The Effect of WiFi Offloading on Pricing Wireless Services

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ABSTRACT

WiFi offloading has been recently proposed as a cost-effective solution for coping up against the unprecedented increase in the mobile data traffic volume. However, apart from reducing the operational costs of a network operator, WiFi offloading can be also promoted as an alternative low-cost access service for users with low willingness-to-pay. In this paper, we consider a monopolistic scenario of a Mobile Virtual Network Operator (MVNO) offering LTE and WiFi access services and find the optimal pricing decisions. We further illustrate that the presence of reluctant users to switch to the WiFi service could increase the profits of the MVNO.

Keywords

Pricing, Economics, Mobile Virtual Network Operator, WiFi Offloading, Access Market

1. INTRODUCTION

Offloading has been recently proposed as a candidate solution for delivering data, originally targeted for cellular networks, using complementary network technologies, such as WiFi, femtocell. This promising solution could significantly save the operational cost of a network operator, especially when existing deployed complementary network infrastructure is exploited.

References [8, 1] experimentally evaluate the benefits that offloading can bring to network providers and users. In [2], real data are used to measure how much offloading can be achieved with varying number of access points (APs), as well as to investigate the minimum number of APs that can guarantee the desired quality of service for data delivery. Other works focus on incentive frameworks enabling third-party resource owners to share their infrastructure [5, 3].

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Several research efforts study the economic aspects of offloading and delayed traffic. Delayed offloading alleviates mobile data explosion, by persuading users to wait for a certain time period before they send their delay-tolerant traffic to exploit users’ chance to meet a WiFi AP. In [11], an incentive framework is proposed based on a reverse auction mechanism, where users proactively express their delay tolerance by submitting bids, and the provider buys the delay tolerance from the users. Lee et al. [7] investigate the economic benefits due to delayed WiFi offloading. They model a market based on a two-stage sequential game between a monopoly provider and users and focus on the impact of different pricing schemes. In the same spirit, [4] proposes a time-dependent pricing scheme for mobile data, which incentivizes users to delay their traffic from the higher- to lower-price time zone.

However, the delayed offloading cannot be always considered as a likely option for the end-users, especially for real-time applications and services. Furthermore, most of the works in the literature do not capture the behavioral dimension of users’ decisions, since a fraction of users may be unwilling to use an alternative access service like WiFi. Our paper is motivated by the need to investigate the Wi-Fi offloading, not only as a cost-effective solution, but also as an emerging business domain.

The paper intends to provide answers to the following questions: Which are the optimal prices for charging two substitute services provided by a single network operator to maximize his profits? How does the users’ willingness-to-pay affect pricing decisions for charging the LTE and WiFi services? How such pricing decisions could be influenced by users being reluctant to switch to WiFi? Are there incentives for the network operator to make investments for extending the WiFi access network coverage?

We consider a model for estimating the profits of a network operator and derive analytical expressions for the profit-maximizing prices of the two offered substitute services. The network operator may affect the user decision for selecting an access service according to the announced prices. The key contributions can be summarized as follows:

- a macroscopic modeling framework for analyzing a monopoly market, where a network operator offers two substitute services, namely an LTE and a WiFi access service,
- an analytical estimation of the optimal pricing of the offered access services.

To the best of our knowledge, this is a first attempt to model the added value of the WiFi offloading, considering WiFi
access as a substitute and not as a supplementary service within the market, taking also into account the behavioral dimension of users’ decisions.

2. MODELING FRAMEWORK

In this section, we establish a formal model that captures the pricing decisions of a Mobile Virtual Network Operator (MVNO) and model how end-users select one out of the two offered access services.

2.1 MVNO Decision

We consider an MVNO leasing access (capacity in access and backhauling components) to the cellular network of a Mobile Network Operator (MNO) within a geographical region. The MVNO is being charged by the MNO based on a cost function of the total traffic sent via the network of the latter. The MVNO has already deployed a fixed number of WiFi hotspots, distributed within the region. The capacity of the WiFi infrastructure is sufficient to cover the generated user traffic demand. The backhauling of the WiFi access network is a typical fixed (e.g., metro/ethernet) network, owned by the MVNO. We can assume that the WiFi backhauling cost is marginal for the MVNO and thus has been eliminated from the analysis. Furthermore, it is assumed that the LTE network has full access network coverage, while the WiFi access network has partial coverage. We denote the fraction of the WiFi coverage area by the parameter $r$. The MVNO has incentives to offload traffic from the LTE network to the WiFi access network in order to reduce his operational cost due to the LTE network lease.

