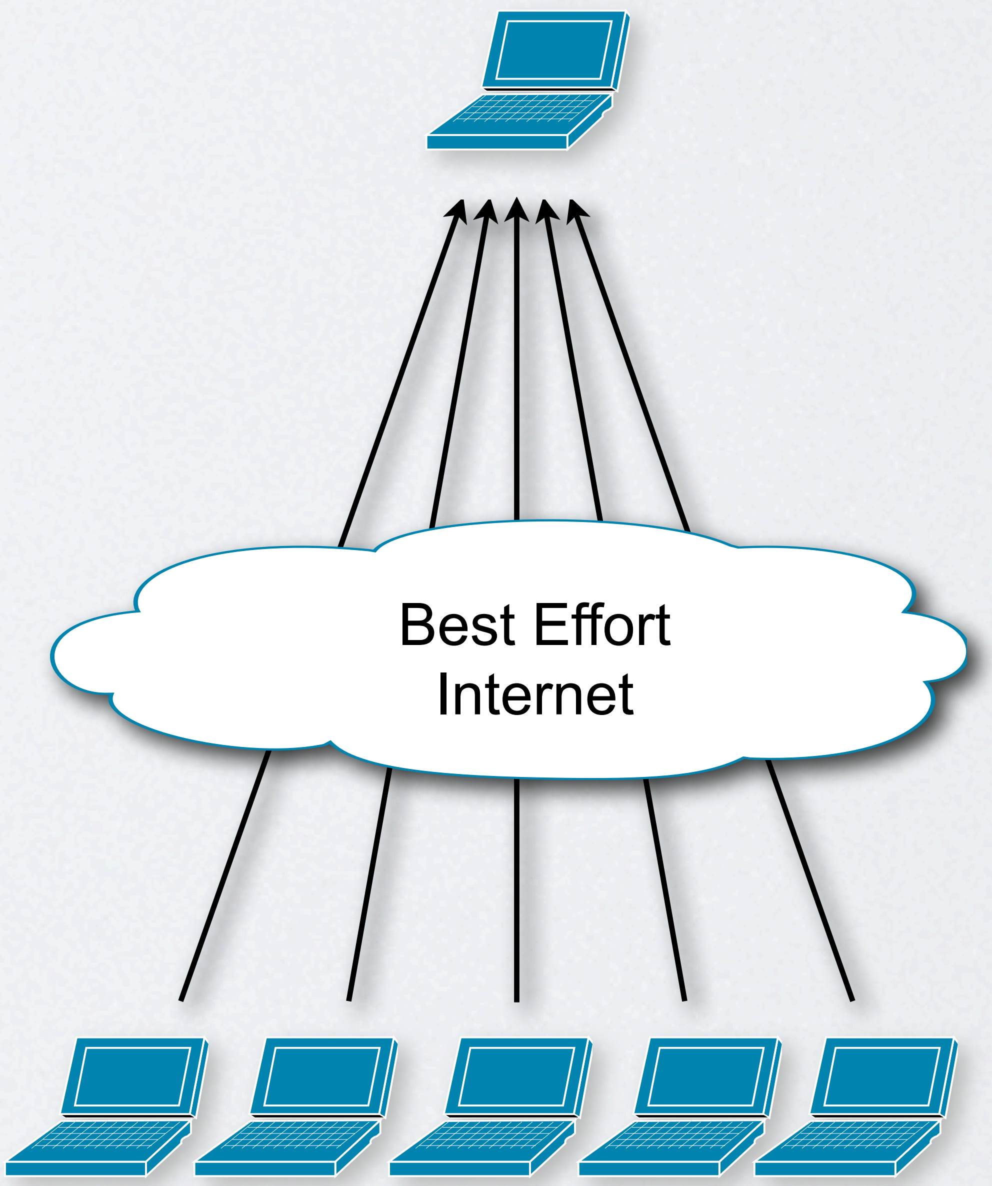
Hidden Action in QoS-aware Overlays

Raul Landa
Networks and Services Research Laboratory
Department of Electronic and Electrical Engineering
University College London

QoS-Aware Overlays

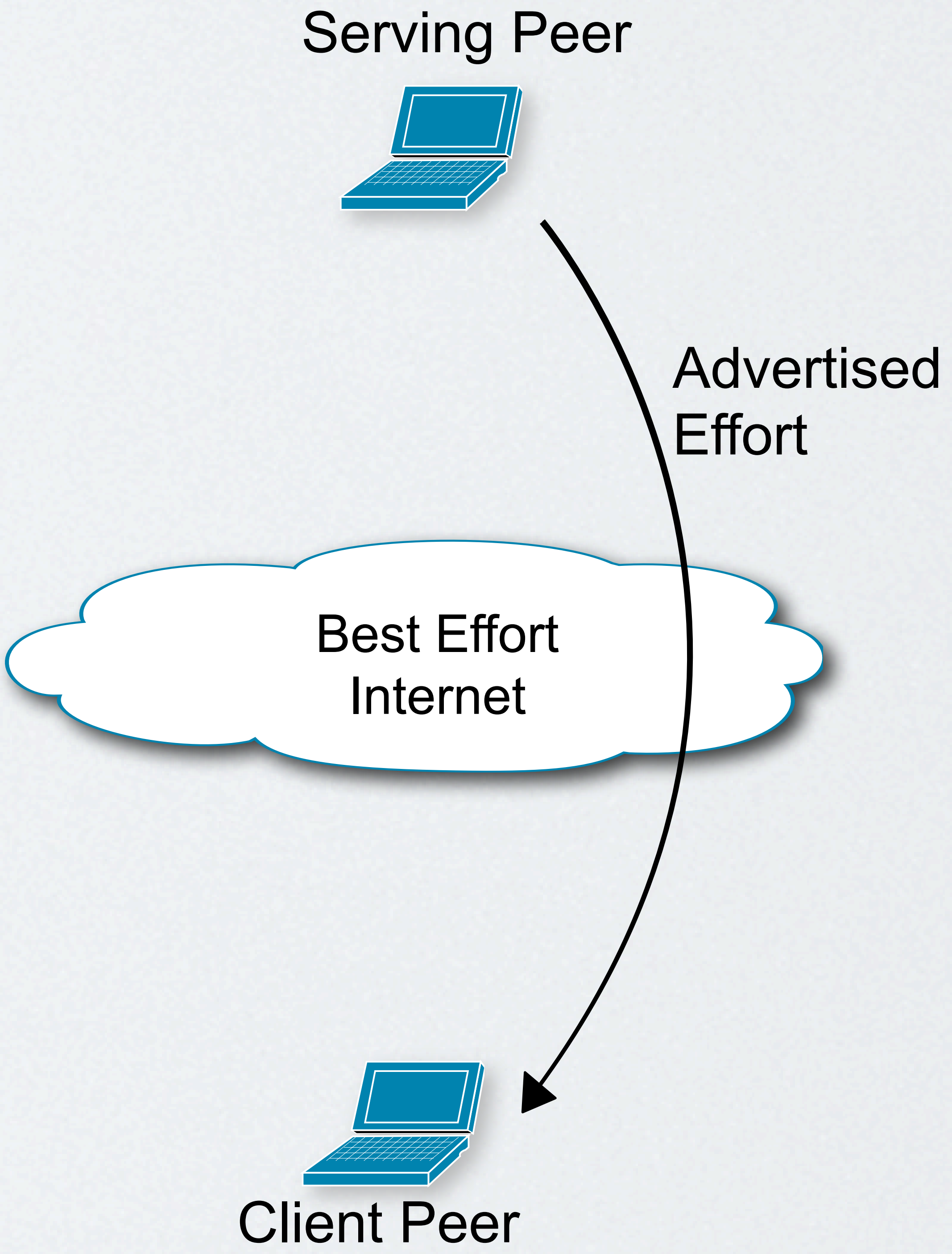
- Any single overlay link experiences intermittent QoS
  - A peer-to-peer aggregate, though, can provide consistent service quality

