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Game-theoretic evaluation of competing wireless access networks for offering Mobile Internet

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Abstract

In this paper a complete business case for the rollout of a municipal wireless access network for offering Mobile Internet is evaluated. Two different business players, a municipality deploying a WiFi network and a mobile virtual network operator (MVNO) offering 3G femtocells, are considered. A case study is performed in the city of Ghent (Belgium) and different customer classes and service offers are defined. First of all, a net present value (NPV) analysis is elaborated for the two stand-alone cases in order to estimate their economic viability. For both players, a positive business case is found in the city centre of Ghent. In a second step, the influence of competition between these two market players is modelled by applying game theory. The optimal rollout strategy as well as the price setting for both players is evaluated. Due to the high initial investments for deploying WiFi access points throughout the whole city, the municipality tends to postpone its rollout one or two years, whereas the 3G femtocell operator will start as soon the technology allows a mass deployment. Regarding the price setting strategy, both players balance each other leading to slightly higher service tariffs, when no extra competitors are considered.

Keywords
wireless access, WiFi, 3G femtocells, business case, game theory

1. Introduction

When deploying a wireless access network for Mobile Internet, a whole range of technical configurations can be considered. Different access technologies are available (e.g., WiFi, (Mobile) WiMAX, 3G femtocells), a diversity of backhaul solutions are possible (e.g., fixed, wireless mesh or a combination of them), different levels of coverage can be aimed for (e.g., local hotspots, full outdoor coverage or even full indoor coverage), multiple antenna heights can be chosen (influencing the signal propagation), etc. This paper compares some useful alternatives for deploying a new wireless access network, mainly intended for indoor usage. Studies on wireless network usage show that more than 70% of data traffic originates from indoors (Chandrasekhar, Andrews & Gatherer, 2008). Moreover, a wireless access network could be highly effective for mass-market mobile TV, video and audio services indoors. A recent McKinsey report, for example, highlighted that 35% of mobile TV is watched at home (Tiller, 2007).

To assess the general feasibility of a wireless access network rollout, an investment analysis is performed based on a net present value (NPV) evaluation. At the cost side, an accurate dimensioning of the number of access points / base stations and the required backhaul equipment is combined with a detailed cost model containing capital (CapEx) as well as operational (OpEx) expenditures. At the revenue side, the user adoption is modelled by defining different user groups (inhabitants, tourists, students and business users) and predicting their market potential for the offered wireless services.

In addition, the influence of competition between different market players offering Mobile Internet access is modelled by applying game theory. In game theory, two or more different players (e.g., each deploying a different wireless network) are considered, and every player can choose from different strategies (e.g., different rollout speed, rollout area, price setting). For every strategy, the outcome or payoff (in this case the NPV) is calculated. As the different players will choose their strategy independently at the beginning of the period, a payoff matrix containing the payoffs of each player for all possible combinations of potential strategies can be determined. The Nash equilibriums (NEs) – defined as a set of strategies, one for each player, where no player will gain anything by unilaterally changing its strategy – can then be derived from the payoff matrix.

A case study is elaborated for a wireless network rollout in the city of Ghent (Belgium). Two competing operators are defined for offering Mobile Internet: a municipality deploying a WiFi network, and a fixed-line telecom operator, acting as a mobile virtual network operator (MVNO), deploying a 3G femtocell network. The WiFi network will be deployed throughout the city (e.g., access points installed on lampposts or building façades), while the 3G femtocells will be installed at the user’s home to locally offer a better service than the available 3G macrocells. WiFi has the advantage of being a widely-used technology and allowing an easy deployment. Otherwise, a good coverage is needed to convince people to take a subscription and a municipality has no existing customer base. 3G femtocells are an upgrade of the existing 3G network, and will only be installed when needed. Otherwise, while (almost) every laptop is currently equipped with a WiFi card, this is not yet the case for 3G technology. The proposed adoption curve for Mobile Internet, predicting the total number of customers, will then be divided between the two operators taking into account the above trade-offs. Note that the considered technology choices for both players correspond to the most realistic options. On the one hand, a municipality will probably be unable to rollout a local 3G network, due to the required licenses and the more complex network architecture. On the other hand, for a telecom operator, it is a very risky business case to offer full WiFi coverage in a city without any socio-economic and legal advantages, as increased opportunities for the city and its inhabitants, and guarantees about building permits for installing the WiFi access points.

In Section 2, a technical overview of the two considered wireless access network technologies – WiFi access points and 3G femtocells – is presented. Section 3 describes the business case and adoption modelling for a Mobile Internet service in the city of Ghent. Section 4 and 5 evaluate the economic viability of the WiFi and 3G femtocell network, respectively. In Section 6, the competition between both players is studied in detail. Extra attention is given to the market segmentation between two competing players, based on price differences, churn rates, promotions and rollout years. A game-theoretic evaluation is performed for different strategies taken by both players. Finally, Section 7 formulates some conclusions and future work in the field.

2. Wireless access network technologies

This section gives a technical description of the two wireless access network technologies that are used in this paper, WiFi access points and 3G femtocells, respectively.

2.1 WiFi access points

WiFi (Wireless Fidelity) is a certification label for wireless local area network (WLAN) devices that comply with the international IEEE 802.11 standards and sub-standards. Those labels are distributed by the WiFi Alliance, and interoperability between different products is ensured that way. There are different flavours of the IEEE 802.11 standard, where 802.11a (approved in 1999), 802.11b (approved in 1999), 802.11g (approved in 2003) and 802.11n (approved in 2009) are presently the most wide spread variants.

In contrast with mobile networks, like GSM, UMTS, HSDPA, which are typically deployed and managed by a telecom operator, WiFi devices were primarily intended to be installed and managed by the customer himself. By installing a WiFi access point, which forms the central wireless connection point, a customer is able to deploy a wireless (home) network (a WLAN). This WLAN is then mostly connected to the (cabled) broadband Internet connection of the customer. Some telecom operators, however, are nowadays also exploiting WiFi access points (hotspots) at public places (such as in motorway restaurants, train stations, airports, coastal towns…) to offer their clients a fast wireless Internet connection at those places as an extension to their main telecom services. Note that besides the method described above (known as infrastructure mode), WiFi also allows users to communicate directly with each other without access point (known as ad-hoc mode).

Two non-licensed radio frequency bands are defined for WiFi, i.e. 2.4 GHz and 5 GHz. (The original IEEE 802.11 standard also stated infrared physical layer (PHY) specifications, but they are hardly used today.) The b/g-standards operate in the 2.4 GHz frequency band for which only three low-interfering 20 MHz channels can be chosen among the 13 available channels in Europe (or 11 in the USA). The a-standard operates in the 5 GHz band providing 12 low-interfering 20 MHz channels, but compared to the 2.4 GHz band it suffers from degraded signal propagation. The n-standard can be enabled in the 5 GHz mode, or within the 2.4 GHz band.

IEEE 802.11b uses a PHY air interface with Direct Sequence Spread Spectrum (DSSS) as a signal spreading technique and can achieve a data rate of 11 Mbps in a 20 MHz channel. IEEE 802.11g can be considered to be the successor of 802.11b and it is backwards compatible with the latter. It uses an Orthogonal Frequency Division Multiplexing (OFDM) PHY air interface, and a maximum achievable PHY data rate of 54 Mbps per 20 MHz-channel can be attained. IEEE 802.11a also uses an OFDM PHY air interface, allowing data rates up to 54 Mbps (but operating in the 5 GHz band, as already mentioned). For the IEEE 802.11n standard (IEEE P802.11n/D3.00, 2007), the data rate is extended to 65 Mbps by using, among other things, more OFDM data subcarriers and higher Forward Error Correction (FEC) code rates. Besides, the 802.11n standard also supports multiple antenna techniques like Multiple-Input Multiple-Output (MIMO), which can extend either the data rate or the range of the WiFi signals. For outdoor access points, MIMO is better used to extend the wireless range while keeping a 65 Mbps channel, than to increase the data rate (note that environmental conditions such as line-of-sight (LOS) could have a negative impact on the achievable data rate gain by MIMO). Besides, the 802.11n standard supports a channel bandwidth of 40 MHz by merging two channels (so-called channel bonding) and provides thus a higher data rate of two times 65 Mbps, but this poses interference problems, especially in the 2.4 GHz frequency band (with only three non-overlapping 20 MHz channels).

In this paper, we use the 802.11n standard because of the higher throughput and the possibility to use MIMO, compared to the 802.11a/b/g standards. As 802.11n has just recently been certified (IEEE Standards Association, 2009), a lot of products on the market today are still based on draft 2.0. Certified products will however soon hit the market (Churchill, 2009). For the wireless municipality network, we expect to work within the license-free 2.4 GHz frequency band, and we choose for a 20 MHz channel bandwidth, sacrificing larger data rates for reduced interference.

2.2 3G femtocells

The third generation of mobile telephony (3G, like UMTS) refers to the transformation of the digital mobile telephony technology (2G, like GSM, as successor of 1G referring to analogue mobile phones) to a full mobile Internet access technology. UMTS uses a new radio interface in comparison with GSM, the Universal Terrestrial Radio Access (UTRA) radio channel. It includes Wideband Code Division Multiple Access (W-CDMA) for the transmission of the data traffic from multiple users. Uplink and downlink are separated by Frequency Division Duplex (FDD); this means that uplink and downlink are separated by assigning them different frequencies.

