Hybrid Data Pricing for Network-Assisted User-Provided Connectivity

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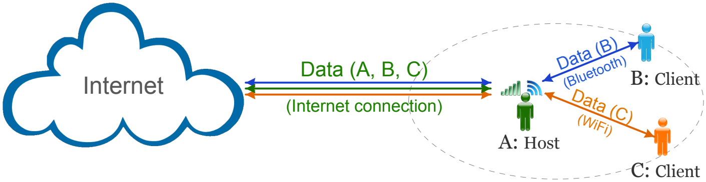
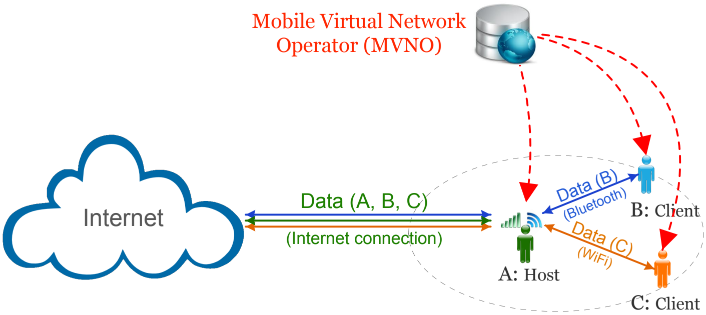
User-Provided Connectivity (UPC)



- UPC: Mobile users (clients) connect to the internet through the hosting of other mobile users (hosts).
  - ⋆ Key challenges: Security and Incentive

Network-Assisted UPC



- Network-Assisted UPC: A network operator (e.g., an MVNO) is introduced to address the security and incentive issues in UPC.
  - ★ Real Case: Karma (https://yourkarma.com)

Focus of This Work

Incentive Issue

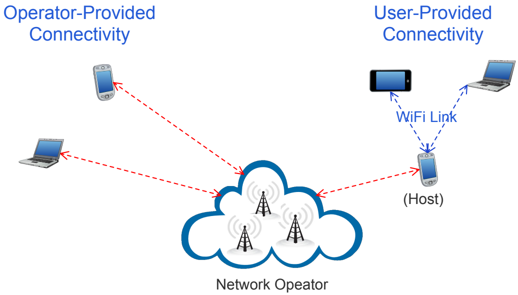
- How to design a proper incentive mechanism for the MVNO to ensure the UPC between hosts and clients?

Outline

1. Background
2. System Model
3. Game Analysis
4. Conclusion

User-Provided Connectivity (UPC)

- UPC vs OPC
  - Operator-Provided Connectivity (OPC): Users connect to internet through devices of network operators (e.g., base stations);
  - User-Provided Connectivity (UPC): Users connect to internet through devices of users (e.g., mobile phones);



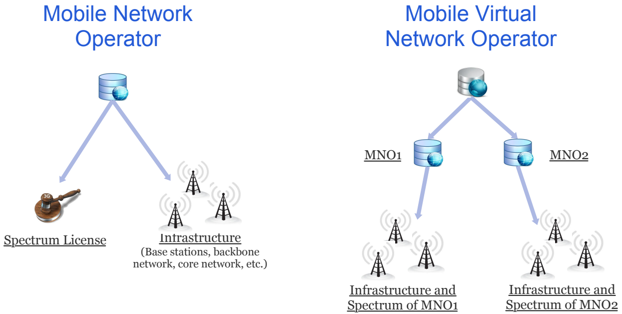
User-Provided Connectivity (UPC)

- Benefits
  - Coverage Extension
  - Service Extension
  - Resource Saving
- Challenges
  - Security
  - Economics (Incentive)

- The challenges motivate our study of Network-Assisted UPC.
  - An MVNO is introduced to address the security and incentive issues.

Mobile Virtual Network Operator (MVNO)

- MVNO vs MNO
  - Mobile Network Operator (MNO): Spectrum License, Network Infrastructure;
  - Mobile Virtual Network Operator (MVNO): No Spectrum License, No Network Infrastructure, but Leasing Spectrum and Infrastructure from MNOs;



Mobile Virtual Network Operator (MVNO)

- Benefits
  - Easy to deploy (fast, low cost, etc.)
  - Coverage aggregation (inter-national coverage)
  - Proximity to end-market (flexible pricing plans)

- By Oct. 2012, there are 634 active MVNOs worldwide.
  - Virgin Mobile (launched in 1999), operating in 6 countries
  - LycaMobile (launched in 2006), operating in 16 countries
  - Karma (launched in 2012), operating in USA
  - ...