The MVNO is considered to be the only service provider in a specific geographical area. In this monopoly market, two substitute services are offered: the LTE and WiFi access. Since the WiFi service is not always available, end-users are able to transmit their data either via WiFi or via LTE, or even remain disconnected. In this framework, the decision-making process consists of two phases: the price determination of both access services by the MVNO, and the service selection by the end-users. We do not investigate market evolution in terms of setting different prices by the MVNO, or selecting a different service based on QoE parameters (i.e., data-rate, WiFi coverage) by the end-users, at the start of each epoch.

The expected profit is the total revenue from both services minus the operational cost. We assume that volume-based charging is applied to end-users, thus the expected revenues are given by the price/bit multiplied with the expected received traffic, for the provided WiFi and LTE access services correspondingly. The only cost for the MVNO is the cost for the volume transmitted to the LTE network of the MNO which is considered to be linear. The linearly increasing network cost is commonly used in the analysis of cost in cellular markets [7, 10].

The MVNO decision determines the prices $p_1$ and $p_2$ for charging both access services. The rationality of the MVNO implies that he sets feasible prices such that his profit is positive. The expected profit of the MVNO is given by:

$$\pi(p_1, p_2) = E(x_{LTE})(p_1 - c) + E(x_{WiFi})p_2$$

(1)

where the $c$ is the LTE wholesale price/bit charged by the MNO, the $p_1$ and $p_2$ indicate the retail price/bit charged by the MVNO for the LTE and the WiFi service, respectively, and the $x_{LTE}$ and $x_{WiFi}$ are random variables that indicate the fraction of the total traffic transmitted via LTE and WiFi, respectively.

2.2 End-User Decision

Consider a large number of users who can send their traffic towards a destination through two different access networks. The users are either stationary or mobile moving with low velocity, and the duration of the performed sessions is short. Hence, the fraction of users that will perform vertical hand-off is omitted from our analysis.

We consider a population of users that are homogeneous with respect to their traffic demand and with a willingness-to-pay (WtPay) that varies according to a uniform distribution ($u \sim U[0, R]$). We further assume that there is a reservation price $R$, which is the maximum price/bit that a user is willing to pay, preventing the MVNO to charge arbitrarily high prices. If the announced prices set by the MVNO are higher than a user’s WtPay, the latter will not select this service. Moreover, we consider homogeneous users with similar traffic demand. The theoretical distribution of the total traffic demand does not affect the analysis, since the model focuses on users’ allocation among the access networks (which can be viewed as a proxy for the total traffic allocation). The users’ WtPay and the total traffic demand are considered to be independent random variables. Furthermore, due to the full coverage of the LTE network, we assume that the LTE is a premium access service and therefore the announced price for the WiFi service will be lower. Hence, $p_2 < p_1 \leq R$.

Seeking to capture the behavioral dimension of users’ economic decisions and its impact over market prices, we consider $w_0$ as a switching elasticity threshold, which represents user’s zero propensity to switch. In particular, when a user’s WtPay is greater than $w_0$, he will constantly choose the LTE network for sending his data, regardless of the announced price for the WiFi service. We call this user segment as switching inelastic users, while switching elastic users are those who are flexible to switch from the LTE service to the WiFi one when this is feasible. We can easily envisage a fraction of end-users with high WtPay to be completely reluctant to adopt an alternative low-cost access service, like WiFi. The above assumption is compatible with the principles of behavioral economics, which is primarily concerned with the bounds of rationality of economic agents. An interesting model that focuses on users’ bounded rationality is presented in [6].

A couple of questions may arise; what is the physical meaning of $w_0$ and how can a network operator be aware of this parameter? The acceptance of a new service could vary according to demographic and psychological characteristics of a specific market. Hence, the threshold $w_0$ is expected to be higher within an urban area than a rural area. This information could be provided either by market research, or by crowd-sourcing platforms such as U-map [9] which collects users preferences and builds user profiles. In our model, we consider that this threshold is exclusively related to user’s WtPay. We assume that a user with low WtPay is more interested in buying an alternative lower-cost access service than a user with a higher one.

