Migration to Next Generation Access Networks: a Real Option Approach

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Abstract—**Increasing bandwidth demand, European goals and competition with other fixed access networks, require the upgrade of the traditional copper networks towards more future-proof networks. Fibre to the Home is seen as the most future proof network, but this upgrade is expensive, causing considerable delays in the rollout. However, migration paths over intermediate solutions like Fibre to the Cabinet offer a wide range of flexibility opportunities. This paper analyses this migration and the resulting scale, scope and switch options using a real option analysis.**

Keywords-case study; telecommunications; real options; techno-economic; next generation access networks

I. Flexibility in the Migration Towards Fixed Next Generation Access Networks

In light of the goals set out by the European Commission in the Digital Agenda for Europe [1], the traditional copper access networks do no longer suffice. Fixed next generation access networks (NGAN) are necessary to provide the required symmetrical bandwidth of up to 100 Mbps to end users. Fibre to the Home (FttH) networks are seen as the most future proof network technology, and require the replacement of the copper last mile with fibre cables. However, the rollout costs of such FttH networks are very high, and are one of the reasons the rollout of FttH networks is delayed in Europe [2].

Several solutions have been proposed to speed up the rollout of these networks. A new telecom business model with competition on a shared physical infrastructure [3], or a joint infrastructure rollout with different utility operators are only a few solutions [4]. However, in these studies, the focus is on the rollout of FttH as a one step migration, while several intermediates exist, like Fibre to the Cabinet (FttC) and Fibre to the Premises (FttP). Installing more fibre-rich networks based on a gradual migration scenario covering these intermediates offers various benefits. The installation can follow customer demand, with extra capacity only being installed when required. Another option is that the operator chooses to rollout first in regions where the installation is economically viable. In this paper, focus is on the first option, where the existing copper access network is upgraded in several phases towards Fibre to the Cabinet (FttC) and eventually FttH.

Of course, introducing such a stepwise migration impacts the economic assessment of the business case. Not only are some key parameters like customer uptake uncertain in the long term, but the operator also gains various flexibility options during the different phases of the project. If the first installation suffices to provide high bandwidth to all customers, there is no need to start the rollout of extra network capacity. Additionally, the network can be used to offer new services to the customers. Adding the value of such flexibility is typically done by performing a real option analysis (ROA) [5]. Several option valuation techniques exist, and they compute the value of the option at maturity given the probability distribution of the underlying uncertainties. The static project is compared with the project including the exercised option and the best path is chosen.

During the past decade, real option theory has gained a lot of attention in telecom oriented techno-economic research. Several case studies have been published, most of them focussing on large telecom infrastructure rollout [6–10]. Such rollout is typically related to a large investment covering several years, which allows for flexibility in the rollout path. Since these projects also cover larger areas, both the rollout area and speed can be changed during the project to optimize the return on investment. However, next to infrastructure rollout related real option cases, service oriented cases have also been studied, e.g. [11] studied the options in the rollout of internet service on board for a Belgian rail operator.

In this paper, a realistic business case is studied for the rollout of NGAN in the United Kingdom (UK), including different real options. The initial business case considered in section 1 is the upgrade of the copper network towards an FttC network. However, due to uncertainty on customer uptake, this upgrade could prove to be insufficient in the future. In section 2, the impact of these uncertainties on the initial business case is assessed, together with the possible real options the operator has to react to. After introducing the methodology to calculate the value of these options in section 3, section 4 continues with the standard NPV analysis of the business case. In section 5, this analysis is extended with a quantitative assessment of the different real options present in the case. Section 6 wraps up the extended business case evaluation.

II. CASE STUDY: MIGRATION OF THE ACCESS NETWORK TO FTTC

To respond to the increasing demand for bandwidth and speed, the existing networks no longer suffice and need to be upgraded towards more efficient networks. To lift the constraints of these traditional copper networks, fibre needs to be brought closer to the customer. This process results in networks with higher capacities, going from FttC over FttP and FttH, with the latter as the final step in the migration process. However, the upgrade of the existing copper network towards FttH comes at a high cost, ranging between €450 and €2.000 per home passed (HP) [2]. In order to reduce these large investment costs and spread them over a longer period in time, a more stepwise migration is studied in this paper.

The incumbent operator currently possesses a nationwide copper access network, which was already upgraded towards Fibre to the Central Office. This upgrade allows offering customers ADSL services, with download speeds between 8 Mbps and 24 Mbps. However, in light of the European goals set forward in the Digital Agenda, the increasing bandwidth demand by customers and the competition with cable networks, the operator is forced to upgrade his network to allow for higher speeds. Indeed, the Digital Agenda envisions speeds above 100 Mbps for 50% of subscribers [1] and cable networks are more efficient in offering higher speeds.

In the basic business case, the operator upgrades his network to an FttC network, which allows offering VDSL services. Two important infrastructure upgrades are required in the access network. First, fibre has to be brought closer to the customer. The existing copper network between the local exchange (LEX) and street cabinets needs to be replaced by fibre optic cables. Secondly, new equipment is required in the LEX and the street cabinets need to be replaced and provisioned with Digital Subscriber Line Access Multiplexers (DSLAMs). However, with an uncertain customer uptake, the operator has to decide on the optimal cabinet size. Either large cabinets are installed, which can host a connection to all households in the cabinet area, or smaller cabinets are deployed, dimensioned for an estimated uptake percentage.