It is the third generation partnership project (3GPP) that tries to provide uniform standardizations for these and other 3G flavours. The 3GPP is a collaboration agreement that brings together a number of telecommunications standards bodies, mainly for the European market. A similar project exists in the USA: 3GPP2 for e.g., the 1xEV-DO technology. Currently release 99 is the version of UMTS that is used. Other releases (R4 - originally Release 2000, R5, R6 and R7) are already specified to further improve the UMTS technology. Although supported theoretical bit rates vary from 6 to 1872 kbps, a user nowadays typically gets up to 384 kbps for R99 handsets in the downlink connection. The successor of UMTS is HSDPA, introduced in the 3GPP release 5 standards. It improves the downlink data rate for UMTS by using shared channels for different users, among some other things. As this is an improvement of the 3G UMTS standard technology, it is called a 3.5G technology. Paradoxically, HSDPA enables a wider coverage than UMTS R99 due to the adaptive modulation and coding and the fast scheduler in the base station, which provides more granularity in terms of radio and resource management (Nortel, 2005). Although supported theoretical bit rates vary from 0.9 to 14.4 Mbps, a user nowadays typically gets up to 3.6 Mbps for HSDPA handsets. 3GPP standards beyond release 5 will further improve the data rate due to MIMO and other new technologies. Release 6 introduces High Speed Uplink Packet Access (HSUPA), new antenna array technologies (beam forming and MIMO) and a new uplink transport channel E-DCH (Enhanced Dedicated Channel) and targets 28.8 Mbps downlink and 5.8 Mbps uplink. HSUPA clearly improves the uplink, and is sometimes referred to as 3.75G technology. Release 7 introduces evolved High Speed Packet Access (HSPA) or HSPA+. The target is 42 Mbps downlink and 22 Mbps uplink through higher order modulation (up to 64 QAM).

By installing a femtocell at the user side, the customer will obtain a more stable and energy efficient 3G (or 3.5G / 3.75G) signal indoors. A femtocell is a small cellular base station designed for use in residential or small business environments. It connects to the service provider's network via the customer's broadband connection instead of connecting via the local mast. So there are no additional costs for deployment nor energy at the site since all is provided by the customer. A femtocell typically supports two to five mobile devices in a residential setting. A femtocell is sometimes referred to as a home base station, access point base station, 3G access point, small cellular base station and personal 2G-3G base station (Tartara Systems, 2009). The 3GPP's term for a 3G femtocell is a Home Node B, or HNB. Femtocells operate at very low radio power levels - less than cordless phones, WiFi or many other household devices. This substantially increases the battery life, both on standby and talk time (Chambers, 2008).

Femtocells are able to provide exceptional cellular service with a typical coverage range of tens of meters at high data rates. For instance, PicoChip's PC 8209 femtocell supports 7 Mbps HSDPA (PicoChip, 2007). For an operator femtocells are attractive, since they can significantly increase the achievable data rates on their mobile network at the customer's property. This is very interesting since delivering high-quality mobile services inside buildings is on one hand a tough challenge for 3G because it uses higher frequency bands where radio signals attenuate more rapidly. On the other hand are fast data rates only possible when the quality of the signal is strong (Baines, 2007). Individual connections to the femtocell reduce traffic on the macrocellular network, thereby improving the quality of the network for the remaining users since a macrocell has to share its bandwidth amongst all users in a potentially large coverage area, which limits the user throughput (Clausen, 2008). Unlike WiFi, femtocells use licensed radio spectrum, so must be operated and controlled by a mobile network operator (MNO). Thus it will work with only one MNO, and thus encourages all users in a household to switch to the same operator.

In this paper, we consider that the macrocell 3G (or 3.5G / 3.75G) network of a MNO is extended with femtocells installed by a fixed network operator at the customer side. The fixed network operator then provides access to its customers through both femto- and macrocells (by having agreements with the MNO for the latter), and is therefore said to act as mobile virtual network operator (MVNO). The exactly used technology (UMTS, HSDPA,...) will depend on the network of the MNO.

3. Business case definition

3.1 Rollout area

We have chosen the city of Ghent as rollout area for the business case in this paper. Ghent is located in the Northern part of the country (Flanders) and is currently the third largest city in Belgium, with 240,000 inhabitants. Next to these ‘full-time’ inhabitants, Ghent is also the largest student city of Flanders, housing over 50,000 students during large parts of the year. When tourism is considered, Ghent attracts more and more tourists every year. According to recent figures, almost 395,000 tourists visited Ghent in 2008, a number that is expected to keep rising. Together with about 16,000 businesses on its territory, the city of Ghent has a large potential customer base for wireless access network users.

The exact rollout area is based on previous research conducted by Van Ooteghem et al. (2009). A business case was developed for a municipal WiFi and/or WiMAX rollout, and it showed that the best rollout area is the centre region of Ghent. This zone houses 42% of the inhabitants, and almost 90% of the students. The rollout zone covers the historical city centre, so we assume all tourists will be covered by the network. Concerning businesses, only a small proportion is located in the city centre. Most of these companies (85%) are so-called small and medium enterprises (SMEs). Still some larger companies are also housed in the rollout area, and most of the university personnel work in the centre of Ghent.

3.2 User adoption

In this paper, we use the Gompertz model (Harrison and Pearce, 1972) to estimate the user adoption of Mobile Internet through the years. It forms an asymmetric S-shaped curve, with the adoption slowing down as it progresses (Figure 1). More precisely, the Gompertz curve assumes that the period of increasing growth of adoption is shorter than the period in which this growth is decreasing and in which it is adjusting to its saturation level.

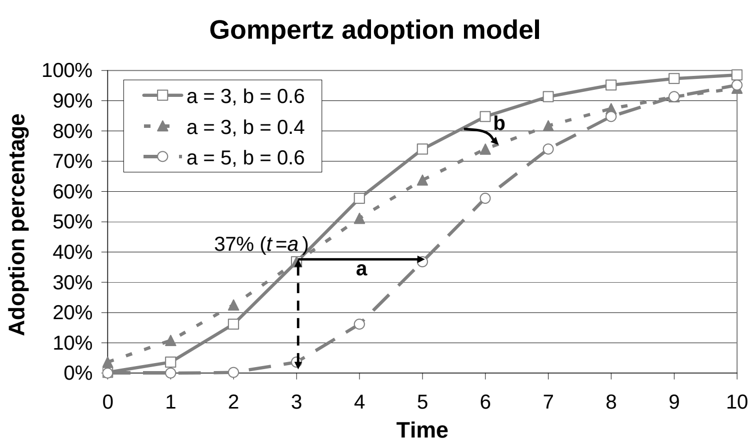

Figure 1: Illustration of the Gompertz adoption model

The cumulative market share according to the Gompertz model, as illustrated in Figure 1 for m = 100%, is given by:

$$S(t) = m \cdot \exp[-\exp(-b(t-a))]$$

Where:

m = maximum market share
a = inflection point, which occurs at an adoption of 37%
b = adoption rate (defining the slope of the curve)

The users are subdivided in several classes: inhabitants, students, tourists and business users. The parameters for their respective Gompertz adoption curves have been proposed in Van Ooteghem et al. (2009). Table 1 lists the parameters for each class of customers.

Table 1: Gompertz parameters for each customer class

Parameter	Inhabitants	Students	Tourists	Business
a (year)	2011.5	2011.5	2011.5	2011.5
b	0.64	0.64	0.64	0.64
m	20%	33,3%	5%	5%

In Section 6.3.2, a price setting game is played. We have implemented the impact of the price on the service adoption. When players offer a yearly price reduction, the maximum market share rises with 10%. The impact of changing prices is modelled using a type 1/x function. In the hypothetical scenario of a free service, with prices dropping to 0, almost everyone will use the service. So the maximum market share will be close to 100%. In the other extreme a price of infinity, no one will pay for the service, so the maximum market share will then drop to 0%.

3.3 Business players

This paper studies the impact of the introduction of two wireless access networks in one area. Two players, a municipality and a mobile virtual network operator (MVNO), each offering the same service, but using another technology, will battle for a piece of the market share. This section describes both players in more detail.

3.3.1 Player 1: Municipality - WiFi network

Van Ooteghem et al. (2009) describes the economic feasibility of the introduction of a wireless access network by a municipality. The municipality can form the driving force behind the deployment of the wireless telecom infrastructure. The business case for a municipality is substantially different than for a commercial telecom operator, as the major motivation for municipalities lies in the field of social welfare. The main strength for a municipality is the facilitating role it could play in the rollout. A reduction in administration, giving right of way, trust (from inhabitants and companies), etc. will give the project a more feasible outlook in terms of costs and rollout speed. Knowledge and experience about networks is the main weakness for the municipality. This could be solved when other partners are involved in the project. Additionally, the negative perception about human exposure also has to be tackled, e.g., by accurately informing the inhabitants about the impact of wireless technologies and its potential health effects. The most important opportunities for the municipality are image, city competitiveness, economic development, decrease in ICT expenses, productivity increase, social benefits (e.g., bridging the digital divide, lower prices for Internet services), eGovernment services, etc. The main threats are financial involvement (possibly violation with EU competition regulation) and competition with other telecom operators.

Van Ooteghem et al. (2009) considers several technical scenarios for the wireless network deployed by a municipality. WiFi and WiMAX are assumed to be the most suited technologies for this purpose. For this paper, where two competing wireless networks are deployed in the same area, we choose the most profitable technical scenario for the municipality rollout, i.e. using WiFi access points for the customer access (hotspots) as well as (part of) the backhauling (connected to a fixed backbone network).

Four subscription schemes are considered for accessing the WiFi network: free (based on advertising), low-bandwidth and high-bandwidth monthly subscriptions and vouchers. For the assumed subscription prices, we refer to the business case described in Section 4.

3.3.2 Player 2: Mobile virtual network operator - 3G femtocell network

The second service provider in this study is an MVNO deploying a 3G femtocell network. Unlike WiFi hotspots, 3G femtocells use licensed radio spectrum, so the network must be operated and controlled in collaboration with an MNO. The majority of the MVNOs is consumer-focused and most have a focus on price sensitivity as their unique selling point, and they let the MNO manage the complete network infrastructure. Leading MVNOs, however, now deploy their own core network infrastructure in order to facilitate the means to offer value-added services to their customer base. The goal of offering value-added services is to differentiate versus the incumbent MNOs, preventing the MVNO from needing to compete on the basis of price alone. The latter type of MVNOs is considered in this paper. Note that the MNO will not ban MVNOs from using their access network as they are also advantageous for the MNO because rather than competing with the MNO’s own offering, these services will boost network usage and are for the hard-pressed mobile license holders a means of deriving revenue to offset the enormous cost of building 3G networks. Furthermore, MNOs often find it difficult to succeed in all customer segments. MVNOs are a way to attack specific, targeted segments. They mean lower operational costs (billing, sales, customer service, marketing) and help fight churn. The opportunity for MNOs to take advantage of MVNOs generally outweighs the competitive threat.

