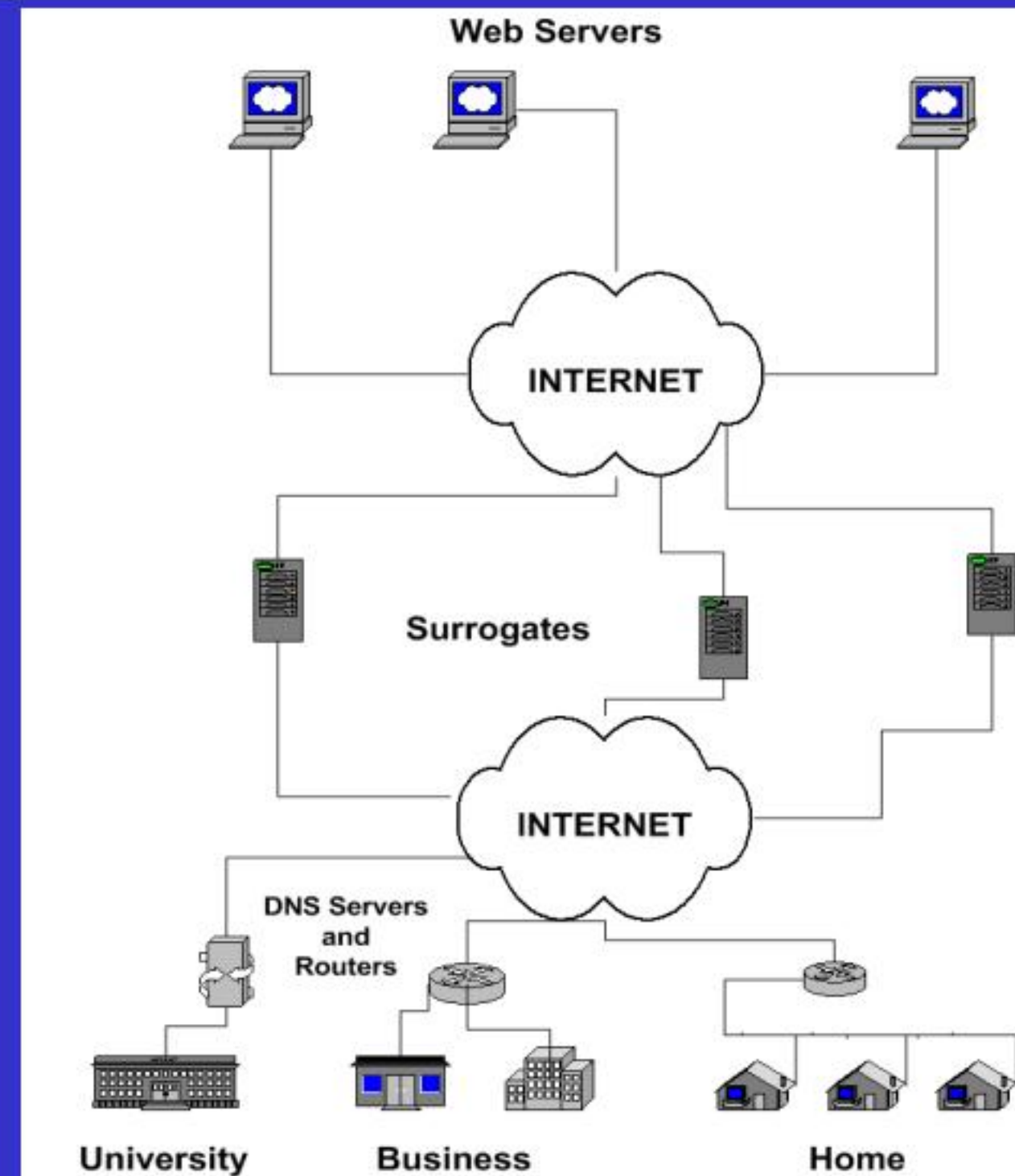


Fast Web Page Downloads by Competitive Content Delivery Networks

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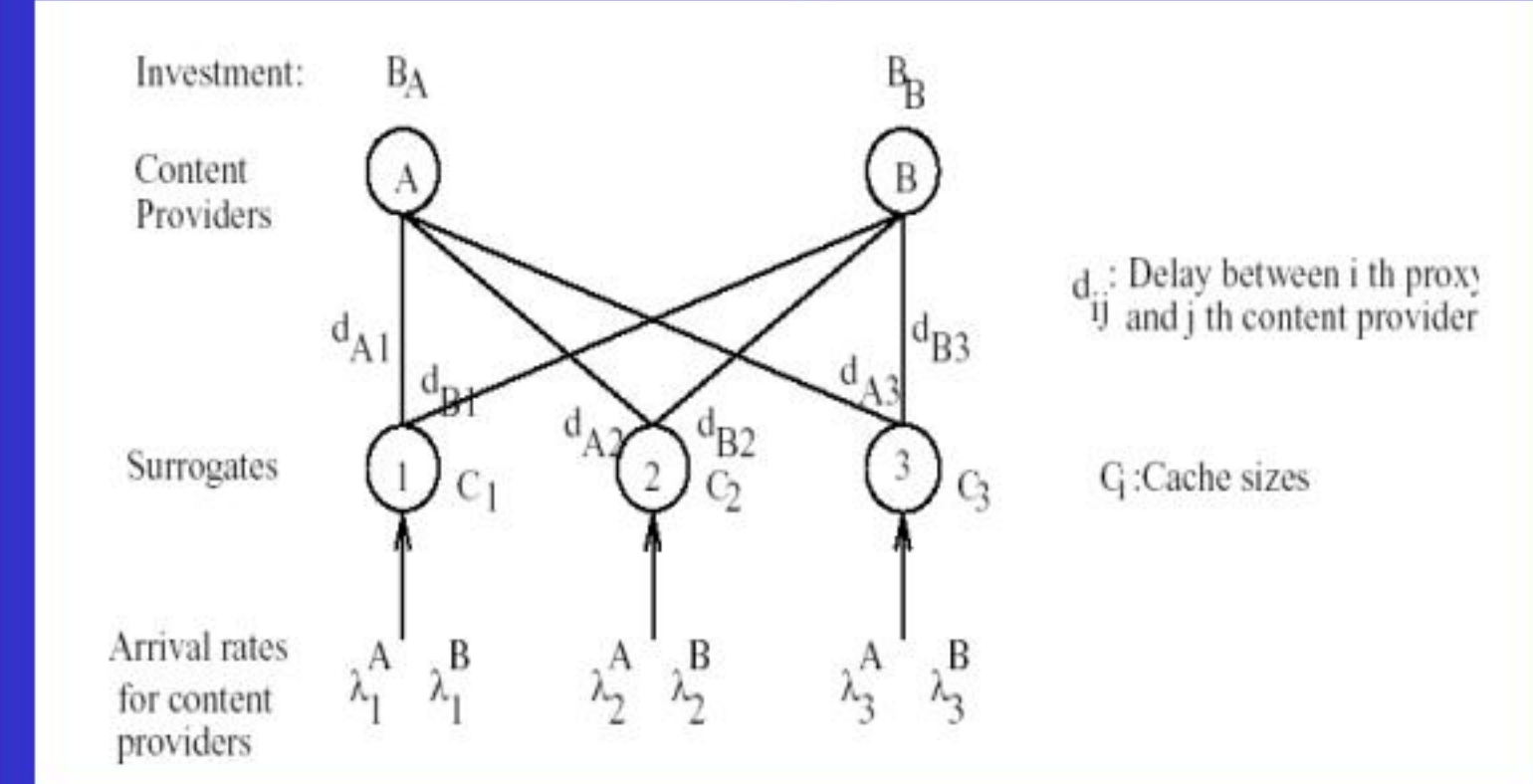
- Most of the user requests are for a few popular objects.
 - Web sites may become overloaded and propagation delays may cause high retrieval delays.
 - It is common practice to use caches to store popular objects to improve user latency and reduce the network load.
- Speculative (best-effort) caching:
 - Proxy caches are placed at gateways, ISPs, etc. and serve incoming user requests if the requested object is available, otherwise user request is forwarded to the WAN.
 - User requests are served without any QoS.
 - Transparent proxy, mirror sites are examples.



