From Experimentation to Citywide Rollout:
Real Options for a Municipal WiMax Network in the Netherlands

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Abstract: The paper undertakes a techno-economic analysis of a WiMax network in the unlicensed band (5 GHz) based on a network design for a medium sized, sub-urban community. WiMax (Worldwide Interoperability for Microwave Access) networks based on IEEE802.16 group of standards have been heralded as "serious competitor" and even as a disruptive technology in the local loop at a time when commercial field trials and initial deployment of these technologies unfold throughout Europe. As traditional net present value (NPV) calculation taking the current European regulatory and legislative framework into account showed that high technical and market uncertainty would delay the implementation of a municipal WiMax network, a real options analysis has been undertaken to examine these uncertainties. An expanded NPV calculation, which included the option to expand, provided positive results. Due to licensing fees and coverage performance of base stations, differences in profitability emerged between WiMax networks operating in the unlicensed (5 GHz) and licensed band (2.5/3.5 GHz). The entry of commercial wireless providers in 2008 in the licensed WiMax band is expected to have repercussions for the viability of municipal WiMax networks.

Key words: WiMax, European legislation, municipal networks, real options.

Recently wireless broadband technologies have been gaining ground in Europe, in particular, due to residential and business users extending their DSL (Digital Subscriber Loop) or cable modem connection via Wi-Fi (Wireless Fidelity) certified technology. As numerous types of devices are equipped with wireless technology based on various standards (i.e. IEEE802.11, IEEE802.16, Bluetooth and Ultra wideband for interconnection purposes), WiMax certified technologies have been considered as one of the most promising developments in the area of wireless local access[1].

[1] Even if 3G-related broadband technologies like UMTS and HSPA belonging to the group of wireless broadband technologies are still growing.

WiMax (Worldwide Interoperability for Microwave Access)[2] networks based on IEEE802.16 group of standards have been heralded as a serious competitor and even as a disruptive technology in local access markets (BAR & PARK, 2006). The potential of these networks is currently being tested in a number of commercial field trials and initial deployments throughout Europe (BALLON *et al*., 2005). Expectations are high as IEEE802.16 standard-based networks should achieve greater coverage and bandwidth compared to earlier generation IEEE802.11 networks (i.e. Wi-Fi technologies). Furthermore, WiMax certified technologies allow extending outside reach as previous generations of Wi-Fi technologies have been limited[3]. Based on new advanced techniques[4], WiMax certified technologies are suitable for usage in rural as well as in suburban and urban areas.

Combined with newly evolving possibilities for mobile broadband connectivity, IEEE802.16 based technologies offer a new platform for many shared applications (e.g. in the area of multimedia). As current wireless broadband networks can foster regional integration, economic growth and provide for better public services (LEHR *et al*., 2006), the expectation is that WiMax certified technologies will allow even greater functionality. Although cities have been keen to capture the benefits of citywide wireless networks, Europe is lagging behind the United States in the deployment of wireless networks in the unlicensed frequency bands (BALLON, 2007; VAN AUDENHOVE *et al*., 2007).

The European Commission (EC) has been favourable to public participation in municipal wireless networks if they are considered as part of the European drive towards realizing the goals of the Lisbon Agenda, in line with the New Regulatory Framework of 2003 and/or compatible with Article

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[2] A common misunderstanding similar to the misconception related to Wi-Fi is that WiMax is a technology. WiMax certification can be awarded to products which comply with certain predefined guidelines. This certification is based upon a single group of global standards, IEEE802.16. If a product meets the set requirements, it will be certified implying that every component of the product complies with predefined certification profiles based on IEEE802.16 technical specifications.

[3] In theory, WiMax certified products should be able to reach speeds of 70 Mbit/s over 70 kilometres of distance, but in practice these values are reported to be multiple times lower depending on the operational context. Many factors like line-of-sight (LOS), building density and climate conditions influence this performance. Some manufacturers indicate a typical bandwidth of 10 to 30 Mbps and a cell radius of 1 to 5 kilometres in the licensed bands of 2.5 and 3.5GHz.

[4] Techniques such as Orthogonal Frequency-Division Multiplexing modulation (OFDM) and Multiple-input multiple-output (MIMO) antenna diversity have significantly improved non-line-of-sight (NLOS) performance.

87(1) of the EU Treaty on State Aid. In addition, these networks should operate within the European guidelines on radio spectrum.

Table 1 - Official WiMAX operating frequencies

Band	*Operating frequencies*	*License required*
2.5 GHz	2.5 to 2.69 GHz	Yes
3.5 GHz	3.3 to 3.8 GHz	Yes (few exceptions)
5 GHz	5.25 to 5.85 GHz	No

Source: Intel Corporation, 2006

Due to high uncertainty and high sunk costs, private market parties have been reluctant to invest in the roll-out of municipal WiMax networks. High uncertainty does not only concern future technological, demand and market developments but also regulation with respect to the allocation of licences in Europe and in particular in the Netherlands[5]. There, the numbers of frequencies[6] that are available for Wireless Access Systems including Radio LANs have been limited. The 5.4GHz frequency band remains currently the only band that can be used for a citywide wireless network (see Table 1). Even the allocation of licenses has to be in line with the European legislatory and regulatory environment, the set up of auctions in the European Members States and the costs for licenses are still country specific and are important for the cost structure of WiMax networks. In addition to (possible) license costs, setting up a WiMax network includes more than just a radio-access network and customer premises equipment. These costs are industry specific and cannot be recovered[7].

