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TSIN02 Internetworking

Lecture 6 – Network economics

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Literature

- Networked life: 20 Questions and Answers, Mung Chiang

- Materials for this lecture are taken from:

  Chapter 11: Why do AT&T and Verizon Wireless charge me $10 a GB?

  Chapter 12: How can I pay less for my Internet connection?

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Outline

- Background to today's pricing situation in wireless access
- Utility and demand functions, mathematical description
- Arguments for usage-based rate
- Smart data pricing, focusing on time dependent pricing
- Schematic of time dependent pricing
- Waiting function, price optimization

The Driving Forces for Capacity Demand

- Device features and resolution: AT&T experienced 50 times increase in mobile data demand just in a month after the introduction of iPhone I in 2007.
- LTE speed: LTE has higher throughput than 3G and GSM.
- Video: 65-80 % of the Internet traffic.
- Cloud services: incur a lot of data usage.
- Capacity-hungry apps: half a million apps with an increasing number of them are capacity-hungry.

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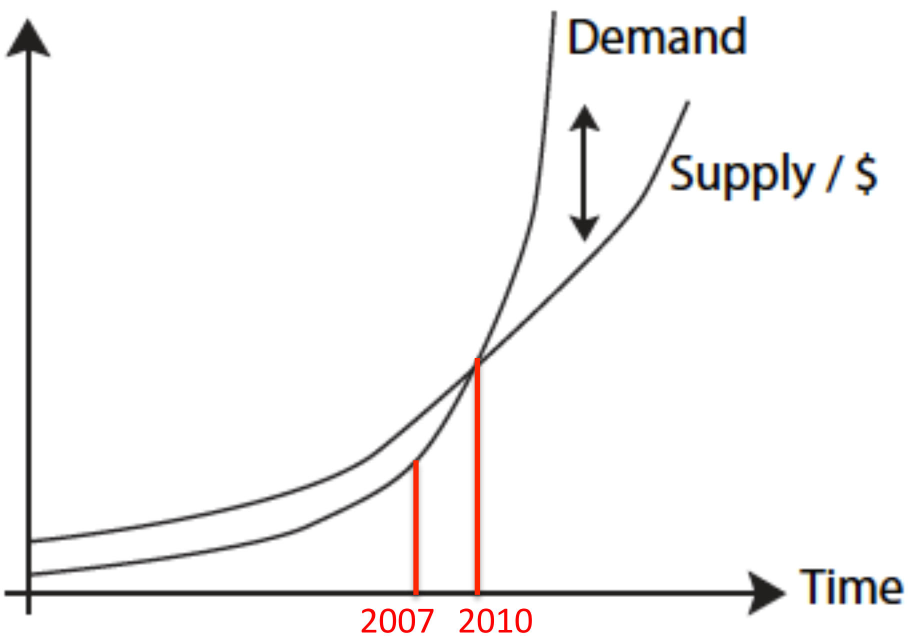
Data Pricing in the US Market

- Flat rate: unlimited traffic, before 2010
- **Why flat rate?**
  - Simple to provide in terms of bidding services
  - Simple to explain to the consumers
  - Increasing demand
  - Capturing market share
  - Demand < Supply/$
- Usage-based after 2010: **Demand > Supply/$**

Why Change From Flat to Usage-Based?

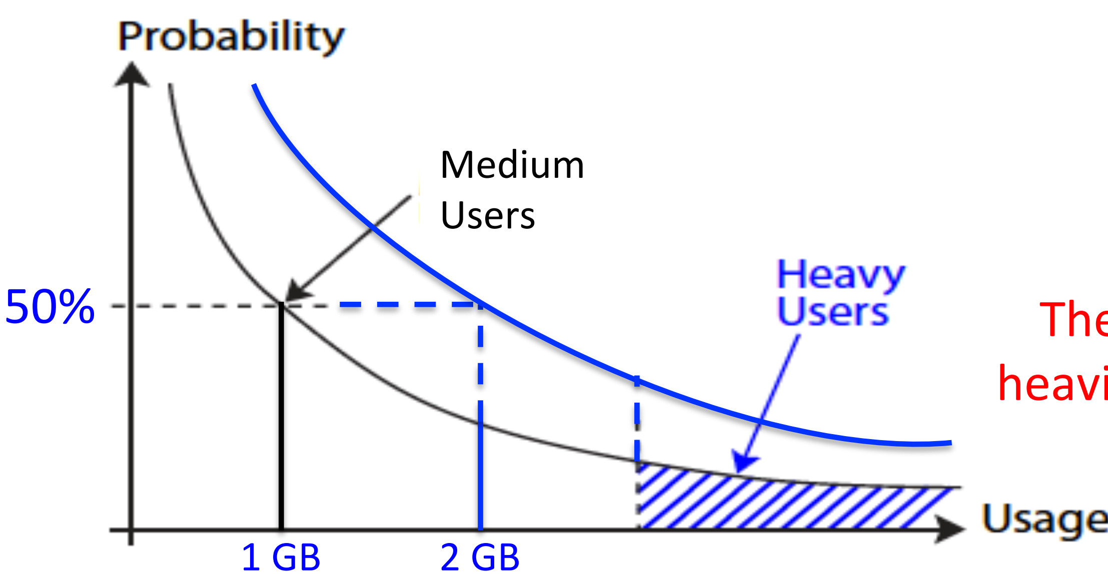
- The introduction of iPhone not only changed forever the software and computer industry but also the communication and networking industry.
- iPhone increased demand and twisted the shape of demand curve projected over the years.



