Competition among Online-Gaming Service Providers[1]

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***Abstract*—*Game as a Service* (GaaS)[1] has recently been deployed to cope with the limitations of user devices (storage, computing power, energy). The pricing schemes –essentially flat-rate– implemented by providers are simple, but the consequences of the price levels and the offer contents on demand repartition are involved. In this paper, we introduce a model for the interactions among competing network providers offering GaaS solutions, in order to study their competition in terms of prices and selection of games to propose. We illustrate some trade-offs that network provider face, between the attractiveness of a game and its incurred costs.**

I. Introduction

Recent evolutions in the gaming industry fostered the emergence of multi-player gaming platforms while gaming has become mainstreamed. Proprietary gaming devices remain, but need to be periodically upgraded by end-users. Moreover, more and more games are available for smartphones with limited CPU and RAM capacity. This situation leads to a great market opportunity for Cloud Computing Providers (CPs) to propose services to end-users and negotiate with Game Editors to host their products. However, such services, combined with the real-time requirements of multi-player game interactions, involve Quality of Service (QoS) guarantees including at a network level as demonstrated by the authors of [3], [5]. Hence, Network Providers (NPs) of end-users play a key role in making Game as a Service viable, by providing appropriate bandwidth and delay guarantees[2].

The new market of online-game services is very likely to be highly competitive, since every Network Provider can easily add this possibility to the services proposed to its customers, through commercial agreement with Cloud Providers. We therefore consider that competition has to be taken into account, and intend to use tools from game theory to analyze the interactions among the stakeholders. In this paper, we present a study of the competition between Network Providers for video-games offered by Cloud Providers. To do so, we introduce a user demand model to analyze the interactions among NP decisions in terms of prices and offer content, and investigate their equilibrium strategies.

II. Game as a Service model

A. The GaaS stakeholders

In the studied scenario, illustrated in Figure 1, Network Providers compete for users, through pricing and through the composition of their game package offer. A game package offer is a set of games associated to a level of QoS an NP promises to deliver. On the other hand, Network Providers need to reserve from Cloud Providers the capacity necessary to satisfy their end-user demand. Cloud Providers are assumed to have already composed their game offer (i.e., they have set up agreements

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[2]As an example, two French NPs, Free and SFR propose gaming solutions to their end-users. In the case of SFR, the gaming service is charged separately from the Internet flat-rate access.

with Game Editors to choose the games they aim to offer access to) and can provide streaming access to a set of games for a given unit price.

We assume that the strategic variables of the Cloud Providers are static for this part of the scenario. They are actually defined when Cloud Providers negotiate with the Game Editors access to game content, but those decisions occur at a larger time scale than the one we focus on here, and are as a result considered fixed by the competing Network Providers. Therefore, Cloud Providers are not active participants in the interaction studied here.

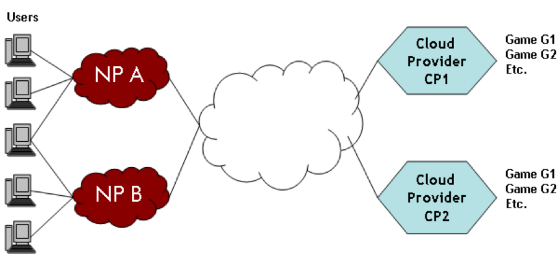

Figure 1. The different interacting agents in a GaaS scenario

We denote the total set of games that Cloud Providers offer, by $\mathcal{L}$. Each element $\ell \in \mathcal{L}$ is a game, but could also represent an indivisible group of games sold together. Then each Network Provider i composes its offer, by selecting some elements in $\mathcal{L}$ to form a bundle denoted by $\mathcal{L}_i$.

B. Decision variables

We list here the different stakeholders, and their strategic possibilities. Note that all prices indicated here are per time unit (say, per month).

Cloud Providers (denoted by h) set the unit price $(c_{h,i,\ell})$ that is charged to each Network Provider i, for accessing each game $\ell \in \mathcal{L}$. To simplify the study, we assume that the capacities of cloud providers are always sufficient to satisfy the demand from Network Providers. As previously mentioned, those variables are assumed fixed for us, when studying the competition between Network Providers.

Network Providers (denoted by i in the set $\mathcal{I}$) can play on the set $\mathcal{L}_i$ of games to propose to users, and on the retail price p_i. They also have to reserve some capacity $Q_{i,\ell}$ to the different games in $\mathcal{L}_i$, that is bought from cloud providers (with a unit cost $c_{h,i,\ell}$); however as we will see, that capacity will be estimated by Network Providers based on the anticipated demand, and will therefore not be a strategic variable studied here.

Users make decisions regarding the selection of a Network Provider; this includes the possibility of choosing not to subscribe to any service.

