Wireless Sensor Network-based service provision: a three-sided market model

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***Abstract*—In order that the Internet of Things (IoT) realize its full potential, it has been claimed for the IoT industry to follow the smartphone recipe of market-creating innovation. Indeed, the main mobile apps platforms derive a significant part of their brand value and pricing power from their reputation to have most innovative apps coming to them. Having witnessed that the same steady stream of developer-driven innovation is already emerging in IoT, demand for IoT-based services will be driven by this growing innovative community of IoT developers. In order to make it possible, main players should focus on building platforms that support third party applications instead of developing applications for their own devices.**

As a way to materialize the above idea, we propose a business model for IoT-based services where a platform creates a multi-sided market. The business model comprises a platform that serves as an intermediary between human users, app developers and Wireless Sensor Networks, so that the users use the apps, and the apps process the data supplied by the sensor networks. The platform, acting as a monopolist, posts a fee for each of the three sides so as to maximize its profit. We conduct an analysis of the profit maximization problem faced by the platform.

We show that the relative strength of the value that advertisers attach to the users determines the platform price structure. All in all, a high valuation is beneficial for all agents (users, platform, developers, and WSNs).

I. Introduction

This work aims to model the provision of Wireless Sensor Network(WSN)-based services. Our work is mainly motivated by two previous contributions:

- The discussion by Bohli, Sorge, and Westhoff [1], which concludes that the commercial success of sensor-based services needs that both the appropriate market structure and corresponding pricing schemes be well understood.
- The extension of the "platform" business model, where companies such as Apple, Google or Amazon have succeeded, to the Internet of Things by Schuermans and Vakulenko [2].

More specifically, we aim to analyze a business model for WSN-based services where a platform creates a multi–sided market.

A. *IoT and multi–sided markets*

There have been various attempts to define a multi–sided market. We present below the most popular ones.

Armstrong [3] defines multi–sided markets as "markets in which two or more groups of agents interact via intermediaries or platforms. Surplus is created—or destroyed in the case of negative externalities—when the groups interact. [...] In a set of interesting cases, cross-group externalities are present, and the benefit enjoyed by a member of one group depends upon how well the platform does in attracting custom from the other group."

Rochet and Tirole [4] roughly define multi-sided markets as "markets in which one or several platforms enable interactions between end-users and try to get the two (or multiple) sides 'on board' by appropriately charging each side." But they go further and define "a two-sided market as one in which the volume of transactions between end-users depends on the structure and not only on the overall level of the fees charged by the platform."

Finally, Hagiu and Wright [5] believe that "At the most fundamental level, MSPs [multi–sided markets] have two key features beyond any other requirements (such as indirect network effects [referring to [3]] or non-neutrality of fees [referring to [4]]). They enable direct interactions between two or more distinct sides. [And] each side is affiliated with the platform."

Videogame platform and operating systems, first, and mobile apps, more recently, are examples of two-sided platforms, and they have been very successfully implemented. Based on the observation of the mobile apps market, [2] argues that "the evolution in mobile in the past 6 years holds a clear lesson for the Internet of Things. To realize its full potential, the fledgling Internet of Things industry needs to follow iOS's and Android's recipe of market-creating innovation."

According to the authors, "iOS in particular derives a significant part of its brand value and pricing power from its reputation to have most innovative apps coming to iOS first." And, having witnessed that "the same steady stream of developer-driven innovation is already emerging in IoT", they argue that "wide-ranging and often unexpected devices, services and apps that come from a growing community of Internet of Things developers is the main factor that will drive demand for IoT to unseen heights." Finally, in order to make it possible, "instead of creating applications around specific devices (a parking app using parking sensors, a mobile app to unlock my door, and so on), data from all kinds of inputs can be gathered on a central platform." In other words, the platform should focus on supplying data and providing support