[5] In the Netherlands, as in other European countries, several deployments of WiMax networks in the licensed bands are planned by large network operators depending on the results of the license auction at the beginning of 2008. Currently there is only one initiative to deploy a citywide wireless network (Wireless Leiden).

[6] This includes the following frequencies: 2400 – 2483.5 MHz, 5150 – 5250 MHz, 5250 – 5350 MHz and 5470 – 5725 MHz. As many consumers devices are based on Wi-Fi certified technology that operate within the 2.4GHz, this band for interference reasons has been unsuitable for the deployment of a citywide network. Due to restrictions of limited power levels and indoor usage only, the frequency bands 5150 – 5250 MHz and 5250 – 5350 MHz are also unsuitable for outdoor networks.

[7] In any case, a citywide wireless network requires the deployment of many antenna towers and base station controllers in the entire area. Increasing capacity by installing additional sector antennas afterwards, does not decrease the initial capital and operational expenditures significantly since the towers and controllers for the vast majority of these costs. To achieve profitability with the services provided by the WiMax network, however, the economics of the entire network have to be taken into account. They include backhaul infrastructure, and installation and leasing costs. These sunk costs are incurred at the initiation of the project, i.e. before the profitability of the project is known.

In the European Union, the high uncertainty and costs surrounding municipal WiMax networks seem to indicate that they do not outweigh their benefits. In order to evaluate the costs and benefits of WiMax networks, the value of a delay option has to be considered in addition to the direct cost of investing. Real options methodology (KULATILAKA & AMRAM, 1999; LUEHRMAN, 1998; SMIT & TRIGEORGIS, 2004) can be used to investigate the size of sunk costs which constitutes a barrier to entry (ALLEMAN & RAPPOPORT, 2006; PINDYCK 2005, KULATILAKA *et al.*, 2000). Recently, studies have focused on detailed investigations of investment in wireless broadband networks (HARMANTZIS & TANGUTURI, 2007).

Legislative and regulatory framework in the European Union

The EC approved public involvement in municipal networks if they were considered in line with the New Regulatory Framework of 2003 and compatible with Article 87(1) of the EU Treaty on State Aid. There have been at least three options under which public involvement in these networks has been considered as being admissible under provisions on State Aid: a) if it could be shown that the Market Economy Investor Principle has been implemented; b) if a case for Services of General Economic Interest could be made; and c) if it could be shown that these networks were used internally i.e. within the public institution. The EU legislative and regulatory framework also provides leeway for an innovation rationale for municipal wireless networks if they can be considered as part of the European drive towards realizing the goals of the Lisbon Agenda 2004-09 to make the EU "the most competitive and dynamic knowledge-driven economy by 2010". Even if the regulatory and legislative environment in the Netherlands has been, in general, in line with EU regulations, the Dutch Telecom Law has been more stringent with respect to the involvement of municipalities in the area of telecommunications. More specifically, Article 5.14(1) of the Dutch Telecom Law - effective since February 2007 - explicitly prohibits municipalities from providing electronic communication networks or services.

Real options methodology applied wireless broadband networks

A binomial decision tree with risk-neutral probabilities is used to approximate uncertainty inherent in the design of a municipal WiMax network. This method developed in BRANDÃO, *et al* (2005) is based on two assumptions: first, the value of the project will follow a Geometric Brownian

Motion (GBM) process with constant volatility; second, the present value of the project without options is the best unbiased estimator of the market value of the project (Market Asset Disclaimer or MAD assumption) (COPELAND & ANTIKAROV, 2001). Hence, the value of the project without options serves as underlying asset in the replicating portfolio. To solve the real options problem, four values are required before the binomial tree can be constructed: a) the underlying assets, b) the volatility of the project returns d) the length of the project, and d) the risk-free rate. These values are required to approximate the GBM estimator of the evolution of the project value over time. The value of the underlying asset can be taken from the preceding traditional Discounted Cash Flow (DCF) projection valuation according to the MAD assumption. The volatility has been estimated using the market proxy approach. The length of the project has been assumed to be five years. The risk free rate has been based on the interest rate of long-term national bond (currently at around 4 percent) provided by the Dutch Central Bank in August 2007.

Options for municipalities to participate in city-wide WiMax networks

Due to the existing legislatory and regulatory environment in the Netherlands, the options for municipalities to participate in municipal WiMax networks have been limited. An ownership model with a participating municipality covering all aspects (i.e. design, installation and operation stage) of a municipal WiMax network is difficult to sustain. The chosen model is based on non-profit ownership as "the non-profit model is more likely to serve underprivileged neighbourhoods" (PEHA *et al*., 2007).