Note that in reality, user decisions are individual, and could be modeled based on a utility function. Nevertheless, we are only interested in overall demands for Network Providers, and will thus consider an aggregated demand function for each Network Provider, without extending the model granularity down to the user level.

C. Demand modeling

Users are not assumed to be aware of QoS constraints of Network Providers [3], [5]: rather, Network Providers are supposed to anticipate the demand and adjust the capacity to buy from Cloud Providers. That assumption is consistent with most selling contracts, where the seller (here, the Network Provider) ensures that a given quality will be met. Consequently, users are supposed to be sensitive only to the content of the package offer and the price asked by the Network Providers.

For those reasons, the total demand D_i (number of customers) at each provider i depends on the prices of all providers and the content of the offer of all providers. It is expected to be decreasing (resp. increasing) in i's price (resp. set of games offered), and increasing (resp. decreasing) with the ones of the competitors.

We now describe the specific demand function considered in this paper: we assume that the demand D_i for each Network Provider i is given by

$$D_i = d_{i,0}\left[1-\alpha_i p_i + \sum_{j\neq i}\beta_{ij}p_j\right]^+ \times \Delta_{\mathcal{L}_i} \quad (1)$$

with

$$\Delta_{\mathcal{L}_i} = \prod_{\ell}\left(1-\kappa_\ell \mathbb{1}_{\{\ell\notin\mathcal{L}_i\}} + \eta_\ell \mathbb{1}_{\{\ell\in\mathcal{L}_i\}}\left(\sum_{j\neq i}\frac{\mathbb{1}_{\{\ell\notin\mathcal{L}_j\}}}{N}\right)^2\right)$$

where N is the total number of Network Providers.

The term $d_{i,0}[1-\alpha_i p_i + \sum_{j\neq i}\beta_{ij}p_j]^+$ represents the impact of the prices of all providers on demand. It is the general expression of a linear demand model in a situation of competition (see, e.g., [2] for a presentation of the most used models). The term $d_{i,0}$ represents the demand for Network Provider i if all prices were null, while $\alpha_i > 0$ represents the "direct" effect of price p_i on the demand of Network Provider i: increasing p_i leads to a decrease in i's demand (since some users will prefer a competitor or will renege using the service). Finally, $\beta_{ij} > 0$ represents the "indirect" effect of the price p_j of a competitor

j on the demand of i: when competitors increase their price, some of their customers may change providers and switch to i. We should usually have $\alpha_i > \sum_{j \neq i} \beta_{ij}$, i.e., the direct effect of price exceeds the secondary (indirect) effect.

The second term $\Delta_{\mathcal{L}_i}$ represents the impact of the content of the offer of all providers on demand. For each game $\ell \in \mathcal{L}$, the term $\left(1 - \kappa_\ell \mathbb{1}_{\{\ell \notin \mathcal{L}_i\}} + \eta_\ell \mathbb{1}_{\{\ell \in \mathcal{L}_i\}} \left(\sum_{j \neq i} \frac{\mathbb{1}_{\{\ell \notin \mathcal{L}_j\}}}{N}\right)^2\right)$ models the impact on demand D_i of the providers choices to offer that game:

- κ_ℓ can be interpreted as the proportion of users who are interested in game ℓ: if Network Provider i does not offer that game (i.e if $\ell \notin \mathcal{L}_i$), it is likely to loose a proportion κ_ℓ of its demand.
- $\eta_\ell < \kappa_\ell$ represents the corresponding indirect effect: if the competitors do not offer some game that a provider i proposes, this may drive their customers to provider i. We consider a convex (here, quadratic) form to highlight some monopoly effects that occur when the proportion of providers offering some specific game is very small.

The following assumption is classically made when considering linear demand models [1], [4]:

Assumption A *If all providers simultaneously increase their prices by the same amount, then no provider gets more demand. Formally,*

$$\forall i \in \mathcal{I}, \quad \alpha_i > \sum_{j \neq i} \beta_{ij}.$$

D. Utility of Network Providers

Each Network Provider i is sensitive to its overall revenue π_i, that can be expressed as

$$\pi_i = \underbrace{p_i D_i}_{\text{revenue}} - \underbrace{\sum_{\ell \in \mathcal{L}_i} \bar{C}_i^\ell(Q_i^\ell)}_{\text{capacity costs}}, \tag{2}$$

where $\bar{C}_i^\ell(Q_i^\ell)$ is the total price that Network Provider i has to pay to its chosen Cloud Provider for the capacity necessary to run game ℓ.

