Assessing the Potential Opportunities of User-Provided Connectivity

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Workshop on Information & Communication Systems and their Application to Vertical Sectors

Montevideo, Uruguay, March 16-18, 2015
Acknowledgments

• This talk is based on joint work with M. H. Afrasiabi (Ph.D. student at Penn) and was funded by NSF grant CNS-0915982

• All errors and/or lack of clarity are, however, my own doing

• More details can be found at


Premises

• The rise of the sharing economy
  • Car sharing, e.g., Uber, Lyft, RelayRides, Zipcar, car2go, etc.
  • Home sharing, e.g., Airbnb, HomeAway, VRBO, Wimdu, 9flats, etc.
  ⇒ Connectivity sharing: FON, AnyFi, airfy, (KeyWifi), Comcast XFINITY WiFi sharing, etc.

• The user as the infrastructure
  • Organic growth
  • Lower costs

But when and how does it work or be made to work?
The FON Model (Over 14 Millions Users)

- FON users trade ability to access other users’ WiFi hotspots for reciprocation (i.e., allowing other FON users to access their own WiFi hotspot)
- Alternative options are also possible, e.g., provide access in exchange for compensation but without reciprocation rights
Framing the Investigation

Key features behind a “user as the network” system

• The network value depends on adoption
  – More users means broader coverage
  – But, with more users, having to share (whether at home or on the road) becomes more likely

• It also depends on how often users need access to and can access shared resources
  – FON’s main benefit is while “roaming”
  – FON is only useful if you can find a FON spot

• Finally, it depends on cost, pricing, and possible “compensation” (for sharing)
Methodology

• Develop and analyze a “stylized” analytical model
  – Simplifying assumptions for analytical tractability
  – Explore solutions’ structure
  – Extract insight and guidelines

• Validation through numerical evaluation and simulations
  – Relaxation of simplifying assumptions
  – Do major outcomes still (qualitatively) hold?
High-Level Model Definition

• Consider a service offered to a (very) large population of heterogeneous users
• Users evaluate the service and adopt (purchase), only if they derive positive value from it
  – Value is measured through a utility function incorporating different parameters that characterize the service and its users
  – As mentioned, a key aspect of a FON-like service is that its value changes with its adoption (because of positive and negative externalities)
Specifying The Model

- Users’ heterogeneity is in their roa**ming** propensity $\theta$, $\theta \in [0,1]$.
  - The main feature of a FON-like service is connectivity while away from home.
- Utility of user with roaming value $\theta$ given a set of adopters $\Theta$:
  
  $$ U(\Theta, \theta) = F(\theta, \kappa(\Theta)) + G(m(\Theta)) - p(\Theta, \theta) $$

  - $F(\cdot, \cdot)$: value of connectivity (at home and while roaming).
  - $\kappa(\Theta)$: service coverage given $\Theta$.
  - $G(\cdot)$: (negative) impact of roaming traffic, and positive impact of possible compensation.
  - $m(\Theta)$: volume of roaming traffic generated by $\Theta$ adopters.
  - $p(\Theta, \theta)$: service price for user $\theta$, given $\Theta$.

User $\theta$ adopts iff $U(\Theta, \theta) > 0$.
Making Things Tractable
(To Facilitate Analytical Insight)

- Linear value functions and uniform distributions
  - Value is proportional to frequency of connectivity
  - $\theta$ is uniformly distributed in $[0,1]$
  - Users are uniformly distributed over service area
    - Service coverage $\kappa$ equals adoption level $x$
  - Roaming patterns are uniform over service area
    - Roaming traffic $m$ is evenly distributed across adopters
  - Each user contributes one unit of traffic

- Utility is then of the form
  \[
  U(\Theta, \theta) = (1 - \theta) \gamma + \theta x(\Theta) - cm(\Theta) - p(\Theta, \theta)
  \]
  - $\gamma$ is value of home connectivity, $r$ is value of roaming
    connectivity, and $c$ is impact of roaming traffic (minus any
    compensation) – We assume $c < r$
Questions of Interest

• When can the service succeed and generate substantial value?
  – Maximum total welfare?
  – When are maximum welfare and maximum adoption congruent?

• What pricing strategies?
  – Pricing controls
    • Users adoption
    • Provider’s ability to extract welfare from users
    • Whether welfare or profit is maximized, or both
  – Complexity of implementation (how much information)
A Two-Prong Investigation

1. Characterizing system welfare
   – How useful is the service and for whom?

2. Exploring pricing strategies and their impact
   – A benchmark: Discriminatory pricing
   – Four practical pricing strategies with different levels of implementation complexity
Where Is The Value in UPC?