- Overlays can provide service differentiation through
  - Peer selection
  - Differentiated resource allocation



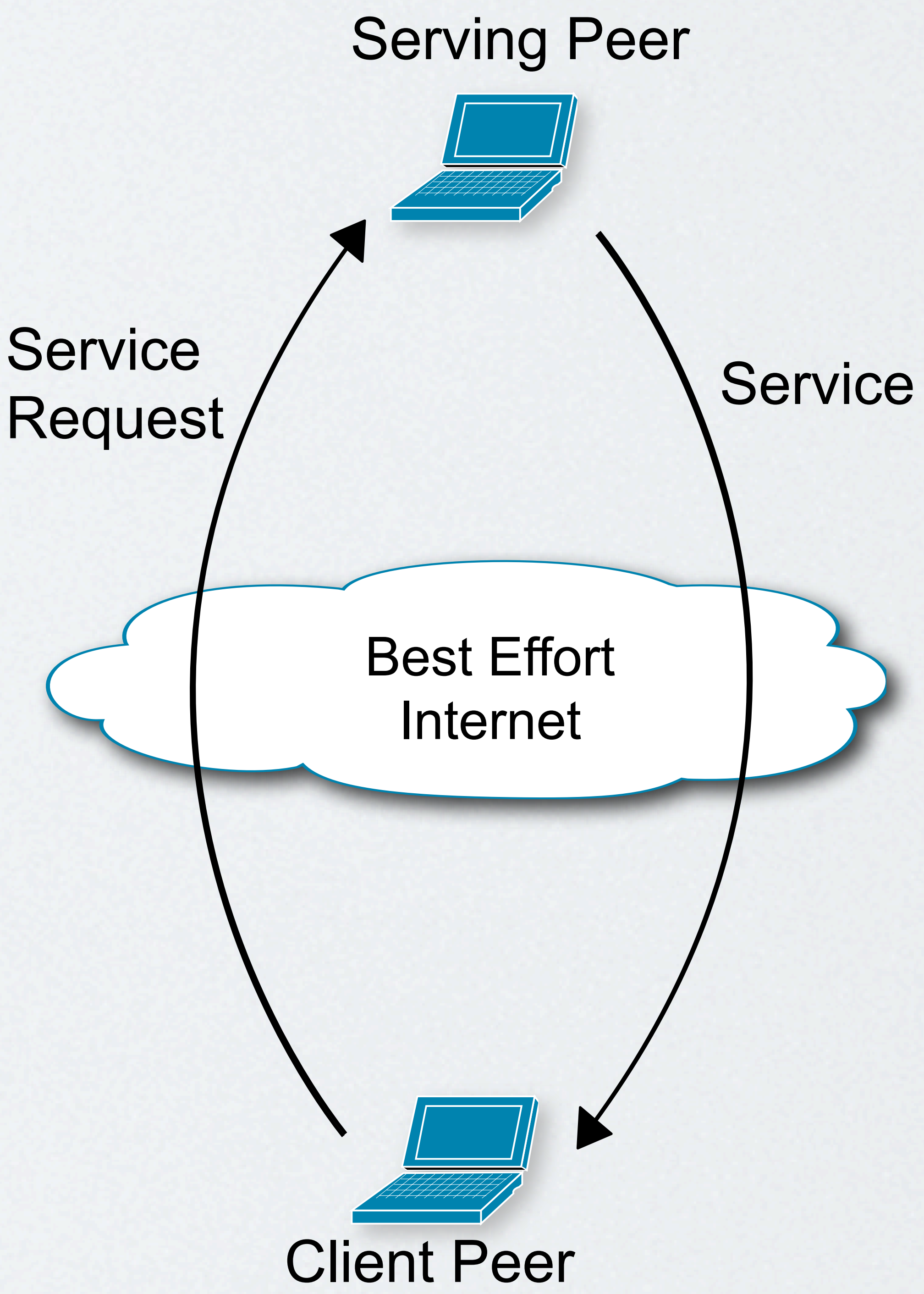
Motivation - Why Hidden Action?

- Delay-sensitive services require efficient scheduling mechanisms
- However, peers are ***strategic***, and can
  - Advertise false QoS information



Motivation - Why Hidden Action?

