The Wi-Fi Roaming Game

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Punch Line

- Users sensitivity to bandwidth (and possibly delay) affects their Internet bills.

- The right value for roaming charges that wireless providers should pick to maximize their revenue.

Motivation

Unplanned city-wide wireless mesh networks.
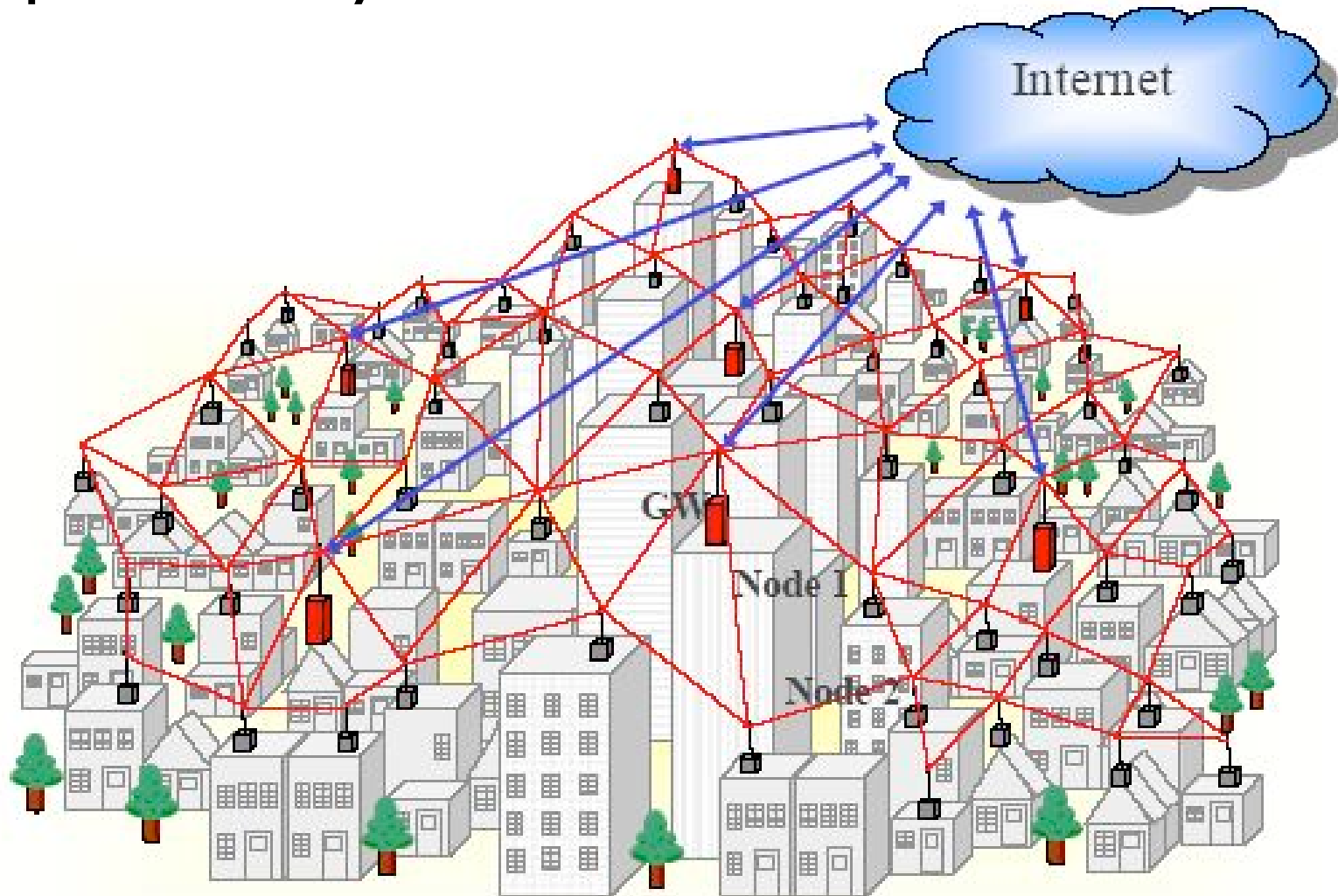
Motivation

Operators prefer to invest in crowded areas (e.g. malls)

The city mall will be covered by multiple providers.

Motivation

- With hand-off:

  - Operators can take advantage of each other's infrastructure to provide full coverage.

  - Users can get better service when their operator infrastructure is overloaded.