Content Delivery Market

- Publishers invest in the surrogates for improved user latency.
- Surrogates compete among each other for publisher business and sell caching and bandwidth resources.
- No cooperation between market agents other than resource price advertisements.

Content Delivery Network Model



- ### Content Delivery Problem
- Publishers subscribe for content delivery services from the CDNs.
 - Objective: Maximize total net average publisher utility.
 - Publisher utility is a concave function of the average latency the users retrieve the publisher's content.

$\beta_i^j = \lambda_i^j w_i(d_{ij}) / x_i^{1-\alpha}$ is the gain factor

x_i^j is the total caching space allocated to publisher i in surrogate j .

$$U_i(x_i^j) = \sum \beta_i^j (x_i^j)^{1-\alpha}$$

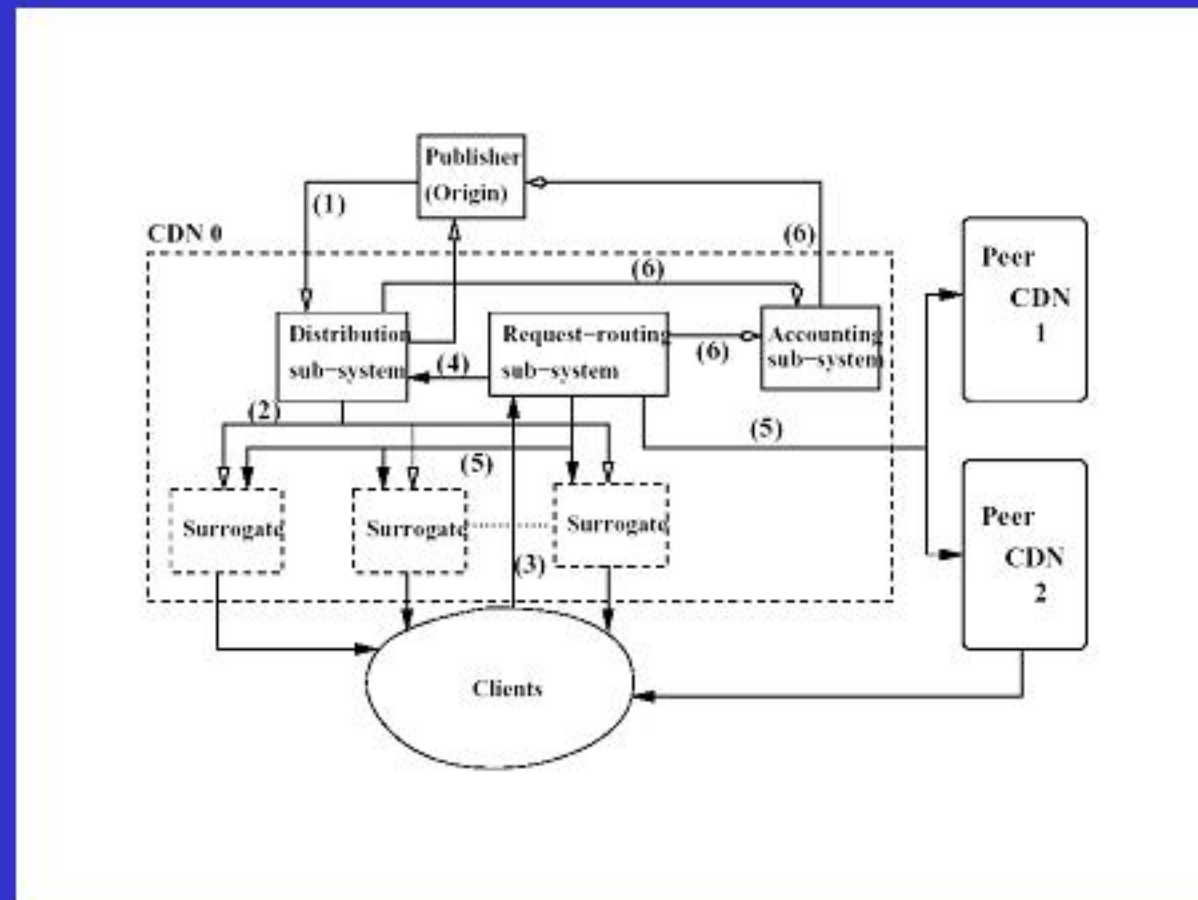
Publisher benefit, total additional delay improvement from use of surrogates