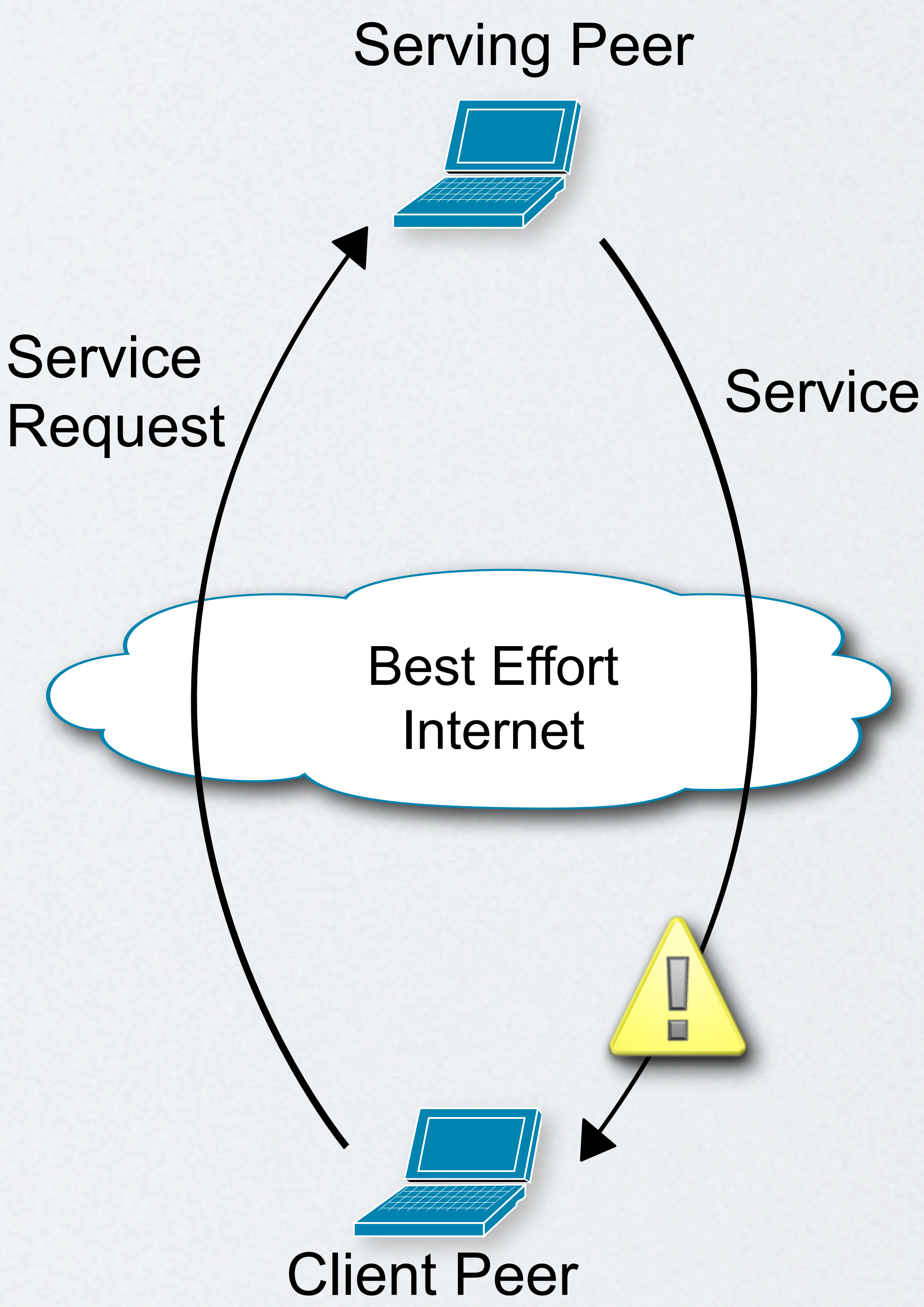
- Delay-sensitive services require efficient scheduling mechanisms
- However, peers are ***strategic***, and can
  - Advertise false QoS information
  - Deliver QoS that does not correspond to their advertised QoS



Motivation - Why Hidden Action?

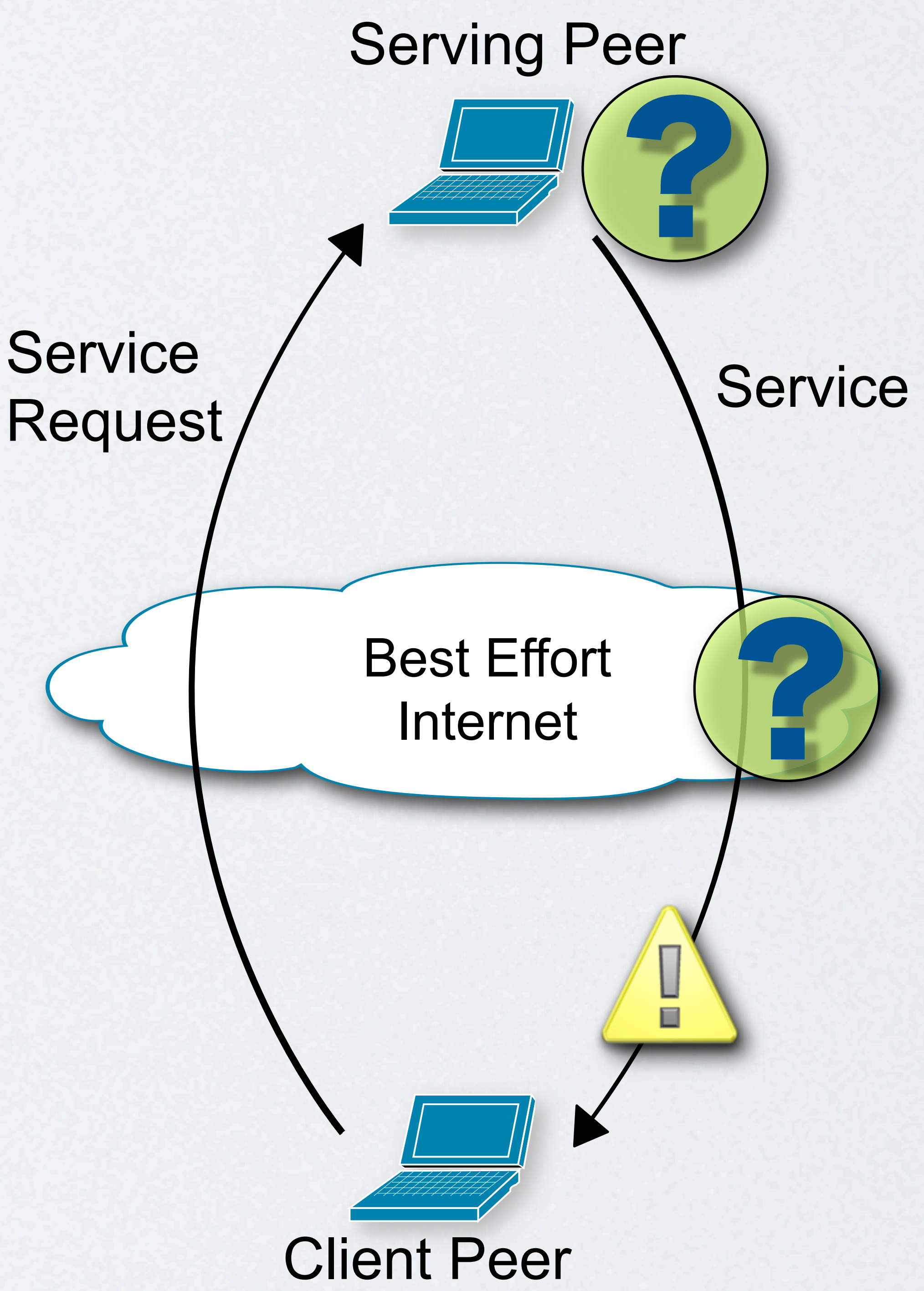
- The actions of the Serving Peer are **unobservable** to the Client Peer

- In case of unsatisfactory QoS, the Client Peer is unable to distinguish between 2 cases:



Motivation - Why Hidden Action?