Given the announced prices $p_1$ and $p_2$ by the MVNO for the LTE and the WiFi access service, respectively, the available options of an end-user $i$ for selecting a service are the following:
• If $w_i \in [w_i, R]$ and $p_1 \leq w_i$, the user is switching inelastic, which means that he sends his traffic only via the LTE network and pays $p_1$/bit. Otherwise, if $p_1 > w_i$, the user remains disconnected.

• If $w_i \in [0, w_i]$, the user is switching elastic, which means that he sends his traffic via WiFi and pays $p_2$/bit, given that $p_2 \leq w_i$ and there is a WiFi AP close to him. If there is no WiFi AP available close to the user, the latter sends his traffic via the LTE network and pays $p_1$/bit, given that $p_1 \leq w_i$. Otherwise, if $p_2 > w_i$ and $p_1 > w_i$ correspondingly, the user remains disconnected.

3. PRICE ESTIMATION FOR THE ACCESS SERVICES

3.1 MVNO Profits

In this section, we derive the profits of the MVNO by considering his potential pricing decisions. Assuming that the MVNO sets both prices $p_1$, $p_2$ higher than $w_i$, then no user will select the WiFi service. The MVNO will obtain some revenues only from switching inelastic users with WtPay higher than $p_1$.

If the MVNO sets prices $p_1$, $p_2$, so that $p_2 \leq w_i < p_1$ the WiFi access service will be selected by switching elastic users with WtPay between $p_2$ and $w_i$, assuming they are within WiFi coverage area. The LTE service will be selected only by switching inelastic users with WtPay higher than $p_2$.

In case where $p_2 < p_1 \leq w_i$, there will be two groups of users remaining disconnected: i) users with WtPay lower than $p_2$ and ii) switching elastic users with WtPay between $p_2$ and $p_1$ who are out of the WiFi coverage. The probability for remaining disconnected is $\frac{c}{c + p_1} (p_1 - p_2) \frac{1}{1 - c}$.

The WiFi access service will be selected by switching elastic users within WiFi coverage and WtPay between $p_2$ and $w_i$. The probability for sending traffic via WiFi will be $\frac{c}{c + p_1} \frac{w_i - p_1}{R}$. The LTE access service will be selected by all the switching inelastic users, as well as by the switching elastic users with WtPay between $p_1$ and $w_i$ who are out of the WiFi coverage. The probability for sending traffic via the LTE network will be $R - w_i + (w_i - p_1) \frac{1}{1 - c}$. The expected profits of the MVNO are given by

$$\pi(p_1, p_2) = \begin{cases} (p_1 - c) (1 - \frac{c}{c + p_1}) & w_i < p_2 < p_1 \\ \frac{c}{c + p_1} \frac{w_i - p_1}{R} + (p_1 - c) (1 - \frac{c}{c + p_1}) & p_2 \leq w_i < p_1 \\ \frac{c}{c + p_1} \frac{w_i - p_1}{R} + (p_1 - c) R - w_i + (w_i - p_1) (1 - c) & p_2 < p_1 \leq w_i \end{cases}$$

3.2 Optimal Pricing Decision

The objective of the MVNO is to choose the optimal $p_1$, $p_2$, in order to maximize his profits.

**Proposition 1.** Given the switching elasticity threshold $w_i$ of an access market, the WiFi coverage range $R$ and the cost $c$ set by the MNO, the optimal prices of the MVNO are computed as follows:

$$p_1^*(w_i) = \begin{cases} \frac{c + R}{2} & w_i \leq \frac{c + R}{2} \\ w_i & \frac{c + R}{2} < w_i \leq \frac{c + c + R}{2} + R \\ \frac{c + c + R}{2} - R & w_i > \frac{c + c + R}{2} + R \end{cases}$$

Remark: The optimal price set by the MVNO for charging the LTE service is bounded:

$$p_1^* \in \left[w_i, \frac{c + R}{2} \right]$$

4. NUMERICAL ANALYSIS

This section shows our numerical analysis for the defined market. We obtain some useful insights.

(a) Impact of users’ switching propensity: It is not straightforward whether the MVNO will set $p_1$ to be lower or higher than $w_i$. Let us investigate the potential scenarios.

