Economics of Public Wi-Fi Monetization and Advertising

Haoran Yu[1,2], Man Hon Cheung[1], Lin Gao[1,3], and Jianwei Huang[1]

[1]Department of Information Engineering, The Chinese University of Hong Kong

[2]Department of Electrical Engineering, Yale University

[3]School of Elec. and Info. Eng., Harbin Inst. of Technology Shenzhen Grad. School, China

Public Wi-Fi is everywhere

Background

Venues: largest public Wi-Fi providers

- Top 3: Retailers > Cafes & Restaurants > Hotels

Venues	Retails	Cafes & Restaurants	Hotels	Others	Total
Wi-Fi hotspots	5,763,907	4,259,351	397,905	1,808,234	12,229,397

Predicted Wi-Fi Ownership by Venue Type, 2018 ©WBA

- Reasons to provide Wi-Fi
  - Enhance customers' experiences
  - Provide location-based services (*e.g.*, navigation, billing, social interaction)
- Question: It is costly to deploy and operate the public Wi-Fi networks. How do venues generate revenue?

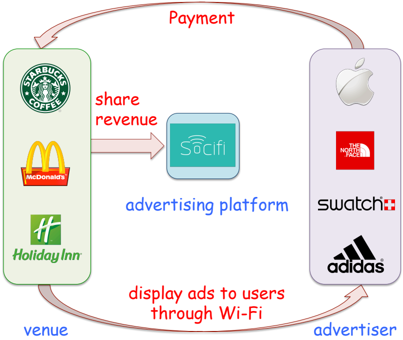
First Approach: Ad Sponsored Wi-Fi Access

Users watches an ad (*e.g.*, 30sec) and then connect Wi-Fi for a certain period (*e.g.*, 30min)

play sponsored video *(advertisement)* and connect

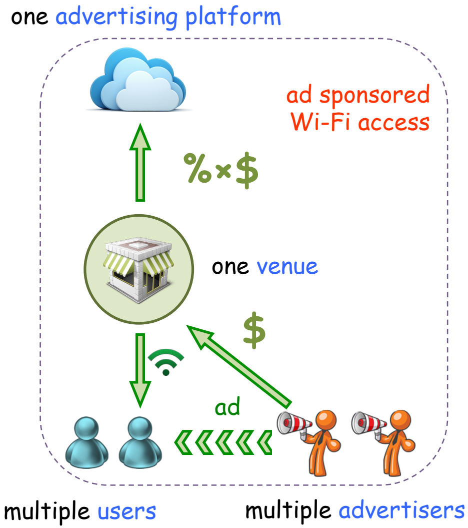
First Approach: Ad Sponsored Wi-Fi Access

- Advertising platform (*e.g.*, SOCIFI) organizes a two-sided market between venues and advertisiers
- Example:
  - Starbucks (venue) displays Apple's (advertiser) ad to users in Wi-Fi;
    - ★ User watches the ad, and uses Wi-Fi for 30min for free
  - Apple pays Starbucks based on the ad display times;
  - Starbucks shares 30% revenue with SOCIFI (advertising platform)



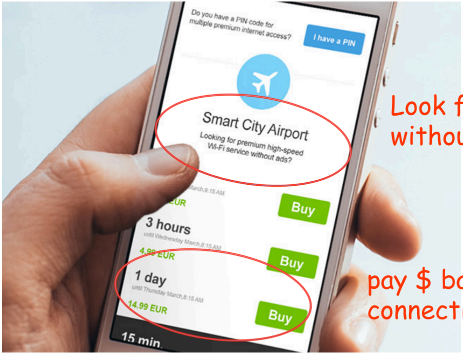
First Approach: Ad Sponsored Wi-Fi Access

Illustration of ad sponsored Wi-Fi access



Second Approach: Premium Wi-Fi Access

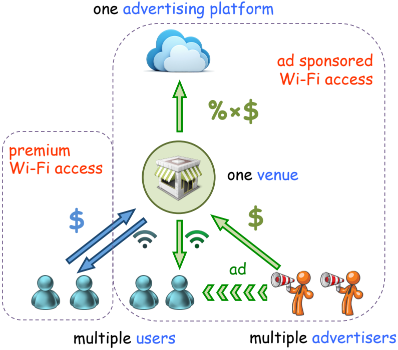
Users directly pay the venue to use Wi-Fi



Look for Wi-Fi without ads?

pay $ based on connection time

Public Wi-Fi Monetization Ecosystem



Understand each decision maker's optimal behavior

- Advertising platform: What is the ad revenue sharing proportion?
- Venue:
  - How much to charge advertisers for displaying ads?
  - How much to charge users for premium access?
- Each advertiser: How many ads to display at the venue?
- Each user: Which Wi-Fi access type to choose?