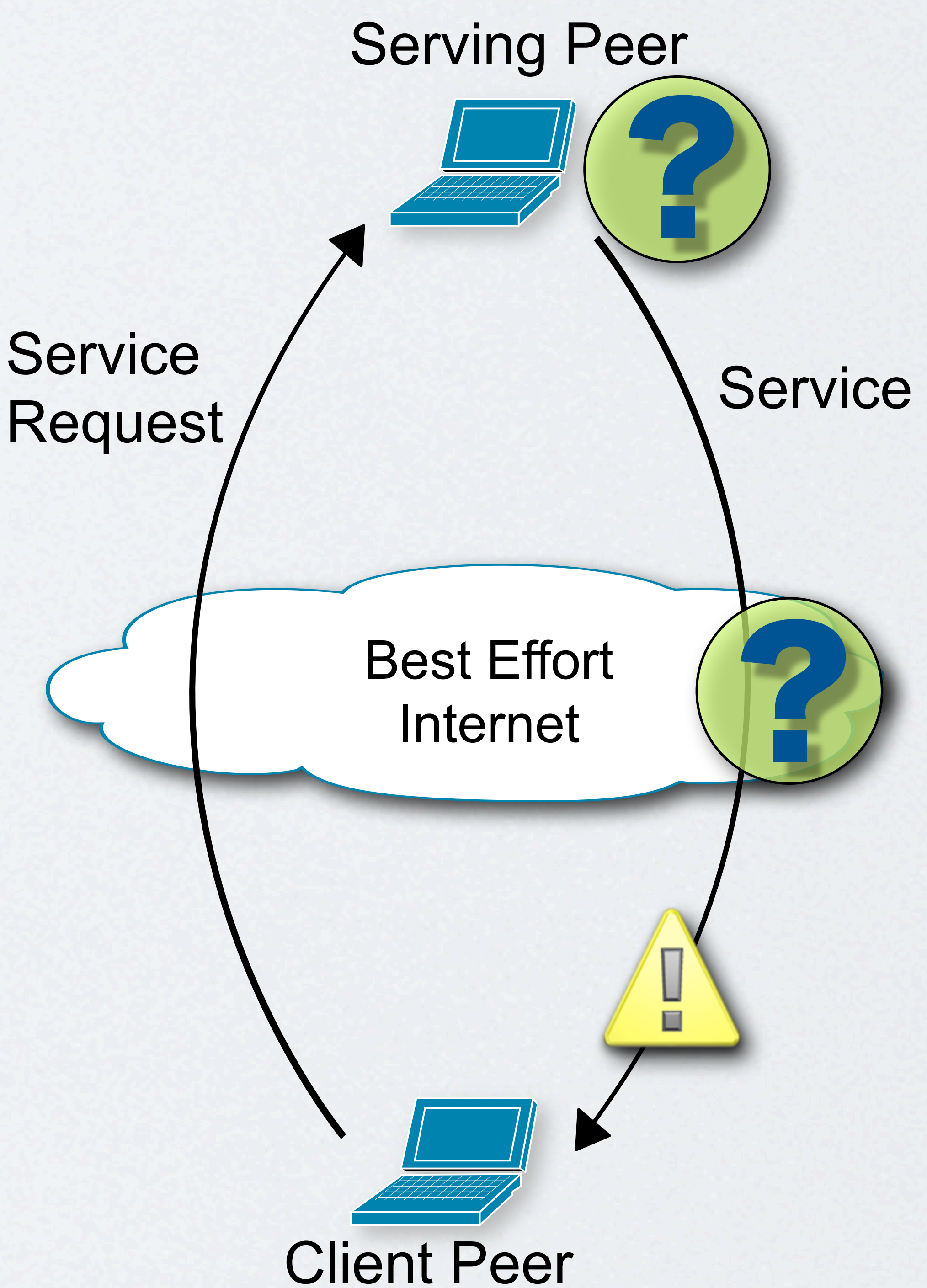
- The actions of the Serving Peer are **unobservable** to the Client Peer
- In case of unsatisfactory QoS, the Client Peer is unable to distinguish between 2 cases:
  - The **serving peer** exerted insufficient effort
  - The end-to-end **network conditions** were adverse



Motivation - Why Hidden Action?

- The Serving Peer can fail to deliver its advertised service quality, and then blame it on the network

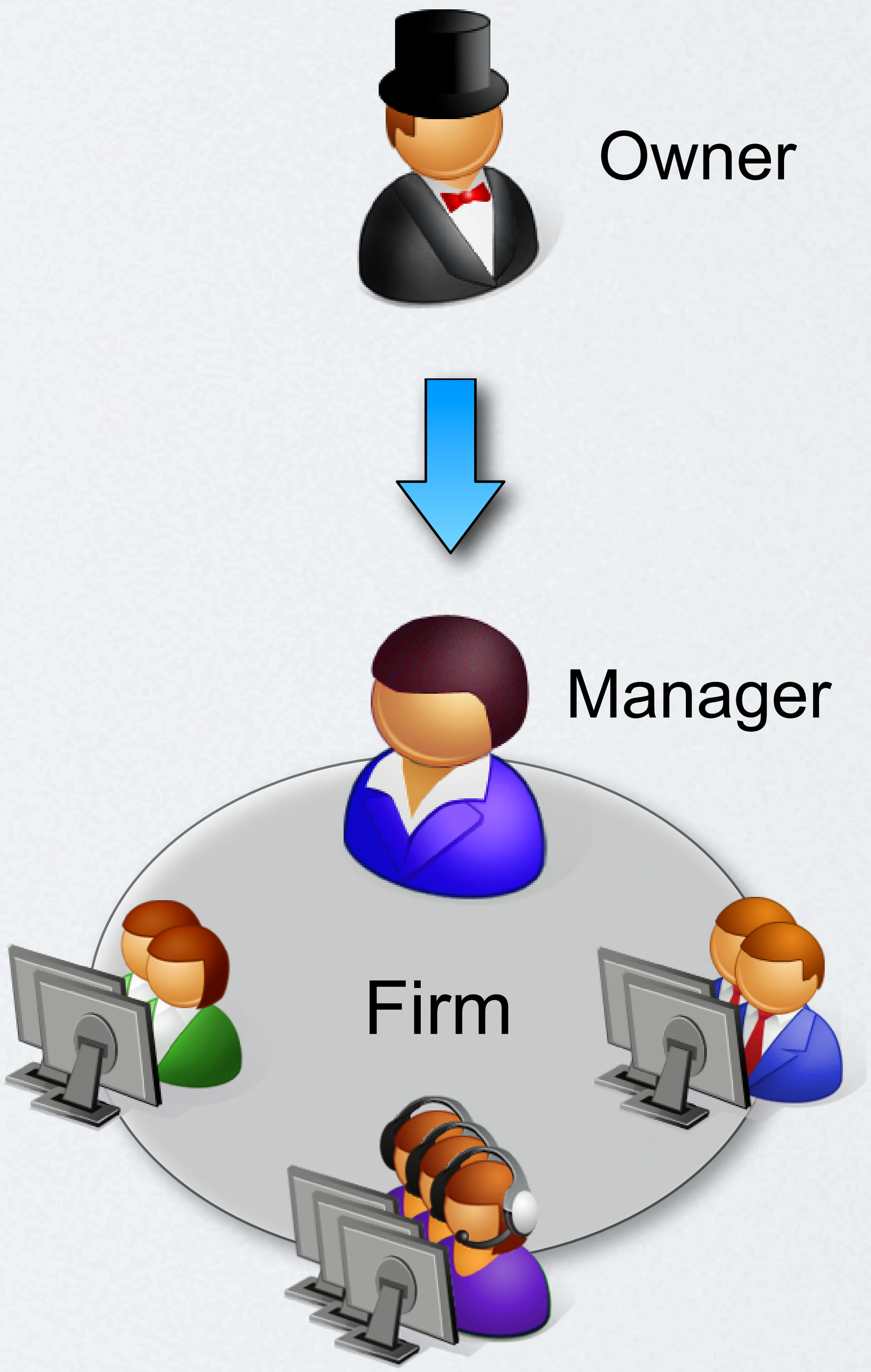
- How can we deal with this ***Hidden Action*** scenario?