The leading MVNO considered in this paper already offers fixed-line broadband access, which can be used as backhaul network for the femtocells. The MVNO forms a consortium with an MNO, and the latter receives e.g., a fixed monthly fee per femtocell customer (see Section 5.1) for the use of the mobile license. The introduction of the network will be performed nationwide. For the MVNO, the main network investments are the adaptation of the core infrastructure for interfacing with 3G femtocells (over the customer’s fixed-line broadband connection) and with the 3G macrocells (the Node-B’s) of the MNO. Some 3G specific core components will need to be purchased, but after these initial investments, femtocells can be sold to every customer nationwide. To compare the nationwide introduction with the municipal introduction of the WiFi network, all capital expenditures will be scaled down based on the number of potential customers.

For the customers, only one service subscription (with the MVNO) is required to use both 3G macro- and femtocells. We do not differentiate between different subscriptions schemes that could be offered for marketing purposes. Here we only consider a single type of subscription, which can be extended with a subscription to some added value services.

3.4 Business case evaluation

A standard economic evaluation method is the net present value (NPV) calculation. To calculate the NPV, the yearly cash flows are discounted and then added up. A usual choice for this discount factor is the weighted average cost of capital (WACC). For telecom projects a WACC between 10% and 15% is common, depending on the overall risk of the project. This project uses a WACC of 12%, based on the combination of high risk due to an unfamiliar technology and low risk of the small capital expenditures. The business cases considered in this paper are evaluated over the period 2010–2019.

Note that, when launching a network, several investments need to be made by the network operator. The cost of some of these investments is very operator specific, so estimates come with a great degree of uncertainty. However, the models used for this paper are built in such a way that values can be changed easily when more detailed information is available.

4. Economic viability of deploying WiFi access points

This section briefly describes the business case for deploying a WiFi access network by a municipality. A more extended version can be found in Van Ooteghem et al. (2009).

4.1 Costs

4.1.1 Capital expenditures (CapEx)

WiFi access points

WiFi access points are installed on lampposts or building façades throughout the city. The cost of an outdoor WiFi access point, including installation, is estimated at €900 and we assume an average price decrease of 5% each year.

A detailed dimensioning tool is used for calculating the number and optimal location of the access points. In this step the physical and technical information (e.g., height, location, power, antenna gain, receiver sensitivity) is used in combination with the path loss model according to the technology set considered (Van Ooteghem et al., 2009). This dimensioning step is very important as the number of access points will also be the driver for other cost components (like site rental) and optimizing it will lead to an overall decrease in equipment and installation cost.

Wireless backhauling

Backhaul connectivity is delivered by a combination of wireless and fixed backhauling: a meshed wireless backhaul connects some neighbouring WiFi access points, of which one access point is connected to a fixed backhaul network. The dimensioning calculations for the WiFi access points are reused for determining the required number and locations of the backhauling access points. From this dimensioning, the wireless backhaul (mesh network) cost can be calculated as the cost of providing these access points with the additional network equipment. An extra cost of €150 per backhauling access point is assumed. The fixed backhaul network is rented from a fixed-line network operator and is considered as an OpEx cost.

Core equipment

An investment must take place in central infrastructure (core equipment) such as access gateways, routers, servers and general network operating centre (NOC) infrastructure like cooling and power supplies. For the WiFi network, the cost for core equipment is estimated at 10% of the WiFi access and backhauling equipment.

4.1.2 Operational expenditures (OpEx)

Site rental

The cost for renting the location to install a WiFi access point will be depending on the height, size, and availability. As already mentioned, the access points will be installed on street lampposts (where possible) or building façades and we assume a height of 6m. This site rental cost offers a great opportunity for a municipality as they might have access to a lot of public infrastructure, and the average cost per site (including maintenance of the site) is estimated at €120 for public sites and €240 for private sites. The minimal number of sites to deploy for providing the requested coverage and bandwidth is found from the dimensioning step.

Fixed backhauling

As mentioned in the section about wireless backhauling, a number of access points are connected to a fixed-line backhaul network, and we assume a volume-dependent connection price ranging from €250 to €500 per connected access point per year.

Planning, operations and maintenance

The cost of continuous planning will be driven by the number of newly to install access points. Operations and maintenance will be driven by the equipment type and volume. We consider an annual wage cost of €50,000 for planning 430 access points per person and €40,000 for operating 800 access points per person. Maintenance costs are a percentage of the CapEx cost of the respective equipment. This cost block can also be denoted as Operations, Administration and Maintenance (OA&M).

Customer relationship management (CRM)

As the name suggests, the costs within customer relationship management (CRM) will be fully driven by the customers. As such, CRM is not considered to be dependent on technology, bandwidth or coverage parameters. We can distinguish following important blocks:

Sales: is driven by the number of customers subscribed to the wireless services and the number of pricing schemes provided (e.g., pre-paid, fixed subscription, usage based). A yearly expense of 10% of the subscription revenues is foreseen, based on Lannoo et al. (2008).

Helpdesk: is driven by the number of customers subscribed to the wireless services. However not all customers are expected to contribute in equal part to these costs. Based on Lannoo et al. (2008), we assume that new customers make two phone calls per year to the helpdesk in the year they join the operator, while existing customers only make one. A phone call lasts about ten minutes on average. The helpdesk is staffed with employees who receive an annual wage of €40,000. The helpdesk has a capacity utilization of 70%.

Marketing and advertising: is driven by the size of the full potential customer base and marketing strategy such as a dedicated value per potential customer. For the WiFi network in the city of Ghent, we assume a yearly marketing cost of €80,000 Dedicated marketing strategies will focus on a smaller customer group, especially promotions on subscriptions will be fully driven by the amount of new customers subscribing to this promotion. On average, there is a promotion of a free subscription for two months for 50% of the new subscribers.

4.2 Revenues

The revenues for a municipality are divided in two parts: direct and indirect.

4.2.1 Direct revenues

The first category of revenues can be directly derived from the forecasted number of customers. For the free Internet service, advertising will be allowed, which leads to fixed revenues per customer. The other services are priced lower than competitor services offered by telecom operators, as increased competition and thus lower tariffs are motives for the municipality to invest in such networks. An overview of the revenues for the considered wireless municipality network can be found in Table 2. A tax rate of 21%, i.e. the value added tax (VAT), is deducted from the direct revenues. This way, only revenues the operator really receives are taken into account.

Table 2: Overview of the subscription fees per WiFi service

Service	Subscription fee (incl. VAT)	Offered bandwidth	
		Downstream	Upstream
Free subscription (revenue via advertising)	€ 5	512 kbps	128 kbps
Low-bandwidth subscription	€ 12	1 Mbps	256 kbps
High-bandwidth subscription	€ 20	3 Mbps	512 kbps
Vouchers (per card)	€ 9	1 Mbps	256 kbps

An estimation of the relative interest of each customer class for a certain service is shown in Table 3. Inhabitants will mainly be interested in a free service (in addition to their existing broadband connection), while students will use the WiFi service as primary connection and will thus be interested in a better bandwidth offer than the free service. Tourists will mainly buy vouchers, just as business users. However, depending on the amount of usage time, the latter customer class can also show interest in a monthly subscription.

Table 3: Interest of each customer class for a certain WiFi service

Service	Inhabitants	Students	Tourists	Business
Free	70%	5%	-	-
Low-bandwidth	20%	70%	5%	20%
High-bandwidth	10%	25%	-	20%
Vouchers	-	-	95%	60%

4.2.2 Indirect revenues

Indirect revenues are not directly linked to the main activity, here selling wireless access to the customers. They are caused by additional advantages experienced by providing the main activity. More in particular for the considered case, in which a municipality rolls out a wireless network, examples of such advantages are: efficiency gains in public services, the development of an eGovernment platform, attracting more high tech companies and educated citizens, enabling new business opportunities, etc. Considering the broad range of influences a wireless deployment might have on a municipality, its companies and citizens, predicting the total impact in detail is infeasible. By leaving it out of the revenue model, on the other hand, you neglect a potentially important part of the revenues.

For estimating the (monetary) impact of the indirect effects on the economy of the municipality, we distinguished between four main drivers as listed below.

Fixed (or no driver)

The setup of a wireless platform enables new public and private applications to be deployed. This in turn could allow (future) benefits e.g., efficiency gain, cost reductions.

Customer based

As customers are the main users of the wireless platform, many indirect effects could also be traced back to those customers. Examples are the influence of eGovernment applications which are directly driven by the actual number of participating customers, word-of-mouth effects (positive image, attracting new citizens) which are driven by the number of contacts each customer has with others, etc.

Service based

While some applications (e.g., tourist or other localized information) only require local connectivity (around the point of interest) and limited bandwidth, other applications such as web browsing and video services might benefit from an increase in both wireless coverage and bandwidth.

Investment based

The investments (or part of it) made for deploying a new wireless network will (preferably) be spent in companies regionally close to the municipality and as such part of the invested money can be expected to flow back into the local economy.

4.3 Investment analysis

For the investment analysis, all costs and revenues are combined for a case study in the city of Ghent, using the assumptions from Section 3. The four customer classes (inhabitants, students, tourists and business users) are taken into account, and they can choose between four different services (free, low-bandwidth, high-bandwidth and vouchers) as indicated in Table 2. Figure 2 presents the NPV of the project over the period 2010–2019. In the first years a high investment cost is needed to deploy the access points throughout the city, and at that time the user adoption and corresponding revenues are still too low to cover all these costs. For the WiFi case, we find a discounted payback period of seven years and after ten years an NPV of about €3.2 million is attained.

