Charge</th>
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<tbody>
<tr>
<td>Premium</td>
<td>( \kappa \mu )</td>
<td>( $c/\text{unit traffic} )</td>
</tr>
<tr>
<td>(( M, \kappa \mu, \mathcal{P} ))</td>
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<tr>
<td>Ordinary</td>
<td>( (1 - \kappa) \mu )</td>
<td>( $0 )</td>
</tr>
<tr>
<td>(( M, (1 - \kappa) \mu, \mathcal{O} ))</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\textsuperscript{st} stage, ISP chooses $s_I = (\kappa, c)$ announces $s_I$.
  - 2\textsuperscript{nd} stage, CPs simultaneously choose service classes reach a joint decision $s_{\mathcal{N}} = (\mathcal{O}, \mathcal{P})$.

- Outcome (two subsystems):
  - $(M, \kappa \mu, \mathcal{P})$: set $\mathcal{P}$ (of CPs) share capacity $\kappa \mu$
  - $(M, (1 - \kappa) \mu, \mathcal{O})$: set $\mathcal{O}$ 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

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

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  - 1\(^{st}\) stage, ISP chooses \( s_I = (\kappa, c) \) announces \( s_I \).
  - 2\(^{nd}\) stage, CPs simultaneously choose service classes reach a joint decision \( s_{\mathcal{N}} = (\mathcal{O}, \mathcal{P}) \).

- 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 $\Psi$

- $\Phi = \frac{CS}{M}$
- $\Psi = \frac{IS}{M}$

Graphs show the comparison for different values of $c$ and $\kappa$. The graphs are labeled with $\nu = \frac{\mu}{M}$, where $\nu$ is a variable representing $\mu$. Each graph compares the utility for different values of $\kappa$. The graphs are structured with $c$ values of 0.1, 0.3, 0.5, 0.7, and 0.9, with corresponding $\kappa$ values for each.
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

- Profitability of CP $v_i$
- Value to users $\phi_i$
High price $c$ is bad when

Profitability of CP $v_i$

Value to users $\phi_i$
Oligopolistic Analysis

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

- **Difference with monopolistic scenarios:**
  - Users move among ISPs until the per user utility \(\Phi_I\) 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 $s_J = (0, 0)$
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

Public Option

User Utility
SENATOR, WHAT DO YOU THINK ABOUT THE PUBLIC OPTION?..