Hidden Action in Microeconomics

- The owner of the firm delegates it to a manager, which is paid a salary
- The manager can exert **low** or **high** effort
- The firm can yield **good** or **bad** results
- This creates an **externality** on the owner

- How to give an incentive to the manager to exert **high** effort?



Hidden Action in Network Overlays

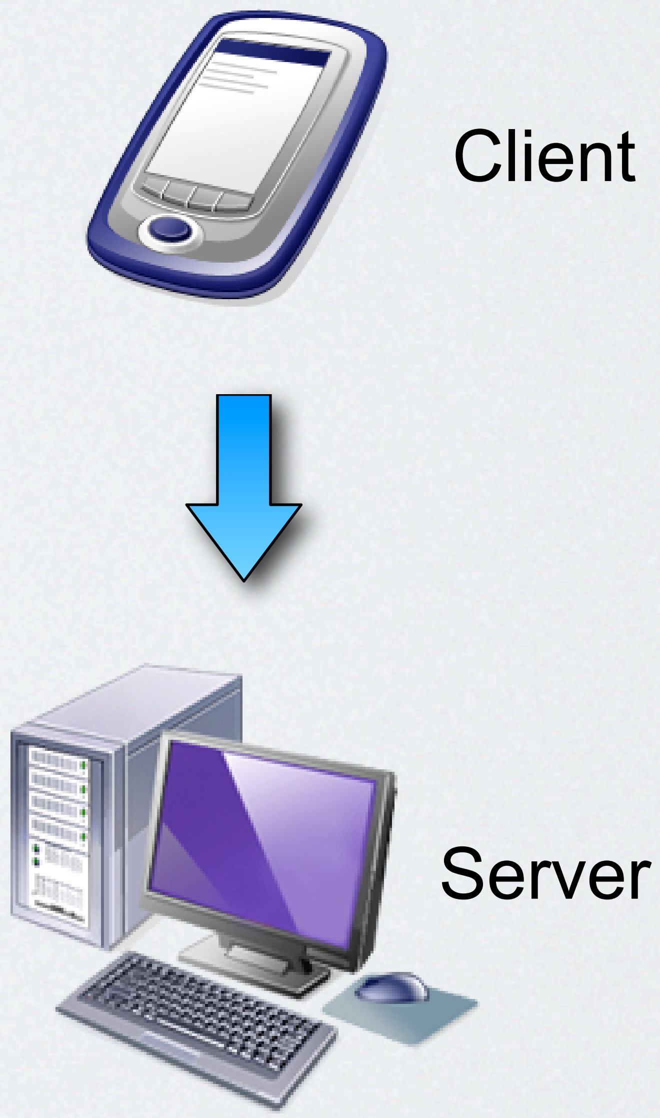
- A client peer requests a service from a server peer
- The server can either **meet** or **ignore** its advertised effort level
- The client can experience **good** or **bad** service quality as a result

- How to give an incentive to the server to **meet** its advertised effort level?

Service Differentiated Payment

- Service quality is correlated with transaction outcome
  - Higher server effort increases the probability for high service quality, and vice versa

- The client can provide **differentiated payments**
  - High payment if the service quality is good
  - Low payment if it is not



Elements of the Model

ϕ	ϕ_+	High Server Effort
	ϕ_-	Low Server Effort
q	q_+	High Service Quality
	q_-	Low Service Quality
ψ	$\psi_+ = \psi(q_+)$	High Payment to Server
	$\psi_- = \psi(q_-)$	Low Payment to Server

Transaction Outcomes

- The service quality q is probabilistically dependent on the server effort ϕ:

p_+	*Client* experiences **high** quality (q_+), *Server* devotes **high** effort (ϕ_+)
$1 - p_+$	*Client* experiences **low** quality (q_-), *Server* devotes **high** effort (ϕ_+)
p_-	*Client* experiences **high** quality (q_+), *Server* devotes **low** effort (ϕ_-)
$1 - p_-$	*Client* experiences **low** quality (q_-), *Server* devotes **low** effort (ϕ_-)

Utility for the Client

$$U_c(q, \psi) = q^\beta - \psi$$

Client Utility

Service Quality Received

Payment to Server

- The expected utility given that $\phi = \phi_+$ is:

$$U_c^+ = p_+ U_c(q_+, \psi_+) + (1 - p_+) U_c(q_-, \psi_-)$$

High Quality

Low Quality

Utility for the Server

$$U_s(\psi, \phi) = \psi^\alpha - \phi$$

Server Utility | Payment Received | Effort put in Service

- The expected utilities in terms of server effort are:

High Effort

$$U_s^+ = p_+ U_s(\psi_+, \phi_+) + (1 - p_+) U_s(\psi_-, \phi_+)$$

High Quality | Low Quality

Low Effort

$$U_s^- = p_- U_s(\psi_+, \phi_-) + (1 - p_-) U_s(\psi_-, \phi_-)$$

Calculating Optimum Payments

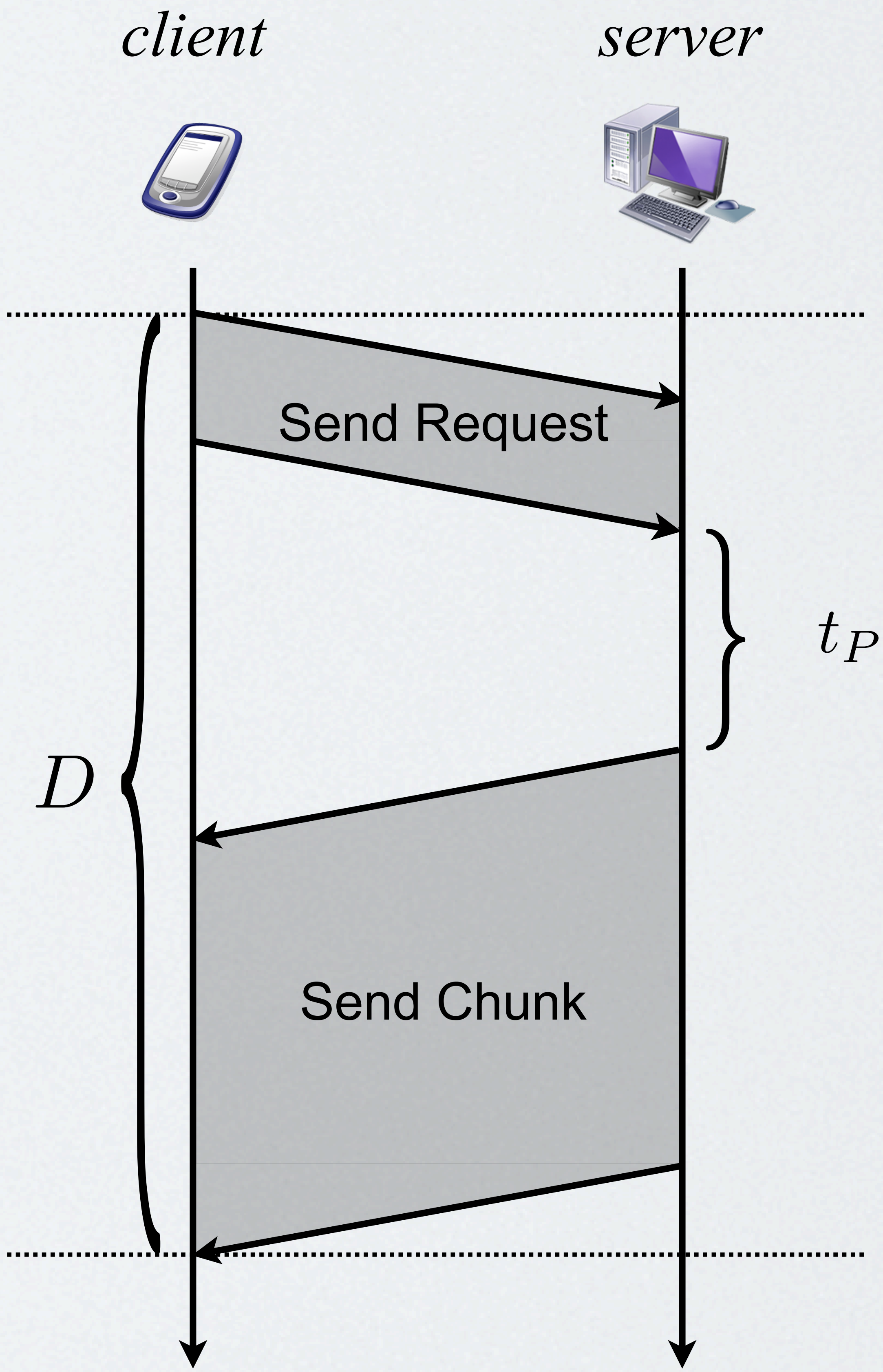
- We assume that there is a market-defined "going rate" that gives the server a utility of U_r.

- The optimum payments ψ_+ and ψ_- can be found by solving the following optimization problem:

$$\text{Maximize:} \quad U_c^+$$
$$\text{Subject to:} \quad U_s^+ \geq U_r \quad \text{(rationality)}$$
$$\text{And:} \quad U_s^+ \geq U_s^- \quad \text{(incentive compatibility)}$$

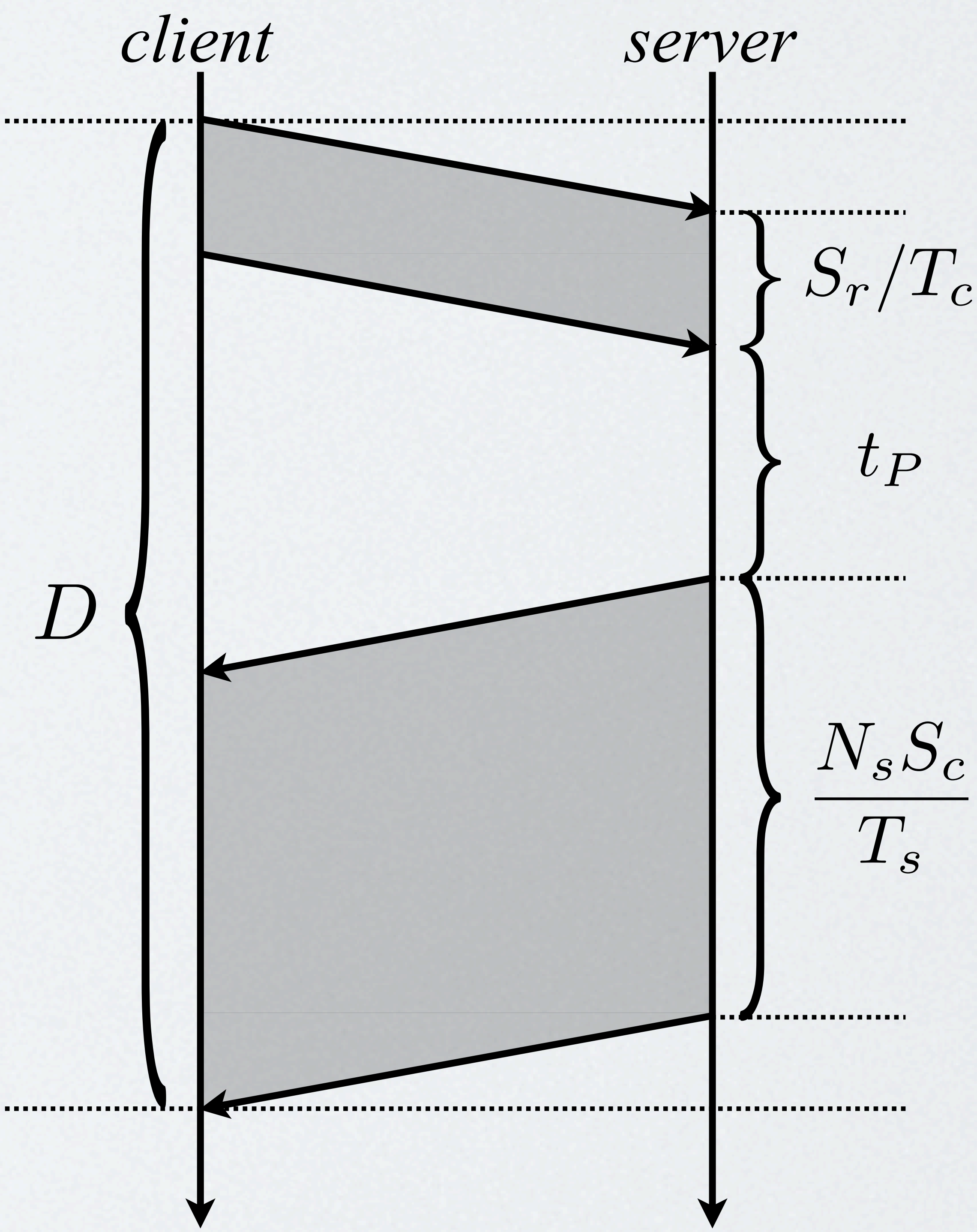
A simple scenario

- Delay-sensitive chunk transfer
- The server peer advertises its effort level using a market system:
  - The maximum time before starting chunk delivery (t_P)
- The client estimates transaction time distributions using this effort level