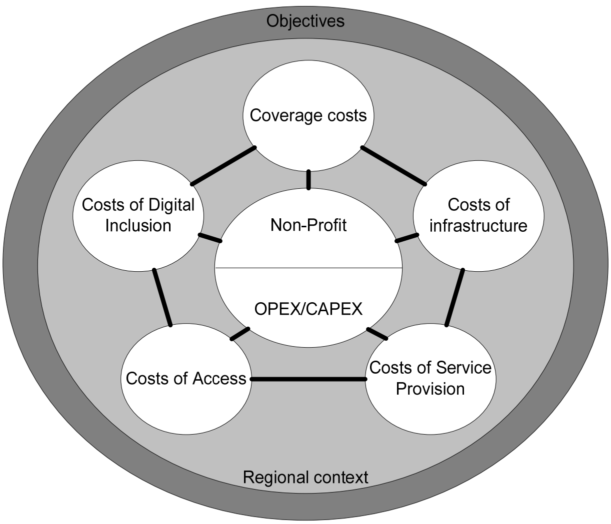
The economics of municipal WiMax networks

Even if there is a growing interest to implement citywide wireless broadband networks in the license-exempt band, just a few European cities are offering (or intend to offer) these networks. Currently, most municipalities have developed an own distinct variant of their municipal wireless broadband network mainly based on Wi-Fi certified technologies (for an overview see BALLON *et al*., 2005; LEHR *et al*., 2006)[8]. The cost modelling

[8] The international experience, in particular in the United States, has shown that there are a variety of ownership structures and cost model assumptions depending a) on the existing supply structure and extent of participating municipality (LEHR *et al*., 2006) (TAPIA *et al*., 2006),

has concentrated on the following cost components: a) costs of offering (full) coverage; b) installation costs; c) costs of providing backbone infrastructure; d) costs of service supply; e) costs of providing access; and f) costs for overcoming digital divide issues (digital inclusion) (PEHA *et al.* 2007) (see Figure 1). The city of Eindhoven with more than 210,000 inhabitants has been taken as an example for the implementation of municipal WiMax network in a medium sized, suburban city [9].

Figure 1 - Cost model for a municipal WiMAX network



Cost model assumptions

(a) Cost of (full) coverage

A fully ubiquitous wireless broadband network is difficult to set up as a number of technical and economic factors have to be taken into account. If a high quality wired backbone is not available in every part of the city, it can be difficult and too expensive to serve these areas leading to limited coverage. Another technical difficulty can be the presence of many buildings which

b) the source of funding (FTC STAFF, 2006) or c) the technological characteristics of the wireless broadband technology (WIRELESS TASK FORCE, 2006).

[9] For purposes of coverage prediction areas with household densities of 500 per square kilometre or higher are regarded as urban areas (ELNEGAARD, 2006; SMURA, 2006).

negatively influences propagation of radio signals. A lack of mounting points can also result in decreased coverage in certain areas. Moreover, not all areas of a city are profitable to be covered with a wireless broadband network. This is because citizens in particular areas might not have sufficient income to afford paid subscription to the network or even to buy equipment to use the internet at all.

Constructing a network which also provides ubiquitous indoor coverage costs significantly more than a network with outdoor coverage only. Several additional antenna sites are required for indoor coverage leading to a substantial increase in costs. In practice, network providers often only guarantee outdoor coverage and therefore design their network for this purpose. In this case, users can still make indoor use of the network since networks happen to provide unintended coverage in many homes after deployment. In the model the usage of IEEE802.16e based technology including advanced antenna techniques is assumed. Other technical assumptions are listed in Table 2.

Table 2 - Technical assumptions citywide network Eindhoven

Property	*Amount*
Sectorization	3 sectors / BS
Channel width	10 MHz
Channels	3

(b) Investment costs

Non-profit ownership should guarantee the provision of activities in the public interest without profit maximizing purposes (PEHA *et al*., 2007). No city staff or funding is necessarily needed to operate and support the network. Nonetheless a city could still be in control of short and long-term operations, management and other activities by drawing up the statutes of the foundation. Difficulties with raising funds to sustain the network are an important disadvantage of a non-profit ownership and operation (PEHA, et al., 2007; San Francisco Budget Analyst, 2007).

A non-profit organization will own and operate the network. The costs of equipment, labour costs for installation and maintenance are of major importance for the construction of a fully operating municipal WiMax network. In addition, the costs for leasing antenna sites and interconnection bandwidth need to be incorporated in the analysis (see Tables 3 and 4).

Table 3 - Capital expenses

Item	*Cost in Euros*
BS controller	12500
BS sectors	25000
BS installation	3750
Site installation	3000

Sources: adapted from (ELNEGAARD, 2006; GUNASEKARAN & HARMANTZIS, 2005; SMURA, 2006; THORSTEINSSON, 2005)

Table 4 - Operational expenses

Item	*Cost*
Maintenance and administration	10% of CAPEX
Tower / Antenna site lease	6300 Euros/yr
Wired backhaul data leased line	3500 Euros/bs/yr

Sources: adapted from (ELNEGAARD, 2006; GUNASEKARAN & HARMANTZIS, 2005; SMURA, 2006; THORSTEINSSON, 2005)

(c) Costs of providing backbone infrastructure

A wireless broadband network benefits most from an extensive well-developed wired backbone infrastructure. Such backbone infrastructure provides best performance in terms of speed and reliability. However, users of the municipal wireless network need to be interconnected with this infrastructure. A choice has to be made whether (or not) to use the existing (partial) network infrastructure or to (partially) construct a new backbone network. The decision is mainly depending on the availability of existing wired infrastructure using fibre optics, copper telephone lines and coaxial cable. Furthermore, the construction of a new wired backbone infrastructure is expensive. In case of scarcely existing wired broadband infrastructure, a wireless backbone can be a good alternative.