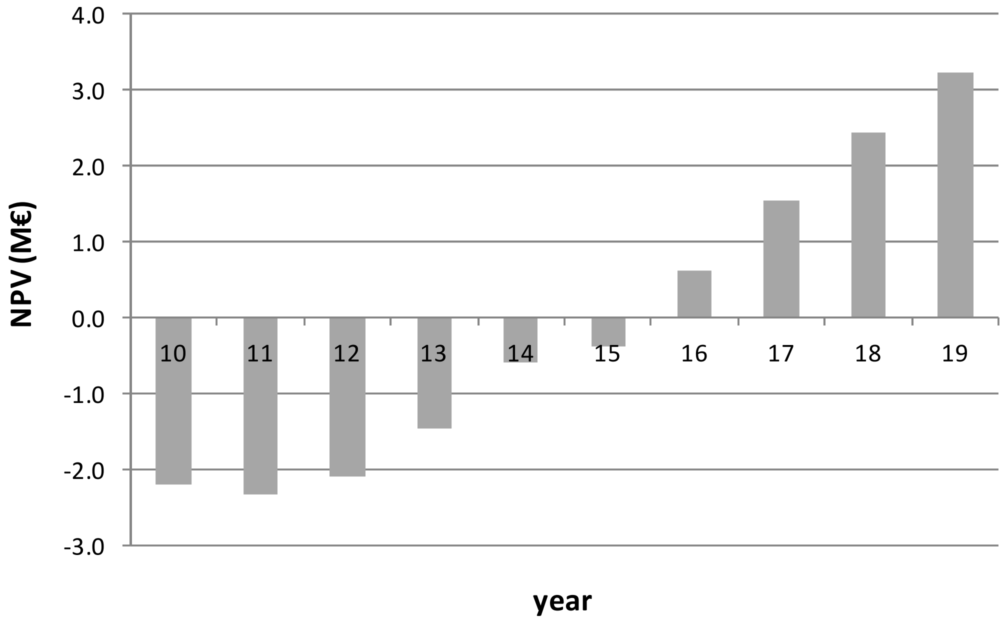

Figure 2: NPV evolution throughout the project lifetime for the WiFi network

5. Economic viability of deploying 3G femtocells

This section develops the business case for the femtocells. Since some important network investments are required in the core infrastructure for enabling the introduction of femtocells, an operator will typically opt for a nationwide launch. To make both cases comparable and to apply competition modelling at a municipality level, a municipal rollout is considered in the calculations of the 3G femtocell business case. Therefore, costs incurred by the operator that introduces a nationwide 3G femtocell network will be scaled down to the municipal level. The number of potential users in the rollout area is about 2% of the total predicted users in Belgium. All capital expenditures will be scaled down to this factor.

5.1 Costs

5.1.1 Capital expenditures (CapEx)

Femtocells

Currently, femtocells cost between €150 and €190. However, vendors are working hard to make 3G femtocells cheaper in the future, aiming at a price of €75 within two years. In year 0, we set the price at €175, in year 1 and 2, €125 and €75, respectively. From year 3 on, we expect an average price decrease of 5% each year. Femtocells subsidized by the operator are classified as equipment installed at the customer premises. The useful lifetime for this type of equipment is five years, which means that after five years, the operator needs to replace these cells. The amount of subsidization for the renewed cells is equal to the original amount of subsidization.

Core equipment

In order to launch the service, a femtocell gateway needs to be installed and integrated with the existing back office systems, like provisioning and billing. An operator with a nationwide network faces a cost of €5 million to €10 million (Signal Research Group, 2009). In comparison with other European operators, the Belgian operators are rather small, so installation and integration costs will be on the downside of this price band. After five years, additional investments to replace or update the gateway are provisioned, estimated at 20% of the indexed original installing and integration cost.

The operator has to choose the type of femtocell that will be installed at the customer side. This 3G femtocell will be provided by one vendor, selected by the operator. Femtocell vendors will offer testing models for free, seen the opportunities for them if they are selected by the operator as preferred supplier. The femtocells will be tested by a team of engineers. We expect that this testing can be done in half a year by a team of five engineers. Given the average gross monthly income for engineers with eight years of working experience of €4,000, this comes about €120,000.

5.1.2 Operational expenditures (OpEx)

Operations, administration and maintenance (OA&M)

We make a distinction between OA&M for the femtocells and for the core equipment.

OA&M of the femtocells: when operating a femtocell network, a recurring cost is assumed for operating and maintaining these femtocells. In addition, when a femtocell is deployed inside the residence, the fixed-line broadband access network will suffer from an increase in data usage, which would not have existed without the femtocell. A total expense of €8 per customer per month is taken into account for making the femtocells operational, based on Chandrasekhar et al. (2008).

Network maintenance of the core equipment: we consider the maintenance cost as a fraction of the CapEx for the installation of the femto gateway. According to Clausen, Ho, and Samuel (2008), this cost amounts to about 12% of the CapEx.

Mobile license

License costs vary from country to country depending on regulations, and can be either CapEx or OpEx (WiMAX Forum, 2004). In some countries, they are obtained for several years e.g., by an auction process. The paid amount can then be considered as a CapEx cost. In other countries, the operator has to pay a yearly fee to the regulator to lease the spectrum, which then corresponds to an OpEx cost. The license cost typically depends on the channel bandwidth (amount per MHz), and can further depend on e.g., the population of the covered area or the number of used BSs. As the exact cost is also determined by the market situation, it is difficult to estimate a correct cost. We have assumed a fixed annual cost, based on a mix of diverse sources, that the MVNO will pay to the MNO to lease its license.

Customer relationship management (CRM)

For the CRM cost, we refer to the WiFi network (Section 4.1.2), as we assume that this cost will be independent of technology, bandwidth or coverage parameters. For a fair comparison between both players, we have used the same model for their CRM cost. Only for the marketing costs, the

3G femtocell operator has a scale advantage as it deploys a nationwide network, and in this way we assume a marketing cost of only €30,000 per year, when scaled down to the city of Ghent.

5.2 Revenues

For a commercial operator, whose core business is situated in the telecom sector, only direct revenues are considered. The business case uses closed access femtocells, allowing only members of the home to use the cell. Several introduction scenarios are possible. The biggest decision the operator has to make is about the subsidization of the 3G femtocells. The considered possibilities are listed in Table 4, together with the monthly subscription fee.

Scenario 1 examines the economic feasibility of 100% subsidization, scenario 2 of 50% and scenario 3 of 0%. In scenario 4, a combination of the full subsidization and no subsidization is investigated. The first years after introduction, femtocells will be expensive. This results in a high percentage of people opting for 100% subsidization. With prices of femtocells declining fast due to technological innovations, more and more people will choose for 0% subsidization, thus buying their own femtocell. At introduction, 80% of customers choose for full subsidization. With femtocell prices dropping, the homo economicus notices that it is in their own advantage to buy the cell themselves, since they win back the initial investment fast due to a lower subscription fee. In the last year of our analysis, only 20% of the new customers opt for full subsidization in scenario 4.

The monthly subscription fees charged by the operator will depend on the amount of subsidization. When the femtocell is fully subsidized by the operator, it charges a higher monthly fee. Only one basic service is offered to all customer classes, and the subscription fees can be found in Table 4 for the 4 subsidization scenarios. Note that we assume that tourists will not be able to use this service, as they have no fixed location to install a femtocell. Fees are chosen so they can compete with current market prices for similar services in Belgium. Again a tax rate of 21% is deducted from the direct revenues (cf. Section 4.2.1) to incorporate only revenues the operator really receives.

Table 4: Scenario overview for the 3G femtocell network

Scenario	Subsidization by the operator	Monthly subscription fee (incl. VAT)
Scenario 1	100%	€20
Scenario 2	50%	€18
Scenario 3	0%	€15
Scenario 4	Combination	Weighted average of €20 and €15

The use of closed access 3G femtocells increases the possibilities for the operator to offer enhanced services to the users. These include offering a virtual home number, SMS alerts and automatic photo/video upload. Most of these enhanced services have close to 100% margin. Based on Signal Research Group (2009), we foresee an estimate of €5.20 per femtocell. However, it is obvious that not all users will choose to use these enhanced services. As explained in Signal Research Group (2009), mostly families with teenagers will be interested in these extra services. In our revenues, this is included by adding extra revenues for enhanced services for households with three or more members, in Belgium representing about 40% of all households.

Since different adoption curves were used for different market segments, this will have an impact on the total revenues. Inhabitants will not buy a femtocell per user, but per household.

The total number of adopting inhabitants is therefore divided by the average size of a household in Ghent, this is 2.10 members per household. On the other hand, students will take one femtocell per user. For the business users, the calculation is made as follows. About 85% of the companies in the city centre of Ghent are SMEs. They have significant fewer employees, and with an average of two femtocells, they could cover their entire workforce. The large enterprises, with more than 100 employees, will need more femtocells to cover their work floor. An average of 20 femtocells per company is taken into account.

5.3 Investment analysis

For the investment analysis, all costs and revenues are combined for a case study in the city of Ghent, using the assumptions from Section 3. Figure 3 presents the NPV of the project over the period 2010–2019 for the four revenue scenarios proposed in Table 4. All four scenarios have a clearly positive NPV in 2019. Even if a shorter project lifetime is considered, investment will pay off, since the NPV is positive or nearly positive for all scenarios from year 4, i.e. a discounted payback period of four years, which is much smaller than for the WiFi business case. This can easily be explained as a femtocell is only installed at the time the user subscribes to the service, while full WiFi coverage throughout the whole city is needed from the beginning. It is also obvious that scenario 1 is most attractive, with an NPV reaching about €3.4 million after ten years. We can conclude that subsidization of femtocells by the operator pays in the long run.