When $w_i$ is low, a high fraction of users will choose by default the LTE service, regardless of the announced WiFi price. Hence, for low values of $w_i$, the WiFi access service adoption will be limited. In this case, the optimal price for the LTE service depends only on the reservation price $R$ and the variable cost $c$ charged by the MNO, and not on the WiFi coverage area. As $w_i$ increases, the probability of selecting and connecting to the WiFi service by the end-users increases too. Thus, the MVNO chooses to set $p_1$ equal to $w_i$, encouraging only the users with zero propensity to switch, to select the LTE service. High value of $w_i$ implies a higher fraction of switching elastic users, who select an access service only based on whether they are within the WiFi coverage zone. Since the price for charging the LTE service is always higher than the corresponding WiFi service, the MVNO has the incentive to set $p_1$ so that $p_1 < w_i$, but never below $\frac{c + R}{2}$. This pricing decision will promote the LTE service to the switching elastic users being out of the WiFi coverage. Based on the above remark, we observe that the MVNO either decides to offer the LTE service only to the switching inelastic users, or he sets the price lower than $w_i$, in order to gain additional profits from users with high WtPay, being however out of the WiFi coverage.

(b) Impact of WiFi coverage: The optimal price for charging the WiFi access service does not depend on the WiFi coverage area. This is due to the fact that users’ decision only depends on their WtPay and their propensity to switch. Figure 1 depicts the optimal price set by the MVNO for charging the LTE access service, as a function of users’ switching elasticity threshold $w_i$, considering different WiFi coverage zones. For high value of $w_i$ assuming high WiFi coverage (e.g. 95%), the MVNO has the incentive to set the price for the LTE such as to be selected only by the switching inelastic users. As the WiFi coverage lowers, the MVNO sets $p_1$ lower than $w_i$ in order to gain additional profits by the switching elastic users being out of the WiFi range. To normalize our results, we set $R = 1$.

(c) Impact of MNO cost: As the $c$ increases, the average MVNO profit obtained by the LTE service decreases. Figure 2 depicts the optimal price set by the MVNO for charging the LTE access service, as a function of users’ switching elasticity threshold $w_i$, considering different cost per traffic unit set by the MNO. The result is rather expected, since as price/bit charged by the MNO increases, the average profit tends to be zero. Hence, for high values of $c$, the MVNO has the incentive to set $p_1$ close to the reservation price $R$.

Figure 3 shows the profits of the MVNO when he sets the optimal prices, depending on the WiFi coverage range, as well as on users’ switching elasticity threshold $w_i$. As the WiFi coverage range $R$ increases, the profits of the MVNO...
are increased too. This reveals the incentives of the MVNO to extend his WiFi access network coverage. Interestingly, for high values of \( r \), we observe that the MVNO does prefer having a fraction of switching inelastic users choosing by default the LTE service, as he gains higher profits due to their higher \( \text{WtPay} \). The results reveal the impact of the behavioral dimension of users’ decisions on the profits of the MVNO.

5. CONCLUSIONS AND FUTURE WORK

In this paper, we focused on the pricing decisions of an MVNO offering two substitute access services (LTE and WiFi). WiFi offloading is used not only as a solution for reducing operational cost as mentioned in other works in the literature, but also as a substitute service for customers with relatively low \( \text{WtPay} \). Given the WiFi coverage and the MNO cost, we proved that the MVNO either decides to offer the LTE service only to the users with zero propensity to switch to WiFi, or he sets the corresponding price lower than the switching elasticity threshold, in order to gain additional profits from users with high \( \text{WtPay} \) being out of the WiFi range. Additionally, we captured the behavioral dimension of users’ decisions and their impact over the announced prices. A counter intuitive result is that there are cases where the presence of reluctant users to switch to WiFi could increase the profits of the MVNO.

Our future work will consider more complex scenarios, including competition among different network operators, while employing different charging schemes. We also plan to study the interactions between network operators and end-users, assuming evolutionary price determination and service selection, at the start of each epoch. Finally, we will further investigate the economic incentives of a network operator to deploy additional APs or insert WiFi hotspots embedded to home routers which may share a second public SSID to extend the WiFi access network coverage.

6. REFERENCES