The Real World

- Associated Press, August 27, 2004, "*Sprint, SBC Announce Wi-Fi Roaming Pact*"

- wi-fiplanet.com, August 17, 2004, "Wi-Fi Roaming in Athens"

- wi-fiplanet.com, October 12, 2004, "*Nomadix Claims Largest Wi-Fi Footprint*"
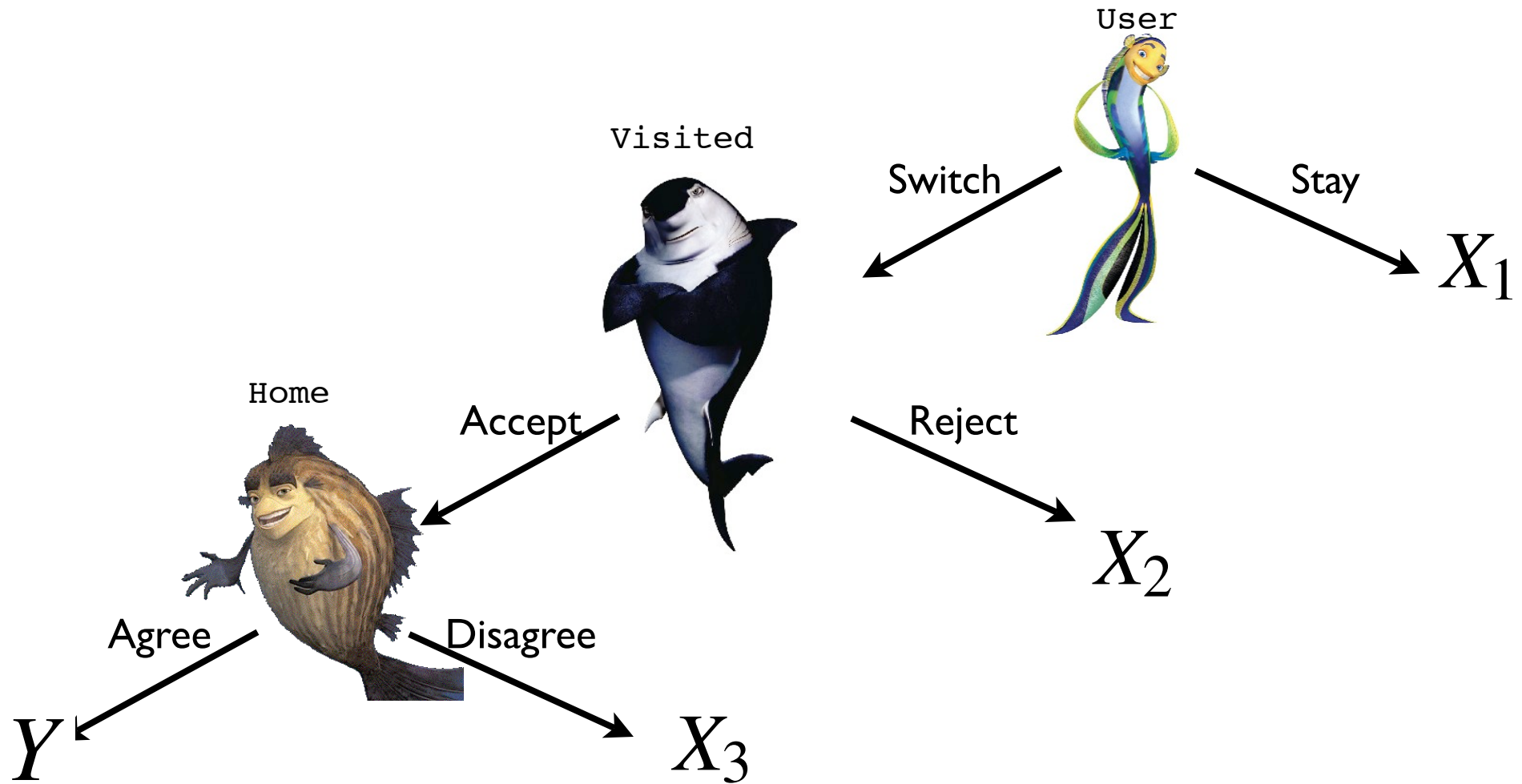
Economic Aspects

How to charge roaming users to maximize profit?

