Pricing Wireless Access Services: The Effect of Offloading and Users' Bounded Rationality

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Abstract—**Offloading through WiFi access networks has been recently proposed as a cost-effective solution for coming up against the unprecedented increase in the mobile data traffic volume. However, apart from reducing the operational costs of a network operator, WiFi access can be also promoted as an alternative low-cost 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 make the optimal pricing decisions. We further show that the presence of reluctant users to switch to the WiFi service could increase the profits of the MVNO.**

I. 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 and femtocell. This promising solution could significantly save the operational cost of a network operator, especially when existing deployed complementary network infrastructure is exploited.

Experimental studies evaluate the benefits that offloading can bring to network providers and users [1]. In [2], real data are used to measure how much offloading can be achieved with varying number of access points (APs) that can guarantee the desired Quality of Service (QoS) for data delivery. Apart from QoS metrics, 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 sending their delay-tolerant traffic, when in coverage of a WiFi AP. In [3], an incentive framework is proposed based on a reverse auction mechanism, where users proactively express their delay tolerance. Lee *et al.* [4] investigate the economic benefits due to delayed offloading and focus on the impact of different pricing schemes. In the same spirit, [5] proposes a time-dependent pricing scheme.

The delayed offloading cannot be always considered as a likely option for the end-users, especially for real-time applications and services. Typically the community has focused on the WiFi offloading as a complementary service for minimizing network operators' cost, rather than as a business strategy to perform load balancing and profit optimization. Last but not least, none of the aforementioned papers capture the user decision-making process given that a fraction of users may be unwilling to use an alternative access service like WiFi.

The paper is motivated by the need to answer 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 willingness-to-pay of users affect pricing decisions for charging the LTE and WiFi access 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 LTE and WiFi as two substitute access services,
- 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 offloading, considering WiFi access as a substitute and not as a supplementary service within the market, taking also into account socio-economic aspects of the user decision-making.

II. Modeling Framework

Motivated by the fact that many fixed operators extend their business and address mobile markets without deploying their own infrastructure, we focus on Mobile Virtual Network Operators (MVNOs). This section establishes a formal model that captures the pricing decisions of an MVNO and models how end-users select one out of the two offered access services.

A. MVNO Decision

We consider an MVNO leasing access (capacity in access and backhauling components) to the cellular network of an MNO (Mobile Network Operator) 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 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. We do not consider the MNO participating in the market, since we intend to investigate whether the MVNO has incentives to promote WiFi as an additional substitute access service, or whether this implies cannibalization of his LTE access service.

In this framework, the decision-making process consists of two phases: the price determination of both access services by the MVNO, and then the service selection by the end-users. We do not analyze the market evolution in terms of pricing service selection based on Quality of Experience (QoE) parameters (e.g., data-rate, WiFi coverage) by the end-users, at the start of each epoch. However, assuming that the capacity of both networks is sufficient to ensure at least an acceptable QoE level, users' decision over service selection is expected to be mainly cost-driven. Otherwise, users' decision-making process can become more sophisticated taking into account QoE metrics.

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, respectively. 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 [4], [6]. Since the WiFi backhauling cost is considered to be marginal, the MVNO has incentives to offload traffic from the LTE to the WiFi network in order to reduce his operational cost due to the LTE network lease.

The MVNO 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:

$$\pi(p_1, p_2) = E(X_{LTE})(p_1 - c) + E(X_{WiFi})p_2 \quad (1)$$

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} indicate the fraction of the total traffic transmitted via LTE and WiFi, respectively.

B. End-User Decision-Making Process

Consider a large number of users who can send their traffic towards a destination through two different access networks. Their session duration is relatively short. The users are either stationary or mobile moving with low speed. Hence, the fraction of users that will perform vertical handoff is omitted from our analysis.

We consider a population of users with a willingness-to-pay (WtPay) that varies according to a uniform distribution ($w \sim U[0, R]$). We further assume a reservation price R, which indicates the maximum price/bit that users are willing to pay, preventing the MVNO to charge arbitrarily high prices. If the announced price of an access service set by the MVNO is higher than the WtPay of a user, the latter will not select this service. Moreover, we assume homogeneous users with respect to their traffic demand, thus the allocation of the users among the different wireless access networks corresponds to the distribution of the total traffic demand. The WtPay of users 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 it has a higher cost than the WiFi service (hence, $p_2 < p_1 \leq R$).