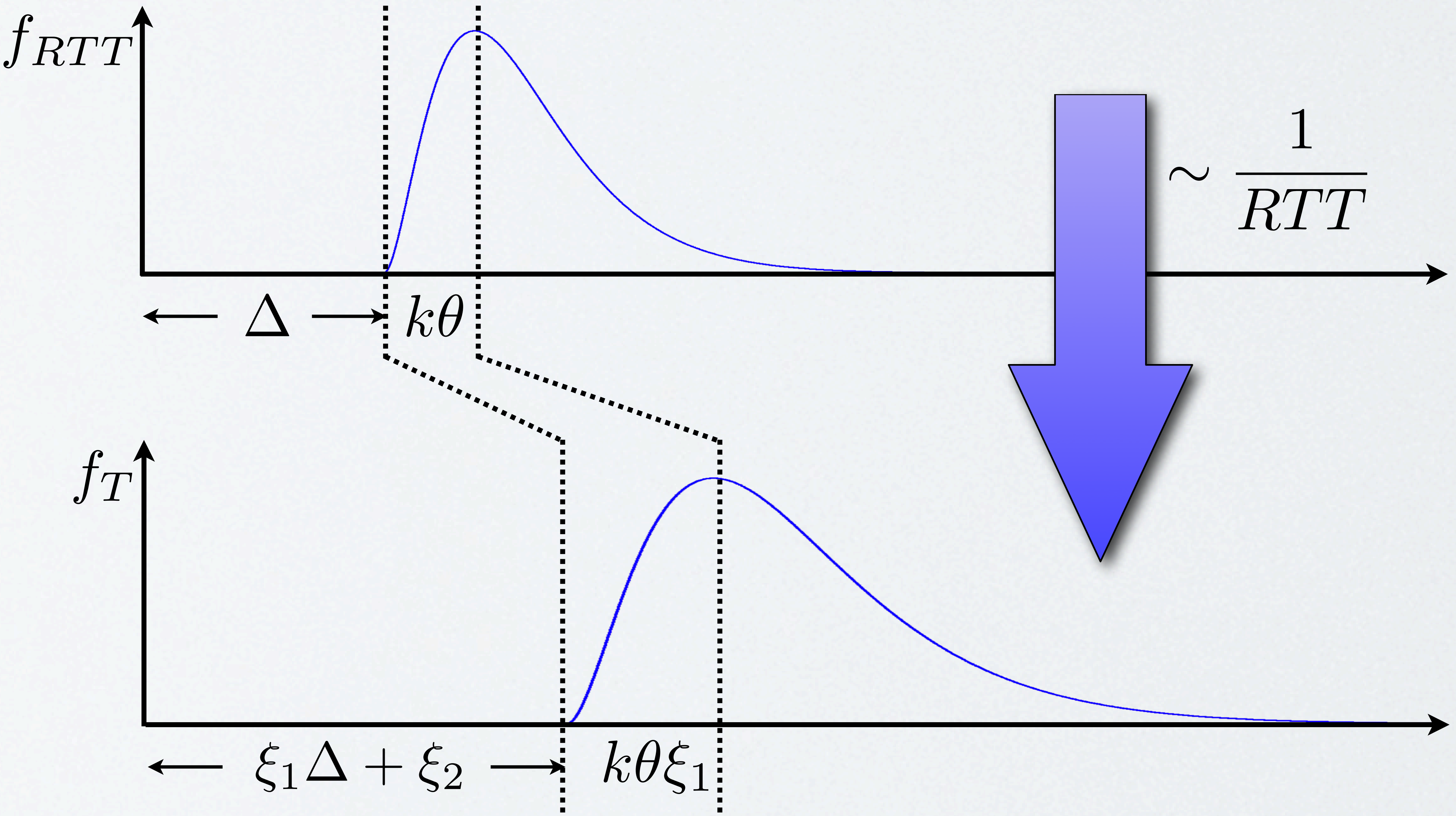


Modeling Transaction Outcomes

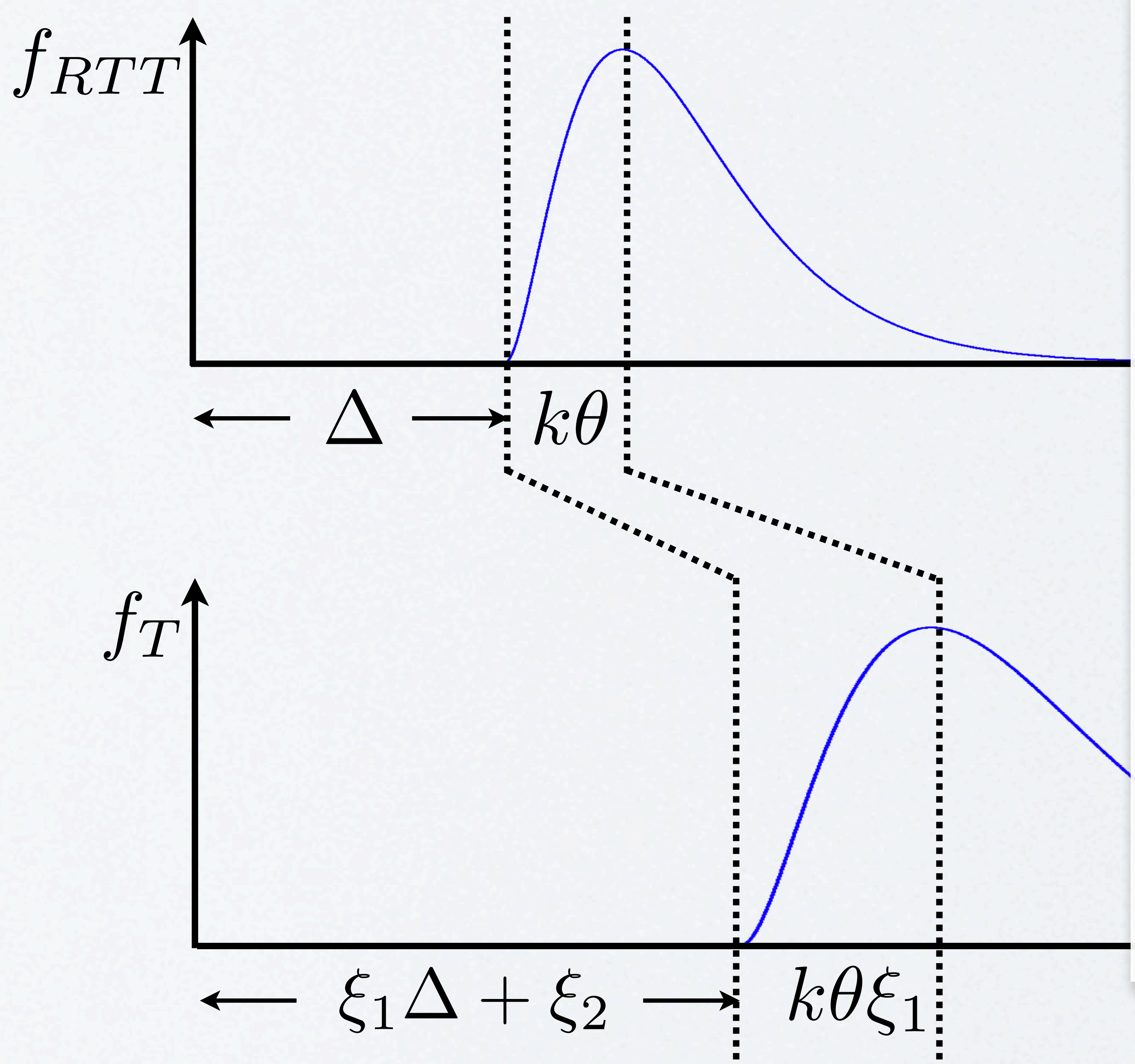
- We model RTT using a shifted Gamma distribution
  - Mukherjee (1994)
  - Bolot (1993)
- We use a TCP model as an illustrative example
  - Padhye, Firoiu, Towsley and Kurose (1998)