The Karma Model

- Our work is based on the Karma Model (https://yourkarma.com).
  - Provide 4G services (with usage-based pricing) to its customers, using the cellular networks with which it has a relationship.
  - Unique feature: User-provided connectivity (UPC)
    - ⋆ *Karma enables its customers to operate as WiFi hotspots (hosts) and route traffic for other users (clients).*

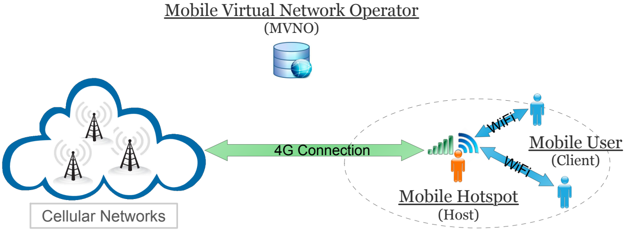


Fig. Illustration of the Karma model

The Karma Model

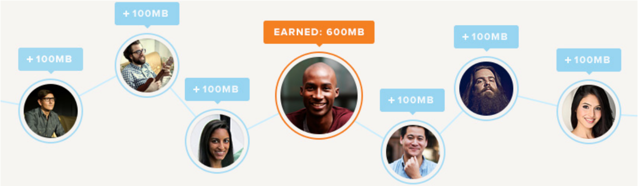
- Cost of hosts
  - Data payment
  - Quality of service degradation
  - Energy consumption
- Problem: *How to incentivize users to operate as hosts?*

The Karma Model

- Karma's approach
  - Connectivity sharing, not data sharing
    - ★ Hosts only pay the data they actually consume, and clients pay their own data usage.
  - Free data quota
    - ★ Hosts are rewarded certain free data when routing traffic for others.

The Karma Model

- Karma's free data reward strategy
  - Every host gets 100MB of free data when he shares his connectivity with every new mobile user at the first time.



- Drawbacks
  - *Easy to employ, but fail to provide consistent incentives!*

Our Purpose

- We want to design a pricing and rewarding strategy that provides consistent incentives to hosts.
- Our approach
  - We generalize the Karma strategy in the following aspects:
    - ⋆ Flexible free data quota – not fixed, but proportional to the data he routes for other users.
- Key problem: *How to design the best pricing and free data quota rewarding policy to maximize the MVNO's revenue?*

Outline

System Model

- Players: MVNO, MNO, Host, Client
  - MVNO leases network resource from MNOs;
  - MVNO serves its subscribers (Hosts and Clients) using leased resource;
    - ★ Hosts have 4G connections, and operate as hotspots;
    - ★ Clients have no 4G concoctions, and connect to internet through a host;

System Model

- We focus on the interactions of MVNO, Host, and Client.
  - How much the MVNO pricing the hosts and clients?
  - How much the MVNO rewarding the hosts?
  - How much data the hosts forwarding for the clients?

System Model

- One MVNO
  - Pay MNOs a usage-based data wholesale price w;
  - Charge subscribers (hosts and clients) a usage-based data price p.
  - Reward hosts a free data quota ratio θ.
- Hosts: $\mathcal{I} \triangleq \{1, ..., I\}$
  - Transmit their own traffic;
  - Operate as WiFi hotspots and route traffic for clients;
- Clients: $\mathcal{N} \triangleq \{\mathcal{N}_1, ..., \mathcal{N}_I\}$
  - $\mathcal{N}_i$: Access to internet through a host i;
- Time-slotted operation: $\mathcal{T} = \{1, ..., T\}$

System Model

- Parameters in one period (of T slots) for each host i:
  - $\mathbf{R}_i \triangleq \{R_{i1}, ..., R_{iT}\}$: the 4G capacity of host i;
  - $\mathbf{D}_i \triangleq \{D_{i1}, ..., D_{iT}\}$: the total client demand to host i;
    - ⋆ Shiftable vs Non-shiftable
  - $\boldsymbol{\xi}_i \triangleq \{\xi_{i1}, ..., \xi_{iT}\}$: the unit energy cost incurred by host i for transceiving one byte of data via the WiFi connection;
  - $\boldsymbol{\epsilon}_i \triangleq \{\epsilon_{i1}, ..., \epsilon_{iT}\}$: the unit energy cost incurred by host i for transceiving one byte of data via the 4G connection;

System Model

- MVNO Modeling
  - Strategy: Decide price p_i and free data quota ratio θ_i to every host i
  - Objective: Maximize the total revenue (payoff)

MVNO's Payoff

$$V(\mathbf{p}, \boldsymbol{\theta}; (\mathbf{x}_i, \mathbf{y}_i)_{i\in\mathcal{I}}) = \sum_{i=1}^{I} \sum_{t=1}^{T} \Big(p_i \cdot (x_{it} - \theta_i \cdot y_{it}) + p_i \cdot y_{it} - w \cdot (x_{it} + y_{it}) \Big)$$