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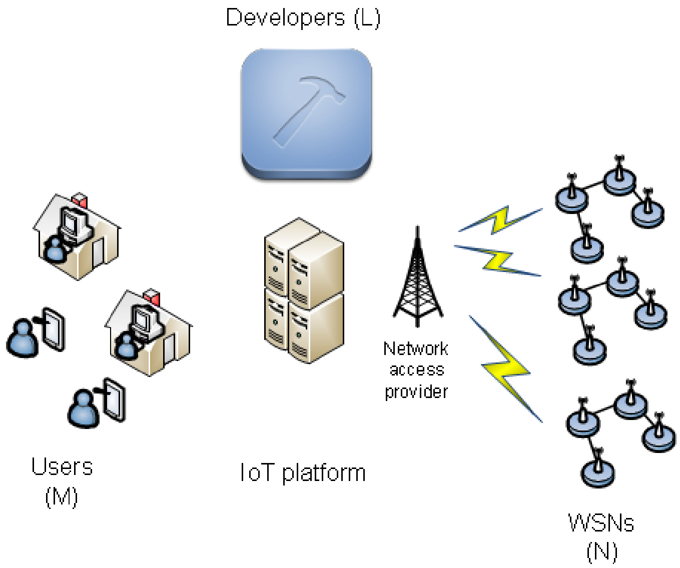

Figure 1. Scenario

to third-party applications.

B. Objectives and structure

Based on the above, this work proposes a business model for a platform which intermediates between three sides of the IoT market: the users, the application developers, and the data sensors.

Our aim is to model the interaction between the agents of the IoT market in order to identify the relevant cross externalities present and to analyze its influence on the profits and welfares in the equilibrium.

The paper is structured as follows. In the next section, the business model is described, as well as the specific model for each agent, including the payment flow, the modeling decisions and assumptions made, e.g., the utility expressions used in the analysis. In Section III, we present and discuss some numerical results to illustrate the main characteristics of the model. Finally, Section IV draws some conclusions.

II. Model description

The scenario modeled in this work is shown in Fig. 1. It comprises:

- N wireless sensor networks (WSNs)
- one IoT platform
- L developers
- M users

Basically, the platform gathers the data that is sensed by the WSNs and developers make use of the data for composing apps. The platform also provides the means to make these apps available for the users. The payment flows for all agents in the scenario are detailed in Fig. 2 and are explained in the following subsections.

A. Wireless sensor networks

There exist N Wireless Sensor Network (WSN) islands. Each WSN island senses data that is gathered by the platform.

WSN j generates data and is paid an amount f by the platform, which is the same for all WSNs. Note that we are anticipating that the platform will not charge the WSNs but will pay them a fee. WSN j pays a network access fee to the network access provider, which depends on its upload requirements, which may be stated in terms of data rate or data volume, for instance. These requirements are denoted as s_j, and the network access fee is given by γs_j, where γ is then a price per upload capacity unit. We assume that the number of WSNs is sufficiently high so that each is assumed to take prices γ and f as given.

We model the heterogeneity of the WSNs by means of s_j, which is a sample of a random variable $\mathcal{S}$ uniformly distributed in the interval $[0, 1]$.

Therefore, provided that WSN j joins the platform, it will get the profit

$$\Pi_j^s = f - \gamma s_j. \tag{1}$$

WSN j will join the platform if $\Pi_j^s \geq 0$, which is an event with probability

$$\mathrm{P}\left(f - \gamma \mathcal{S} \geq 0\right) = \mathrm{P}\left(\mathcal{S} \leq \frac{f}{\gamma}\right) = \Psi\left(\frac{f}{\gamma}\right), \tag{2}$$

where $\Psi(\cdot)$ is defined as follows:

$$\Psi(u) \equiv \begin{cases} 0 & \text{if } u < 0 \\ u & \text{if } 0 \leq u < 1 \\ 1 & \text{if } 1 \leq u. \end{cases} \tag{3}$$

The number of connected WSNs $\mathcal{N}$ (i.e., the WSNs that join the platform) is then a random variable and the expected number of connected WSNs, n, is equal to

$$n = \mathbb{E}[\mathcal{N}] = N\Psi\left(\frac{f}{\gamma}\right). \tag{4}$$

Finally, the WSNs' welfare WW is defined and computed as follows:

$$\begin{aligned} \mathrm{WW} \equiv N\,\mathbb{E}[\Pi^s] &= N \int_0^{\min(\frac{f}{\gamma},1)} (f - \gamma s) ds \\ &= \begin{cases} N\frac{f^2}{2\gamma} & \text{if } 0 \leq f/\gamma \leq 1 \\ N\left(f - \frac{\gamma}{2}\right) & \text{if } 1 < f/\gamma. \end{cases} \end{aligned} \tag{5}$$

B. App developers

There are L app developers that may access the data gathered by the platform in order to compose the apps, which would then be offered to the users.