Transaction Time Distribution



Transaction Time Distribution



- ξ_1 and ξ_2 are functions of:
  - The request and response message sizes
  - The server processing time
  - The number of clients sharing the server upload
  - The IP packet size
  - The packet loss probability
  - The retransmission timeout value

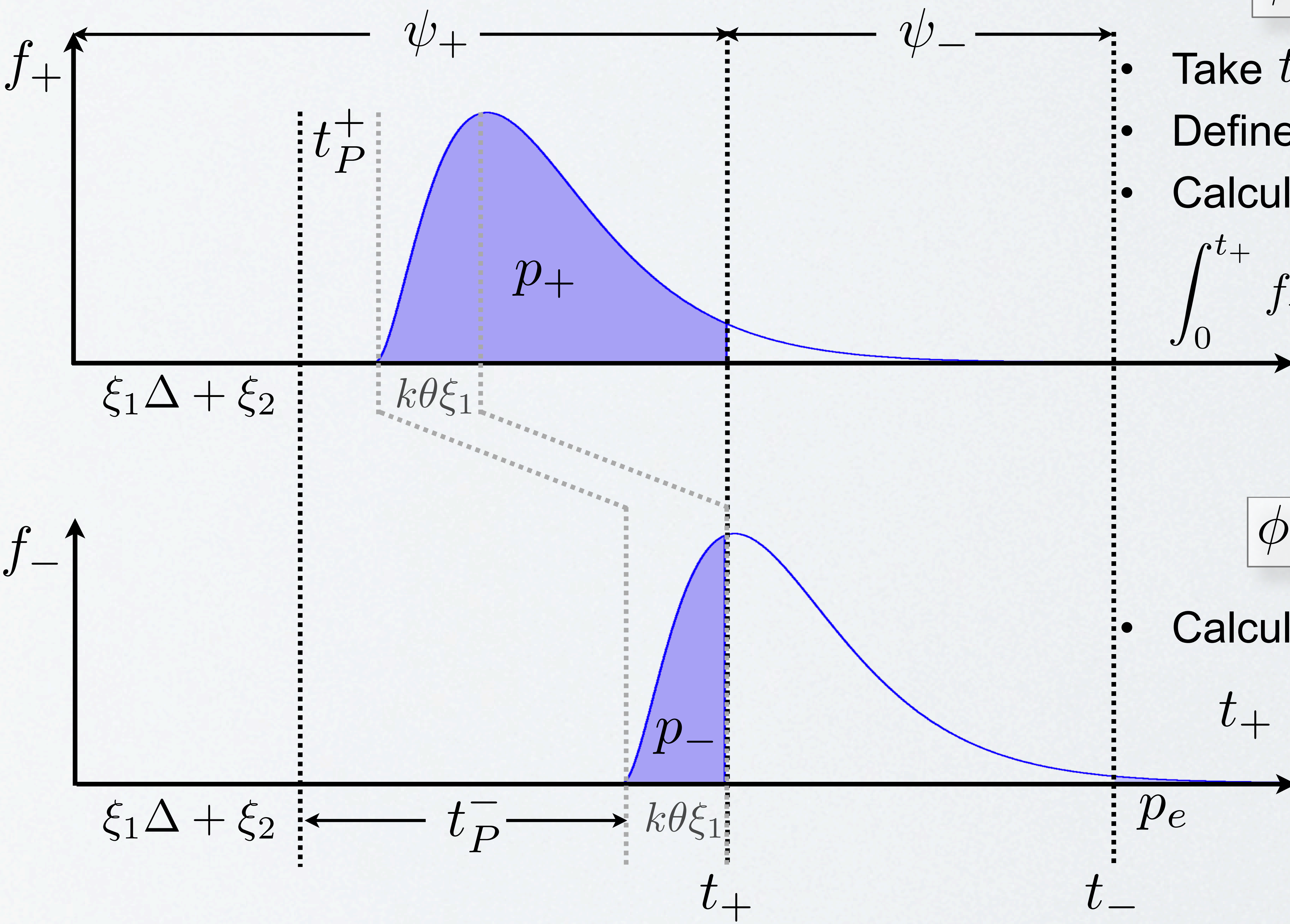
Transaction Outcome Probabilities

- The client defines two deadlines:

t_+	The estimated transaction resolution time if the server actually delivers its advertised effort
t_-	The absolute maximum transaction delay that the client is willing to tolerate for the transaction

- We have thus two tiers of service:
  - **High** Quality: $D < t_+, \; q = q_+, \; \psi = \psi_+$
  - **Low** Quality: $t_+ < D < t_-, \; q = q_-, \; \psi = \psi_-$

Transaction Outcome Probabilities



$\phi = \phi_+$

- Take t_P^+ as given
- Define p_+
- Calculate t_+ so that

$$\int_0^{t_+} f_+(x)dx = p_+$$

$\phi = \phi_-$

- Calculate t_P^- so that

$$t_+ = \mathbb{E}[f_-]$$

Conclusions

- QoS-aware overlays are susceptible to **Hidden Action** problems
- The **Principal-Agent** model can be used to address them
- We require statistical models of the interactions between peer and network behavior

Questions?