- ★ x_{it}: the total data that host i consumes at slot t;
- ★ y_{it}: the total data that host i routes for other users ($\mathcal{N}_i$) at slot t;

System Model

- Host Modeling
  - Strategy
    - $\boldsymbol{\alpha}_i = \{\alpha_{it}, ..., \alpha_{iT}\}$: the percentage of host i's 4G capacity (at every slot) that will be scheduled for his own data;
    - $\boldsymbol{\beta}_i = \{\beta_{it}, ..., \beta_{iT}\}$: the percentage of host i's 4G capacity (at every slot) that will be scheduled for serving other clients;
    - $x_{it} = \alpha_{it} \cdot R_{it}$, and $y_{it} = \beta_{it} \cdot R_{it}$.
  - Objective: Maximize the total payoff, including
    - Utility from consuming data
    - Payment to the MVNO
    - Energy consumption

Host i's Payoff

$$J_i(\boldsymbol{\alpha}_i, \boldsymbol{\beta}_i; p_i, \theta_i) = U_i(\mathbf{x}_i) - \sum_{t=1}^{T} p_i \cdot (x_{it} - \theta_i \cdot y_{it}) - \sum_{t=1}^{T} \epsilon_{it} x_{it} - \sum_{t=1}^{T} (\epsilon_{it} + \xi_{it}) \cdot y_{it},$$

System Model

- Host Service Modeling
  - Elastic service: concave utility function $U_i(\cdot)$
    - ★ Achieve a higher utility when consuming more data;

$$U_i(\mathbf{x}_i) = \log(x_{i1} + ... + x_{iT})$$

  - Inelastic service: step utility function $U_i(\cdot)$
    - ★ Achieve a certain utility when consuming a minimum amount of data;

$$U_i(\mathbf{x}_i) = \begin{cases} v_i, & \text{if } \sum_{t \in \mathcal{T}} x_{it} \geq B_i; \\ 0, & \text{if } \sum_{t \in \mathcal{T}} x_{it} < B_i. \end{cases}$$

System Model

- Problem Formulation – Hybrid Pricing Game
  - Game leader: the MVNO
    - ⋆ Deciding price and free data quota reward to every host;
  - Game follower: Hosts
    - ⋆ Deciding how much data they are going to consume for themselves, and how much they are going to route for clients.

Outline

Step II – Host's Decision

Host i's Problem

$$\max_{\boldsymbol{\alpha}_i, \boldsymbol{\beta}_i} \quad J_i(\boldsymbol{\alpha}_i, \boldsymbol{\beta}_i; p_i, \theta_i)$$

$$\text{s.t., (a) } \alpha_{it} + \beta_{it} \leq 1, \quad \forall t \in \mathcal{T}$$

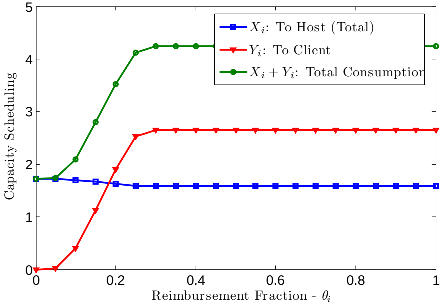
$$\text{(b) } \beta_{it} \cdot R_{it} \leq D_{it}, \quad \forall t \in \mathcal{T}$$ (Non-shiftable demand)

or

$$\text{(b) } \sum_{t=1}^{T} \beta_{it} \cdot R_{it} \leq D_i$$ (Shiftable demand)

- $\boldsymbol{\alpha}_i = \{\alpha_{it}, ..., \alpha_{iT}\}$: the percentage of host i's 4G capacity (at every slot) that will be scheduled for his own data;
- $\boldsymbol{\beta}_i = \{\beta_{it}, ..., \beta_{iT}\}$: the percentage of host i's 4G capacity (at every slot) that will be scheduled for serving other clients;

Step II – Host's Decision

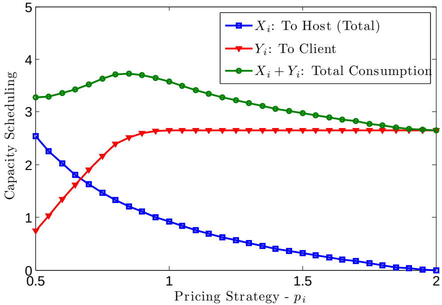


Observation

- X_i decreases with θ_i (Blue curve);
- Y_i increases with θ_i (Red curve);
- $X_i + Y_i$ increases with θ_i (Green curve).