Optimization Problem

$$(S_i) \max_{\{x_i^j\}_{j=1}^J} U_i(x_i)$$

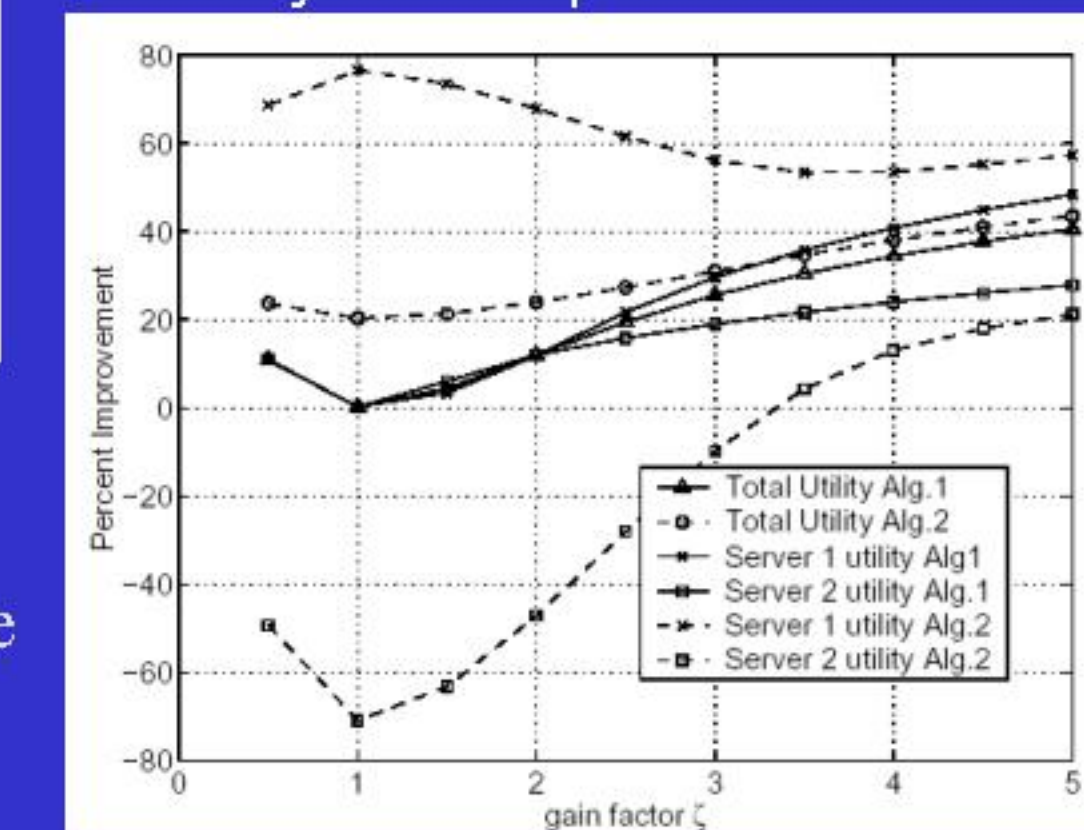
subject to (1) $\sum_{j=1}^J x_i^j p_j \leq B_i$