Job's inequality of capacity
$D'(t) \gg S'(t)$

Why Change From Flat to Usage-Based?

- The projected distribution curve will move to the right over the years, which means that medium users will also consume more.
- The <u>cost structure</u> of the ISP's is **driven by the heavy users**, i.e. the long tail of the distribution.
- If the cost of ISP's is driven by heavy users and the revenue does not grow with them, then ISP's have problem.



Probability distribution of usage

The tail is getting longer and heavier with time to the carriers

What are the Options?

- Raise price: increase the flat rate for everyone as demand increases.
- Cap heavy user's traffic: restrict users beyond certain consumption limits.
- Usage-based: charge based on actual use.
- Throttle: volume is unlimited, but speed will be lower as user consume more.
- Offload: from a congested network to a less congested network, e.g. from 3G to Wi-Fi.
- **Smart data pricing** (will discuss in the second part of the lecture)

What are the Considerations?

- Economic viability: if the carriers don't see healthy enough profit margin and revenue amount then, they'll no longer offer services.
- Consumer choice: give consumers the ability to choose among carriers, among service plans, and among their digital lifestyles.
- Fairness: it's not fair that light users subsidize heavy users. Why should light users be paying for heavy users?

Utility Function

- The Utility function is a common modeling tool in economics to capture "how happy/satisfy" a user would be if a certain amount of resource is allocated to the user.
- Total Utility: aggregate sum of satisfaction or benefit that an individual gains from consuming a given amount of goods or services.
- Marginal Utility: additional satisfaction, or amount of utility gained from each extra unit of consumption.

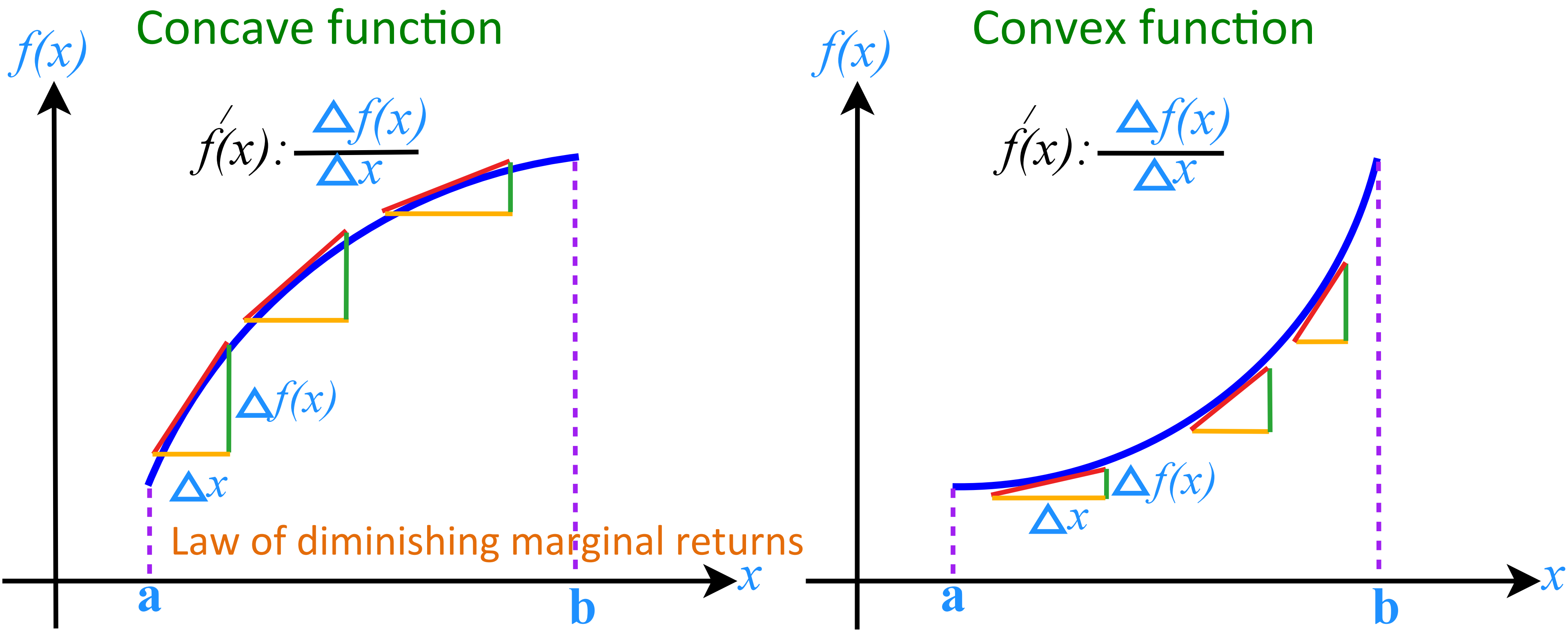
Utility Function
Eating Chocolate bar

- Your marginal Utility (and total Utility) after eating one chocolate bar will be quite high.
- If you eat more bars, the pleasure of each additional bar will be less than the pleasure you received from eating the one before. Law of diminishing marginal Utility

