Economics of technological games among telecommunications service providers

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I) Introduction

- Emergence of 4G wireless technologies (LTE and WiMAX)
- In many countries : regulated competition between wireless operators
- Some wireless operators already own wireless infrastructure and some others have a licence cost reductions provided by the regulation authority.

=> Questions :

- Given the infrastructure state of an operator and the future arrival of a competitor, which 3GPP systems effectively need to be kept and effectively proposed ?
- Which set of technologies will a new operator have to propose ?
- Which consensual positions may exist between them ?
- How can a regulation authority influence their choice ?

I) Introduction

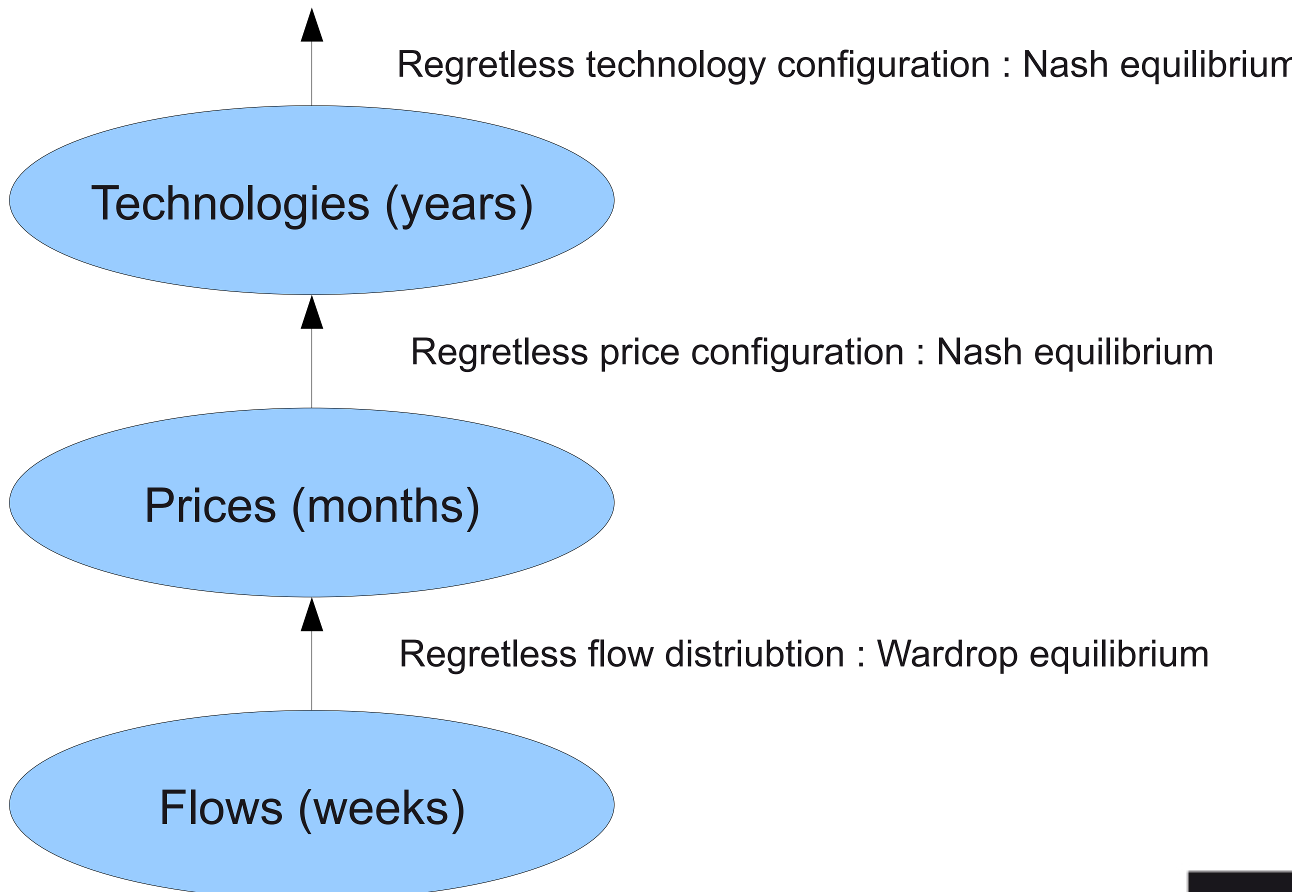
Example :