(2) $\sum_i x_i^j \leq C_j, j = 1, \dots, J.$

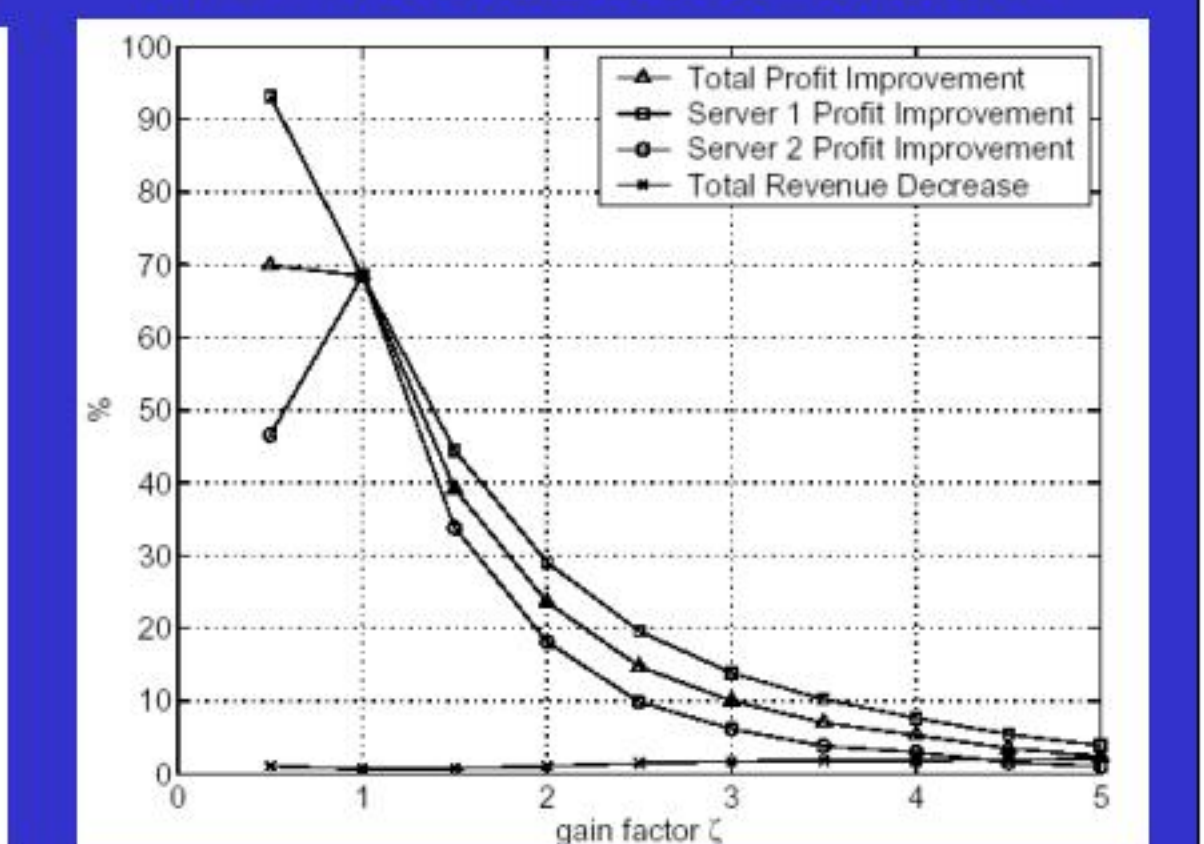


- Web server is the point the content first enters the Internet.
- Publishers ultimately control the content and its distribution.
 - Publishers may negotiate SLA (Service Level Agreement) in terms of average user latency, storage capacity or the extend of geographical coverage of the content.
- Surrogate is a delivery server other than the origin server.
 - Limited storage and transmission bandwidth resources.

Publisher Latency Improvements with System Optimum Solution



Publisher Latency Improvements With Market-based Solution



- ### CDN System Operation
- 1) Publisher selects a desired level of QoS. In terms of caching space, geographical dissemination, average user latency.
 - 2) Disseminate content according to the desired QoS, user request distribution, location and capacity of the surrogates.
 - 3) Direct user requests to the appropriate surrogates. URL re-routing, application-level routing, transparent proxies.
 - 4) May periodically re-arrange objects and/or QoS.
 - 5) Direct user requests to peer CDNs, if it is optimal.
 - 6) Keep access records for accounting.

- Distribution Sub-system coordinates the activity of moving publisher's content to one or more of the surrogates.
- Request-Routing Sub-system (RRS) coordinates the activity of directing a client request to a suitable surrogate.
- Accounting Sub-system determines the methods for measurement and pricing of the distribution and delivery activities.

CONCLUSIONS

- Performance of non-cooperative market approaches the system optimum solution.
- Unlike system optimization, market-based operation enables improvement of benefits of the individual publishers.