In order to capture some of the socio-economic aspects of the user decision-making and their impact over market prices, we consider w_t as a switching elasticity threshold, which represents users' zero propensity to switch. In particular, when the WtPay of a user is greater than w_t, he will constantly choose the LTE network for sending his data, regardless of the announced price for the WiFi service. We consider such users as *switching inelastic* ones. On the other hand, *switching elastic* users are considered to be flexible to switch from the LTE service to the WiFi one whenever WiFi is available due to its lower price. This assumption implies that a user with low WtPay is more interested in buying an alternative low-cost WiFi access service than a user with a higher one. The above assumption is compatible with the principles of *behavioral economics*, which is primarily concerned with the bounds of rationality of economic agents [7]. Service providers may potentially take advantage of such users' bounded rationality in order to increase their profit.

A couple of questions may arise; what is the physical meaning of w_t and how can a network operator be aware of this parameter? The acceptance of a new service could vary according to demographic and socio-economic characteristics of a specific market. This information could be provided either by market research, or by crowd-sourcing platforms, such as u-map [8] which aims to collect user preferences and build user profiles. The parameter w_t characterizes a specific market in a certain region; for example, the threshold w_t is expected to be higher within an urban area than a rural one, since urban area users are potentially more willing to use an alternative WiFi access service. In this paper, we consider that this threshold is exclusively related to the WtPay of users. We plan to extend our model by relating w_t not only with users' WtPay, but also with other parameters, such as the perceived QoE, for defining more sophisticated and realistic user decision-making strategies. In that way, we can model users with high WtPay who eventually switch to the WiFi service when it is available.

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:

- If $w_i \in (w_t, R]$ 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 $w_i \in (0, w_t]$, 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 in proximity, 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 $p_1 > w_i$ respectively, the user remains disconnected.

III. PRICE ESTIMATION FOR THE ACCESS SERVICES

A. MVNO Profits

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_t, then no user will select the WiFi service. The MVNO will obtain some revenues only from the switching inelastic users with WtPay higher than p_1.

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

In case where $p_2 < p_1 \leq w_t$, there will be two user groups remaining disconnected; i) the users with WtPay lower than p_2 and ii) the switching elastic users with WtPay between p_2 and p_1 who are out of the WiFi coverage. The probability of remaining disconnected is $\frac{p_2 + (p_1 - p_2)(1-r)}{R}$. The WiFi access service will be selected by the switching elastic users within WiFi coverage and WtPay between p_2 and w_t. The probability of sending traffic via WiFi will be $\frac{w_t - p_2}{R} r$. 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_t who are out of the WiFi coverage. The probability of sending traffic via the LTE network will be $\frac{R - w_t + (w_t - p_1)(1-r)}{R}$. The expected profits of the MVNO are

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

B. Optimal Pricing Decision

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

Proposition 1: Given the switching elasticity threshold w_t of an access market, the WiFi coverage range r and the cost c set by the MNO, the optimal prices of the MVNO are[1].

$$p_1^*(w_t) = \begin{cases} \frac{c+R}{2} & w_t \leq \frac{c+R}{2} \\ w_t & \frac{c+R}{2} < w_t \leq \frac{cr-c-R}{-2+r} \\ \frac{w_t r + cr - c - R}{2(r-1)} & w_t > \frac{cr-c-R}{-2+r} \end{cases}$$

[1] The proof is available at nes.aueb.gr/wons-proof.pdf.

$$p_2^*(w_t) = \frac{w_t}{2}$$

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

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

IV. NUMERICAL ANALYSIS

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

(a) Impact of the switching propensity of end-users: It is not straightforward whether the MVNO will set p_1 to be lower or higher than w_t. Let us investigate the potential scenarios. When w_t is low, a high fraction of users will choose the LTE service, regardless of the announced WiFi price. Hence, for low values of w_t, 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_t 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_t, encouraging only the users with zero propensity to switch, to select the LTE service. High value of w_t 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 $p_1 < w_t$, 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 aforementioned 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_t to gain additional profits from the switching elastic users with high WtPay, being however out of the WiFi coverage.

(b) Impact of the 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 the decision of end-users 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 the switching elasticity threshold w_t, considering different WiFi coverage zones. For high value of w_t 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_t in order to gain additional profits by the switching elastic users being out of the WiFi coverage range. To normalize our results, we set $R = 1$.