Outline

1. Modeling

2. Utility functions

3. Roaming for delay-insensitive users

4. Future work

The Game

User

Visited

Switch

Stay

X_1

Home

Accept

Reject

X_2

Agree

Disagree

Y

X_3

Game States

User stays with the home provider

$$\begin{cases} X_1 \\ X_2 \\ X_3 \end{cases}$$

User switches to the visited provider

$$Y$$

Formal Definition

Wi-Fi roaming is a perfect information extensive-form game $G = (N, A, Z, u)$

- ◆ Set of agents $\quad N = \{user, home, visited\}$

- ◆ Set of actions $\quad A = \{A_{user}, A_{visited}, A_{home}\}$

- ◆ Set of terminal choice nodes $\quad Z = \{X_1, X_2, X_3, Y\}$

- ◆ Utility function $\quad u$

Visited Operator

Utility function

$$U_{visited} = \begin{cases} R_v - C_{congestion} - C_v & \text{if visitor is admitted} \\ 0 & \text{otherwise} \end{cases}$$
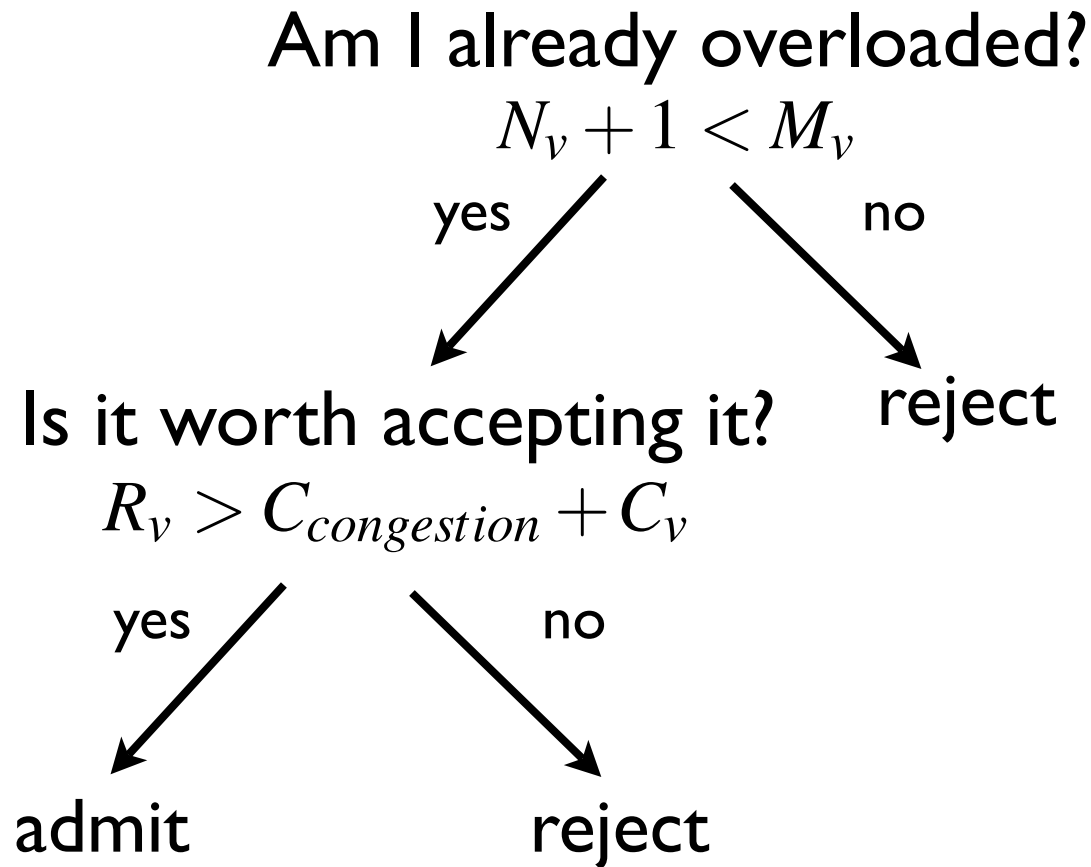
C_v Service cost

R_v Revenue (from the home operator)

$C_{congestion}$ Congestion cost of admitting the visitor

Visited Operator

Decision process

Am I already overloaded?

$$N_v + 1 < M_v$$

yes   no

Is it worth accepting it?

$$R_v > C_{congestion} + C_v$$

yes   no

reject

admit   reject

Home Operator

Utility function

$$U_{home} = \begin{cases} R + S - R_v & \text{hand-off} \\ R - C_{congestion} - C_h & \text{no hand-off} \end{cases}$$

C_h	Service cost
S	Switching cost
R	Revenue (from the subscriber)

Users

Utility function

$$U_{user} = \begin{cases} \alpha B_h - \beta D_h - R & \text{no hand-off} \\ \alpha B_v - \beta D_v - R - S & \text{hand-off} \end{cases}$$