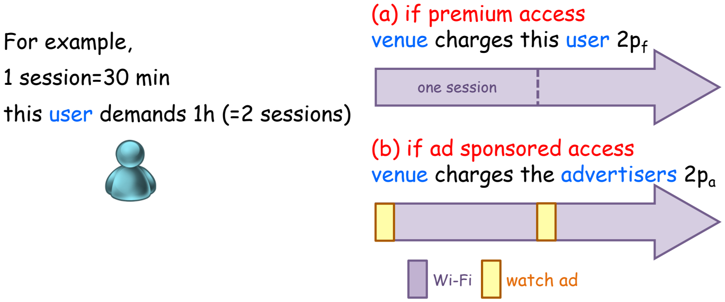
System Model: Advertising Platform

Ad revenue sharing ratio $\delta \in [0, 1]$: the fraction of the ad revenue the venue needs to transfer to advertising platform.

System Model: Venue

Two decision variables:

- Wi-Fi price p_f (premium access): if a user chooses premium access, venue charges the user p_f per session;
- Advertising price p_a (ad sponsored access): if a user chooses ad sponsored access, venue charges the corresponding advertisers p_a per displayed ad.



System Model: Users

- Consider N users, and each user's type $\theta \sim U\left[0, \theta_{\max}\right]$ describes its valuation for Wi-Fi access
- A user's access choice $d \in \{0, 1\}$:
  - $d = 0$ denotes the ad sponsored access;
  - $d = 1$ denotes the premium access.
- A type-θ user's payoff in one session is:

$$\Pi^{\text{user}}(\theta, d) = \begin{cases} \theta(1-\beta), & \text{if } d = 0 \text{ (ad sponsored access)}, \\ \theta - p_f, & \text{if } d = 1 \text{ (premium access)}, \end{cases} \tag{1}$$

  where $\beta < 1$ captures the inconvenience of watching ads.
- The number of sessions that a user demands within the considered time period (*e.g.*, one week) follows the Poisson distribution with parameter $\lambda > 0$. Parameter λ describes users' visiting frequency at the venue.

System Model: Advertisers

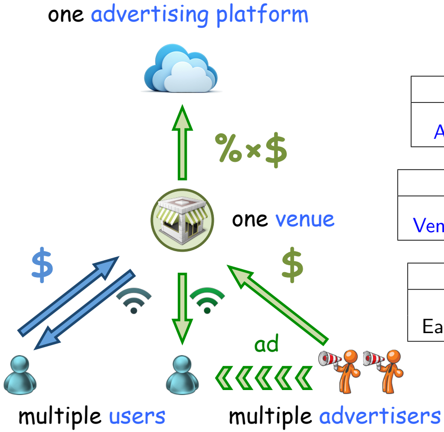
- Consider M advertisers, and each advertiser's type $\sigma \sim U[0, \sigma_{\max}]$ describes its popularity (the popularity decreases with σ).
- An advertiser's strategy $m \geq 0$: number of ads to display at the venue
- A type-σ advertiser's payoff

$$\Pi^{\text{advertiser}}(\sigma, m) = \underbrace{as(\sigma) N\varphi_a(p_f)\left(1 - e^{-\frac{m}{N\varphi_a(p_f)}}\right)}_{\text{Utility}} - \underbrace{p_a m}_{\text{Payment}} \qquad (2)$$

  - a: unit profit of showing the ad to a targeted user
  - $s(\sigma)$: popularity of the advertiser (decrease with σ)
  - $N\varphi_a(p_f)$: number of users choosing the ad sponsored access
  - $\left(1 - e^{-\frac{m}{N\varphi_a(p_f)}}\right)$: probability for a user to see the advertiser's ad (obtained via computation), and is concavely increasing in m
  - p_a: advertising price (set by the venue)

Three-Stage Stackelberg Game

Solution: backward induction (Stage III→Stage II→Stage I)



Stage I

Advertising platform specifies the sharing policy δ.

⇓

Stage II

Venue specifies Wi-Fi price p_f and advertising price p_a.

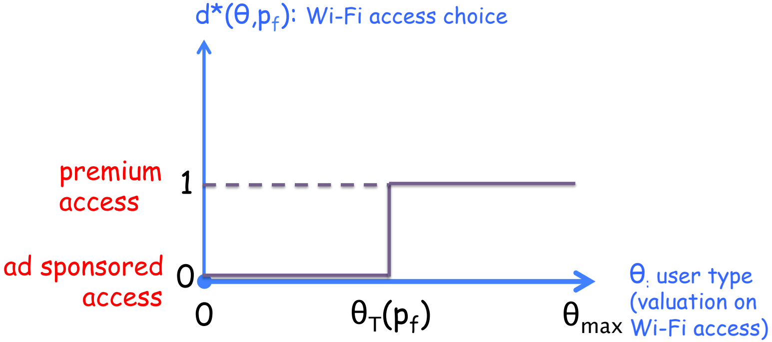
⇓

Stage III

Each User with type θ makes access choice d;
Each Advertiser with type σ purchases m ad spaces.