Each developer receives an advertising revenue that is dependent on the total number of platform subscribers and on its quality as a developer. Specifically, the advertisers pay a revenue to developer k that is equal to $\alpha m^e n^e q_k$, where

- m^e is the number of users that the advertisers expect that will subscribe;

- α is the valuation that the advertising agents attach to each subscriber;
- n^e is the number of WSNs that the advertisers expect that will connect;
- the quality q_k is a sample of a random variable $\mathcal{Q}$ uniformly distributed in the interval $[0, 1]$.

Implicit in the above expression is the fact that the quality of each developer increases proportionally with the number of WSNs, i.e., $n^e q_k$.

On the other hand, each developer should pay an access fee d to the platform in order to access the data and to offer its applications.

Then, a developer registered for the platform will obtain a profit equal to:

$$\Pi_k^d = \alpha m^e n^e q_k - d. \tag{6}$$

Developer k will register for the platform if $\Pi_k^d \geq 0$, which corresponds to an event with probability

$$\begin{aligned} \mathrm{P}\left(\alpha m^e n^e \mathcal{Q} - d \geq 0\right) &= \mathrm{P}\left(\mathcal{Q} \geq \frac{d}{\alpha m^e n^e}\right) \\ &= \Psi\left(1 - \frac{d}{\alpha m^e n^e}\right). \end{aligned} \tag{7}$$

The number of registered developers is then a random variable $\mathcal{L}$ and its expected value, l, is equal to

$$l = \mathbb{E}[\mathcal{L}] = L\Psi\left(1 - \frac{d}{\alpha m^e n^e}\right) \tag{8}$$

Finally, the developers' welfare DW is defined and computed as follows:

$$\begin{aligned} \mathrm{DW} &\equiv L\,\mathbb{E}\left[\Pi^d\right] = L\int_{\min\left\{\frac{d}{\alpha m^e n^e},1\right\}}^{1} \left(\alpha m^e n^e q - d\right) dq \\ &= \begin{cases} L\frac{\alpha m^e n^e}{2}\left(1 - \frac{d}{\alpha m^e n^e}\right)^2 & \text{if } 0 \leq \frac{d}{\alpha m^e n^e} \leq 1 \\ 0 & \text{if } 1 < \frac{d}{\alpha m^e n^e}. \end{cases} \end{aligned} \tag{9}$$

C. Users

Users are interested in accessing a range of sensor-based apps that the platform makes available to them.

Each user pays an access fee p to the platform, and this payment entitles the user to download and use apps. We assume that the users' quality of experience (QoE) depends on the diversity of the developers registered to the platform, since the higher the number of different app developers available through the platform, the more satisfactory the user experience is [6]. And it also depends on the number of the WSNs connected to the platform, since the higher the number of WSNs supplying data to the platform, the more satisfactory the user experience is.

We denote l^e as the number of app developers that the users expect that will register. We assume that the users expect that n^e WSNs will connect, that is, that their expectations are the same as the advertisers' expectations. The utility that user i receives when subscribing to the platform is then given by:

$$u_i = \beta l^e n^e \omega_i - p \tag{10}$$

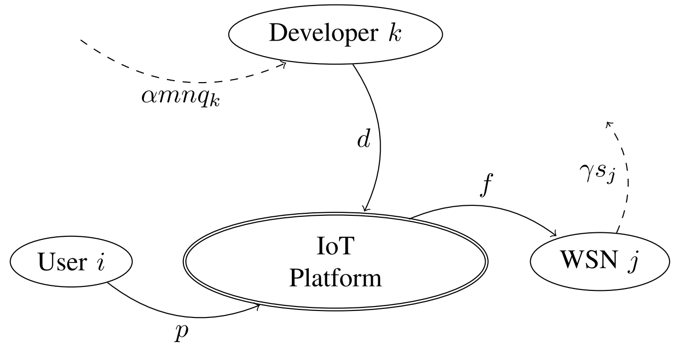

Figure 2. Payment flows in the model

where ω_i is the willingness to pay for the QoE of the ith user, and β is a conversion factor.