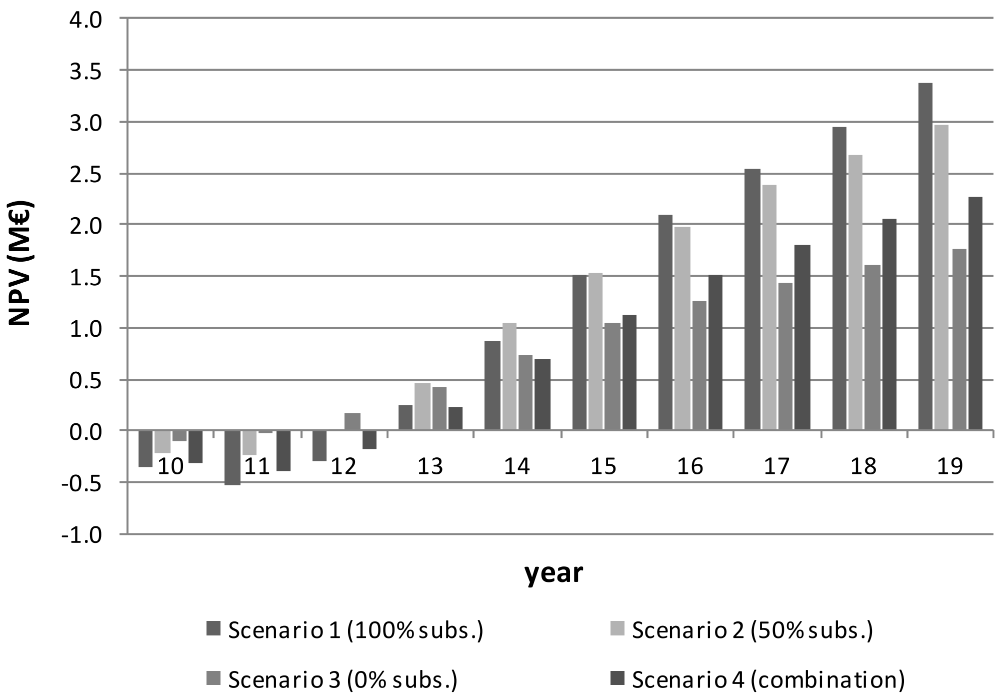

Figure 3: NPV evolution throughout the project lifetime for the 3G femtocell network

6. Competition modelling

6.1 Game theory

By means of game theory we try to get a closer look into the effects of interaction between different business players. To this aim, we have to build an integrated model, in which the outcome for each player will be depending on its own actions but also on the actions of the other players. We refer to Felegyhazi and Hubaux (2006) for a thorough tutorial and references to game theory. Game theory is there defined as "*A discipline aimed at modeling situations in which decision makers have to make specific actions that have mutual, possibly conflicting, consequences*". Often decision makers are referred to as players, actions are referred to as strategies, and consequences are referred to as payoffs.

The interaction of two players can consist of competition or cooperation. In this paper we only consider non-cooperative (or competitive) games. The players will compete for some good or reward. In the case evaluated in this paper, and often in business cases, the customer will be the aim of the competition. In the next section we propose an integrated adoption model that is used for estimating the customer response to the actions of two competing providers. Using game theory, we have then investigated different games with a municipality rolling out a WiFi network and an MVNO rolling out 3G femtocells. In each game we assume both players to act at the same time and have sufficiently good knowledge of each others possible strategies and payoffs. These assumptions allow representing the game by means of a payoff matrix. This matrix has a payoff for both players for each possible combination of strategies (one strategy for each player). This is called the strategic form of the game. This representation allows using tools for searching equilibrium states in the game. Such an equilibrium state is a set of strategies (one for each player) at which both players are not inclined to change their strategy. Solving a game comes down to finding one or preferably all equilibrium situations. Within the remainder of this paper we use the following equilibrium concepts:

- *The Nash equilibrium (NE)*: This is the most commonly known equilibrium, which is defined as a situation in which no player can gain by unilaterally changing its strategy. In a pure NE, each player will use a pure strategy, while in a mixed NE the players can play probabilistic combinations (or mixes) of strategies (Felegyhazi and Hubaux, 2006). Such mixes are more useful when repetitively playing the game. A game with fully rational players, using this equilibrium as criterion, is expected to result in one of the NE being chosen. It is easy to check in the exemplary game shown in Figure 4 how the situations (1B, 2B) or (1C, 2B) are no NE as player 1 can gain by changing its strategy into 1A. In both situations player 2 would rather change to 2A. The NE in this situation is (1A, 2A), where neither player 1 nor player 2 can gain by changing their strategy unilaterally.
- *Iterated (strict) dominance*: Typically static games (the game has one stage in which the players interact) can also be reduced or solved by removing strict dominated strategies. These dominated strategies have a strictly lower payoff than another (dominant) strategy for all possible counter strategies. No fully rational player would play a (strict) dominated strategy, but would instead play the (strict) dominant strategy. As such the (strictly) dominated strategy can be removed (deleting row or column from the payoff matrix) for the considered player. By iteratively using this approach for the different players, we can in some cases end up with strict dominant strategies. In Figure 4 we first can eliminate 1B and 1C as they have a lower payoff for player 1 in all situations than 1A. This dominant strategy is indicated in black. In the remaining (black) game, we find that 2B is strictly

dominated by 2A for player 2. Finally we find the same NE. Any solution derived by iterated (strict) dominance is a NE.

- *Quantal response equilibrium (QRE)* (McKelvey and Palfrey, 1995): This equilibrium uses bounded rationality instead of full rational behaviour (as for NE). It resembles a more realistic case in which the players are assumed to make errors in their decision process, but still have the highest probability of choosing the strategy with the best payoff. This equilibrium has one free parameter (per player), called λ. This λ more or less corresponds to the rationality or experience of the players. For a λ of ∞, i.e. a fully rational or high experience game this results in the NE for the game. For a λ of 0 the players show no rationality in their decision and all strategies have equal probability.

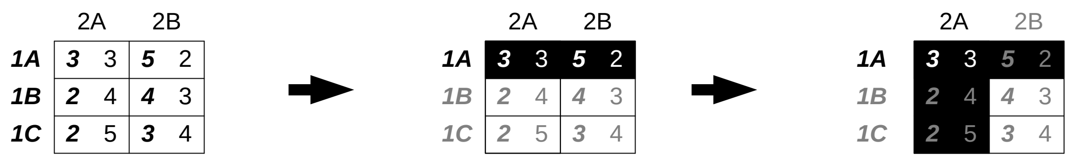

Figure 4: Game solved using iterated (strict) dominance

6.2 Market segmentation between multiple players

Based on the general adoption curves (see Section 3.1) the adoption for multiple players in a competitive environment is modelled using the following equations.

$$Adoption(x,y,z) = \begin{cases} Share(x,2010,z) * GenAdopt(2010,z), & \\ \qquad if \;\; y = 2010 & \\ [1-Churn(y,z)] * Adoption(x,y-1,z) & \\ + Share(x,y,z) * \{GenAdopt(y,z) - [1-Churn(y,z)] * GenAdopt(y-1,z)\} & \\ \qquad if \;\; y > 2010 & \end{cases}$$

Where:

- ***Adoption*(*x*,*y*,*z*)** is the adoption of player *x* in year *y* for customer class *z*
- ***Share*(*x*,*y*,*z*)** is the market share of player *x* in year *y* for customer class *z*, with: $\sum_x Share(x,y,z) = 1$, for every year *y* and every customer class *z*
- ***GenAdopt*(*y*,*z*)** is the general adoption in year *y* for customer class *z*
- ***Churn*(*y*,*z*)** is the churn rate in year *y* for customer class *z*
- ***x*** = player {municipality, mobile virtual network operator}
- ***y*** = year {2010, …, 2019}
- ***z*** = customer class {inhabitants, students, tourists, business users}

Several factors will be influencing the distribution of the total market between multiple players. In our model, churn rate and a general market share parameter are defined.

Churn rate

The churn rate refers to the proportion of contractual customers or subscribers who leave a supplier during a given time period. Existing churn rates for the ADSL services within the residential market are about 20% (Allen et al., 2005). The same churn rate is used in this research. The two considered players offer the same service, so they will suffer from a similar churn rate. In our model, each year, 20% of the existing customers will be redistributed between both players.

Market share

The general market share parameter includes the rollout year, the price for the services and the promotion given by the players. Below the calculations of this parameter are shown:

$$Share(x,y,z) = rollout(x,y) * [weight1 * price(x,y,z) + weight2 * promo(x,y,z)]$$

Where:

- ***weight1*** and ***weight2*** determine the importance of the factors price and promotion. Their sum is 1. In this paper, *weight1* is chosen as 75% and *weight2* as 25%.
- ***rollout*(*x*,*y*)**, ***price*(*x*,*y*,*z*)** and ***promo*(*x*,*y*,*z*)** are discussed below.

