Pricing Internet Access
-- How To Engineer Your Monthly Bill

Mung Chiang, Princeton University
Some 2010 (WSJ) Headlines

3rd UPDATE: Verizon Wireless To Unveil Tiered Data Plan Oct 28

FCC Unveils Billing Rules

AT&T Sees Hope on Web Rules
Executive Sees Positive Step in Google-Verizon Proposal on Broadband Regulation

AT&T Dials Up Limits on Web Data
New U.S. Push to Regulate Internet Access

Broadband Plan Faces Hurdles
What Your New Bill May Look Like

### Quick Bill Summary

<table>
<thead>
<tr>
<th></th>
<th>Sep 17 – Oct 16</th>
</tr>
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<tbody>
<tr>
<td>Previous Balance (see back for details)</td>
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**Total Charges Due by November 11, 2010**: $203.53

---

**Time of usage discount**: $69.88

**Usage price**: $50.99

---

**Guaranteed express delivery**

---

**Some of the 45 types of taxes I pay**

---

**Charges**

<table>
<thead>
<tr>
<th>Monthly Access Charges</th>
<th>80.00</th>
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<tbody>
<tr>
<td>AC Family SharePlan 1400 10/17 – 11/16</td>
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| Usage Charges                        |       |

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<th>SharePlan minutes</th>
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<td>1400 (shared)</td>
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Why

Pricing can lift the pressure valve off the Internet traffic explosion
Issues at Stake
1. Four Questions of Pricing

- **What** to Charge?
- **Whom** to Charge?
- **How much** to Charge?
- **How** to Charge?
2. Universal Coverage

- FCC National Broadband Plan
  - How to improve *reach and speed* of US broadband access?
  - Who’s going to pay the $350B bill?
    - Consumer?
    - Taxpayer?
    - Others?
3. Network Neutrality

- **Different Definitions:**
  - Access/choice ✔
  - Competition/No monopoly ✔
  - Equality/No discrimination ✗

- **Tough Issues:**
  - Efficiency-fairness tradeoffs in parties with conflicting interests
  - Incentives for innovation and consumer experience
Colors of Neutrality

- Red: vertical integration and service limitation ✗
- Orange: protocol/user-ID based discrimination ✓
- Yellow: usage-based pricing ✓
- Green: traffic management and QoS provisioning ✓

Roles of government?

- Enable viable competition, or ✓
- Regulatory micro-management? ✗
4. ISPs Two Problems

- **Profit margin**
- **Commoditization**

**ISP Value Generation**
- Telecom and Internet applications and services
- Transport (operations at massive scale)
- Infrastructure (traditional communications research)

**Distribution**
- Revenue
- Cost

**Bandwidth consumption**
New Business Models for ISPs

- Avoid commoditization
- Offer value-added services beyond connectivity service
- Bridge content-pipe divide
  - Need a new interface between ISP and content/app providers
- Innovate pricing
  - Pricing as Network Management (if timescales match)
Nature of This Talk

- Not on specific model/analytic/numerical results
- Not an exhaustive overview of pricing literature
- Not on non-access Internet pricing or general network economics
- A biased path traversing vertices of the problem space
- And samples challenges facing the research community
Two-Way Interactions: Subject

- Pricing changes technology
- Video ads in support of cheap app/content
- Technology changes pricing
- Heterogeneous wireless platforms
Two Way Interactions: Method

- Engineering research benefits from economics research
- 2-sided, utility model, game, auction, etc.
- Economics research benefits from engineering research
- Dynamically varying interaction model
Sample Scenarios
5-Party Interactions

- Vendors
- Transportation Operator
- Distribution Operator
- Content/App Consumer
- Content/App Producer
Basic Benchmark

Cost recovery via median-user, 1-sided pricing is challenging
Cost Recovery

The Potential of 2-sided pricing
Adding Server by ISP

Localization of traffic
Impact on middle mile cost recovery
Distribution by CDN

CDN contract and net cost reduction
How to charge between CDN and ISP
Distribution by P2P

P2P dynamically changes traffic distribution
Video Multicasting

The challenges of scaling up multicast streaming
Regulatory issue of bundling
Heterogeneous wireless networks co-existing
Much more complicated ownership issues
The Four Questions
Q1. How Much to Charge?

- From **flat rate** to **usage based** (often monthly volume)
  - Tiered-pricing
  - Piecewise-linear pricing curves
    - Control flat-rate part or slope of usage-based part

- Flat rate inefficient (e.g., Berkeley INDEX experiment 1998)
- Why did it prevail for so long: attract eyeballs AND
Time for Usage-Based Pricing

Bandwidth demand

Bandwidth supply / $

time
A Typical Pricing Graph
A Sample of Utility Model

\[ U_i(x) = \sigma_i U_{\alpha_i}(x) \]

utility level

1/elasticity

\( x \) depends on
flow and time

\[ U_\alpha(x) = \frac{x^{1-\alpha}}{1-\alpha}, \quad \alpha \neq 1 \]

\[ = \log x, \quad \alpha = 1 \]
Unconstrained Revenue Max.