Additionally, mounting points are needed for a wireless broadband network to fit transmitting equipment. These mounting points should preferably have a certain altitude, power availability and should be close to the intended backbone for interconnection[10]. For fast and reliable

[10] For example, street light poles usually have these beneficial characteristics. Some municipalities own street light poles in their municipality; others have sold them to private firms. Leasing these poles back from private firms can be very expensive. Public buildings are also often used as antenna sites. Selecting and obtaining the right mounting points can be a delicate activity. If a municipality owns the street light poles then they generally give rights of way to

interconnection with the Internet, location of antenna sites and optimal wireless coverage, choices have to be made that influence the overall technical and economical performance of the municipal WiMax network.

In Eindhoven, a citywide fibre optics network is currently operating[11]. The assumption is that at the time of construction of a network in the unlicensed band sufficient fibre infrastructure will be available for backhaul usage; therefore there is no need for any wireless backhauls.

(d) Costs of service supply

Three service options exist: retail only services, wholesale only services or both. In our case, a non-profit organization will operate the network on a wholesale basis. Wholesale service is about distributing access and support to a group of ISPs. Wholesale bit stream service tariffs will be 75% of the retail tariffs (SMURA, 2006). As the municipality does not serve as an anchor/launching customer, there are no fixed revenues included in the cost benefit analysis (CBA). Most municipal wireless networks are operating at speeds up to 2 MBit/sec. In order to prevent congestion, bandwidth has mostly been capped in these networks.

(e) Costs of providing access

An important factor for the rapid take-off and viability of municipal wireless networks has been the cost of providing access. A commonly used option to offer access *via* municipal wireless networks has been two-tiered: a) providing of low speed free access, possibly ad-supported to all citizens; and, b) providing higher bandwidth options for a fee. This option has mostly been chosen to stimulate adoption of internet access by citizens in poorer areas[12].

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mount equipment on street light poles and public buildings for no or a small fee in order to stimulate citywide network deployment.

[11] Although the network extends to the boundaries of the city, it is not as fine-grained and extensive as it should be. The city council in Eindhoven has set the goal that all homes, businesses and organizations should have access to fixed fibre based broadband infrastructure by the year 2010.

[12] In cases where municipalities have been involved in the implementation of a wireless broadband network, arrangements have been made to provide services affordable for as many citizens as possible. Municipalities have used their rights-of-way permission to negotiate lower access fees for citizens.

Data on adoption of wired fixed broadband in the Netherlands are utilized to forecast demand of wireless broadband access. These data have been compared to the growth of mobile phone subscriptions in the Netherlands. As a result, the adoption curve for wireless broadband access in the city of Eindhoven is projected to follow the trend of both adoption curves for mobile phone and fixed broadband access subscriptions. The forecasted demand with respect to the growth rate of subscribers is shown in Table 5.

Table 5 - Expected subscribers in city of Eindhoven

Year	'08	'09	'10	'11	'12	'13	'14	'15	'16
Subscribers	0	3,80	8,03	16,83	34,22	62,35	89,80	103,0	106,8
%change			52.7	52.3	50.8	45.1	30.6	12.8	3.6

To be able to compete with 3G mobile data services such as UMTS, HSDPA and other broadband services, subscription prices are expected to be equal or less than those for these services. Monthly flat fee subscription rates for Wi-Fi hotspot services range from €15 to €29. For fixed broadband services such as DSL or coaxial cable rates range from €21 to €27 in the Netherlands for connections up to 2 MBit/sec download in 2005 prices (LEINONEN *et al*., 2006). In the case of telecom providers flat fee rates for mobile phones have been recently introduced for €10 a month relatively slow broadband connection of below 1800 Kb/sec (HSDPA). Wireless broadband flat fee subscriptions for notebook usage range from €32.50 to €89.25 a month depending on data usage limits ranging from 200 to unlimited MBit a month. As these are current estimates, further competition from new 3G mobile data service providers might actually increase demand uncertainty for a citywide municipal wireless network as it leads to lower demand and decreasing prices.

In general, flat fee subscription rates for wireless broadband will most likely range from around €20 to €50 depending on choice of speed and data limit. Assuming that one-third of the users are business customers, the average ARPU will be €30 for retail providers. So the average ARPU range will be €27 to €46.[13] Wholesale providers typically have revenue of 75% of the retail price.

[13] The minimum is calculated assuming the minimal price for business is €40 and €20 for consumers; 2/3*20+1/3*40= €27. Similary the maximum is calculated as 2/3*50 + 1/3*40= €46.

(f) Costs for overcoming digital divide issues (digital inclusion)

A citywide wireless broadband network could reduce the amount of excluded citizens on the condition that access is affordable for everybody and that citizens have equipment and skills to use the Internet. The costs for overcoming digital divide issues (digital inclusion) are closely related to the particular way access and coverage are designed. In the CBA no special tariffs or other arrangements were taken into account to deal with digital exclusion. At a later stage these special arrangements can be included.

Results and conclusions of CBA analysis

There are two cases for setting up a municipal WiMax network in the unlicensed as well as licensed band. The analysis showed a best and a worst case in terms of coverage and other costs of the project (except for license fee if the network operates in the licensed band). The license fee has been considered as being constant. For both scenarios, also minimum predicted costs for all equipment and maintenance were taken into account. They were combined with the maximum coverage predictions implying minimum amount of base stations. It was also assumed that operational and capital expenditures per base station are similar for equipment operating in the licensed as well as the unlicensed band. Table 6 lists the results of the traditional discounted cash flow valuation at the end of five years. The internal rate of return (IRR) is calculated using the discounted cash flows generated over a five year period.