Value of user $\theta$: $(1 - \theta)\gamma + \theta rx - cm(\Theta) - e$, $e = \text{cost}$

- Different users see different changes in the value they contribute as adoption varies
  - Low $\theta$ users see decreases in utility as $x$ increases
  - High $\theta$ users see increases in utility as $x$ increases
Maximizing Welfare

Value of user $\theta$: $(1 - \theta)\gamma + \theta r x - c m(\Theta) - e$, $e = \text{cost}$

- Two main welfare regimes
  1. $\gamma \leq (r - c)$, welfare is maximized at full or zero adoption depending on service cost, $e$
  2. $\gamma > (r - c)$, intermediate regime can emerge

- **Intuition**: When home connectivity value is
  - low relative to the net value of roaming connectivity, service cost is the main factor
  - high relative to the net value of roaming connectivity, limiting adoption can be preferable when service cost is high
From Welfare to Profit

- Provider seeks control on converting welfare into profit
- Pricing is the tool that realizes this goal
  - Users’ heterogeneity implies pricing heterogeneity
  - Pricing also affects adoption (service value varies)
- Discriminatory pricing as an impractical benchmark
  - Each user’s price set to “value + cost – $\varepsilon$”, $\varepsilon > 0$
    - $p(\Theta, \theta) = [(1 - \theta)\gamma + \theta\rho\xi - cm(\Theta) - e] + e - \varepsilon$
  - Realizes full adoption (all users have positive utility $\varepsilon > 0$)
  - Can arbitrarily adjust transfer of welfare between users and provider
  - Note: Setting $p(\Theta, \theta) = e$, also results in a provider’s profit of 0, but does so very differently (more on this later)
Pricing Strategies

- We investigate four (practical) pricing policies that offer different trade-offs between efficiency and complexity:
  1. **Usage based pricing**, $p_h$ per unit of traffic from home and $p_r$ per unit of traffic while roaming
  2. **Hybrid pricing**, fixed price $p_h$ for home connectivity, and $p_r$ per unit of traffic while roaming
  3. **Fixed price $p$** for home and roaming connectivity (FON model)
  4. **Pricing options**: Users choose the best of two alternatives
     a. Fixed price $p_h$ for home connectivity and free roaming
     b. Fixed price $p_h$ for home connectivity, $p_r$ per unit of traffic while roaming, and compensation of $b$ per unit of roaming traffic using their home access
Usage-Based Pricing

- Mimics discriminatory pricing (based on roaming profile, $\Theta$)
  - $p(u_h, u_r) = p_h \cdot u_h + p_r \cdot u_r - a$, ($a$ is allowance, and $u_h$ and $u_r$ are home and roaming usages, respectively)
  - $p_\Theta = p_h(1 - \Theta) + p_r,\Theta x(\Theta) - a$
  - $U(\Theta, \Theta) = \gamma(1 - \Theta) + r,\Theta x(\Theta) - cm(\Theta) - p_h(1 - \Theta) - p_r,\Theta x(\Theta) + a$

  Set $p_h = \gamma$ and $p_r = r$, $\Rightarrow U(\Theta, \Theta) = a - cm(\Theta)$, $\forall \Theta$, i.e., for all users

  - Full adoption, *i.e.*, $x([0,1]) = 1$, (hence, maximum welfare) is readily realized by setting $a > cm([0,1])$ ($= c/2$ for uniform roaming traffic)
    $\Rightarrow$ All users have the same positive utility

- Allowance, $a$, is a “control knob” for arbitrarily shifting welfare from users to provider (from 0 to max value)
Usage-Based Pricing Summary

• A highly effective though complex policy
  – Can simultaneously maximize welfare and profit
  – Can be “tuned” to arbitrarily shift welfare from users to provider

• Note: Maximizing welfare may require subsidies
  – \( p_\theta = \gamma(1 - \theta) + r\theta - a = \gamma - a + \theta(r - \gamma) \)
    • \( p_\theta < 0 \iff \theta < (a - \gamma)/(r - \gamma) \)
  – Sedentary users must be enticed to stay when value of home connectivity, \( \gamma \), is low compared to allowance, \( a \)
Hybrid Pricing