Rollout year

When there is one player who delays its rollout, the model allocates all predicted customers to the other players during these years.

$$rollout(x,y) = \begin{cases} 1, \text{ if player } x \text{ rolls out in or before year } y \\ 0, \text{otherwise} \end{cases}$$

Price

It is not the price in se that will persuade people to choose for one service, but the price difference with the other similar services. Mobile Internet is a relative new service, and data about the influence of price differences on the choice made by customers is hard to find. Rappoport, Kridel, Taylor, Duffy-Deno, and Allemen (2003) studied the residential demand for access to the Internet. The probability that a customer chooses either a cable or ADSL connection was estimated depending on the price difference. If the price difference between cable and ADSL changes, then the probability that a customer will choose for the other network, changes with a factor *priceFact* = 0.0414 / US$ (≈ 0.0476 / €, with 1 € = 1.15 US$, at the time the study of Rappoport et al. (2003) was published). The direction of the probability change depends on the direction of the price change. Since the Rappoport study is situated in the same sector, the value above can be used for the research in this paper.

$$price(x,y,z) = \sum_{S} \left(servShare(S,y,z) * \left[\frac{1}{prov(S,y,z)} - priceFact * priceDiff(S,x,y,z) \right] \right)$$

Where:

- ***servShare*(*S,y,z*)** is the percentage of customer class *z* that will use service subscription *S* in year *y*
- ***prov*(*S,y,z*)** is the number of players providing service type *S* in year *y* for customer class *z*
- ***priceFact*** indicates the change in probability a customer chooses a service due to the price difference, and is assumed to be 0.0476 / € price difference
- ***priceDiff*(*S,x,y,z*)** is the price difference between player *x* and the average subscription price of the other players for service type *S* in year *y* for customer class *z*
- ***S*** = service type {e.g., free, low-bandwidth, high-bandwidth, vouchers}

Promotion

Marketing and advertising will influence the customers' choice. No studies that handle this relationship were found, so we assume a linear relation between the promotion expenses by the provider and the probability a customer chooses for that provider.

$$promo(x,y,z) = \frac{costs(x,y,z)}{\sum_x costs(x,y,z)}$$

Where:

- ***costs*(*x,y,z*)** are the marketing and promotion expenses of player *x* in year *y* for customer class *z*

6.3 Strategies

For the game-theoretic evaluation, the NPV for both players is calculated for the given strategy. These NPVs are used as payoff for the players in the game. The techno-economic model constructed above allows each player to choose its rollout strategy, as well as the price setting of its service. Considering a rollout start within one of the first three years, together with no price reduction or a reduction of 1% or 2%, results in nine different possibilities for each player. Combined with ten initial prices for the service, 90 options are obtained for each player, leading to a 90×90 matrix. Even for this subset of all possible strategies, such games are already hard to solve by a complete search through the solution space.

Therefore we constructed two different sets of games to limit the complexity:

1. Varying the rollout year for both players.
2. Varying the initial price and the possible price reduction. In this case, the optimum obtained from the first game is inserted in the model.

6.3.1 Analysis 1: Variation in rollout speed

In the first analysis, a game is played to determine the optimal rollout year for both players. The start of the rollout for both players is chosen between 2010 and 2012. Player 1, the municipality, cannot only choose its rollout year, but also the rollout speed. The municipality can opt for a gradual rollout in two years. For example, it can start the rollout in a smaller zone, and expanding to the total area in the next year.

For player 2, the MVNO, the different rollout speeds are not considered. Since this player will initially opt for a nationwide rollout and this case is only scaled down to the municipal level to improve comparability, we assume the rollout in the area will be done completely in one time. This does not rule out the possibility this player can change rollout speeds for the national network. However, when it partially rolls out in year x, the municipality will or will not be covered in that year.

These strategies result in an asymmetric matrix, where player 1 has five options, and player 2 three. Table 5 shows the resulting payoff matrix, where 2010G means a rollout spread over 2010 and 2011 and so on. In this matrix, the strict dominant strategy is indicated in negative. One NE is found for this game, corresponding to the following strategy for {WiFi, Femto}: {2011G, 2010}. The outcome of the game will always be this NE, since both players choose for the strategy which gives them the highest payoff considering pure rational and fully informed players. The choice for a gradual rollout by player 1 can be explained by the high investment costs that are required at the beginning of the project, as shown in Figure 2.

All following equilibriums will be compared with this standard scenario. The NPV set for the players is {1.85 M€, 1.02 M€}.

Table 5: Strategic form with dominant strategy for rollout year analysis (NPV in M€)

NPV (M€)		PLAYER 2: FEMTO					
	year	2010		2011		2012	
PLAYER 1: WIFI	2010	1.20	0.82	1.31	0.93	1.60	0.91
	G	1.58	0.82	1.70	0.93	1.99	0.91
	2011	1.58	1.02	1.58	0.93	1.88	0.91
	G	1.85	1.02	1.85	0.93	2.10	0.91
	2012	1.30	1.57	1.30	1.58	1.30	1.40

6.3.2 Analysis 2: Variation in initial price and yearly price reduction

In the second analysis, the price both players charge for their services will be varied, using the optimal rollout strategy according to analysis 1. It is clear from Section 6.2 that the price setting will influence the market segmentation; resulting in a higher or lower market share. Two parameters can be influenced by each player. First, they can change the initial price for the service. For player 1, this is the price asked for its service in the full subsidization scenario. Player 2 offers four different products. We assume this player changes its high subscription price, and prices for vouchers and the low subscription vary proportionally with that price. However, prices for these services can never fall below the free subscription fee + 10%. Since player 2 offers several cheaper services, it will be able to capture a higher market share. Secondly, the price reduction throughout the years can be varied, as it is often assumed that for a comparable service the subscription fee will be reduced during the years.

In a *first* broad game, prices vary between €16 and €24 (in steps of 2€). The price reductions offered by both players can vary between 0% and 2%. Note that we also played games where higher reductions were offered, but no player ever chose a reduction higher than 2% (which explains our choice to limit the reduction to a maximum of 2%). This game is meant as a first indicator for the equilibriums for both players. The resulting payoff matrix can be found in Table 7 (left). The dominant strategies are again indicated in negative. We find two pure NEs and one mixed NE. The pure NEs correspond to the following combination of strategies: {WiFi, Femto} = {€24-0%, €24-1%} and {€24-1%, €24-0%}. The mixed strategy consists of player 1 opting for a mix of €24-0% and €24-1%, while player 2 chooses for €24-0% and €24-1%. All these strategies result in a positive payoff for each player. Note that these higher prices result in higher NPVs for both players. The declining total adoption due to more expensive services is compensated by the higher revenues per customer.

When we analyze this game into detail, we notice that both players tend to choose for the highest price in the spectrum. Therefore, we set up a *second* game, controlling this tendency. In this second game, the option set for each player is {€20, €22, €24, €26, €28}. The resulting strategy matrix is shown in Table 7 (right). In this case, we performed iterated dominance on the payoff matrix. The resulting strategies are indicated in negative. After computation of the NE, seven equilibriums are found, which are listed in Table 6. A logical question is what will be the strategy players will choose eventually. Within bounded rationality, each player will choose the strategy with the best payoff with the highest probability. We calculate the QRE to know the equilibrium with the highest probability. The corresponding probability distributions can be found in Figure 5. The figure displays the strategies with the highest probability. For a λ=0, there is no rationality, and each strategy has an equal chance to be chosen. When the rationality rises, certain strategies climb to a higher probability. In this game, it is clear that the NE that will be chosen by the players will be {€26-1%, €24-0%}. The probability of this strategy is 100% for a higher λ, and thus a higher rationality of the players.

Table 6: NEs for Game 2 - Price Setting

	Player 1: WiFi	Player 2: 3G femto
Pure NEs	€26 – 1% €26 – 0% €24 – 0%	€24 – 0% €26 – 1% €24 – 1%
Mixed NEs	€24 –- 0% / €24 – 1% / €26 – 1% €26 – 0% / €26 – 1% €24 – 0% / €26 – 0% €24 – 0% / €24 – 1%	€24 – 0% / €24 – 1% / €26 – 1% €24 – 0% / €26 – 1% €24 – 1% / €26 – 1% €24 – 0% / €24 – 1%

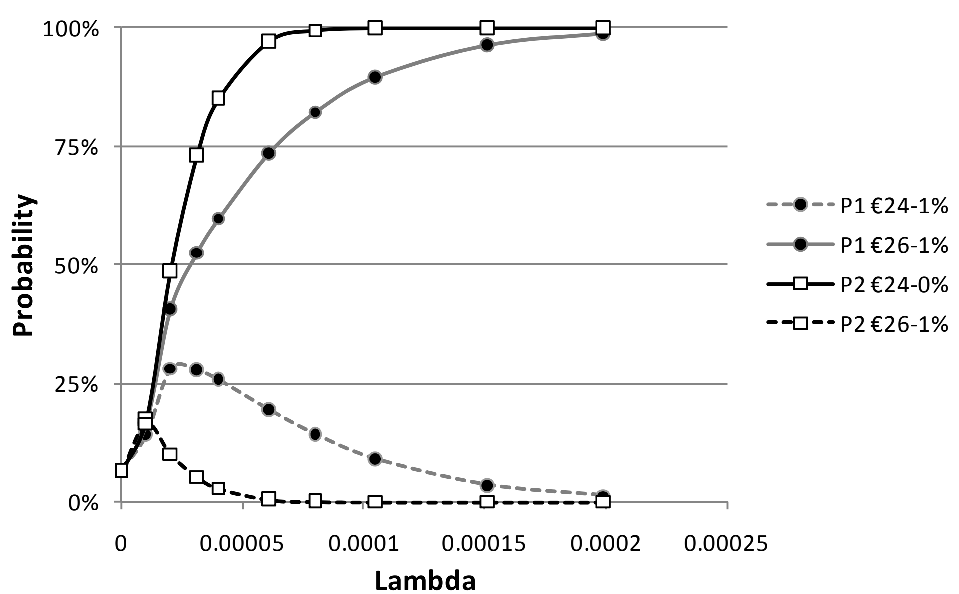

Figure 5: QRE Game 2

Table 7: Strategic forms with dominant strategies for price analysis (NPV in M€): price from €16 to €24 (left), price from €20 to €28 (right)