Table 6 - Results DCF valuation traditional CBA

	Licensed (3.5 GHz)			*Unlicensed (5.4 GHz)*		
	Base	*Best*	*Worst*	*Base*	*Best*	*Worst*
NPV (mln. €)	17.2	31.8	9.8	-11.7	21.3	-106.6
IRR (r=9.0%)	64.3	107.1	35.7	-8.5	50.7	--

A sensitivity analysis showed that license holders in the 3.5GHz and 2.5GHz band can deploy and operate a WiMax certified network, which is financially sustainable as the static NPV has been positive in all cases. In contrast, the static NPV for a network in the unlicensed band has been negative €11.7 million in the base case situation (ranging from -€106.6 million to €21.3 million). Monte Carlo simulation showed an expected static NPV of € -6.4 million. This implies that high uncertainty is involved with respect to capital and operational expenses for a network in the unlicensed band.

The magnitude of Average Revenue Per User (ARPU) has been an important factor in determining the accumulated static NPV for both (unlicensed and licensed) scenarios. In the case of a network in the unlicensed band, the coverage radius has been by far the most important factor. A relatively low coverage range implies relatively large total initial network construction costs. The static NPV for a network in the licensed band has also – as expected – been sensitive to the magnitude of the license fee. These results are in line with findings of BOHLIN (2007).

Real options analysis of municipal WiMax networks

The preceding traditional DCF project valuation has shown that deploying a citywide wireless network in the unlicensed band in a medium sized, suburban city like Eindhoven is financially unsustainable. In particular, technical uncertainty is leading to a negative base case in the project valuation. Incorporating flexibility in the project's design could mitigate the effect of these risks and therefore increase the value of the project. Depending on the type of risks and the context of the project, however, certain options are not viable for wireless broadband networks[14]. Other options might become more important in the near future. As these networks can provide for access diversity, redundancy and disaster recovery in a municipality (like in the Katarina disaster area in New Orleans), business uncertainty for business users might actually be reduced.

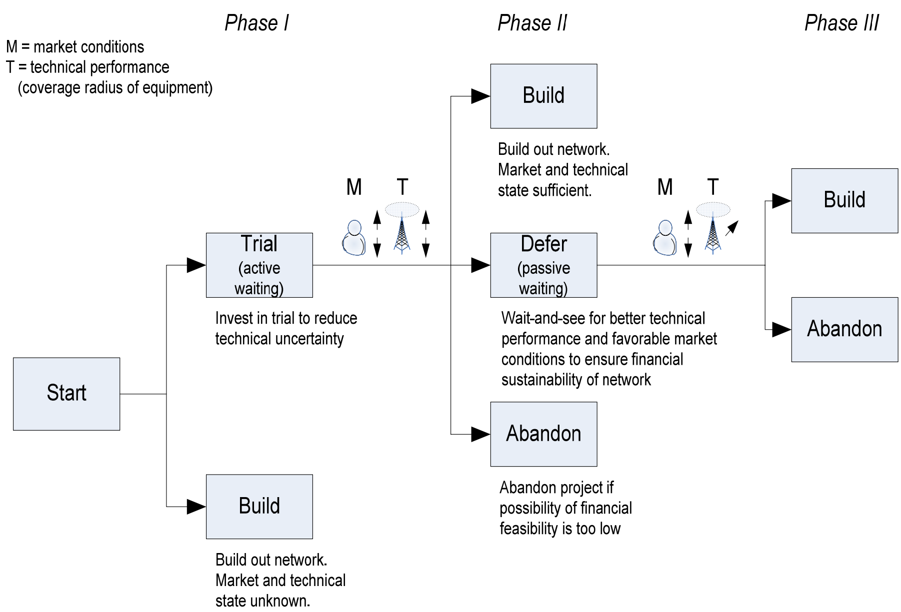
The technical performance of WiMax certified equipment in the unlicensed band of 5 GHz in the city of Eindhoven is unknown and is depending on a variety of factors. This uncertainty could be eliminated by conducting a trial prior to the full deployment of the network. This option, investing in a trial, not only provides insights in the actual performance of

[14] Telecommunication infrastructure investment is strongly technology-related. It limits the options of flexibility within the project design. In the case of a new regional wireless network, the option of network expansion seems irrelevant. Both geographical and capacity expansions do not seem to be useful options in this situation. Since the geographical area of the city of Eindhoven is relatively small, it does not make sense to deploy a wireless network in parts of the city first. Potential customers expect full city coverage and are less likely to subscribe if only one district of its city has coverage. In any case, a citywide wireless network requires the deployment of many antenna towers and base station controllers in the entire area. Increasing capacity by installing additional sector antennas afterwards does not decrease the initial capital and operational expenditures significantly since the towers and controllers contribute to the vast majority of these costs.

WiMax equipment but it also creates the opportunity to see how the market demand for mobile broadband connections develops.

Depending on the technical and market state after the trial, the management can choose between multiple strategies: to build the network, wait-and-see or abandon the project. If market conditions and/or technical state relatively fall short in comparison with what was expected, a wait-and-see strategy could become a valuable option. One advantage of such strategy is that the results of "waiting" can lead to increased technical performance of equipment due to technological progress and declining unit costs. This implies lower initial capital cost consequently resulting in lower operational expenditures. Furthermore, after a period of waiting, the market state could have shifted into a favourable state. One disadvantage of deferring the project relies on missed revenues for that period (see Figure 2).