B Observed bandwidth

D Observed delay

α Bandwidth sensitivity

β Delay sensitivity

Utility Functions

$$X_1, X_2, X_3 : \begin{cases} U_{user} & = \alpha B_h - \beta D_h - R \\ U_{home} & = R - C_{congestion} - C_h \\ U_{visited} & = 0 \end{cases}$$

$$Y : \begin{cases} U_{user} & = \alpha B_v - \beta D_v - R - S \\ U_{home} & = R + S - R_v \\ U_{visited} & = R_v - C_{congestion} - C_v \end{cases}$$

An Example

- Assumptions:

1. Users are not delay sensitive (applications such as BitTorrent): $\beta \approx 0$

2. Congestion costs are negligible: $C_{congestion} \approx 0$

3. Fair bandwidth sharing

4. Uniform distribution of users

5. Static roaming and service charge

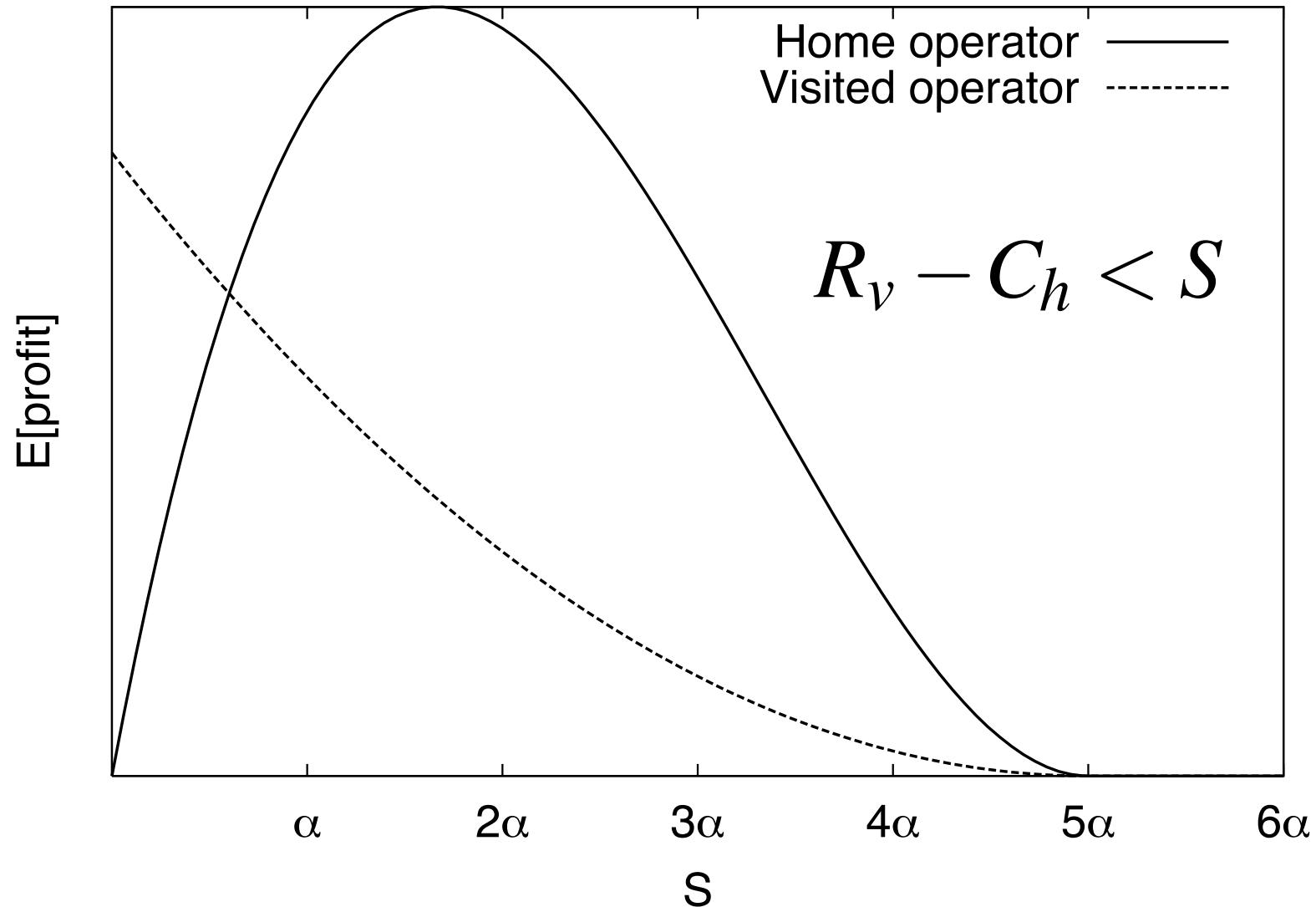**What is the optimal switching cost?**

Hand-off Conditions