- Fixed-price, $p_h$, at home, and usage-based roaming pricing, $p_r$
  
  
  \[ p(u_r) = p_h + p_r \cdot u_r = p_h + p_r \theta x(\Theta) \]

  \[ U(\Theta, \theta) = \gamma(1 - \theta) + r \theta x(\Theta) - cm(\Theta) - p_h - p_r \theta x(\Theta) \]
  \[ = (\gamma - cm(\Theta) - p_h) + \theta(r x(\Theta) - \gamma - p_r x(\Theta)) \]
  \[ = (\gamma - c/2 - p_h) + \theta(r - \gamma - p_r), \text{ at full adoption, } x = 1 \]

- Full adoption is *unique* equilibrium iff
  
  \[ \theta = 0 \text{ user has positive utility, } i.e., p_h < \gamma - c/2 \]

  \[ \theta = 1 \text{ user has positive utility, } i.e., r - c/2 > p_r + p_h \]

  \[ \text{And either } \gamma < c, \text{ or when } \gamma \geq c, \text{ a more complex condition that upper-bounds } p_h \text{ based on a decreasing function of } p_r \]

  \[ \Rightarrow \text{The latter can prevent recouping all welfare as profit} \]
Welfare = profit \Rightarrow \begin{align*}
  p_h &= \gamma - c/2 - \varepsilon \\
  p_r &= r - \gamma - \varepsilon, \quad \varepsilon > 0, \quad \varepsilon \approx 0
\end{align*}

r = 1.6, \ c = 0.8, \ \gamma = 1 \ (>0.8), \ p_h = 0.59, \ p_r = 0.6

As adoption increases, positive and negative externalities compete to change users’ utility. When \( \gamma \geq c \), the relative utility margin of early adopters (low \( \theta \)) is lower, and a “cross-over” becomes possible.
Fixed Price Policy (FON-Like)

- Structurally, a fixed price cannot maximize profit and/or welfare
  - Unable to capture different users’ utility
  - Unable to afford subsidies when needed
- But it has the benefit of simplicity
- Two main questions
  - Price effect on ability to maximize welfare
  - Tension between profit and welfare maximization
Fixed Price Policy Properties

\[ U(\Theta, \theta) = \gamma(1 - \theta) + r\theta x(\Theta) - cm(\Theta) - p \]

\[ U([0,1], \theta) = \gamma - c/2 - p + \theta(r - \gamma) \]

- Maximizing welfare calls for a low enough price
  - \( p < \min \{ \gamma - c/2, \gamma - \gamma^2/(4r - 2c) \} \)
  - Positive utility for \( \theta = 0 \) user at full adoption, and additional condition to avoid “cross-over” as adoption increases

- However, simultaneously maximizing welfare and profit conflicts unless negative impact of roaming traffic, \( c \), is small
The “Cost” of Welfare Maximization

- Targeting maximum service adoption can result in a substantial drop in profit
- Controlling the negative impact of roaming traffic is key to mitigating this
Giving Users Pricing Options

• Motivation: Instead of subsidies, users that roam infrequently are offered compensation, but they have to pay when roaming
  1. Pay $p$ plus pay $p_r$ when roaming, but get compensated $b$ per unit of roaming traffic your home WiFi carries; or
  2. Pay $p$ and roam for free

Seeks to combine the best of fixed-price and hybrid policies

• However, giving users the option to choose between policies adds significant complexity to the analysis
  – Adoption regions can become disconnected
Adoption Progression Under a Two-Price Policy

\[ r = 1.6, \ c = 0.8, \ \gamma = 0.2 \]
\[ p = 0.371, \ p_r = 0.08, \ b = 0.5 \]
Hybrid vs. Fixed vs. Optional Pricing

- **Of note**: Optimizing profit under the hybrid policy still maximizes welfare (though the profit needs not be equal to the maximum possible profit)
- Optional pricing policy offers an intermediate solution between hybrid and fixed-price policies
  - It achieves maximum adoption in most scenarios,
  - It improves profit over the fixed-price policy, though it still lags behind the hybrid policy
Summary

- Unless the value of home connectivity is high relative to the net value of roaming connectivity, **the value of UPC grows with its user-base**
- A **usage-based pricing** scheme offers the **most flexibility** in maximizing value and in allocating it between users and provider, but it has a high implementation cost.
- A **hybrid scheme** offers a possible **trade-off** between efficiency and cost:
  - Main deficiency, somewhat surprisingly, arises when impact of roaming traffic is small
  - It can be addressed through the use of “introductory pricing”
- A **fixed-price scheme** (FON) has the benefit of simplicity, but **can quickly limit adoption in favor of higher profits**:
  - Impact of roaming traffic needs to be tightly controlled
- A **two-price option** can improve on the fixed-price policy at the cost of some additional complexity
- The findings hold under various relaxations of the simplifying assumptions used to facilitate analytical tractability.