  - $X_i = \sum_{t=1}^{T} \alpha_{it}^* \cdot R_{it}$: the total data consumed by host i;
  - $Y_i = \sum_{t=1}^{T} \beta_{it}^* \cdot R_{it}$: the total data consumed by clients in $\mathcal{N}_i$;

Step II – Host's Decision



Observation

- X_i decreases with p_i (Blue curve);
- Y_i increases with p_i (Red curve);
- $X_i + Y_i$ first increases and then decreases with p_i (Green curve).

  - $X_i = \sum_{t=1}^{T} \alpha_{it}^* \cdot R_{it}$: the total data consumed by host i;
  - $Y_i = \sum_{t=1}^{T} \beta_{it}^* \cdot R_{it}$: the total data consumed by clients in $\mathcal{N}_i$;

Step I – MVNO's Decision

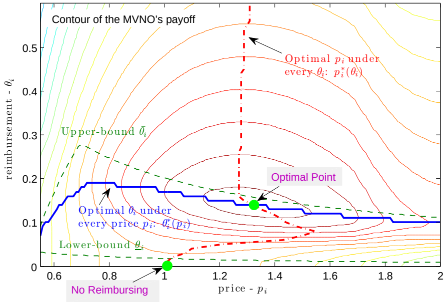
MVNO's Problem for Host i

$$\max_{p_i,\theta_i} \quad V_i(p_i, \theta_i; \boldsymbol{\alpha}_i^*, \boldsymbol{\beta}_i^*)$$

$$\triangleq p_i \cdot (X_i - \theta_i \cdot Y_i) + p_i \cdot Y_i - w \cdot (X_i + Y_i)$$

- $X_i = \sum_{t=1}^{T} \alpha_{it}^* \cdot R_{it}$: the total data consumed by host i;
- $Y_i = \sum_{t=1}^{T} \beta_{it}^* \cdot R_{it}$: the total data consumed by clients in $\mathcal{N}_i$;

Step II – MVNO's Decision



Solution

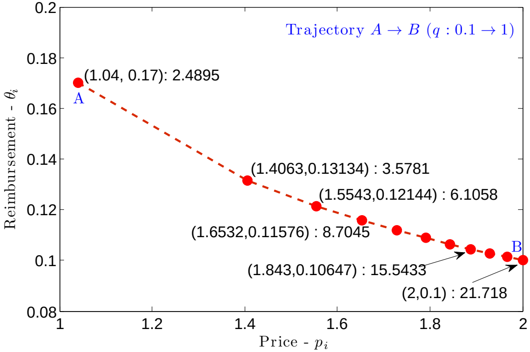
- $\theta_i^*(p_i)$: the optimal θ_i^* under any price p_i (Blue curve);
- $p_i^*(\theta_i)$: the optimal p_i^* under any free data quota θ_i (Red curve);
- (p_i^*, θ_i^*): the intersection (Upper Green point) of $\theta_i^*(p_i)$ and $p_i^*(\theta_i)$.

  - $p_i^*(0)$: the optimal price in a pure pricing system (Lower Green point);

Outline

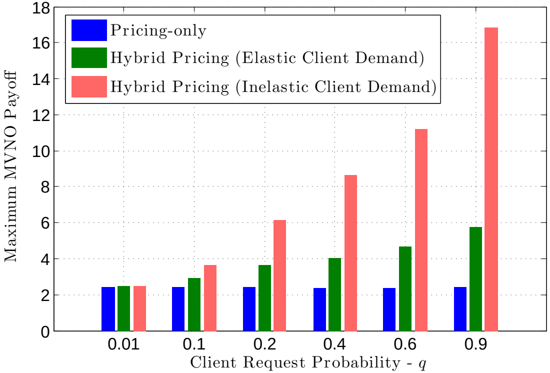
Simulation

- Optimal Hybrid Pricing Strategy
  - q: Clients' service request probability
  - $q : 0.1 \rightarrow 1$: The trajectory changing from point A to point B



Simulation

- MVNO's Optimal Revenue
  - Increase 20% to 135% under the elastic client demand (GREEN bar) when q increases from 0.1 to 0.9;
  - Increase 50% to 550% under the inelastic client demand (RED bar) when q increases from 0.1 to 0.9;



Conclusion

- We propose a hybrid pricing scheme for the network-assisted UPC system;
- We derive the optimal hybrid pricing policy that maximizes the MVNO's revenue.
- Future Extension — Incomplete Information
  - How to derive the optimal hybrid pricing policy when only the stochastic information is available?
  - How to deal with the problem even when the stochastic information is not available?

Thank You

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Network Communications and Economics Lab (NCEL)

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Smart Data Pricing (2nd May, 2014)

- Multi-disciplinary program
- Academic keynote: Alok Gupta (UMN)
- Industry keynote: Keith Cambron (Former President AT&T Lab)