Visited $\quad R_v - C_v > 0$

Home $\quad R_v - C_h < S$
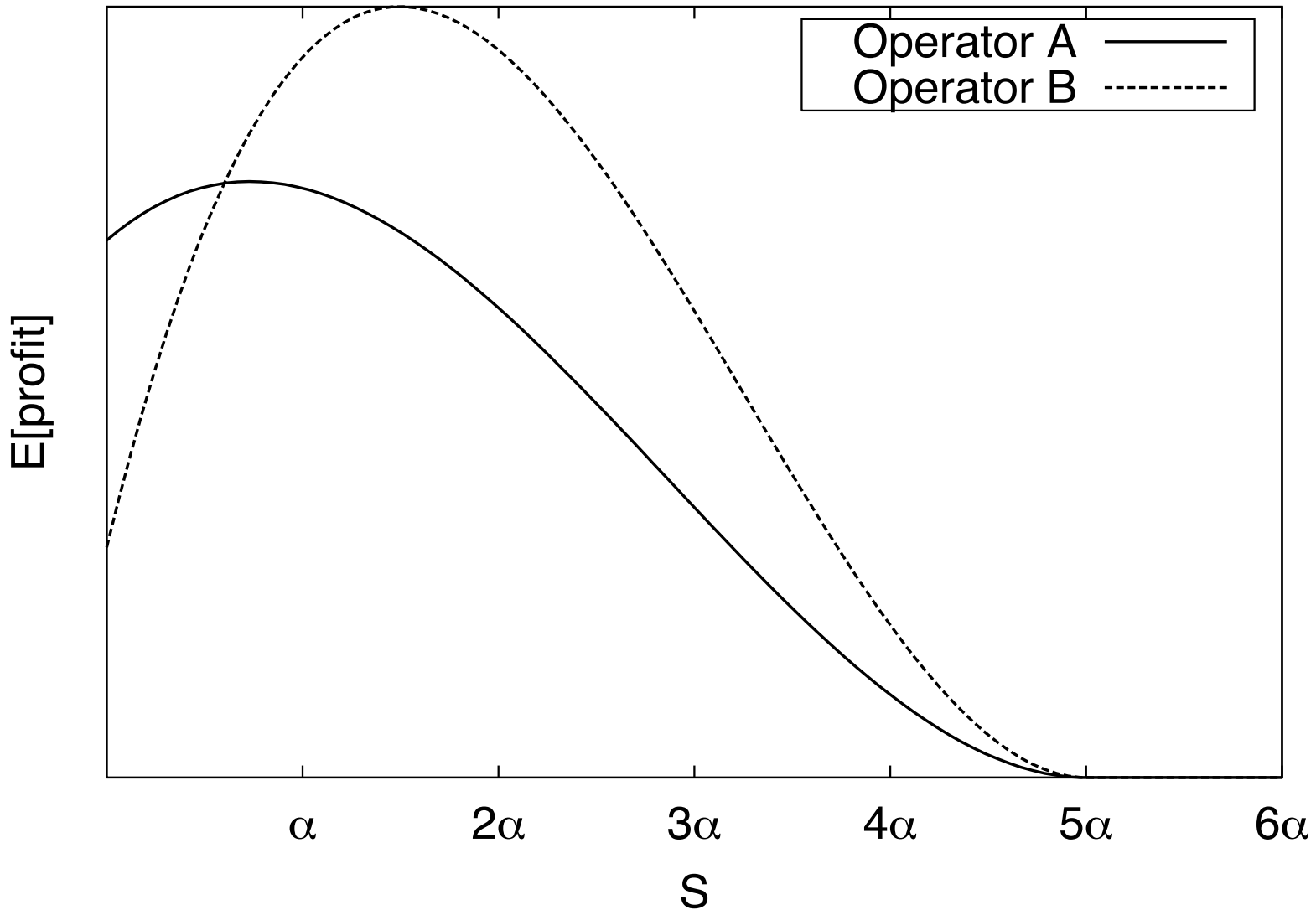
User $\quad \alpha B_v - \alpha B_h > S$

Question: $Pr(B_v(N_v) - B_h(N_h) > \dfrac{S}{\alpha}) = ?$

Expected Profit

Both Roles

A is visited 20% and B is visited 80%

Future Work

○ Relaxing the assumptions:

- ☐ What about delay-sensitive users?

- ☐ What about congestion costs?

- ☐ What about realistic user distribution?

- ☐ What about dynamic roaming charges?

More Future Work

- Users are not smart "game players"

  - Current devices require user intervention for association decisions.

- Wi-Fi MVNO business model?

- How will "free" access points and other types of networks (e.g. GPRS) affect the optimal price?

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