Chocolate Bars Eaten	Marginal Chocolate Utility	Total Chocolate Utility
0	0	0
1	70	70
2	10	80
3	5	85
4	3	88

Source: www.investopedia.com/university/economics/economics5.asp

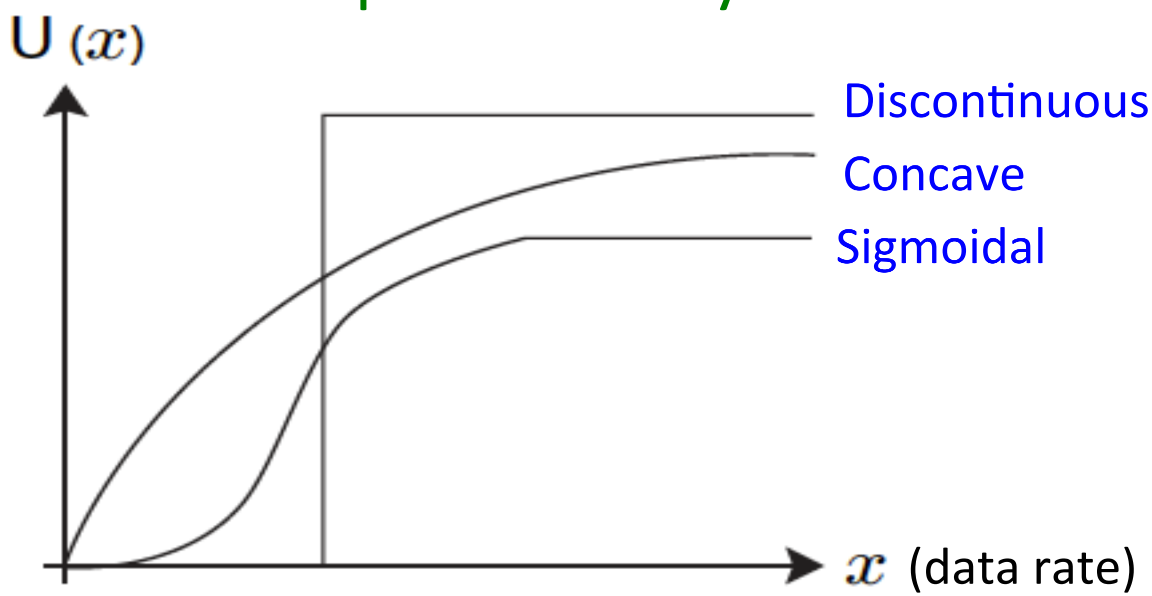
Concave & Convex Functions



- $f(x)$ is strictly **concave** on (a,b) if $f'(x)$ is decreasing on (a,b), i.e., $\boldsymbol{f''(x)<0}$
- $f(x)$ is strictly **convex** on (a,b) if $f'(x)$ is increasing on (a,b) , i.e., $\boldsymbol{f''(x)>0}$

Utility Function for Different Users

Example for utility function



Utility functions in this lecture are:

- Single variable and smooth (continue).
- Increasing: first derivate is positive (**U'(*x*) >0**).
- Concave: the second derivate is negative or zero (**U''(*x*)≤0**); the rate with which the users become happier will be going down as the argument becomes bigger.

How to Compute Utility Function?

- Run an experiment: with real human beings in a focus group study using mean opinion score (MOS).

- Demand function: Utility function and Demand function in some sense are two sides of the same coin. The Utility function can be reverse engineered from the Demand function.

Net utility: $U(x) - px$

Maximize the net utility over user choice.

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How to Compute Utility Function?

Net utility maximization function: **max** [$U(x) - p\,x$] over x

If $U(x)$ is a smooth, increasing, and concave function, then this is a concave maximization problem.

$$U'(x) - p = 0 \Rightarrow U'(x) = p$$

$$U'(x) = p \Rightarrow x = U'^{-1}(p)$$

$$D(p) = U'^{-1}(p)$$

$U(x)$ first derivative is invertible and decreasing function

If a particular x (let say x^*) satisfies the above equation, then x^* is the resulting demand as a function of price p.

U'^{-1} is the Demand function D, thus, the Utility function can be reverse engineered from the Demand function.