Example	WiFi Infr. existence	3G Infr. existence	3G Licence cost reduction
Operator 1	yes	yes	no
Operator 2 (new)	no	no	yes

=> Which technology investment operator 2 has to consider to maximize its revenue and to never regret its choice ?
Which most suitable reaction operator 1 has to choose ?

II) Model
1) Overview

At a nodeB coverage geographical scale :
- 3 levels of competition (observable at different time scales)
- Backward induction : an equilibrium is found from the equilibria of the lower layer



II) Model

2) Basics

- Finite set of technologies T : $T = T_p \cup T_s$

  T_p : technology with unshared bandwidth

  T_s : technology with shared bandwidth

  Technology t capacity (Mb/s): $C_{i,t}$ if $t \in T_p$, C_t if $t \in T_s$

- Finite set of operators N

  Technologies proposed by operator i : S_i

  Average price per flow unit proposed by an operator i : p_i (euros)

  Downlink demand to an operator i on a technology t : $d_{i,t}$ (Mb/s)

  Congestion functions : $l_{i,t}$ if $t \in T_p$; l_t if $t \in T_s$

- Total demand function of users D (Mb/s) on a fixed geographical zone

II) Model

3) First layer : Access network selection by users

Users objective : pay the cheapest flow unit with the smallest congestion.

Perceived price : price taking congestion into account that users intuitively pay.

Perceived price = Price per flow unit + congestion cost

Each couple (operator, technology) has a perceived price.
The users objective is to choose the lowest perceived price proposed by any operator. Global demand is supposed elastic : if the smallest perceived price increases, then the global demand decreases.

Wardrop Equilibrium : family of numbers $(d^*_{i,t})_{i \in N\ t \in S\_i}$ verifying :

$$\begin{cases} \forall i \in \mathcal{N}, \forall t \in \mathcal{S}_i \quad \bar{p}_{i,t} = \begin{cases} p_i + \ell_{i,t}(d^*_{i,t}) & \text{if} \quad t \in \mathcal{T}_p \\ p_i + \ell_t(\sum_{j:t \in \mathcal{S}_j} d^*_{j,t}) & \text{if} \quad t \in \mathcal{T}_s \end{cases} \\ \forall i \in \mathcal{N}, \forall t \in \mathcal{S}_i \quad d^*_{i,t} > 0 \Longrightarrow \bar{p}_{i,t} = \min_{j \in \mathcal{N}, \tau \in \mathcal{S}_j} (\bar{p}_{j,\tau}) \\ \sum_{i \in \mathcal{N}} \sum_{t \in \mathcal{S}_i} d^*_{i,t} = D(\min_{i \in \mathcal{N}, t \in \mathcal{S}_i} (\bar{p}_{i,t})) \end{cases}$$

Property : there always exists a unique Wardrop equilibrium.

4) Second layer : price selection by operators

Operators objective : Find the price per flow unit that maximizes its revenue.

Normal form non-cooperative game G_1 on prices :

Players : operators

Player i actions set : $\{p_i >= 0\}$

Player i utility function :

$$\begin{array}{rcl} \mathbb{R}^{N+} & \longrightarrow & \mathbb{R} \\ R_{1,i} : p & \longmapsto & p_i \times \sum_{t \in \mathcal{S}_i} d_{i,t} \end{array}$$

with $(d^*_{i,t})_{i \in N\ t \in T}$ the Wardrop equilibrium

Nash equilibrium on prices : family of real $(p^*_i)_{i \in N}$ such that every operator i has no interest in changing its price.

