Economic Aspects of Content Distribution in Internet

Presentation of Award – Winning Dissertation
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Presentation Outline

- Problem Description

- Solutions Proposed - Applied

- Business Models

- Economic Dimension - Incentive Mechanisms

Problem Description

◆ Challenges

- Broadband Internet Access Technologies (Cable & DSL modems)
- Supply of rich in content dynamic pages and whole applications over Web
- Reliable delivery of streaming content.

◆ Obstacles

- Bandwidth Scarcity
  ➢ High Transmission Costs
- Overloading of central content servers
  ➢ Delays in creating and delivering dynamic content
- Congestion in Network Backbone and Routers
  ➢ Response delay, Content unavailability

➢ Significant End-user response time increment

Solutions Proposed - Applied

◆ Caching Storage Nodes Deployment at "network edge" near to end users:

- Reduction of Content Requests to Origin Servers
- Reduction of No of packets transmitting in Backbone
- Reduction of end-user time delay.

◆ **Full Replicas (mirrors) deployment**
  ▪ Static content replication from one provider

◆ **Client – Side Caching**
  ▪ Demand – Based Dynamic Storage of popular content in shared caches (caches)

◆ **Content Distribution Networks (CDN)**
  ▪ Virtual Overlay Network of Caches under the supervision of one entity (content distributor).
  ▪ Proactive replication of content – Intelligent Redirection of End Users to optimal storage nodes.
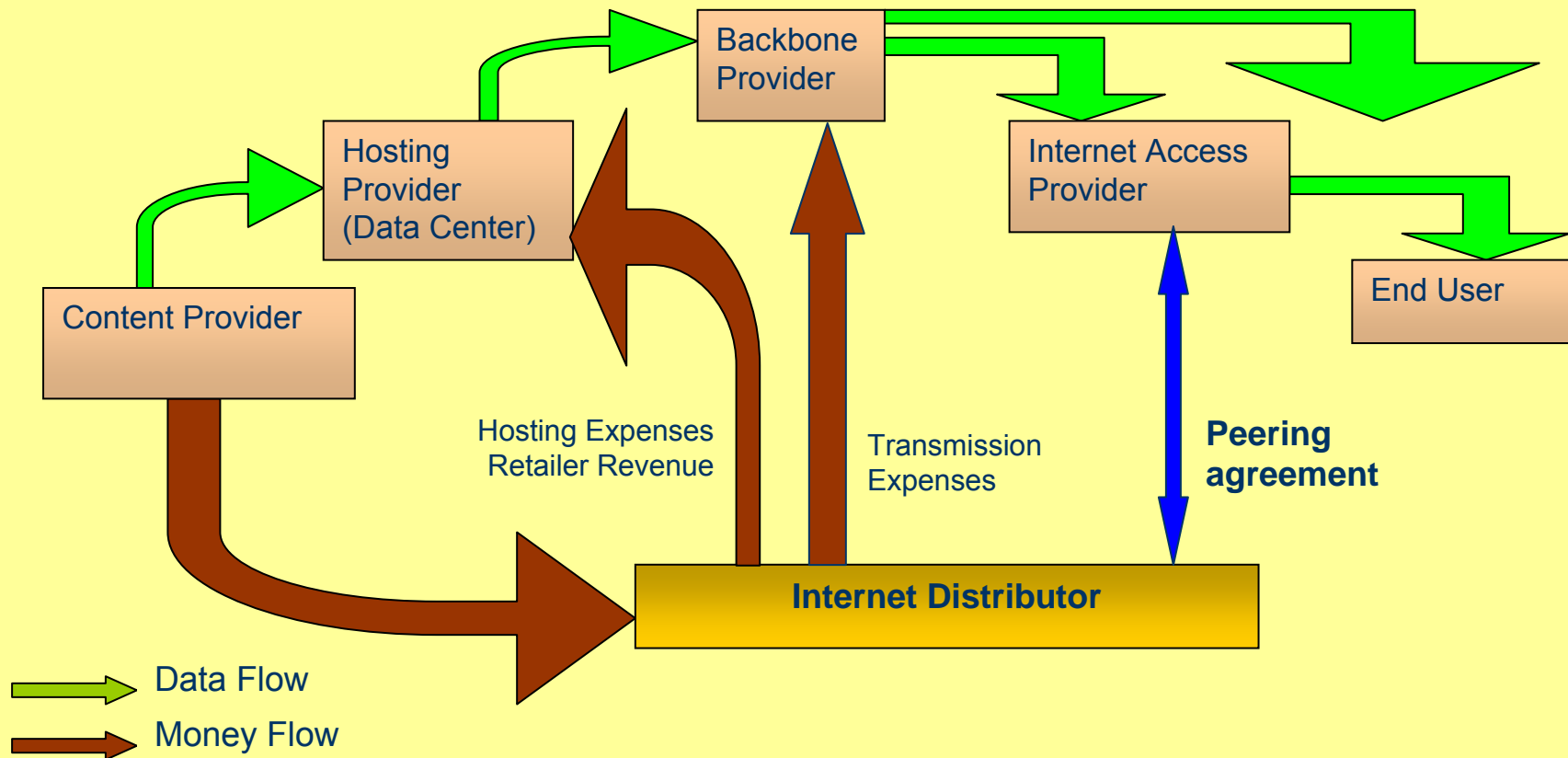
Content Distribution Network (CDN) Architecture