Following [7] and [8], we model a heterogeneous population of M users which are vertically differentiated by their willingness to pay for the QoE of the apps available through the platform. We assume that the willingness to pay is modeled by a random variable Ω uniformly distributed in the interval $[0, 1]$.

Note that we assume that the users are price-takers, which is a sensible assumption for a sufficiently high M.

User i will subscribe to the platform if $u_i \geq 0$, which corresponds to an event with probability

$$\mathrm{P}\left(\beta l^e n^e \Omega - p \geq 0\right) = \mathrm{P}\left(\Omega \geq \frac{p}{\beta l^e n^e}\right) = \Psi\left(1 - \frac{p}{\beta l^e n^e}\right). \tag{11}$$

The number of subscribers $\mathcal{M}$ is then a random variable and its expected value, m, is equal to

$$m = \mathbb{E}[\mathcal{M}] = M\Psi\left(1 - \frac{p}{\beta l^e n^e}\right) \tag{12}$$

Finally, the users' welfare UW is defined and computed as follows:

$$\begin{aligned} \mathrm{UW} &\equiv M\,\mathbb{E}[u] = M\int_{\min\left\{\frac{p}{\beta l^e n^e},1\right\}}^{1} \left(\beta l^e n^e \omega - p\right) d\omega \\ &= \begin{cases} M\frac{\beta l^e n^e}{2}\left(1 - \frac{p}{\beta l^e n^e}\right)^2 & \text{if } 0 \leq \frac{p}{\beta l^e n^e} \leq 1 \\ 0 & \text{if } 1 < \frac{p}{\beta l^e n^e}. \end{cases} \end{aligned} \tag{13}$$

D. Equilibrium

We look for fulfilled expectations equilibria [9] where each side's expectations are fulfilled in (12) and (8) [1],

$$m^e = m \tag{14}$$
$$l^e = l \tag{15}$$
$$n^e = n. \tag{16}$$

The number of subscribers m, registered developers l, and connected WSNs n can be obtained from the solution of (12), (8) and (4), combined with (14)–(16).

[1] An equivalent assumption is that all agents have a perfect foresight [10].

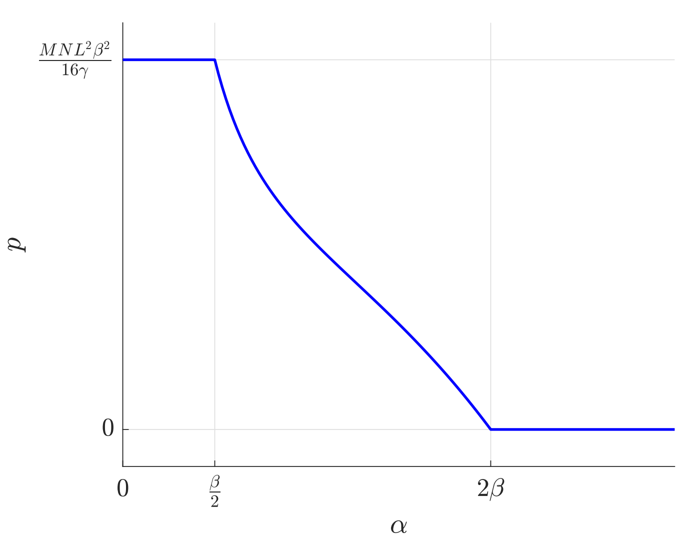

Figure 3. Optimum p as a function of α.