Three Argument why Usage-Based Pricing

Argument 1: Flat rate pricing leads to less net utility

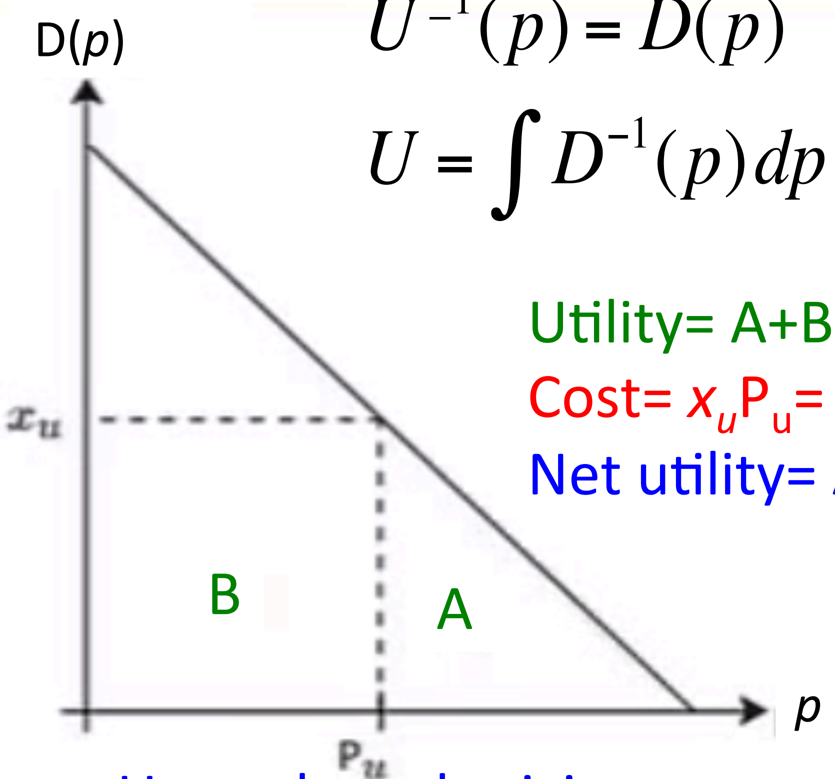
Net utility = Utility – Cost

Remember

$$D(p) = U'^{-1}(p)$$

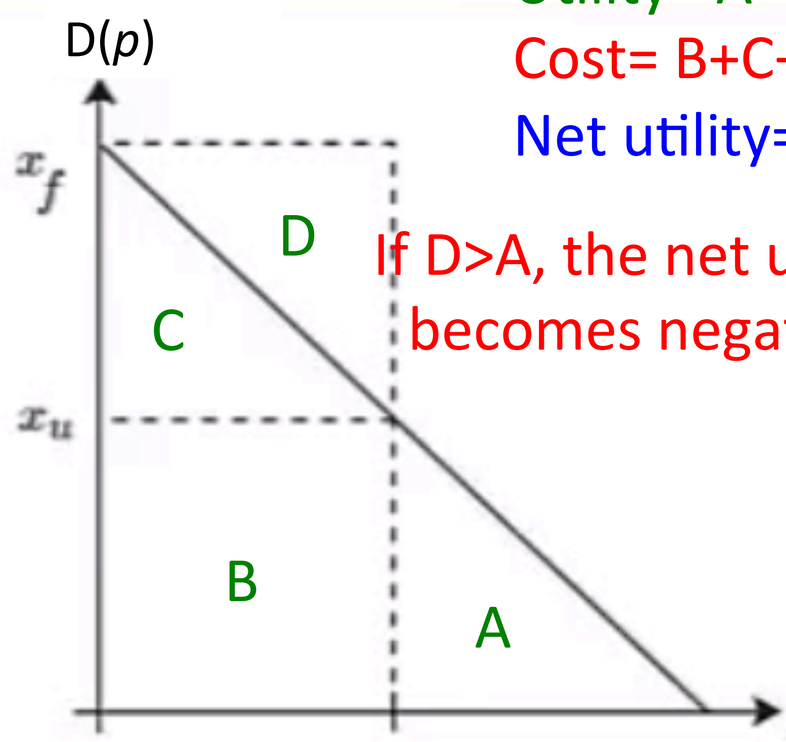
$$U'^{-1}(p) = D(p)$$

$$U = \int D^{-1}(p)\,dp$$



Utility= A+B
Cost= $x_u P_u$= B
Net utility= A

Usage-based pricing



Utility= A+B+C
Cost= B+C+D
Net utility= A-D

If D>A, the net utility becomes negative

Flat rate

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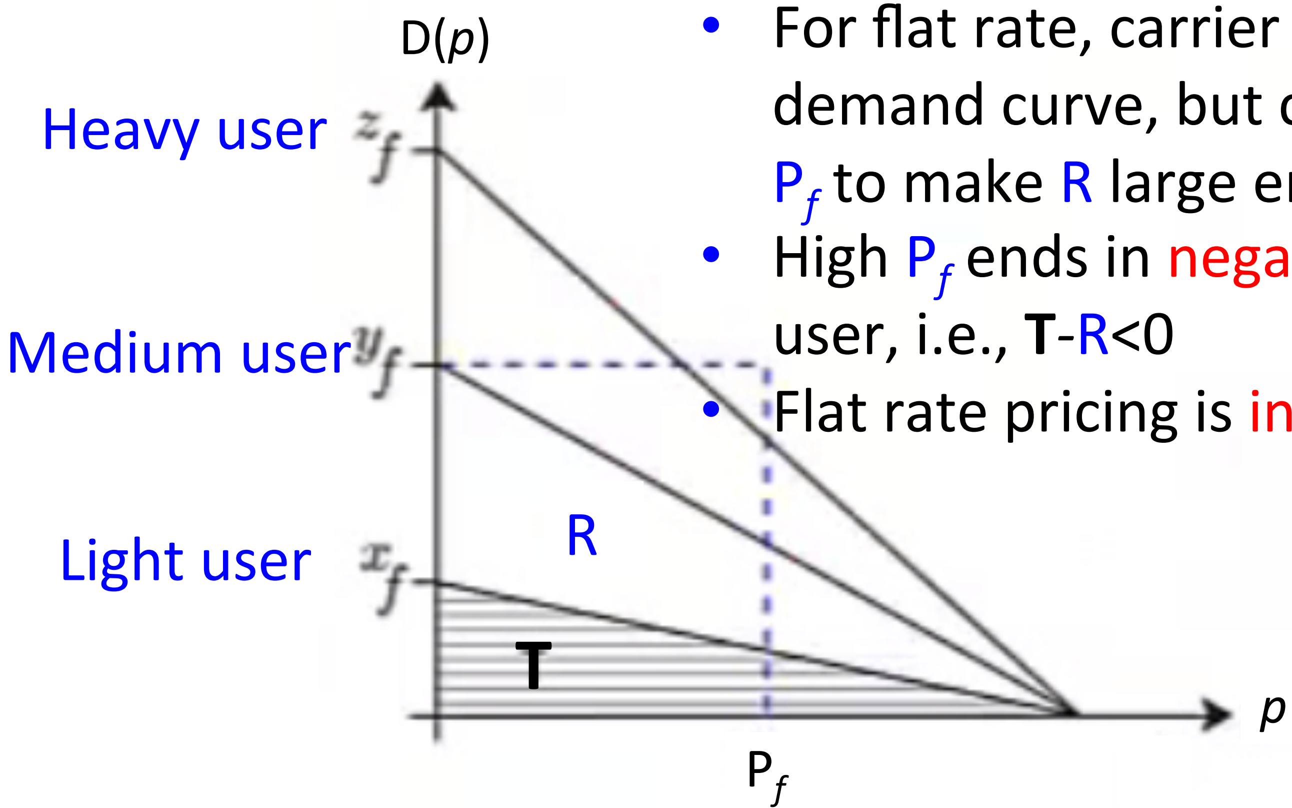
Three Arguments why Usage-Based Pricing

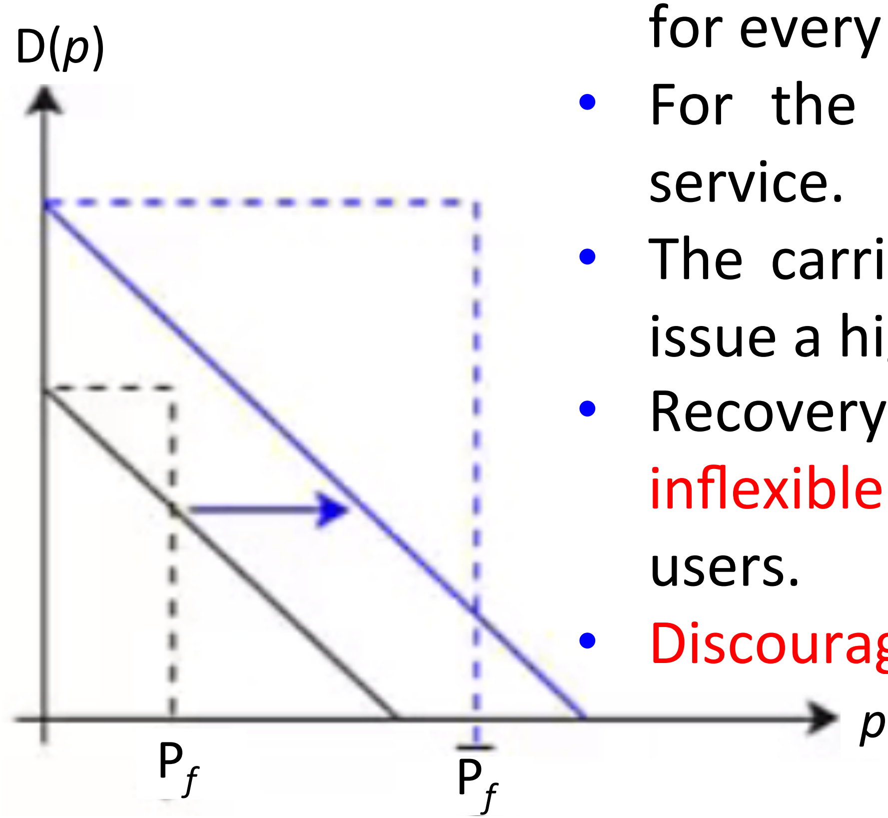
Argument 2: Light users subsidize heavy users in flat rate

- Heavy user has high demand curve for the same price
- Area R (revenue) needs to be large enough
- For flat rate, carrier cannot control the demand curve, but can increase the price P_f to make R large enough
- High P_f ends in negative net utility for light user, i.e., **T**-R<0
- Flat rate pricing is inflexible



Three Arguments why Usage-Based Pricing

Argument 3: The net utility for the light users shrinks with service upgrading



- Service upgrading shifts the demand curve for every user to the right.
- For the same price, the users get better service.
- The carrier pays more to upgrade and thus issue a higher price to recover the cost.
- Recovery cost through a single flat price is inflexible and shrink net utility for the light users.
- Discourage service upgrade in some cases.