Figure 2 - Real options citywide wireless network in unlicensed band



Additional assumptions for real options model

Underlying value of the asset (S_0)

The model used to calculate the static NPV could be improved to calculate the value of the underlying asset. This is justified by the MAD assumption. In order to be able to estimate the underlying value of the asset correlated to the economy, the private risk of technical uncertainty is removed from the traditional DCF model. Additionally, only the revenues are used to estimate the value of the underlying asset, while not including capital expenditures (CAPEX) and operation expenditures (OPEX) in the estimation. The revenues are correlated with the economy, in contrast to these capital and operational expenditures that are mostly influenced by private technical uncertainty. Discounting these revenues using the real interest rate of 8.95% results in an initial asset value of €23.8 million (S_0). The *Volatility (σ)* was estimated at 25 percent and the *risk-free rate (r_f)* based on the interest rate of long-term national bonds at around 4%.

Cost of trial option

To create reliable test results at least two WiMax base stations (BS) need to be deployed and preferably multiple equipment brands should be tested. Due to the small scale of the trial, the price of equipment is significantly higher than in a large-scale deployment. Furthermore, several experienced radio engineers need to be hired. In total, the cost of a 1-year trial is expected to be around €300,000. The trial option is aimed at providing a local experimentation and testing environment that allows different actors like private firms and municipalities to explore and learn from the implementation of WiMax certified technologies and associated services in a (regional) real life setting. Such environment can provide experiences for different actors involved in the implementation of these networks; possible mechanisms for coordinating their activities involve users in the implementation process as well as facilitating (future) private investment in these networks and associated services.

CAPEX and OPEX

Depending on the technical state at the time of deployment, the amount of base stations and therefore antenna sites differs substantially. For CAPEX a base case price of €44250 and €14225 for OPEX per base station is assumed.

Technological uncertainty

While, the extent of coverage a WiMax base station in the 5GHz band will provide in the city of Eindhoven is currently unknown, the minimum, maximum and most likely coverage radius is known. They are respectively 150, 250 and 350 meters. To take this private risk into account, subjective probabilities need to be assigned to each possible state. The expectation is that with a probability of 40%, BS equipment will have a coverage radius of 150 meters, 50% chance of 250 meters and 10% chance of 350 meters.

Technological progress

After the trial, it is assumed that the performance of the equipment increases with a fixed percentage because of technological progress. Initially, this parameter is set to 20% implying that the coverage radius of a base station increases by a factor 1.2 compared to the previous year.

Time to build

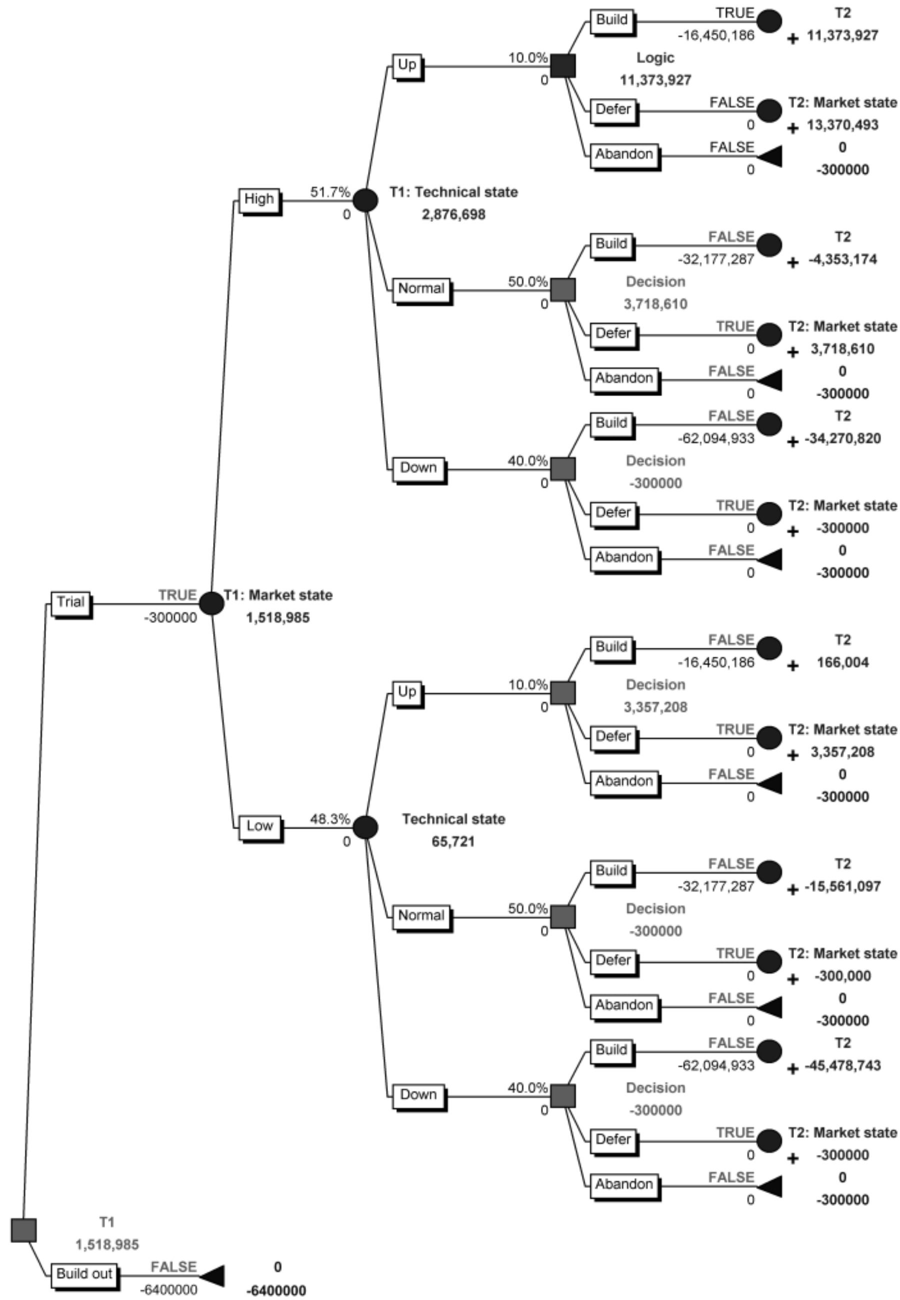
For simplicity the assumption is that a citywide network can be deployed within a period and does not cause any losses in expected revenues due to this construction.