(c) Impact of the 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 the switching elasticity threshold w_t, considering different cost per traffic unit set by the MNO. The result is rather expected, since as the price/bit charged by the MNO increases, the average profit tends to be
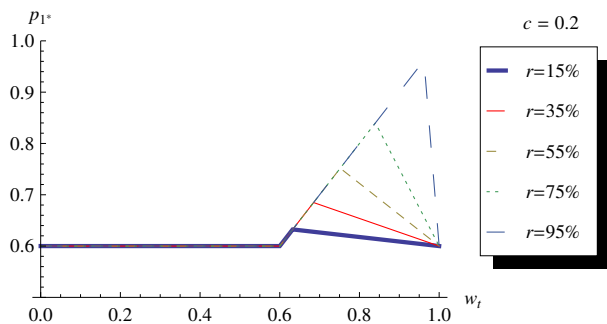
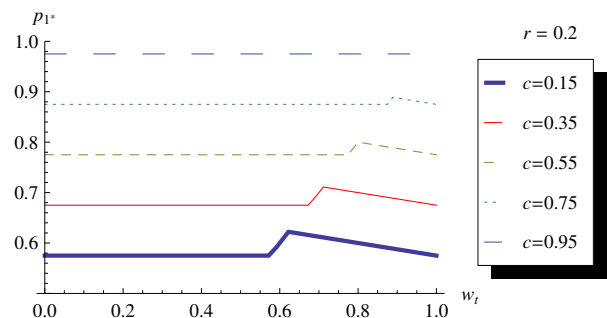Fig. 1. Optimal p_1 as a function of switching elasticity threshold w_t for different WiFi coverage r.

Fig. 2. Optimal p_1 as a function of switching elasticity threshold w_t, for different MNO costs.

Fig. 3. Profits of the MVNO setting the optimal prices, as a function of WiFi coverage r and switching elasticity threshold w_t, when $c = 0.2$.

range. Additionally, we captured the impact of pricing on the user decision-making process, as well as how the population of the switching elastic users affects the pricing decisions of the MVNO. A counter intuitive result is that there are cases where the presence of reluctant users to switch to WiFi increases the profit of the MVNO.

Our future work will consider more complex scenarios, including the competition among network operators and various different charging schemes. We also plan to study the interactions between network operators and end-users, assuming an evolutionary price determination and service selection process. Moreover, additional parameters for defining the switching elastic and inelastic user segments will be incorporated. 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.

ACKNOWLEDGMENT

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 and the switching elasticity threshold w_t. 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 WtPay. The results reveal the impact of users' bounded rationality (since a fraction of users will constantly choose the LTE network for sending their data, regardless of the announced price for the WiFi service) on the profits of the MVNO.

V. CONCLUSIONS AND FUTURE WORK

In this paper, we focused on the pricing decisions of an MVNO offering two substitute access services. Offloading via WiFi can be used not only as a solution for reducing operational cost, but also as a substitute service for customers with a relatively low 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 WtPay being out of the WiFi
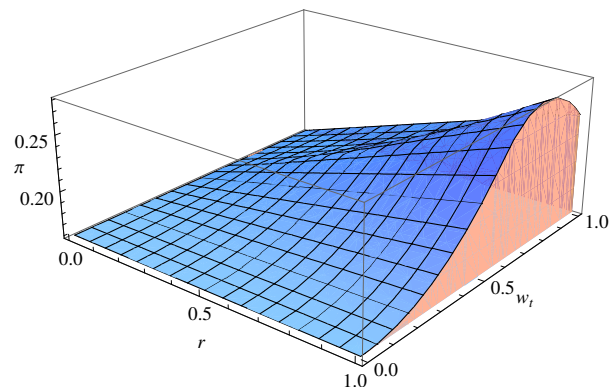
REFERENCES

[1] K. Lee, J. Lee, Y. Yi, I. Rhee, and S. Chong, *Mobile data offloading: How much can wifi deliver?*. IEEE/ACM Trans. Netw., 21(2):536-550, 2013.

[2] S. Dimatteo, P. Hui, B. Han, and V. O. K. Li, *Cellular traffic offloading through WiFi networks*. In IEEE MASS, 2011.

[3] X. Zhuo, W. Gao, G. Cao, and S. Hua, *An incentive framework for cellular traffic offloading*. IEEE Trans. Mobile Comput., 13(3):541-555, 2013.

[4] J. Lee, Y. Yi, S. Chong, and Y. Jin, *Economics of wifi offloading: Trading delay for cellular capacity*. IEEE Trans. Wireless Commun., 13(3):1540-1554, 2014.

[5] S. Ha, S. Sen, C. Joe-Wong, Y. Im, and M. Chiang, *Tube: Time-dependent pricing for mobile data*. In ACM SIGCOMM, 2012.

[6] S. Y. Yun, Y. Yi, D. H. Cho, and J. Mo, *The economic effects of sharing femtocells*. IEEE J. Sel. Areas Commun, 30(3):595-606, 2012.

[7] M. Karaliopoulos, K. Katsikopoulos, and L. Lambrinos, *Bounded rationality can increase parking search efficiency*. In MobiHoc, 2014.

[8] C. Meidanis, I. Stiakogiannakis, and M. Papadopouli, *Pricing for Mobile Virtual Network Operators: The Contribution of U-Map*. IEEE DySPAN, 2014.