* Maximize revenue under **hard capacity constraint**
  * Flat rate / Usage fee: \( \frac{\alpha}{1 - \alpha} \)
  * Maximize **revenue-capacity cost tradeoff**
Constrained Across Flows

- **Quantify** revenue loss from uniform pricing across flows
  - More loss if consumer demand is less elastic
  - Nonlinear pricing (discount at higher rate) mitigates the loss
  - From first to second degree price discrimination
Constrained Over Time

Usage fee depends on traffic volume over a fixed period

Ratio of constrained to unconstrained revenue

$$\frac{\sum_t \left( \frac{\sigma_t}{\sigma^m} \right)^{1/\alpha}}{\sum_t \frac{\sigma_t}{\sigma^m}}$$

Highly inefficient if utility level has large time spread (later) or high elasticity and no QoS degradation allowed
Two Ways Out

- Set price high -> No congestion -> Revenue loss
- Set price low -> Overfill capacity -> QoS degrades

- How much? What’s the tradeoff?

- Set price high -> No congestion -> Sell leftover capacity (later)
Impact of Timescale

Tight timescale QoS protection -> More revenue loss
Impact of Elasticity

Less elastic demand -> Sweeter revenue-QoS tradeoff
Importance of Flat Price

Ratio of usage price in total revenue drops to a constant as QoS requirement loosens
The constant fraction is less as elasticity decreases
Q2. How to Charge?

✴ Next step: Time dependent pricing

✴ Extension: Congestion dependent pricing

✴ **Time-series shaper**: from current 24-hour curve to desired shape

✴ Bring “tail” and “mean” (on time axis) closer

✴ How to make it “work”?

✴ Compare with current practice of binary time-dependent pricing

✴ Compare with time-of-usage pricing in utility industry
Key Factors

✶ ISP’s perspective: balance two costs
  ✶ Cost of worst-case capacity provisioning (capital expenditure)
  ✶ Cost of “rewarding” users willing to shift their traffic (recurring)

✶ User’s perspective:
  ✶ “Time elasticity” depends on time sensitivity of traffic
  ✶ And user’s patience level

✶ How to incorporate user elasticities and optimize price efficiently?
The electricity industry has been developing TDP over the past several years, as reflected in Table I’s summary of existing literature. The motivation for moving away from flat rate pricing is driven by the need to reduce the demand for bandwidth during peak times. TDP can help, either by incentivizing usage to be spread evenly over times of the day, or by actually reducing usage at peak periods. This is especially important for Internet service providers (ISPs) practicing flat rate pricing, who face a dilemma: unlike its cost, ISP revenue does not scale with consumption. The market’s model of users choosing the period in which to use Internet service providers is based on minimizing estimated costs. This pricing model is not flexible enough, as for ISPs. This difference requires modeling arrival and departure of application sessions in our dynamic model.

Previous models use the simplified “representative demand function” to estimate resource demand at peak and off-peak times, while we develop detailed models directly from large-scale data. Some symmetry, and that changing prices based on real-time demand a resource. The following summarizes some key differences compared to prior work:

- LOLM’s model of users choosing the period in which to use Internet service providers in order to minimize estimated costs.
- TDP as users learn to defer part of their Internet usage, rather than the electricity industry’s model where Internet service providers adjust prices based on actual usage.
- LOLM’s model is based on one month of data, while the dynamic model used here incorporates a more realistic representation of user behavior.

To make TDP work well, research on traffic congestion is needed. We also model TDP as users learn to defer part of their Internet usage, rather than the electricity industry’s model where Internet service providers adjust prices based on actual usage.

The methodology in this paper provides a way to quantify the impact of time-dependent pricing based on these factors. The components of the system are illustrated in the following figure.

- **Network Management (estimate user behavior)**
- **Profiling (estimate algorithm parameters)**
- **Price Determination**
- **User Interface (offer users rewards)**
- **User Response (users react to rewards)**

The system includes modules for estimating user behavior, profiling algorithm parameters, determining prices, and offering users rewards. The interface between steps A and B is also shown, as well as step in the control loop.
Some Challenges

- General number of time slots (e.g., 48)
- User patience function \( w(p(\tau), \tau) \) rather than “representative demand function” per time slot
- Arrival and departure dynamics

- Search for an representation leading to efficient computation
- Turns out to be possible
Levelling in Action
Impact of Congestion Definition

Heavier emphasis on congestion alleviation leads to more levelling. Eventually saturates at a level determined by user elasticities.
Q3. Whom to Charge?

- Two sided pricing
- Extreme case: 1-800 service of free Internet access
- CP interest: Elasticity-cost points just right for volume play
Key Factors

- EU: utility maximization (of rate, volume, etc)
- CP: utility maximization
- ISP: max (revenue - bandwidth cost)
  - Competitive or monopoly ISP
- Examine equilibrium behaviors
  - Single ISP
  - Inter-connected multiple ISPs
An Example

<table>
<thead>
<tr>
<th>$b_f$</th>
<th>ISP Competition</th>
<th></th>
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<tbody>
<tr>
<td></td>
<td>EU Price</td>
<td>EU Demand</td>
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<td>EU Price</td>
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<tr>
<td>0</td>
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<td>$6</td>
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<td>20</td>
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<td>2.0 Mbps</td>
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<td>80</td>
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<tr>
<td>100</td>
<td>$17</td>
<td>9.0 Mbps</td>
<td>1.05</td>
<td>$26</td>
</tr>
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CP utility level (or elasticity) increases, EU pays less and demands more
When Will CP See Benefit?