Usage Based Pricing

Summary

- Less waste.
- No subsidy for heavy users from light users.
- Differentiate quality of service.

Smart Data Pricing (SDP)

- Hourly based: instead of how much, it looks at how long.
- Priority pricing: a different class of quality and service.
- Two-sided pricing: ISP charges both the content consumers and the content producers.
- Application dependent pricing: applications occupying a lot of capacity may be charged more.
- Congestion dependent pricing:

  Location dependent

  Time dependent

Time Dependent Pricing (TDP)

- Not just how much the user consumes, but also **when**
- **Leverages:**

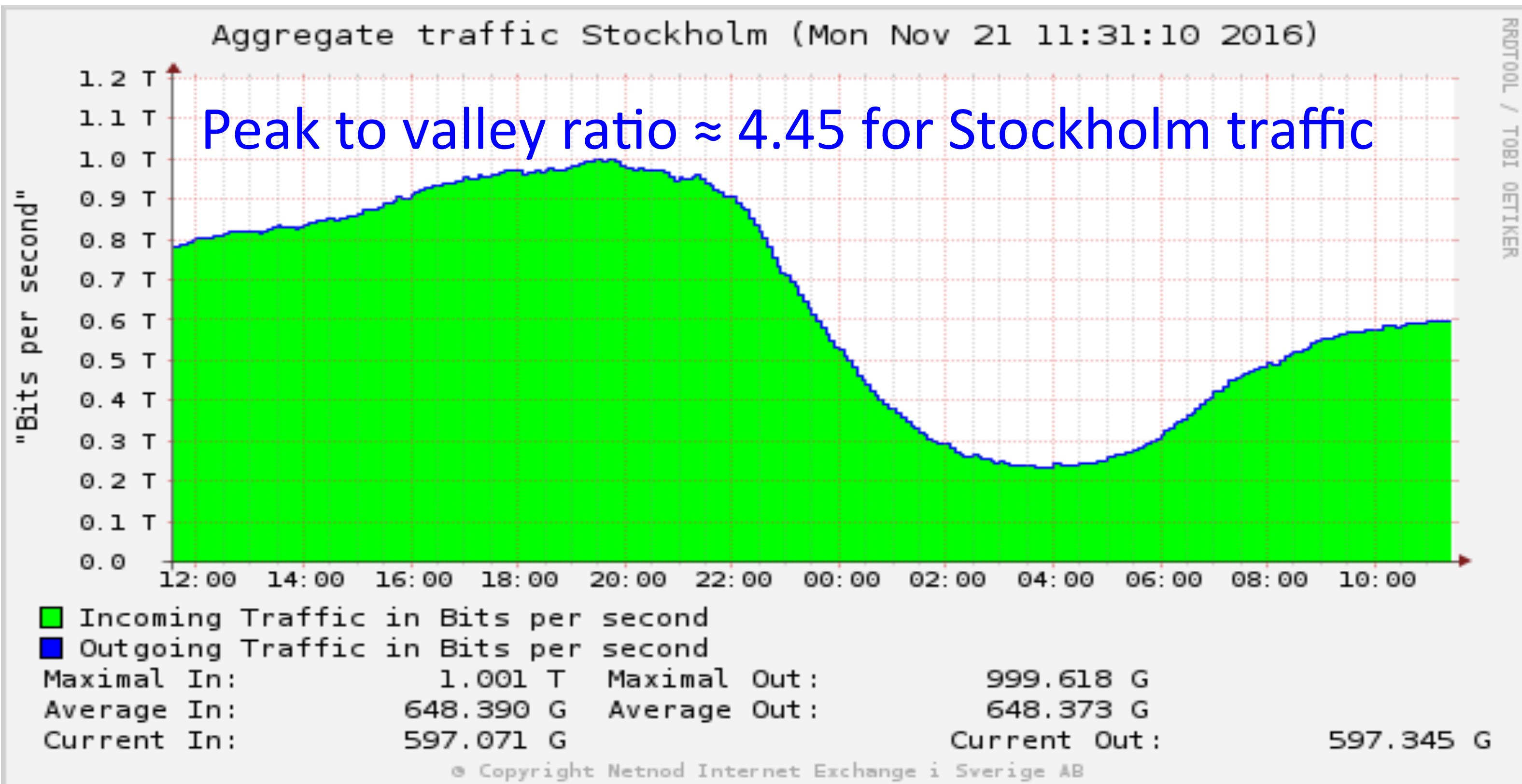
  The big differential between the peak traffic demand and valley traffic demand.

  Dump some of the peak traffic into the valley

  Delay tolerance: large dynamic range.