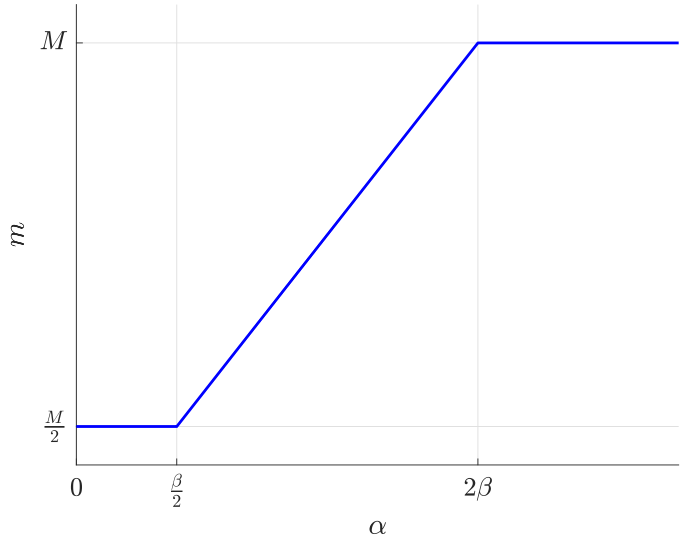

Figure 4. Number of subscribers, m, at the optimum as a function of α.

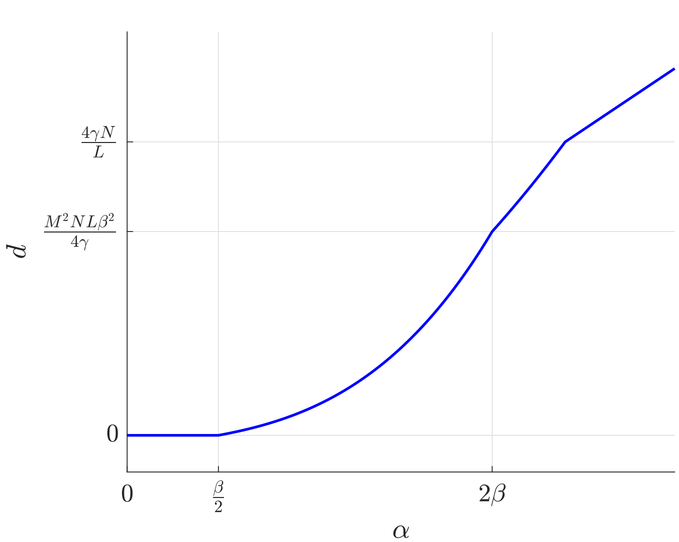

Figure 5. Optimum d as a function of α.

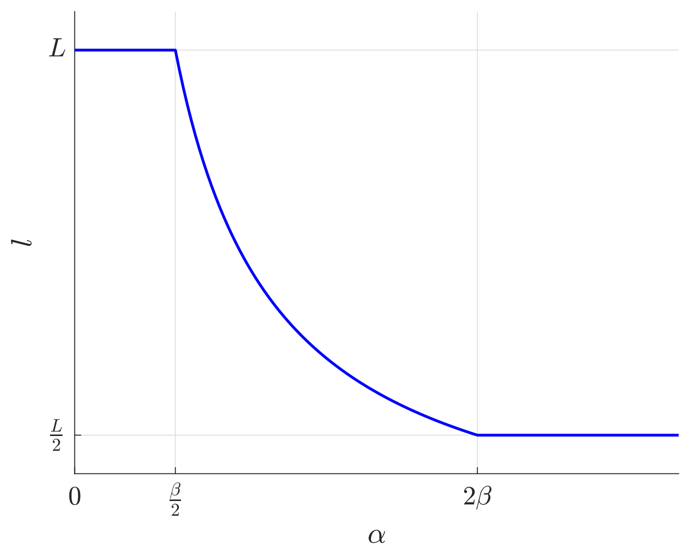

Figure 6. Number of registered developers, l, at the optimum as a function of α.

E. The IoT platform

The platform is assumed to operate as a monopolist. The profit of the platform is given by the revenues from the subscribers and from the registered developers minus the cost incurred in paying the connected WSNs (Fig. 2). We assume that other costs are negligible.

Therefore,

$$\Pi^p = mp + ld - nf \tag{17}$$

where the expressions for m, l and n in equilibrium can be obtained as described in Section II-D.

Assuming that the monopolistic platform is free to set access fees p, d and f, the platform faces the problem of choosing p, d and f to maximize (17), where m, l, n are functions of p, d, f.

$$\max_{p,d,f} \Pi^p(p, d, f). \tag{18}$$

III. Results and Discussion

We have solved the above profit maximization problem analytically. The details of the analytical procedure can be obtained from the authors. In this section, we present and discuss some numerical results to illustrate the main characteristics of the model.