Under ISP competition and low enough CP elasticity, CP gains a lot
Model net neutrality via CP price restriction

Monopology ISP Case

Relax the price restriction -> Impact on surplus and its distribution
Charging CP (1) increases EU surplus
(2) leaves ISP surplus the same
(3) increases CP surplus if EU elasticity high compared to connectivity cost
Inter-ISP Pricing

Biased position on traffic delivery chain

Cooperative:
Revenue sharing contract: dominant ISP asks for transit price lower than marginal traffic delivery cost, plus lump-sum sharing of other ISP revenue

Non-cooperative:
Quantify lost social revenue
Asymmetric NBS to improve both ISPs
Non-cooperative and Bargaining

Stackelberg model: EU-facing ISP is the leader

Example of asymmetric bargaining converging to global optimum
Q4. What to Charge?

- Different services -> Different prices

- New service types:
  - Package service
  - User-specific service
  - Emergency service
New Connectivity Services

- Create new class of services: Scavenger class of service

- Fill in the leftover capacity. Particularly helpful for wireless

- Minimum utility level needed to recover revenue loss due to constraint over time

- $5/month data plans

- No guarantee on near-instantaneous access

- Precise QoS depends on how crowded $5/month plan users are
Paris Metro Pricing

- Differential prices -> Differential services
  - Origin: Odlyzko 2000...
  - Survey: Walrand 2008...
  - Recent development: Chiu Lui et al. 2010...
Pricing Across Hetero Wireless

- Co-existence of multiple wireless platforms owned by different ISPs:
  - 3G/4G, Femto, WiFi

- **Price bundling**: pricing for stickiness

- **Price differentiation**: offload licensed band congestion

- Interaction with interference management on technological plane

- Mobility and hand-off support

- May enable the dissolution of cellular industry’s vertical mode
From Theory To Practice
Model/Analysis is Only 1 Step

- Data, Data, Data
- Prototyping proof-of-concept
- Field trial and industry adoption
- Public education and policy impact
- NECA-EDGE Lab whitepaper June 2010
TUBE

- Time-dependent Usage-based Broadband-price Engineering

- Measurement

- Price optimization engine

- User interface

- User profiling

- Recommendation

- Wireless extension
TUBE Architecture

- Android Device
  - Price and Usage
- TUBE Gateway
  - Price update/hr
  - Usage Sync
- Optimization Engine
- Measurement Engine
- ISP Server
TUBE Architecture
TUBE UI
TUBE UI

Preferences
- Notify when the usage reaches [ ]% of the monthly cap
- Allow following applications from [ ] AM/PM to [ ] PM

Auto Pilot Preferences
- Applications require immediate access to the Internet
  - HTTP
  - HTTPS
  - Skype
  - Google Voice
- Applications do not require immediate access to the Internet
  - P2P Apps
  - Windows Update
  - UDP

Apply
Auto Pilot
TUBE UI

Current Day Throughput

<table>
<thead>
<tr>
<th>Time</th>
<th>Throughput</th>
<th>Max: 65.9</th>
<th>Avg: 54.5</th>
<th>Last: 54.4</th>
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<tr>
<td>Thu 10:00</td>
<td>Green</td>
<td></td>
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<tr>
<td>Fri 00:00</td>
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<tr>
<td>Fri 06:00</td>
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<td>Fri 12:00</td>
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Price

- Red
- Orange
- Yellow
TUBE UI

Protocol Distribution

Application Distribution
Data Collection and Analysis

- Utility Function/Demand Function/Elasticity construction from empirical data and proxies
- Different speed tiers/service offerings impact elasticity a lot
- Substantial statistical challenges

- NECA-Princeton Surveys and Polls to ISPs
Partners

• Data sources and deployment outlets:
  • NECA
  • AT&T
  • Small ISPs
  • Princeton trial user base
Acknowledgements

- Sangtae Ha, Carlee Joe-Wong (Princeton)
- Rob Calderbank, Prashanth Hande, Hongseok Kim (Formerly P)
- Raj Savoor, Steve Sposato and group (AT&T)
- Victor Glass and group (NECA)
- Junshan Zhang (ASU)
- Yuan Wu, Danny Tsang (HKUST)
What We Need (Most)
Challenges in Access Pricing Study

- Model/theory on
  - User profiling: utility and irrationality
  - ISP cost and cooperation/competition in inter-ISP scenarios
- Theory falsification by data
  - Start with falsifiable theory
- Market impact by deployment
  - Start with small user base trials
Your Research Changes Your Bill

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Some of the 45 types of taxes I pay

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Taxes, Governmental Surcharges and Fees

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Wireless Interference Management: From Theorems To Deployments

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January 21, 2010

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