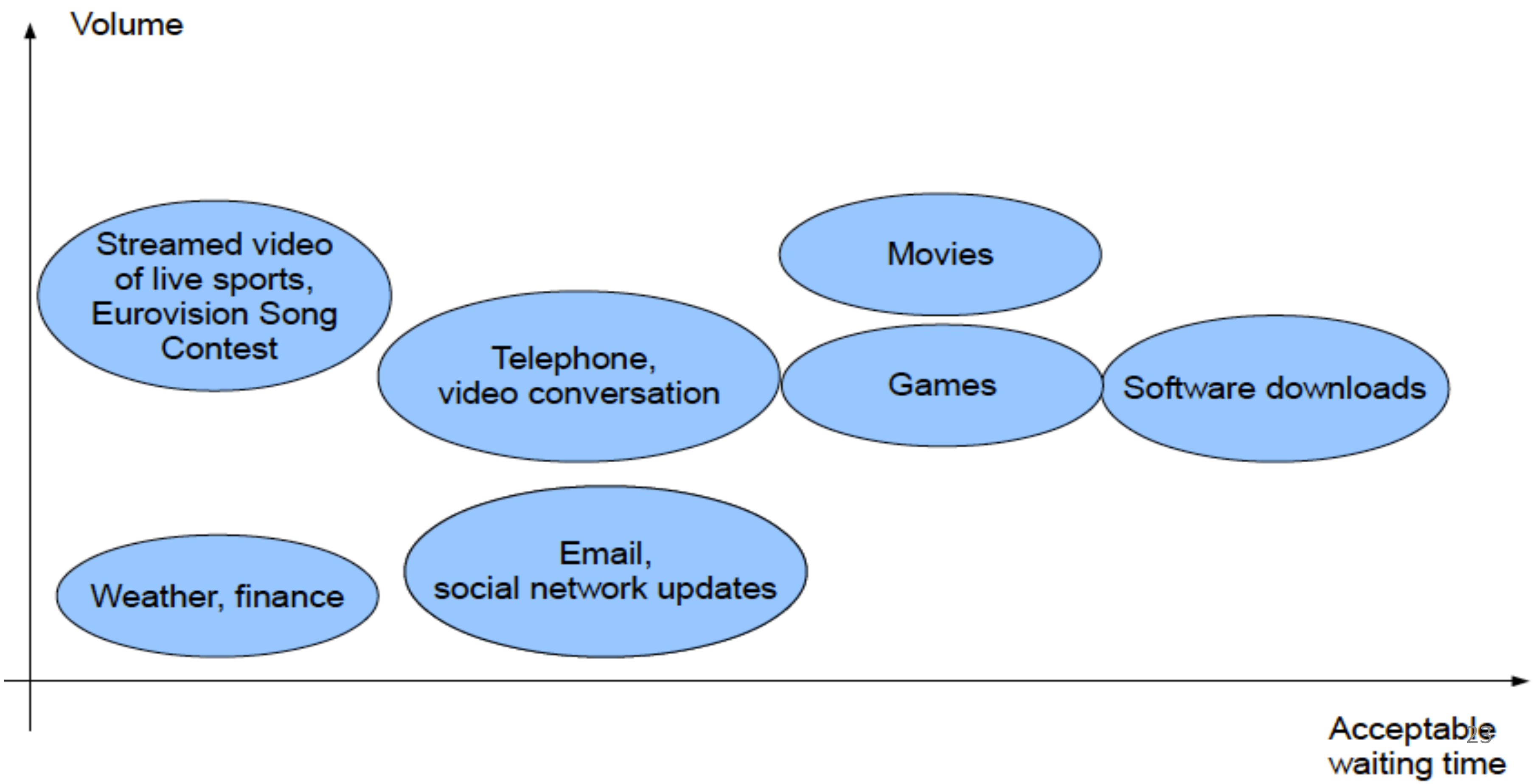
Netnod Statistics

The Sweden-based non-profit organization, which manage one of the 13 DNS root name servers in the world.



Delay Tolerance

Different applications have different delay tolerance, which varies from minutes to several hours.



Time Dependent Pricing (TDP)

- Not just how much the user consumes, but also **when**
- **Leverages:**

  The big differential between the peak traffic demand and valley traffic demand.

  Delay tolerance: large dynamic range.