Specifically, the following graphs show the effect of the variation of α on: the optimum fees (p, d, f), (Figs. 3, 5, 7); the number of users, developers and WSNs (m, l, n), (Figs. 4, 6, 8); the welfare of the users (Fig. 9), developers (Fig. 10) and WSNs (Fig. 11); the platform profit (Fig. 12); and the total social welfare (Fig. 13).

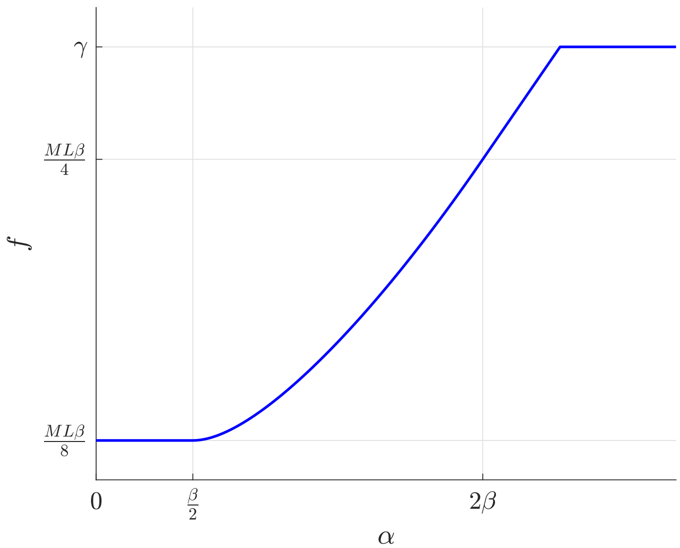

Figure 7. Optimum f as a function of α.

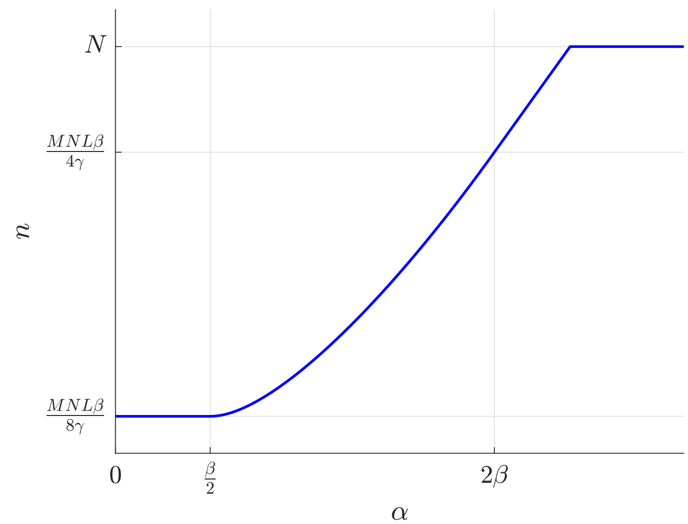

Figure 8. Number of connected WSNs, n, at the optimum as a function of α.

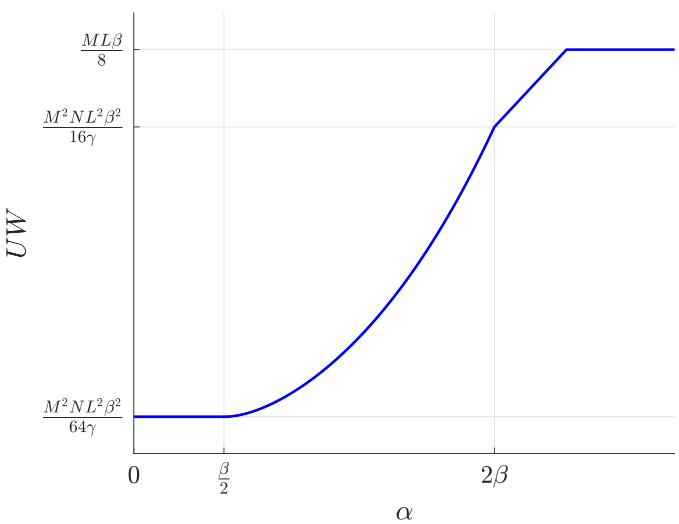

Figure 9. Users' welfare at the optimum as a function of α.