We now specify the capacity constraint that Network Providers are faced with. To do so, we again use the interpretation of κ_ℓ as representing the proportion of users likely to use the game ℓ: if the game interests are assumed independently distributed within the population, then among users interested in at least a game in the set $\mathcal{L}_i$, the proportion of users interested in game $\ell \in \mathcal{L}_i$ is

$$\tilde{\kappa}_\ell(i) := \frac{\kappa_\ell}{1 - \prod_{m \in \mathcal{L}_i}(1 - \kappa_m)}. \tag{3}$$

The value $\tilde{\kappa}_\ell(i)$ is computed as a conditional probability, where the condition (with probability given in the denominator of (3)) is the "probability" (proportion of the population) interested by at least a game in $\mathcal{L}_i$.

Now, it is reasonable to assume that the capacity constraint on each game ℓ be expressed proportionally to the potential demand. Denoting by μ the expected statistical gain (i.e., the proportion of users that are jointly connected to the game service during the busy hour), the capacity constraint could be expressed as

$$Q_i^\ell \geq \tilde{\kappa}_\ell(i) \mu D_i. \tag{4}$$

Under such a model, for each proposed game ℓ Network Providers should buy the exact necessary capacity $Q_i^\ell = \tilde{\kappa}_\ell(i) \mu D_i$. As a result, for Network Provider i, once the set of offered games is fixed the problem of maximizing revenue through prices can be simply formulated as

$$\max_{p_i \geq 0} D_i \times (p_i - c_i), \tag{5}$$

where D_i is given in (1), and

$$c_i := \mu \sum_{\ell \in \mathcal{L}_i} \tilde{\kappa}_\ell(i) \min_h c_{h,i,\ell} \tag{6}$$

is the total price that Network Provider i will have to pay per demand unit in order to provide access to game ℓ with satisfying quality, when for each game the cheapest Cloud Provider is selected.

III. Competition among Network Providers

To study the interactions among Network Providers, we suppose that the choice of game packages is done at a greater time scale than the choice of prices and capacities. We then have a sequential game (the Network Providers first choose the game package they will offer, and then fix their selling price and buy the corresponding capacity), that can be solved by *backward induction* [6]. More precisely, given the fact that package choices are discrete choices, we apply the following procedure:

- for each possible configuration of packages, the game on prices and capacities can be studied (but with the capacity constraint, actually only one decision variable -the price- needs to be considered). We thus obtain the equilibrium (if any) prices and revenues for each package configuration.
- the decisions on game packages can then be studied as a finite game, where Network Provider utilities are, for each configuration, the ones corresponding to the equilibrium of the pricing game.

A. The pricing game

We assume here that each provider has chosen the content of its game offer, so that the only decision variables are prices. Due to the product form of the demand in Equation (1) and the fact that Network Provider revenues are proportional to their demand, the terms $\Delta_{\mathcal{L}_i}$ do not affect the pricing decisions. Therefore we will not write those terms when computing the competition game on pricing, considering only the modified demands

$$d_i := d_{i,0}\left[1-\alpha_i p_i+\sum_{j\neq i}\beta_{ij}p_j\right]^+.$$

Still when the sets of offered games $(\mathcal{L}_i)_{i\in\mathcal{I}}$ are chosen, the revenue of each Network Provider $i\in\mathcal{I}$ is proportional to

$$r_i := d_i\times(p_i-c_i),$$

where for each Network Provider i, c_i is computed in (6). As a result, when Network Provider prices remain in an area such that $d_i>0$ for all $i\in\mathcal{I}$, the revenue of each Network Provider i is a concave quadratic function of p_i. Thus, its maximum is the only point (if any) where the derivative equals zero.

B. The game on offer contents

We will consider the case of two Network Providers, $i=1,2$ competing for two video-games $\ell=1,2$. Four strategies are thus possible: $\mathcal{L}_i\in\{\emptyset,\{1\},\{2\},\{1,2\}\}$. The Nash equilibrium price profile (p_1^*,p_2^*) is then given by

$$p_1^*=\frac{2\alpha_2+\beta_{1,2}+\beta_{1,2}\alpha_2c_2+2\alpha_1\alpha_2c_1}{4\alpha_1\alpha_2-\beta_{1,2}\beta_{2,1}} \qquad (7)$$

$$p_2^*=\frac{2\alpha_1+\beta_{2,1}+\beta_{2,1}\alpha_1c_1+2\alpha_1\alpha_2c_2}{4\alpha_1\alpha_2-\beta_{1,2}\beta_{2,1}} \qquad (8)$$

and the corresponding revenues $(r_i^*)_{i=1,2}$ of both NPs are

$$\begin{aligned} r_1^* &= d_{1,0}\left[1-\alpha_1p_1^*+\beta_{12}p_2^*\right]^+(p_1^*-c_1)\Delta_{\mathcal{L}_1}\\ r_2^* &= d_{2,0}\left[1-\alpha_2p_2^*+\beta_{21}p_1^*\right]^+(p_2^*-c_2)\Delta_{\mathcal{L}_2}\end{aligned}$$

The equilibrium prices and revenues for each strategy chosen by the NPs can therefore be computed for the pricing game. The formulas expressing these parameters are complex and dependent on several parameters, namely the game sensitivities κ_ℓ and η_ℓ, the price sensitivities α_i and $\beta_{i,j}$, and the game costs. Consequently, the study of the higher-level game on offer composition (selecting a strategy $\mathcal{L}_i$ for each provider i), that would take those equilibrium revenues as an input, is not likely to be tractable analytically, even in the restricted use-case of two NPs and two video-games. We therefore turn our attention to a specific numerical example, to illustrate the different game levels.