NPV (M€)			PLAYER 2: FEMTO																													
	Intial price (€)		16						18						20						22						24					
		Red. (%)	0		1		2		0		1		2		0		1		2		0		1		2		0		1		2	
PLAYER 1: WIFI	16	0	1.27	0.09	1.67	-0.05	1.51	-0.32	1.43	0.54	1.79	0.41	1.69	0.22	1.59	0.72	1.94	0.73	1.81	0.61	1.74	0.82	2.09	0.83	1.96	0.74	1.86	0.68	2.24	0.82	2.09	0.79
		1	1.53	0.12	1.46	-0.07	1.35	-0.33	1.70	0.59	1.59	0.42	1.50	0.21	1.85	0.78	1.72	0.68	1.61	0.57	2.01	0.86	1.88	0.76	1.75	0.70	2.14	0.68	2.02	0.74	1.88	0.74
		2	1.34	0.10	1.28	-0.08	1.16	-0.34	1.51	0.54	1.39	0.39	1.31	0.22	1.65	0.72	1.52	0.63	1.40	0.53	1.78	0.79	1.67	0.72	1.53	0.65	1.91	0.59	1.80	0.66	1.67	0.69
	18	0	1.36	0.13	1.75	0.00	1.61	-0.31	1.56	0.63	1.92	0.46	1.81	0.27	1.74	0.87	2.12	0.86	1.98	0.69	1.92	0.95	2.33	1.00	2.15	0.89	2.08	0.93	2.49	0.99	2.35	0.96
		1	1.67	0.18	1.57	-0.02	1.43	-0.32	1.87	0.69	1.74	0.44	1.63	0.24	2.06	0.94	1.93	0.81	1.78	0.67	2.23	0.98	2.12	0.93	1.96	0.83	2.37	0.95	2.25	0.97	2.14	0.89
		2	1.49	0.15	1.41	-0.04	1.27	-0.33	1.68	0.65	1.56	0.43	1.46	0.23	1.84	0.87	1.74	0.75	1.60	0.63	1.99	0.93	1.90	0.87	1.77	0.78	2.15	0.85	2.03	0.88	1.90	0.84
	20	0	1.40	0.19	1.77	0.02	1.62	-0.32	1.63	0.65	1.98	0.54	1.86	0.33	1.85	1.02	2.22	0.95	2.07	0.73	2.05	1.12	2.43	1.17	2.29	1.04	2.24	1.17	2.64	1.20	2.47	1.12
		1	1.71	0.22	1.62	0.00	1.46	-0.30	1.94	0.71	1.82	0.50	1.71	0.30	2.18	1.08	2.03	0.93	1.90	0.71	2.38	1.18	2.23	1.10	2.08	0.97	2.57	1.18	2.43	1.11	2.27	1.06
		2	1.54	0.19	1.46	-0.02	1.32	-0.31	1.77	0.70	1.63	0.46	1.54	0.27	1.99	1.01	1.85	0.87	1.70	0.72	2.16	1.09	2.04	1.02	1.89	0.91	2.35	1.09	2.21	1.02	2.07	0.98
	22	0	1.37	0.22	1.74	0.03	1.56	-0.32	1.62	0.75	1.99	0.62	1.86	0.39	1.88	1.16	2.26	1.02	2.09	0.82	2.13	1.30	2.51	1.34	2.33	1.15	2.35	1.31	2.75	1.41	2.57	1.32
		1	1.71	0.27	1.61	0.04	1.44	-0.32	2.00	0.81	1.84	0.57	1.72	0.36	2.23	1.20	2.09	0.96	1.94	0.77	2.47	1.36	2.33	1.25	2.15	1.10	2.68	1.36	2.54	1.31	2.38	1.24
		2	1.58	0.24	1.47	0.01	1.32	-0.29	1.80	0.75	1.69	0.53	1.57	0.32	2.04	1.13	1.91	0.96	1.77	0.72	2.26	1.26	2.13	1.17	1.98	1.04	2.47	1.29	2.32	1.23	2.19	1.15
	24	0	1.30	0.28	1.65	0.03	1.45	-0.32	1.60	0.83	1.93	0.69	1.79	0.43	1.88	1.26	2.22	1.11	2.06	0.90	2.14	1.46	2.52	1.50	2.32	1.27	2.37	1.50	2.78	1.61	2.61	1.49
		1	1.64	0.32	1.53	0.04	1.36	-0.31	1.95	0.89	1.78	0.64	1.67	0.39	2.24	1.28	2.08	1.05	1.90	0.84	2.51	1.55	2.35	1.42	2.17	1.20	2.75	1.58	2.60	1.50	2.42	1.40
		2	1.51	0.29	1.41	0.05	1.26	-0.32	1.81	0.83	1.65	0.59	1.53	0.36	2.08	1.25	1.93	1.00	1.76	0.79	2.34	1.45	2.18	1.34	2.00	1.17	2.54	1.46	2.41	1.40	2.24	1.31

NPV (M€)			PLAYER 2: FEMTO																													
	Intial price (€)		20						22						24						26						28					
		Red. (%)	0		1		2		0		1		2		0		1		2		0		1		2		0		1		2	
PLAYER 1: WIFI	20	0	1.85	1.02	2.22	0.95	2.07	0.73	2.05	1.12	2.43	1.17	2.29	1.04	2.24	1.17	2.64	1.20	2.47	1.12	2.42	0.98	2.78	1.21	2.61	1.16	2.58	0.66	2.98	0.95	2.78	1.04
		1	2.18	1.08	2.03	0.93	1.90	0.71	2.38	1.18	2.23	1.10	2.08	0.97	2.57	1.18	2.43	1.11	2.27	1.06	2.76	0.99	2.56	1.10	2.40	1.11	2.88	0.68	2.74	0.82	2.55	0.94
		2	1.99	1.01	1.85	0.87	1.70	0.72	2.16	1.09	2.04	1.02	1.89	0.91	2.35	1.09	2.21	1.02	2.07	0.98	2.52	0.87	2.34	0.99	2.18	1.03	2.57	0.64	2.51	0.70	2.33	0.83
	22	0	1.88	1.16	2.26	1.02	2.09	0.82	2.13	1.30	2.51	1.34	2.33	1.15	2.35	1.31	2.75	1.41	2.57	1.32	2.55	1.25	2.91	1.38	2.74	1.36	2.74	0.98	3.12	1.26	2.94	1.28
		1	2.23	1.20	2.09	0.96	1.94	0.77	2.47	1.36	2.33	1.25	2.15	1.10	2.68	1.36	2.54	1.31	2.38	1.24	2.90	1.28	2.68	1.31	2.53	1.26	3.09	0.97	2.88	1.12	2.70	1.19
		2	2.04	1.13	1.91	0.96	1.77	0.72	2.26	1.26	2.13	1.17	1.98	1.04	2.47	1.29	2.32	1.23	2.19	1.15	2.66	1.15	2.47	1.23	2.30	1.16	2.83	0.83	2.65	0.99	2.46	1.08
	24	0	1.88	1.26	2.22	1.11	2.06	0.90	2.14	1.46	2.52	1.50	2.32	1.27	2.37	1.50	2.78	1.61	2.61	1.49	2.62	1.46	2.97	1.60	2.79	1.56	2.84	1.28	3.22	1.53	3.00	1.49
		1	2.24	1.28	2.08	1.05	1.90	0.84	2.51	1.55	2.35	1.42	2.17	1.20	2.75	1.58	2.60	1.50	2.42	1.40	2.98	1.51	2.77	1.49	2.61	1.47	3.19	1.29	3.01	1.40	2.79	1.38
		2	2.08	1.25	1.93	1.00	1.76	0.79	2.34	1.45	2.18	1.34	2.00	1.17	2.54	1.46	2.41	1.40	2.24	1.31	2.76	1.41	2.56	1.38	2.40	1.36	2.97	1.13	2.77	1.26	2.58	1.32
	26	0	1.81	1.31	2.15	1.24	1.95	1.00	2.11	1.62	2.49	1.57	2.27	1.35	2.38	1.70	2.76	1.80	2.59	1.63	2.64	1.66	2.98	1.83	2.80	1.76	2.87	1.57	3.26	1.74	3.03	1.72
		1	2.18	1.39	2.03	1.16	1.85	0.94	2.48	1.70	2.31	1.54	2.15	1.28	2.77	1.79	2.59	1.69	2.42	1.55	3.03	1.71	2.80	1.70	2.61	1.64	3.28	1.59	3.06	1.60	2.84	1.59
		2	2.03	1.33	1.88	1.10	1.73	0.89	2.32	1.59	2.16	1.45	1.99	1.23	2.58	1.66	2.43	1.58	2.25	1.46	2.84	1.61	2.61	1.57	2.44	1.53	3.04	1.43	2.86	1.52	2.64	1.46
	28	0	1.71	1.40	2.02	1.33	1.84	1.08	2.04	1.76	2.38	1.69	2.17	1.45	2.33	1.88	2.70	1.97	2.49	1.76	2.63	1.87	2.96	2.04	2.74	1.95	2.89	1.77	3.25	1.98	3.02	1.92
		1	2.12	1.51	1.93	1.26	1.74	1.02	2.42	1.85	2.25	1.61	2.07	1.38	2.73	1.98	2.56	1.86	2.36	1.68	3.01	1.95	2.78	1.90	2.60	1.83	3.30	1.83	3.06	1.84	2.84	1.80
		2	1.98	1.42	1.83	1.19	1.65	0.96	2.27	1.74	2.13	1.56	1.93	1.31	2.55	1.85	2.40	1.74	2.23	1.60	2.84	1.80	2.60	1.77	2.43	1.71	3.09	1.71	2.87	1.69	2.65	1.67

A *third*, more fine-grained, game is now played. The price option set for player 1 is reduced to {€24, €25, €26, €27, €28} and for player 2 to {€22, €23, €24, €25, €26}. In the previous games, prices jumped €2 every step. This game is meant to control if the optimum is not found between two prices. In Table 9 the results of the analysis are shown. The results of iterated dominance are indicated in negative. This game has five NEs, of which two are mixed strategies. They are listed in Table 8. We use QRE to find the NE with the highest probability. With higher rationality, it is clear from Figure 6 that players will opt for the {€25-1%, €24-0%} scenario.