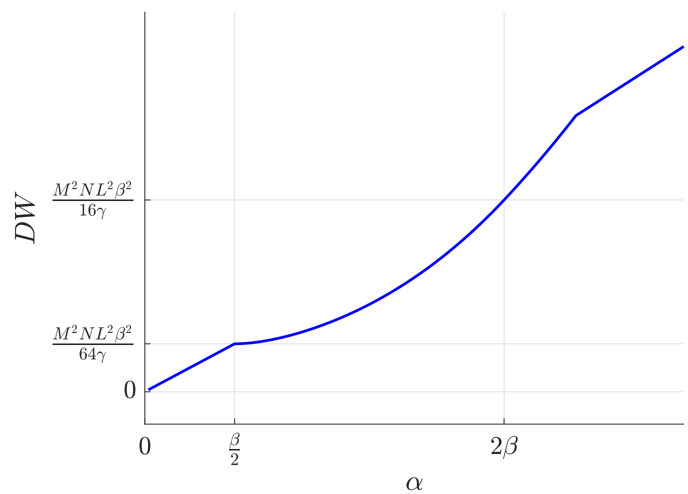

Figure 10. Developers' welfare at the optimum as a function of α.

From these graphs the following observations can be made:

- For $\alpha > 2\beta$, maximum profits are achieved when all users are offered a free subscription service ($p = 0$, Fig. 3) and therefore all users subscribe to the service ($m = M$, Fig. 4). Note that a high value of α means that a user is highly valued by the agents willing to advertise through the apps. Finally, half of the developers subscribe ($l = L/2$). This value can be explained as follows. Given that $p = 0$, the profit of the platform is $\Pi^p = ld - nf$. Since the values n and f do not depend on l nor on d, the profit-maximizing l and d are those that maximize the product ld. From (10), $d = \alpha mn(1 - l/L)$, and since $m = M$, $ld = \alpha Mnl(1 - l/L)$, whose maximum is at $l = L/2$, which is obtained with a fee $d = \alpha Mn/2$.
- For $\alpha < \beta/2$, maximum profits are instead achieved when all developers register for free ($d = 0$ and $l = L$, Figs. 5 and 6). In this case, the subscribers are charged a non-zero price. As a kind of dual situation compared to the previous case, half of the users subscribe ($m = M/2$).
- For intermediate values of α, a fraction of the users subscribes and a fraction of the developers registers, both paying non-zero fees.

The above discussion is applicable for any value of the parameters M, L, N, β and γ. However, these parameters do influence the behavior of the number of connected WSNs (n), the fee f and the welfares and profits. Specifically, n grows with α until it reaches its maximum value $n = N$ and from there it remains constant (Fig. 8). The value of α at which n reaches its maximum value decreases with ML/γ. For $ML/\gamma > 8/\beta$, it can be shown that n would be N for all α. In the graphs discussed below, the value of ML/γ is such that n reaches the maximum at a value of α greater than 2β

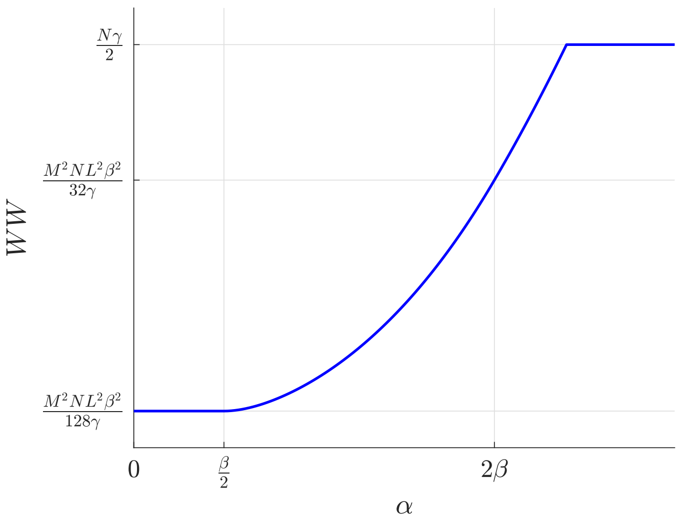

Figure 11. WSNs' welfare at the optimum as a function of α.