Internet

Origin Server

Cache Node
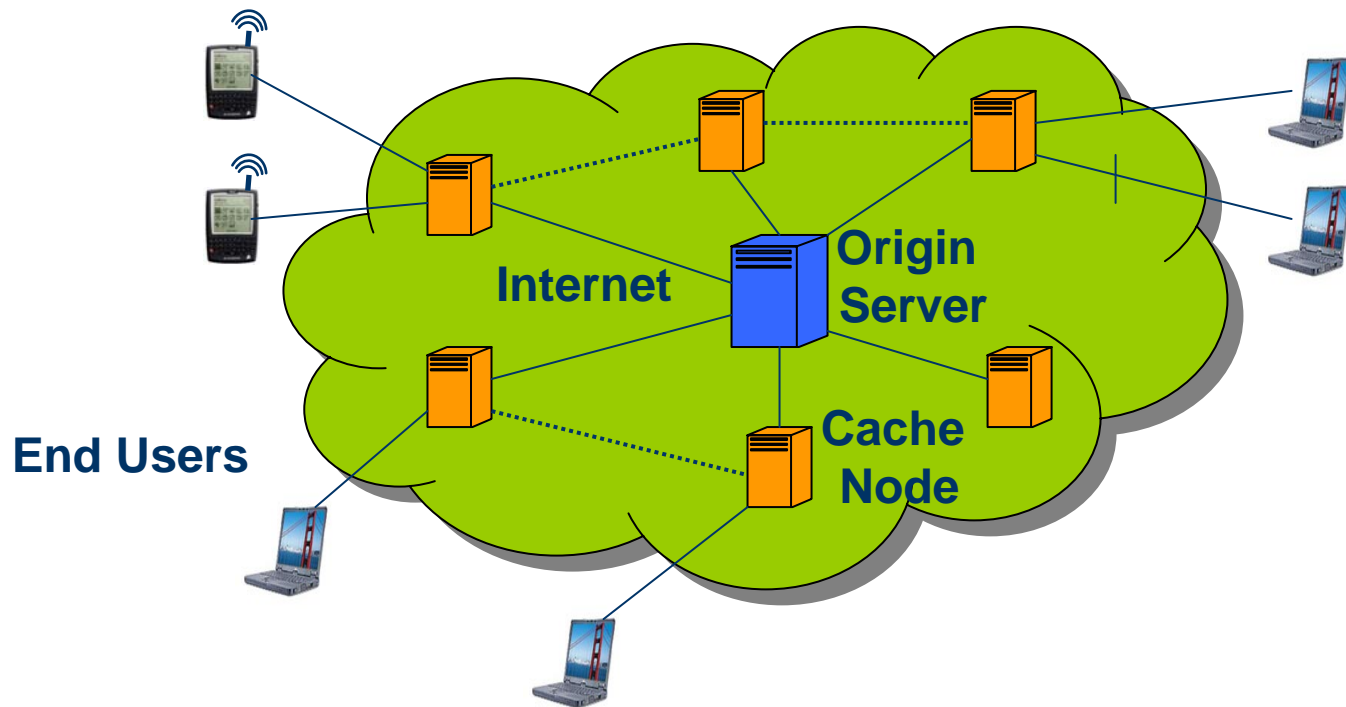
End Users

Business Models (I)

Key Players in Internet Content Distribution

- **Content Providers**
- **Hosting Providers (Data Centers)**
- **Backbone Providers**
- **Internet Service Providers (ISPs)**
- **Content Distributors**
- **End - Users**

Business Models (II)

- *Primary beneficiaries*: Content Providers charged for their content delivery

- *Secondary beneficiaries* : Access Providers and End Users

Backbone Provider

Hosting Provider (Data Center)

Internet Access Provider

Content Provider

End User

Hosting Expenses
Retailer Revenue

Transmission Expenses

Peering agreement

Internet Distributor

Data Flow

Money Flow

Economic Dimension of Caching (I)

- Content Providers as System Users
- Need for efficient resource allocation in order to maximize social welfare
  - Cache Content with higher declared utility
- Users declare service valuation
  - It is in users' interest to inflate their valuations in order to maximize their utility
- Need for Incentive Mechanisms
  - Offer incentives to content providers in order to declare their true valuations

Economic Dimension of Caching (II)

N users, N={1,…,n} - 1 limited-size cache

- User *i* receives utility *U* when consuming *x* units of storage space

$$U_i(x^i) = hits(x^i) * value\_per\_hit = hits(x^i) * (n+B)$$

- *Social Welfare **SW** Maximization*

$$\max SW = \sum_{i \in N} U_i(x^i), \quad s.t. \sum_{i \in N} x^i \leq C$$

n : benefit from faster content delivery

B : bandwidth economies

C : cache size

Incentive Mechanisms – Auction Holding