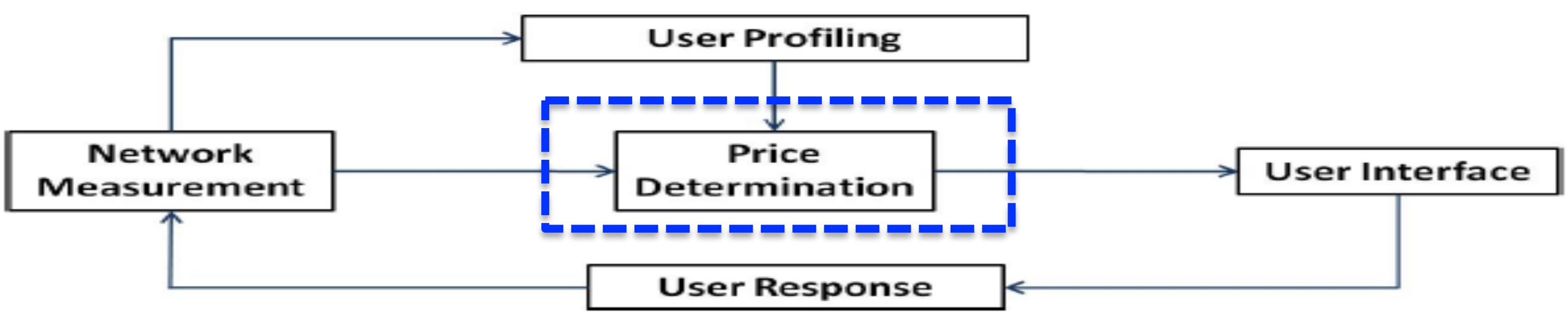
- Challenges

The effectiveness of TDP in any context depends on a ratio, i.e. the ratio between delay sensitivity (or delay tolerance) and demand elasticity (or pricing sensitivity); **how to compute this ratio?**

Hide the complexity from the customers; make it simple and sweet; build a nice user interface.

Schematic of Time Dependent Pricing

- Price determination requires to solve some large scale optimization problem.
- Price determination depends on the reaction expected from the customers, which can be predicted from the user profiling engine.
- The prices are announced through some kind of a user interface.
- The user response through network measurement will partly be stored in the user handset and partly into the network database own by the ISP's.
- The user profiling will then learn from such database.



Feedback loop

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Waiting Function

- Waiting function ***W(t,p)*** measures the user willingness to wait ***t*** amount of time for a given reward ***p***.
- Different network users and applications can be grouped based on their waiting function.
- A simple waiting function $W(t,p) = \frac{p}{(t+1)^{\beta}}$, β≥0, large β means less willingness for waiting.
- Based on the survey in the US, **β** is **2.027** for **YouTube streaming** and **0.6355** for **video downloading from iTunes**.

- Can be used as user profiling and for price determination engine.

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Price Optimization Engine

- Price can be viewed as incentive or reduction (in price) or reward of credit in consumer monthly bill.
- Price should be computed through an optimization problem.

What kind of optimization?

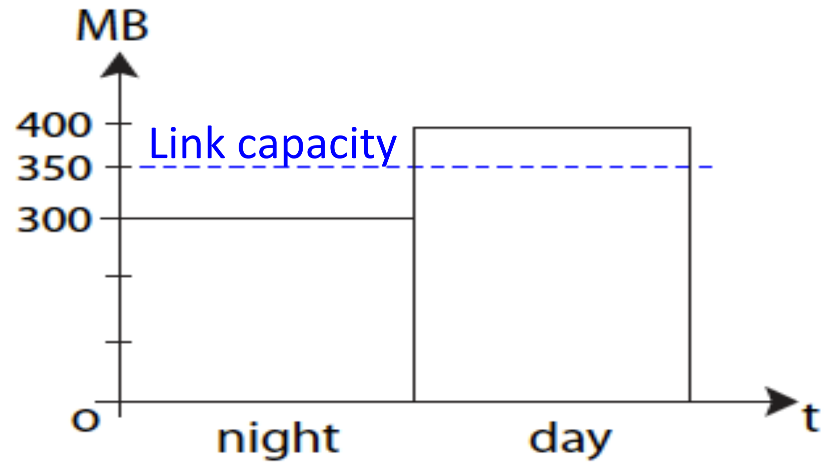
Objective: a.(exceeding capacity) + (rewards)   a: weighting parameter

Constraints: maintain a proper accounting of the traffic for each given period.

Variables: price, rewards.

Example 12.3.2 (From the Book)

	Night	Day
Email	200 MB	200 MB
File Downloads	100 MB	200 MB



	Shift to Night	Shift to Day
Email	$\frac{p_n}{4}$ probability, $200\frac{p_n}{4}$ shifted	$\frac{p_d}{4}$ probability, $200\frac{p_d}{4}$ shifted
File Downloads	$\frac{p_n}{2}$ probability, $200\frac{p_n}{2}$ shifted	$\frac{p_d}{2}$ probability, $100\frac{p_d}{2}$ shifted

Probability of shifting and expected amount of shifted traffic to the day or night

Cost of offering rewards: $$p_n(200\frac{p_n}{4}+200\frac{p_n}{2})+p_d(200\frac{p_d}{4}+100\frac{p_d}{2})$$
$$=150p_n^2+100p_d^2$$

Example 12.3.2 (From the Book)

Amount of traffic shifted into the night: $200\frac{p_n}{4}+200\frac{p_n}{2}=150p_n$

Amount of traffic shifted from night into the day: $200\frac{p_d}{4}+100\frac{p_d}{2}=100p_d$

Amount of traffic during the night under TDP: $300+150p_n-100p_d$

Cost of exceeding capacity during the night: $\max\{0,300+150p_n-100p_d-350\}$
$=\max\{0,-50+150p_n-100p_d\}$

Cost of exceeding capacity during the day: $\max\{0,50-150p_n+100p_d\}$

Objective function:

minimize $150p_n^2+100p_d^2+\max\{0,-50+150p_n-100p_d\}+\max\{0,50-150p_n+100p_d\}$

Princeton Trial of TDP in 2012

- 30% reduction in peak average ratio.
- 107% increase in average usage amount.
- Chopping peaks while raising the sea level.