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)
  - iDA

- Users/Consumers
Net Neutrality: Some History

- Early 2005, Madison River Communications
  - Block VoIP
  - $15,000 fine

- August 2008, Comcast
  - Block Bittorrent packets
  - The FCC imposed no fine, but required Comcast to end such blocking in the year 2008.

- April 6, 2010, Comcast Vs. FCC
  - U.S. Court of Appeals ruled that the FCC has no powers to regulate any ISP.
Net Neutrality: Our Focus

- The content/application side of the two-sided market.
  - Classic example: night club

- Whether a neutral network is beneficial for end-users?
Netflix May Increase Your Internet Fees

Internet service providers across the country mull charging data hogs more, according to new report.

By Sajid Farooq | Thursday, Dec 1, 2011 | Updated 10:15 AM PDT

Netflix and other streaming services may end up causing Internet fees to rise in the U.S.
Network Neutrality (NN)

FREE PASS

Happy?
Paid Prioritization (PP)
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 $\lambda_i$

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

Content unconstrained throughput $\hat{\lambda}_i = \alpha_i M \hat{\theta}_i(=42\text{Kbps})$

Content popularity $\alpha_i(=60\%)$
Demand Function $D_i(\theta_i)$

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

achievable throughput $\hat{\theta}_i$

$\theta_i$
Demand Function $D_i(\theta_i)$

- **Assumption 1:** $D_i(\theta_i)$ is continuous and non-decreasing in $\theta_i$ with $D_i(\hat{\theta}_i) = 1$.
- More sensitive to throughput
- Throughput of CP $i$:
  \[ \lambda_i(\theta_i) = \alpha_i MD_i(\theta_i) \theta_i \]
System Side: Rate Allocation

- Rate allocation mechanism $\Theta(d, \mu)$ maps fixed demands and capacity to throughput

- **Axiom 1 (Throughput upper-bound)**
  \[
  \Theta_i(d, \mu) \leq \hat{\theta}_i
  \]

- **Axiom 2 (Work-conserving or Pareto Opt.)**
  \[
  \lambda_N(\Theta(d, \mu)) = \sum_{i \in N} \lambda_i(\Theta_i(d, \mu))
  = \min \left( \mu, \sum_{i \in N} \hat{\lambda}_i \right)
  \]
Rate Allocation $\Theta(d, \mu)$

- Axiom 3 (Consistency) There exists a family of continuous non-decreasing functions $\Theta(\gamma) = (\Theta_i(\gamma): i \in \mathcal{N})$ such that $\Theta(\gamma_1) \neq \Theta(\gamma_2)$, $\forall \gamma_1 \neq \gamma_2$.

For any $(d, \mu)$, there exists a $\gamma$ satisfying $\Theta(d, \mu) = \tilde{\Theta}(\gamma)$.
Uniqueness of Rate Equilibrium

\[(d^*, \vartheta) \text{ s.t. } d^* = D(\vartheta) \iff \vartheta = \Theta(d^*, \mu)\]

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 \(D_i: \theta_i \rightarrow d_i\)
Rate allocation \(\Theta: \{d_i: i \in \mathcal{N}\}, \mu \rightarrow \{\theta_i: i \in \mathcal{N}\}\)
\(\Rightarrow\) Rate equilibrium \(\{\vartheta_i, d_i^*: i \in \mathcal{N}\}\)
## ISP Paid Prioritization

### ISP Payoff:

\[ c \sum_{i \in \mathcal{P}} \lambda_i = c \lambda_p \]

<table>
<thead>
<tr>
<th></th>
<th>Capacity</th>
<th>Charge</th>
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<tbody>
<tr>
<td><strong>Premium Class</strong></td>
<td>( \kappa \mu )</td>
<td>$c/unit traffic</td>
</tr>
<tr>
<td>((M, \kappa \mu, \mathcal{P}))</td>
<td></td>
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<tr>
<td><strong>Ordinary Class</strong></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$^{st}$ stage, ISP chooses $s_I = (\kappa, c)$ announces $s_I$.
  - 2$^{nd}$ stage, CPs simultaneously choose service classes reach a joint decision $s_{\mathcal{N}} = (\mathcal{O}, \mathcal{P})$.

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

- **Consumer Surplus:** \( CS = \sum_{i \in \mathcal{N}} \phi_i \lambda_i \)
  - \( \phi_i \): 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 \( \mathcal{N} \)

> **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 \( s_N = (\emptyset, \mathcal{P}) \).

> **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 $\Psi$

$\Phi = \frac{CS}{\mu}$

$\Psi = \frac{IS}{\mu}$
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

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

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

$$\text{Profitability of CP } v_i$$

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 \( s_{\mathcal{N}}^I = (\mathcal{O}_I, \mathcal{P}_I) \)

- 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 $s_J = (0, 0)$

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:
  - Hands Off the Internet
  - Public Option
  - Network Neutrality
Regulatory Preference

ISP market structure

Oligopoly

Monopoly

User Utility

Network Neutrality

Hands Off the Internet

Public Option

Hands Off the Internet

Public Option

Network Neutrality

Hands Off the Internet

Public Option

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Network Neutrality

Hands Off the Internet

Public Option
Senator, what do you think about the public option?