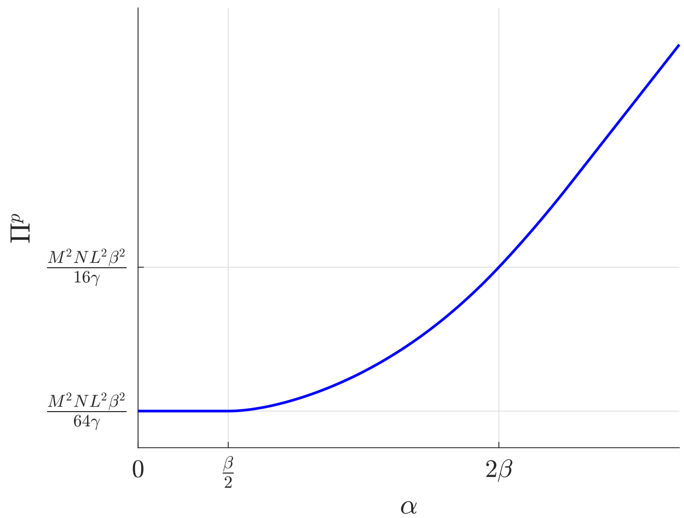

Figure 12. Maximum platform's profit as a function of α.

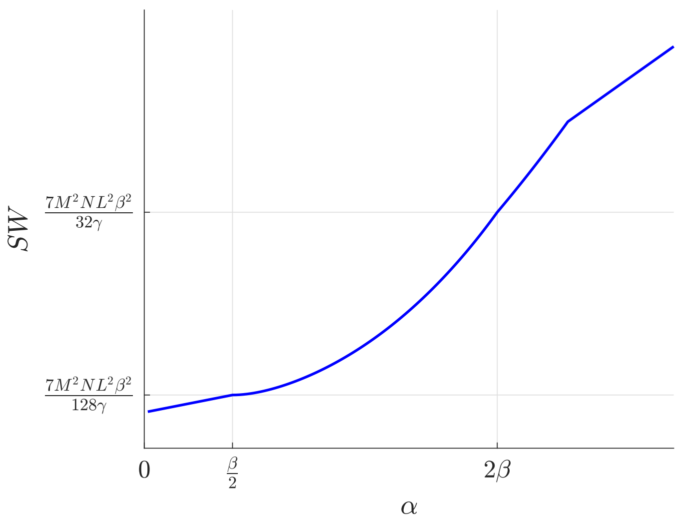

Figure 13. Social welfare at the optimum as a function of α.

(Fig. 8), i.e., where all users subscribe for free.

It can be seen that:

- The users' welfare remains constant until $\alpha = \beta/2$, and from this point it increases with α (Fig. 9), that is, the decrease in the price p (Fig. 3) compensates for the decrease in the number of registered developers l (Fig. 6). It reaches its maximum value when $n = N$.
- The developers' welfare also increases with α (Fig. 10), that is, the increase in the number of subscribers m (Fig. 4) compensates for the increase in the price d (Fig. 5).
- The WSNs' welfare remains constant for $\alpha < \beta/2$, and from this point it increases with α (Fig. 11), as expected from the increase in the fee f (Fig. 7). It reaches its maximum value when $n = N$.
- The platform profit also remains constant for $\alpha < \beta/2$, and from this point it increases with α (Fig. 12).
- Consequently, the total welfare also increases with α (Fig. 13).

IV. Conclusions

A business model for the provision of WSN's-based services has been proposed. This business model features a platform aiming to create a multisided market where users, WSNs and app developers interact and are charged accordingly by the platform. A scenario where only a platform is present in the market is analyzed and the effect of some parameters is computed and discussed.

We have shown that the relative strength of the value that advertisers attach to the users determines the platform price structure. Specifically, profit maximization steers the platform towards subsidizing either the users' subscription (when that valuation is high) or the developers' registration (when that valuation is low). All in all, a high valuation is beneficial for all agents (users, platform, developers, and WSNs).

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