To make their decision about the composition of their offer, Network Providers anticipate what the outcome of the pricing competition will be for each combination of the offer bundles. This is illustrated in Table I for the following parameter values: $D_{1,0}=D_{2,0}=1$, $\alpha_1=\alpha_2=0.06$, $\beta_{1,2}=\beta_{2,1}=0.03$, and $\mu=0.6$. As concerns game popularity and prices, we considered one game that has popularity $\kappa_1=0.2$ and a common (low) cost for both NPs equal to 0.1 monetary units (MU) per demand unit, while another game with popularity $\kappa_2=0.3$ has a different cost for the NPs: here NP1 has free access to the game, possibly due to agreements with the game editor, and NP2 has to pay a high price (10MU per demand unit) to get access to that game. The indirect effects are taken to $\eta_1=\eta_2=0.1$. In Table I, revenue values in bold indicate best-replies of an NP to the strategy picked by its competitor. A Nash equilibrium would then be a cell in the table with both values in bold. We remark that NP1 has a dominant strategy that consists in offering both games, while the best choice of NP2 depends on the choice of its opponent. In particular, it is interesting for NP2 to offer the second game only if NP1 does not offer it, since NP2 would then benefit from being in a monopoly situation. For the situation displayed in Table I, there exists a unique equilibrium where NP1 proposes both games and NP2 only offers the first game.

Of course, the popularity (parameters κ_ℓ) and costs of the games on the market may strongly affect the outcome of the pricing competition, and as a result the contents of the offers proposed by Network Providers. Estimating the values of those parameters would imply carrying out surveys, which is beyond the scope of this paper. We rather intend here to gather the most important parameters in the context of GaaS competition, and to provide a way to understand the phenomena and analyze the strategic choices of the Network Providers.

C. Some numerical results

We studied numerically the situation when the costs to games are the same for both providers, and fixed to 0.1MU per demand unit for the first game. The other parameters are the same as in the previous subsection. We then varied the popularity of the second game, and observed that even if its popularity is very low (with a κ_ℓ parameter of 0.0001, 1000 times smaller than the first game)

NP1 \ NP2	$\emptyset$	$\{1\}$	$\{2\}$	$\{1,2\}$
$\emptyset$	(4.14, 4.14)	(4.15, 5.28)	(4.77, 3.40)	(4.57, **5.32**)
$\{1\}$	(5.29, 4.15)	(5.17, 5.17)	(6.08, 3.41)	(5.68, **5.20**)
$\{2\}$	(6.04, 4.14)	(6.08, **5.29**)	(6.81, 3.32)	(6.53, 5.19)
$\{1,2\}$	(**7.76**, 4.15)	(**7.59**, **5.16**)	(**8.71**, 3.32)	(**8.14**, 5.07)

Table I
THE OFFER COMPOSITION GAME: NP1 CHOOSES A ROW AND NP2 A COLUMN. VALUES IN THE CELL ARE OF THE FORM $(\text{REVENUE}_1, \text{REVENUE}_2)$.

then it is still a dominant strategy for providers to offer it. This can be explained by the fact that offering the game increases the attractiveness of the provider -because of the demand form we consider- while on the other hand the additional capacity costs implied are not that large, since they also depend on the game popularity as specified in Equations (3) and (6).

Trying to generalize those results, this suggests that if providers have the same capacity costs to games then they should try to build an offer as large as possible.

IV. CONCLUSION

In this paper, we propose a model for the analysis of the competition between Network Providers for the delivery of video-games using Cloud rendering. Modeling such a scenario involves using several parameters in order to capture as much as possible the ingredients and issues, which makes the two-level competition game (through prices and offer content) among providers difficult to study analytically as a whole. We provide results for the game on prices, and preliminary (numerical) results for the game on offer contents, to highlight the interactions among providers and the effects of competition.

In future work, we aim to extend this study by expanding the set of stakeholders, in order to understand the interactions among users, Cloud and Network providers. Secondly, an interesting direction to investigate would be to introduce QoS variables, such that demand fluctuates with QoS, hence a tradeoff for providers in terms of QoS investments (possibly through capacity costs). Finally, we also intend to study totally different business models for the GaaS scenario (e.g., where Cloud Providers would be paid by advertising while buying QoS from NPs to attract users).

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