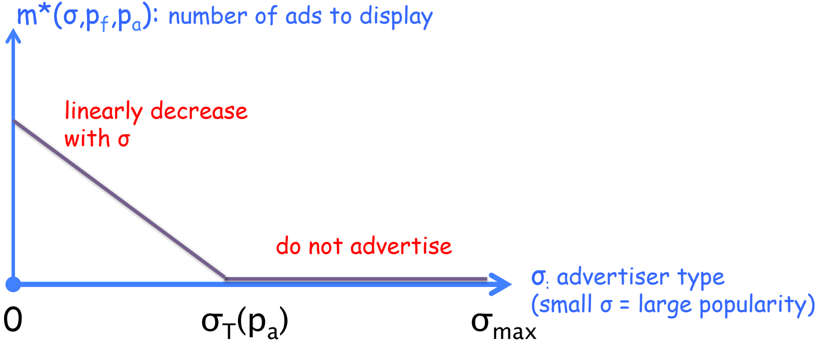
Stage III: Users' Optimal Access Choices

- Users' threshold policy:
  If $\theta < \theta_T(p_f)$, use ad sponsored access;
  If $\theta \geq \theta_T(p_f)$, use premium access.
- Threshold $\theta_T(p_f)$ is non-decreasing in p_f



Stage III: Advertisers' Optimal Advertising

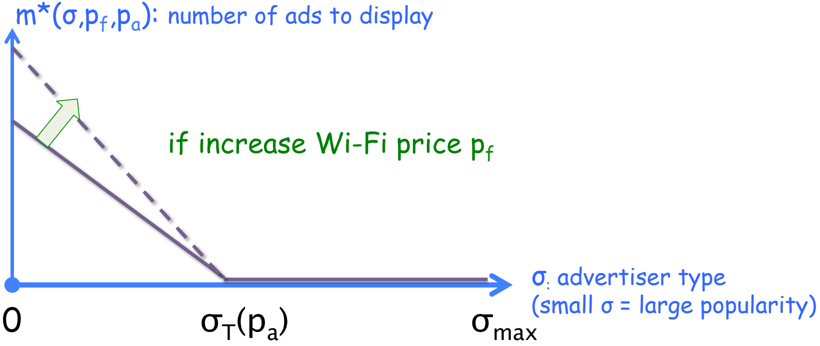
- Advertisers' threshold policy:
  If $0 \leq \sigma \leq \sigma_T(p_a)$, advertise, and number of ads decreases with σ;
  If $\sigma_T(p_a) < \sigma \leq \sigma_{\max}$, do not advertise



Stage III: Advertisers' Optimal Advertising

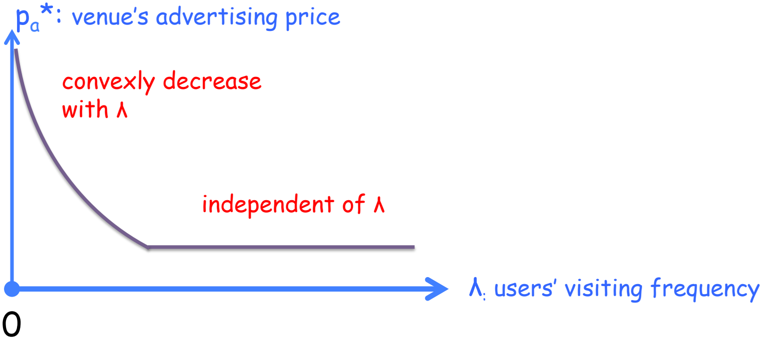
If Wi-Fi price p_f increases (more users choose the sponsored access),

- threshold $\sigma_T(p_a)$ does not change: the number of advertiser types that need to advertise does not change
- slope increases: the advertisers who originally advertise should display more ads



Stage II: Venue's Optimal Advertising Price

Venue's optimal advertising price p_a^* (limit case $M \to \infty$ and $\sigma_{\max} \to \infty$)
(1) p_a^* is independent of the advertising platform's sharing ratio δ;
(2) p_a^* decreases with λ for small λ region (reason: limited ad spaces);
(3) p_a^* is independent of λ for large λ region (reason: enough ad spaces).