The set of Nash equilibria is called $E_2(S)$

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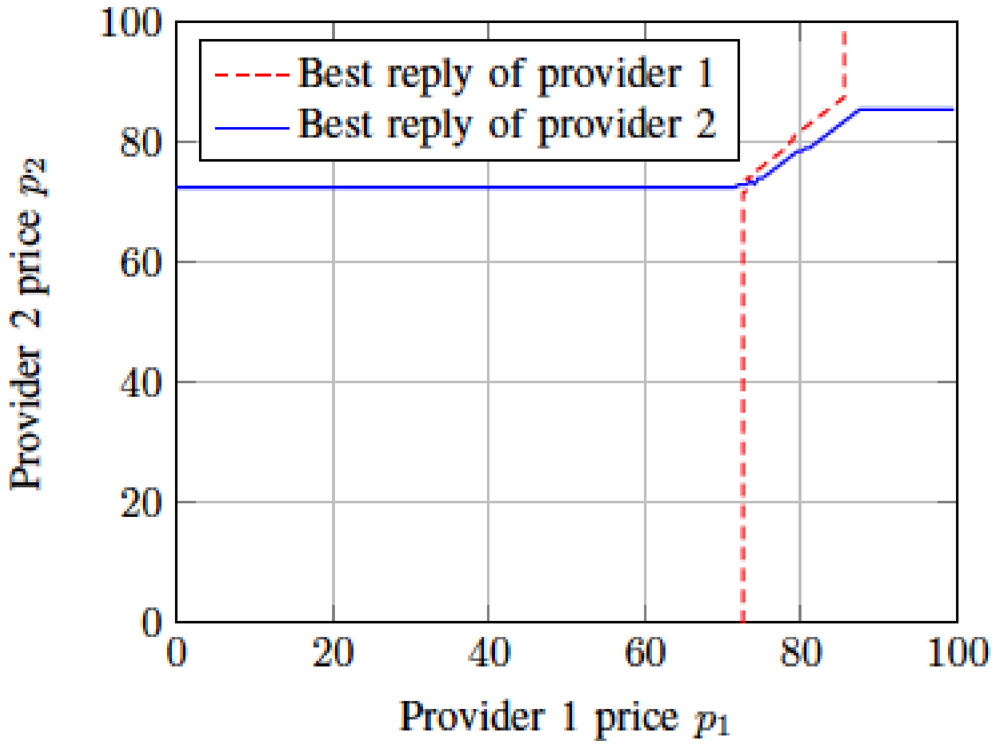
II) Model

4) Second layer : price selection by operators

Example with N = 2 and where both operators only own a single technology with unshared bandwidth.



II) Model

5) Third layer : technologies selection by operators

Operators objective : find the set of technologies that maximize its revenue

Normal form non-cooperative game G_2 on technologies :

Players : operators

Player i actions set : {subsets S_i of T}

Player i utility function :

$$\begin{array}{rcl} A_2 & \longrightarrow & \mathbb{R} \\ R_{2,i} : S & \longmapsto & \begin{cases} R_{1,i}(p^*) - c_{i,S_i} \text{ if } E_2(S) \neq \emptyset \\ -c_{i,S_i} \text{ if } E_2(S) = \emptyset \end{cases} \end{array}$$

where c_{i,S_i} is the total monthly cost paid by operator i, that includes the average infrastructure deplayment cost and the licence cost.

Nash equilibrium on technologies : family of subsets $(S^*_i)_{i \in N}$ of T such that every operator i has no interest in changing its price.

III) Case studies

1) Framework

The regulation authority has just allowed the deployment of a 4G (e.g. WiMAX) technology.
Two operators want to identify the best set of technologies maximizing their profit once deployed such that no regrets can be made by taking into account their current infrastructure and advantages.