Results of the real options analysis

The binomial tree in Figure 3 shows the first three periods (out of five) of the simulation. At the beginning of period one (T_1), the asset value approximately equals €23.8 million, but it slightly differs due to successive rounding errors. If market conditions develop favourably during any single year of the considered period, cumulative discounted revenues could increase up to €58 million in the last year. *Vice versa*, if the market performs worse than expected this value could be only €7.4 million at the end of the five year period. After approximating the present value of the underlying asset over time, flexibility and private uncertainties are built in.

For private companies it is often better to wait for one period to create more value even if the "build out" option yields a positive NPV. In the case of a non-profit organization, deploying a network as soon as possible is much more important as it should include social benefits rather than providing only higher private returns.

Figure 3 - Trial option for municipal WiMAX network



Although the investment is already financially sustainable - based on a private cost and benefits - delaying the investment would result in giving up social benefits for that waiting period. Hence, if the NPV is positive in both cases a non-commercial organization prefers to deploy the network to the option to defer (Upper branch – Figure 3). Since deferring the investment does not imply any loss of capital, the organization could always wait-and-see for one period and decide afterwards to abandon the project if it is not going to be profitable. Abandoning the project after the trial results in a loss of €0.3 million Euros, which is still significantly lower than an expected loss of €6.4 million if no trial is done.

Table 7 - Expanded NPV in case of positive, normal and negative coverage

Technical state: UP			
Market state	**Phase II**	**Market state**	**Phase III**
High	BUILD (+11.4)	High	n/a
		Low	n/a
Low	DEFER (+0.2)	High	BUILD (+6.8)
		Low	ABANDON (-1.0)

Technical state:AVERAGE			
Market state	**Phase II**	**Market state**	**Phase III**
High	DEFER (-4.4)	High	BUILD (+7.5)
		Low	ABANDON (-5.3)
Low	ABANDON (-15.6)	High	ABANDON (-5.3)
		Low	ABANDON (-13.0)

Technical state: DOWN			
Market state	**Phase II**	**Market state**	**Phase III**
High	ABANDON (-34.3)	High	ABANDON (-23.0)
		Low	ABANDON (-35.8)
Low	ABANDON (-45.5)	High	ABANDON (-35.8)
		Low	ABANDON (-43.5)

In summary, the overall value of the project increases substantially when incorporating flexibility in the project. Although the alternative costs amount to an additional €300,000, the expanded NPV is positive with a value of €1.5 million compared to the static NPV of €-6.4 million. Hence, it is advantageous to conduct a trial to overcome private technical uncertainty of coverage radius of equipment in the 5.4GHz band. If after the trial it turns out that: a) equipment performs worse than expected; or b) the market conditions are unfavourable; or c) the loss is only €300,000 in comparison with €-6.4 million (in the case of an all-at-once build out option), the investor can adopt the best strategic and financial solution. Table 7 lists the expanded NPV accompanied with decision advice for each phase according to specific market conditions and technical state of the equipment. Cells with a positive expanded NPV are framed with a thicker border.

When technical performance is lower than expected, the network deployment would inevitably result in losses. In all cases, the best option is to abandon the project after the trial to have maximum losses of €300,000. If the market conditions are still good after a period of waiting and the equipment performs as expected, the realization of the network is financially sustainable. Otherwise, in the case of equipment performing as expected and at least one phase where market conditions are lower than expected; the abandon alternative is the best one. Lastly, if the equipment performs better than expected, a build out is financially sustainable if at one phase market conditions are favourable.