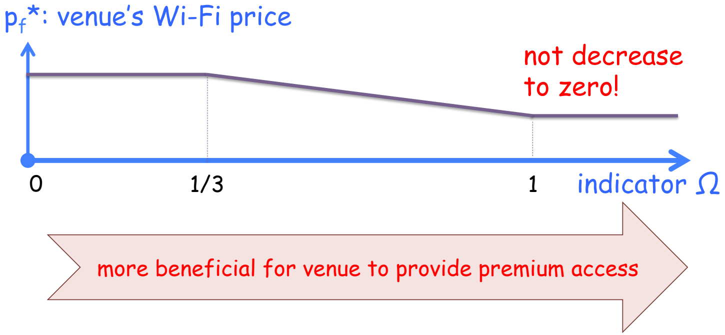
Stage II: Venue's Optimal Wi-Fi Price

Define indicator $\Omega \triangleq \frac{\lambda\beta\theta_{\max}}{ag(\lambda,\gamma,\eta)}$

- Parameters' meanings
  - λ: users' visiting frequency
  - β: users' payoff reduction due to watching ads
  - $\theta_{\max}$: users' maximum valuation on Wi-Fi access
  - a: unit profit for an advertiser of showing the ad to a targeted user
  - γ: the venue's advertising concentration level
  - η: the expected number of advertisers that a user likes
- Intuition: a large Ω implies that the venue can earn more revenue by providing the premium access comparing to the ad sponsored access.

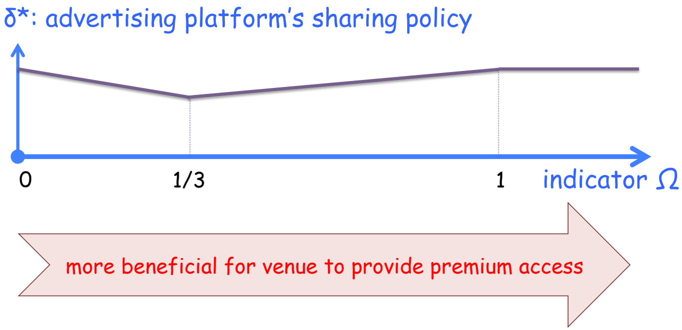
Stage II: Venue's Optimal Wi-Fi Price

- Indicator Ω: a large Ω implies that the venue can earn more revenue by providing premium access comparing to ad sponsored access
- Wi-Fi price p_f^* is non-increasing in Ω



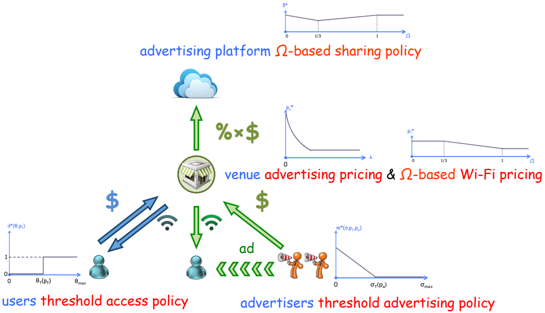
Stage I: Advertising Platform's Optimal Sharing Policy

- Indicator Ω: a large Ω implies that the venue can earn more revenue by providing premium access comparing to ad sponsored access
- Sharing ratio δ^*:
  - first decreases with Ω: attract venue to provide ad sponsored access;
  - second increases with Ω: directly extract more ad revenue from venue



Conclusion and Future Work

- Public Wi-Fi monetization problem
  - Five threshold strategies for decision makers



- Future work
  - QoS differentiation (*e.g.*, premium access with QoS guarantee)
  - Influence of Wi-Fi capacity

THANK YOU

Network Communications and Economics Lab

http://ncel.ie.cuhk.edu.hk

Stage III: ADs' Advertising

AD's optimal advertising strategy

A type-σ AD's optimal advertising strategy is

$$m^*(\sigma, p_f, p_a) = \begin{cases} N\varphi_a(p_f)\left(\ln\left(\frac{a\gamma}{p_a}\right) - \gamma\sigma\right), & \text{if } 0 \leq \sigma \leq \sigma_T(p_a), \\ 0, & \text{if } \sigma_T(p_a) < \sigma \leq \sigma_{\max}, \end{cases} \tag{3}$$

where $\sigma_T(p_a) \triangleq \min\left\{\frac{1}{\gamma}\ln\left(\frac{a\gamma}{p_a}\right), \sigma_{\max}\right\}$ is the *threshold AD type*.

(1) $\sigma_T(p_a)$ and $m^*(\sigma, p_f, p_a)$ decrease with p_a;
(2) $m^*(\sigma, p_f, p_a)$ decreases with type σ.

Stage III: Advertisers' Optimal Advertising

Threshold $\sigma_T(p_a)$ is non-increasing in advertising price p_a