Methodology :

- 3G and WiMax with unshared bandwidth, whereas WiFi with shared bandwidth
- Demand function : supposed linear
- Demand does not exceed technology capacities : congestion functions values : average waiting time of M/M/1 queue of parameters (d,C), where C is a a local capacity value.

Monthly cost differences between operators.

III) Case studies

2) WiFi – 3G

Operator 1 already owns a 3G infrastructure, whereas operator 2 already owns a WiFi infrastructure (Free vs Bouygues Telecom).

1 \2	∅	3G	WiMAX	3G,WiMAX	WiFi	WiFi,3G	WiFi,WiMAX	WiFi,3G,WiMAX
∅	0;0	0;1929	0;2555	0;3716	0;2178	0;3629	0;4047	0;**4778**
3G	1437;0	1167;1679	1057;2198	810;3141	1208;1935	937;3161	826;3493	590;**4000**
WiMAX	2555;0	2198;1549	2040;2040	1665;2875	2237;1837	1865;2954	1708;3238	**1368;3628**
3G,WiMAX	3224;0	2649;1302	2383;1665	1781;2273	**2715**;1616	**2100**;2488	**1834**;2664	1235;**2817**
WiFi	2228;0	1985;1700	1887;2237	1666;**3207**	0;-50	0;-591	0;-874	0;-1415
WiFi,3G	3187;0	2719;1429	2512;1865	2046;**2592**	-1033;-50	-1033;-591	-1033;-874	-1033;-1415
WiFi,WiMAX	4097;0	3543;1318	**3288**;1708	**2714;2326**	-824;-50	-824;-591	-824;-874	-824;-1415
WiFi,3G,WiMAX	**4336**;0	**3558**;1082	3186;1368	2375;**1727**	-1857;-50	-1857;-591	-1857;-874	-1857;-1415

=> 2 Nash equilibria :
{({WiFi,WiMAX},{3G,WiMAX}), ({3G,WiMAX},{WiFi,WiMAX})}

Regulation on licences in France :
Suppose that there are 10 000 similar zones on the french terrirory.
If the second licence price is reduced by 80M€ (initial cost reduction of 240M€), a new Nash equilibrium appears : ({3G,WiMAX}, {WiFi,3G,WiMAX})

III) Case studies

3) WiFi – 3G,WiFi

Operator 1 owns a WiFi infrastructure, whereas operator 2 additionaly owns a 3G infrastructure (Free vs Orange).

1 \2	∅	3G	WiMAX	3G,WiMAX	WiFi	WiFi,3G	WiFi,WiMAX	WiFi,3G,WiMAX
∅	0;0	0;1929	0;2555	0;3716	0;2228	0;3679	0;4097	0;**4828**
3G	1437;0	1167;1679	1057;2198	810;3141	1208;1985	937;3211	826;3543	590; **4050**
WiMAX	2555;0	2198;1549	2040;2040	1665;2875	2237;1887	1865;3004	1708;3288	**1368;3678**
3G,WiMAX	3224;0	2649;1302	2383;1665	1781;2273	**2715**;1666	**2100**;2538	**1834**;2714	1235;**2867**
WiFi	2228;0	1985;1700	1887;2237	1666;**3207**	0;0	0;-541	0;-824	0;-1365
WiFi,3G	3187;0	2719;1429	2512;1865	2046;**2592**	-1033;0	-1033;-541	-1033;-824	-1033;-1365
WiFi,WiMAX	4097;0	3543;1318	**3288**;1708	**2714;2326**	-824;0	-824;-541	-824;-824	-824;-1365
WiFi,3G,WiMAX	**4336**;0	**3558**;1082	3186;1368	2375;**1727**	-1857;0	-1857;-541	-1857;-824	-1857;-1365

=> 2 Nash equilibria :
{({WiFi,WiMAX},{3G,WiMAX}), ({3G,WiMAX},{WiFi,WiMAX})}

Thanks