- Auction holding per time spaces λ for storage space purchase
- Content providers bid for each of their content objects to be cached
- Bids for content objects are of form { B_j, S_j}
  - **B_j object value per byte**
  - **S_j object size in bytes**
- Sort bids in descending order by object value per byte B_j.
- Clearing Price p is the highest losing bid (Second Price Auction - VCG).
- Charge in advance for proactive caching and guaranteed storage in cache until next auction holding.
- Result: Content Objects with higher marginal utility are placed in cache

Incentive Mechanisms – Differentiated Services

- Development motivation : Users valuate caching service in a non-homogeneous fashion

- Quality of Service differentiation per class of content based on Hit-Rate H (e.g. Objective is $H_{high} : H_{low} = 3 : 1$)

- Non-equal space allocation to classes of content
(e.g. 70% of space to high class, 30% of space to low class)

- Need for a feedback mechanism to adapt deviations from objective by readjusting space allocation
(e.g. 70% $\rightarrow$ 80% of space for high class)

- Offer Incentive to users to select class that maximizes their utility by publishing a price *p* per *hit* different for each class of content.

Conclusions

- Insert user valuations in content delivery system in order to maximize social welfare

- VCG Auction Holding

   Plus: Offers incentives for true valuations

   Minus: Inserts complexity in system (based on holding frequency)

- Differentiated Caching Services

   Plus: Satisfies needs of heterogeneous groups of users

   Minus: Necessity of a Feedback Mechanism burdens system

Thank You!