Table 8: NEs for Game 3 - Fine-grained Price Setting

	Player 1: WiFi	Player 2: 3G femto
Pure NEs	€25 – 0% €25 – 1% €24 – 1%	€25 – 1% €24 – 0% €23 – 0%
Mixed NEs	€25 – 0% / €26 – 1% €24 – 1% / €25 – 1%	€24 – 0% / €25 – 1% €23 – 0% / €24 – 0%

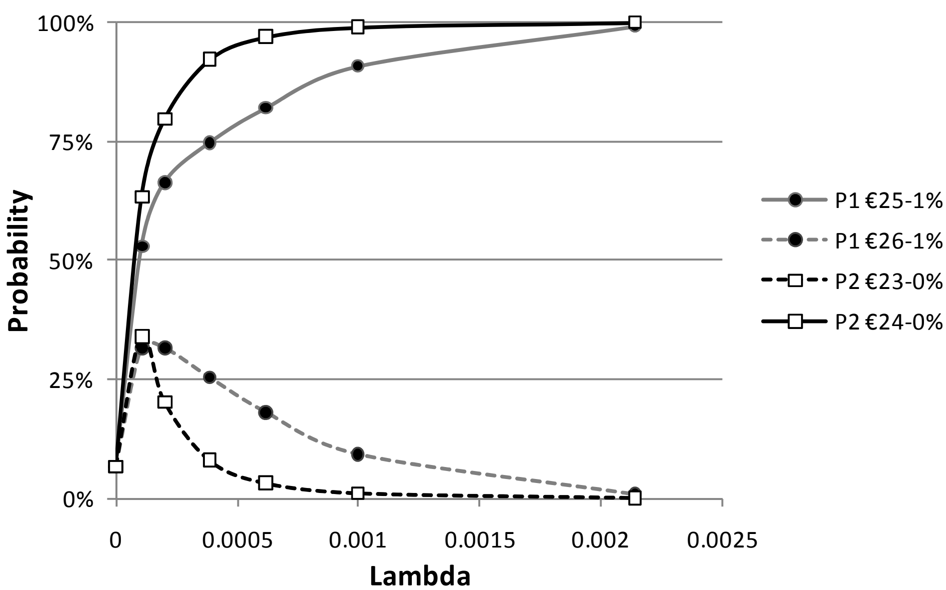

Figure 6: Qre Game 3 - Fine-grained Price Setting

The resulting payoffs are {2.77 M€; 1.68 M€}. Compared to the standard scenario, both players have a significantly higher NPV. With a higher start price, they generate more revenues per customer. But they cannot keep raising prices. Higher prices also result in a lower total adoption of the service. In the most rational NE, the MVNO places a lower price than the municipality offering WiFi. This way, the MVNO manages to capture a higher market share. The municipality has two options to react. It could lower its price as well, thus engaging in a price war. Or it can keep its price the same, since lowering its price would not be beneficial. The lower market share due to a higher price is compensated by higher revenues per customer. Next to that, the municipality also offers cheaper subscriptions, which diminishes the impact of the lower price set by the MVNO.

Table 9: Strategic forms with dominant strategies for price analysis (NPV in M€): price from €24 to €28 (WiFi) and €22 to-€26 (3G femtocells).

NPV (M€)			PLAYER 2: FEMTO																													
	Intial price (€)		22						23						24						25						26					
		Red. (%)	0		1		2		0		1		2		0		1		2		0		1		2		0		1		2	
PLAYER 1: WIFI	23	0	2.13	1.38	2.53	1.42	2.33	1.20	2.25	1.41	2.64	1.49	2.47	1.36	2.37	1.40	2.76	1.51	2.59	1.41	2.48	1.37	2.89	1.52	2.72	1.44	2.59	1.38	2.95	1.50	2.76	1.47
		1	2.48	1.45	2.36	1.33	2.17	1.16	2.60	1.49	2.45	1.39	2.29	1.28	2.72	1.47	2.57	1.41	2.41	1.32	2.83	1.44	2.68	1.41	2.52	1.34	2.94	1.42	2.74	1.38	2.57	1.37
		2	2.29	1.35	2.16	1.25	1.99	1.10	2.40	1.38	2.26	1.30	2.12	1.20	2.50	1.36	2.36	1.31	2.22	1.23	2.61	1.34	2.48	1.30	2.33	1.24	2.72	1.28	2.53	1.32	2.37	1.26
	24	0	2.14	1.46	2.52	1.50	2.32	1.27	2.25	1.50	2.64	1.57	2.47	1.43	2.37	1.50	2.78	1.61	2.61	1.49	2.50	1.49	2.92	1.61	2.73	1.53	2.62	1.46	2.97	1.60	2.79	1.56
		1	2.51	1.55	2.35	1.42	2.17	1.20	2.65	1.58	2.47	1.47	2.31	1.35	2.75	1.58	2.60	1.50	2.42	1.40	2.87	1.53	2.72	1.50	2.54	1.43	2.98	1.51	2.77	1.49	2.61	1.47
		2	2.34	1.45	2.18	1.34	2.00	1.17	2.42	1.47	2.30	1.38	2.13	1.27	2.54	1.46	2.41	1.40	2.24	1.31	2.65	1.45	2.51	1.40	2.36	1.33	2.76	1.41	2.56	1.38	2.40	1.36
	25	0	2.13	1.54	2.49	1.53	2.32	1.31	2.26	1.59	2.63	1.65	2.47	1.47	2.38	1.60	2.78	1.71	2.58	1.57	2.52	1.58	2.93	1.72	2.73	1.62	2.62	1.54	2.99	1.72	2.80	1.66
		1	2.51	1.64	2.34	1.49	2.15	1.25	2.64	1.68	2.47	1.55	2.29	1.42	2.77	1.68	2.60	1.60	2.42	1.48	2.91	1.65	2.73	1.60	2.56	1.52	3.02	1.61	2.80	1.59	2.61	1.55
		2	2.33	1.53	2.18	1.41	2.00	1.23	2.46	1.56	2.29	1.46	2.13	1.34	2.59	1.56	2.42	1.49	2.26	1.39	2.70	1.53	2.55	1.48	2.38	1.42	2.79	1.50	2.61	1.46	2.43	1.44
	26	0	2.11	1.62	2.49	1.57	2.27	1.35	2.24	1.68	2.62	1.73	2.44	1.52	2.38	1.70	2.76	1.80	2.59	1.63	2.52	1.69	2.90	1.82	2.74	1.71	2.64	1.66	2.98	1.83	2.80	1.76
		1	2.48	1.70	2.31	1.54	2.15	1.28	2.63	1.77	2.45	1.63	2.29	1.48	2.77	1.79	2.59	1.69	2.42	1.55	2.90	1.76	2.73	1.70	2.55	1.61	3.03	1.71	2.80	1.70	2.61	1.64
		2	2.32	1.59	2.16	1.45	1.99	1.23	2.46	1.65	2.29	1.53	2.12	1.40	2.58	1.66	2.43	1.58	2.25	1.46	2.71	1.63	2.55	1.58	2.38	1.50	2.84	1.61	2.61	1.57	2.44	1.53
	27	0	2.07	1.69	2.43	1.64	2.21	1.41	2.23	1.76	2.58	1.79	2.38	1.58	2.38	1.79	2.75	1.89	2.54	1.69	2.49	1.79	2.90	1.92	2.71	1.80	2.63	1.76	2.98	1.94	2.78	1.85
		1	2.46	1.78	2.30	1.55	2.10	1.33	2.59	1.86	2.44	1.71	2.26	1.51	2.75	1.89	2.57	1.77	2.41	1.63	2.89	1.87	2.71	1.80	2.55	1.69	3.04	1.83	2.79	1.80	2.62	1.74
		2	2.29	1.67	2.14	1.52	1.97	1.25	2.44	1.74	2.26	1.61	2.12	1.47	2.58	1.76	2.41	1.66	2.25	1.53	2.72	1.73	2.55	1.68	2.37	1.59	2.84	1.69	2.62	1.67	2.43	1.62

6.3.3 *Analysis 3: Impact of price change on rollout scenario*

A last question that arises is the impact of this price setting equilibrium on the optimal rollout scenarios from in analysis 1. We can imagine that due to its lower market share, the WiFi player can opt for a faster rollout to capture its market share faster. The question is if the higher costs incurred by this rollout, are balanced out by the higher revenues. Therefore, the first game is replayed, but now with the price settings found in game 3 of analysis 2. The resulting payoff matrix is shown in Figure 6

Table 10: Strategic form with dominant strategy for second rollout year analysis (NPV in M€)

NPV (M€)		PLAYER 2: FEMTO					
	year	2010		2011		2012	
PLAYER 1: WIFI	2010	2.19	1.32	2.33	1.46	2.65	1.37
	G	2.56	1.32	2.68	1.46	2.99	1.37
	2011	2.51	1.68	2.51	1.46	2.84	1.37
	G	2.77	1.68	2.77	1.46	3.06	1.37
	2012	2.09	2.62	2.09	2.49	1.30	0.91

We find that the rollout speed is not influenced by the new prices. Using iterated dominance, the same equilibrium as in analysis 1 is found. The new price setting by both players does not influence their rollout years or speeds.

7. Conclusions

In this paper a complete business case for the rollout of a municipal wireless access network is evaluated, applied to the city of Ghent. Two different business players, a municipality offering WiFi access and a mobile virtual network operator (MVNO) offering 3G femtocells, are considered. For both players separately, a positive business case is found for the made assumptions, and it is clear that deploying a full WiFi network throughout the city results in a longer payback period (about seven years) than the 3G femtocell offer (about four years). However, it has to be noted that the 3G femtocell network is deployed nationwide and scaled down to the municipal level for obtaining a comparable case. So, such a femtocell rollout is not a valuable alternative for a stand-alone case deployed by the city.

In a second evaluation, both players are brought together in the same competitive market and the optimal strategy for both players is evaluated by using game theory. Due to the high initial investments, the municipality will postpone its rollout one year and choose for a gradual rollout. It cannot wait longer than one year, otherwise too much market share will be lost. The MVNO will immediately start with installing femtocells. Considering the price setting, they tend to increase their prices. However, at a certain point, they cannot further increase their prices since this would lead to too low an adoption rate. In this way, both players form a kind of duopoly and they balance each other.

Up to now, we assumed that both players have commercial interests and want to increase their profits as much as possible. However, a municipality does not only want to optimize its financial profits but also the prosperity of its inhabitants, i.e. creating a social optimum. Studying the influence of a low-profit municipality on the rollout and price setting strategy of the 3G femtocell operator would be an interesting topic for future work.

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