Market uncertainty and municipal WiMax networks

In the preceding real options valuation, the initial value of the underlying asset is completely based on the expected cash flows calculated in a DCF analysis. One assumption underlying the evolution of the value of the underlying asset is the absence of competition. It is assumed that the emerging firm satisfies all demand in the market for wireless mobile broadband connections. Obviously, this is hardly the case in current wireless markets[15]. Consequently, fierce competition is expected, which could drastically change the business potential for firms intending to invest in a

[15] However, third generation (3G) network providers, fixed broadband providers and other firms will compete in these markets. Current 3G telecommunication companies can use their IMT-2000/UMTS spectrum licenses to deploy new wireless broadband networks. Additionally, the European Commission published a new proposal for a Directive that will allow new technologies to coexist with GSM in the frequencies of 900 MHz and 1800 MHz, while preserving the continued operation of GSM in the EU (see COM(2007) 367 final). This proposal, if approved, will further facilitate existing telecommunication companies to deploy wireless broadband networks. In addition, an auction of 190MHZ in the 2.5GHz band in the beginning of 2008 will further increase the availability of spectrum for wireless broadband networks and thus most likely leading to additional entrants in this market.

wireless citywide network in the unlicensed band. BOHLIN (2007) shows that competition might have a medium to high impact on financial sustainability of future mobile broadband networks. In the following, the two scenarios are developed to include the effects of competition based on no investment (scenario 1) or aggressive investment (scenario 2) by private market parties.

Scenario 1 – No investments in Eindhoven

Some firms have already acquired nationwide licenses and have now to decide whether or not to enter different geographical areas in the Netherlands[16]. It is possible that spectrum frequency license holders withdraw or delay their investment in a wireless broadband network in Eindhoven. Although traditional cost benefit analysis suggests that an investment of firms with a spectrum license is highly profitable, due to competitive entry total market profits have to be shared with other entrant firms. In combination with high uncertainties, revenues could drop substantially leading to insufficient income to cover cost. Based on the results of the real options valuation, it is shown that investment in a network in the unlicensed band is financially sustainable. However, such investment is still dependent on technical performance of equipment and the state of the market. If private parties do not invest in a wireless broadband network in Eindhoven, the municipality is able to justify additional financial support.

Scenario 2 – Aggressive coverage strategy

Instead of firms providing coverage in the large cities and rural areas only, other providers might decide to aggressively capture national wireless broadband market by pursuing maximum coverage. By quickly deploying networks in all cities, a firm can try to preempt competitors and differentiate its services by providing maximum coverage. Currently, telecommunication providers with large stocks of capital, nationwide antenna sites and experience might be able to follow this investment strategy. To demonstrate such aggressive coverage strategy, different numerical examples have been developed by PEHA *et al*. (2007) and BOHLIN (2007). They assumed that the entry of (additional) competitors is leading to a decrease in total market

[16] Potential entrants have indicated to initially invest in the metropolitan areas in the Netherlands only (Amsterdam, Rotterdam and The Hague). Furthermore, KPN indicated it is to start services for providing coverage in rural areas only.

share. In this scenario, it has been assumed that two network operators compete against each other, both providing similar wholesale mobile broadband services based on similar prices. Hence, market share of each firm is 50 percent implying 50 percent of total market revenues. Additionally, ARPU is assumed to remain equal over the total project period (see Table 8).

Table 8 - Expanded NPV results in case of positive coverage performance

Technical state: UP			
Market state	**Phase II**	**Market state**	**Phase III**
High	ABANDON (-2.7)	High	BUILD (+3.3)
		Low	ABANDON (-3.1)
Low	ABANDON (-8.3)	High	ABANDON (-3.1)
		Low	ABANDON (-7.0)

The total expanded NPV for a firm with a market share of 50 percent is €-0.8 million. Adding competitors would further decrease revenues, implying even lower financial sustainability of the network. Since it is likely that at least two or more firms will enter, a municipal WiMax network in the unlicensed band will be financially unsustainable. The results of the different scenarios are in line with findings by VALLETTI (2003).

Discussion and concluding remarks

Even if there is a case for municipal wireless broadband network in the unlicensed band, current State Aid regulations by the EU limit the direct funding by municipalities to about €200,000. Based on this investment, an initial trial period can be financed. By (co-)financing a trial period, municipalities can provide a test and experimentation environment in which private parties are able to lower investment and coordination costs, gather more information about the practical performance of the equipment and learn about market conditions. Combined with indirect, non-financial support in the design of the city-wide WiMax network, the municipality can provide conditions for innovation in associated broadband services and experimentation with wireless network equipment.

As firms learn from earlier investment experiences to see how the market develops, they capture benefits of investments of early movers. The firm that moves first cannot capture these benefits of waiting, therefore everybody is likely to wait. Such market situation can "lead to market failure in the form of inefficient underinvestment" (PINDYCK, 2005). However, early investment might be socially desirable as customers can use facilities and scarce radio spectrum sooner. In such situations, intervention of the municipality might be justified. However, technical, demand and market uncertainties, have to be taken into account to implement a municipal WiMax network in the unlicensed band.

The results of the analysis are sensitive to changes in the probabilities attached in the model to demand and technical uncertainty. To account for demand uncertainty, volatilities have been calculated using different telecommunication indices. A higher (lower) volatility - above (below) 25 percent - leads to a higher (lower) net present value of the project. In case of higher (lower) volatility, the trial option becomes more (less) valuable to the municipality. As the probabilities for technical uncertainty have been based on subjective estimations about the pace of technical progress as well as expected coverage of WiMax equipment, expert interviews have been used to verify the estimations. In case a greater probability has been attached to a technical state implying a higher (than expected) coverage of WiMax technology, the net present value of a municipal WiMax network increases. In case of faster (than expected) technological progress, the option value for the option to wait increases, since the WiMax equipment improves over time. Further extensions of the model might take other factors affecting profitability of a wireless municipal network into account like regulatory uncertainty (related e.g. to rights of way) or regional economic growth.

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