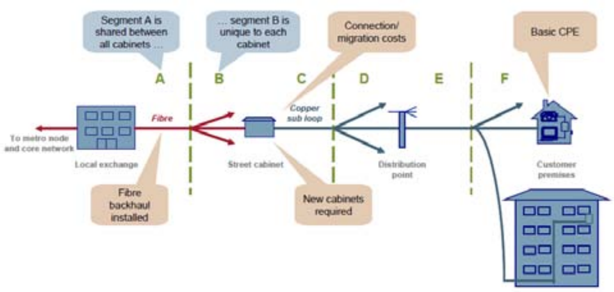


Figure 1. Overview of FttC access network topology [12]

Since our case clearly focuses on the passive network installation, a realistic approximation of this network is necessary. Based on previous research, the local access network is modelled as a tree structure, with the local exchange as source node [12]. For the upgrade of the network, the existing street cabinets are replaced by VDSL cabinets, and the copper cables between the LEX and cabinets are replaced by fibre cables. In the new cabinets, DSLAM line cards will be installed based on the customer demand. In the LEX, line cards towards both the access and core network are provisioned, together with an optical distribution frame (ODF). An overview of the access network topology can be found in Fig. 1. The model for the business case is built around different geotypes [13]. Geotypes are a classification tool for LEX, based on average line length, population density and average number of access lines per exchange. For each geotype, a representative LEX was modelled in [13], containing parameters like the average of each line segment, the number of street cabinets and drop points, etc. The business case analysis will be made for these representative exchanges.

It was already indicated that the initial choice for the operator in the upgrade of the traditional copper network towards FttC is the cabinet size. Either large or small cabinets are deployed. All other necessary equipment is only installed when needed, based on the customer adoption.

III. VALUING THE UNCERTAINTY AND FLEXIBILITY IN THE BUSINESS CASE

Before proceeding with an investment project, it needs to be economically assessed. However, several factors present in this case complicate this exercise. Next to uncertainty surrounding the future customer uptake rate, the related revenues and the costs for the deployment, the operator also faces two distinct rollout scenarios: small or large cabinets. In contrast with the large cabinets, small cabinets are not dimensioned for a full uptake. In this case, the operator risks additional future installations of new cabinets to connect extra customers. However, this risk is linked with managerial flexibility, where the operator can choose between different extension scenarios of these small cabinets. He can choose to do nothing, to install a second small cabinet next to the initial one or connect the extra houses with an FttP connection. Once the FttP network is installed, extra services could be offered to the customers. When linking these options to the 7S framework [14], the first choice is a scale up option, the second possibility a switch up option. The extension scenarios are shown in Fig. 2.

Scenario and sensitivity analysis are used to implement the value of uncertainty in the NPV analysis, but they cannot measure the impact of managerial flexibility. Real option theory can implement the different flexible choices during the project lifetime and make a quantitative evaluation [15]. Given the probability distribution of the underlying uncertainties, real option valuation methods compute the value of the option at maturity.

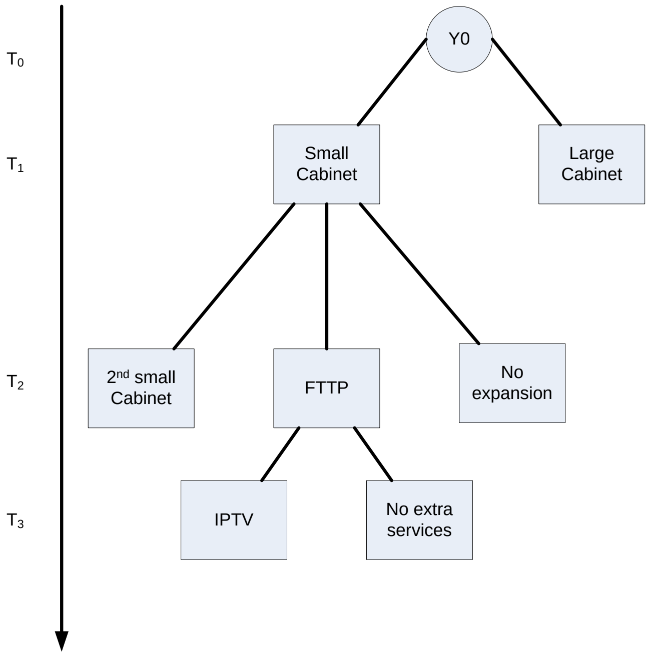


Figure 2. Decision tree for the copper network migration

The question thus arises how the impact of uncertainty, risk and flexibility can be implemented in the standard feasibility analysis. Traditionally, a net present value (NPV) analysis is performed, which consists of predicting all future costs and revenues, discounting them with an appropriate discount factor and adding them. When the NPV is positive, this points towards a positive investment project. However, this analysis does not take uncertainty and flexibility into account [5], since the project is seen as a now or never decision, while these factors clearly impact the case presented above.

To allow for a more realistic business case evaluation by capturing the value of flexibility, several extensions to the NPV analysis have been proposed. With a scenario analysis, the project is assessed on a small number of possible scenarios. In contrast to the standard NPV analysis, which offers only one view of the future, distinct futures can be. In the FttC case, possible scenarios could be the comparison of low, normal and high customer uptake. Other scenarios can also be analysed, e.g. comparing the different passive optical network (PON) technologies [16].

The economic analysis can also be deepened using sensitivity analysis, which is an extension of the scenario analysis. A sensitivity analysis allows analysing the impact of input uncertainty on the output of the techno-economic analysis. With a scenario analysis, only a few discrete scenarios are compared, while this is extended towards a statistical uncertainty distribution on the input parameters in the sensitivity analysis. Input variables can be systematically changed to measure their impact on the final result. Within techno-economic telecom research, it has been used in different papers [17–19].

IV. Real Option Valuation

Several valuation techniques exist to calculate the value of the options present in an investment project. However, only a Monte Carlo simulation can handle realistic cases. Sawilowsky defines the Monte Carlo simulation as a repeated sampling to determine the properties of a phenomenon [20].

To model more realistic business cases, a framework has been developed in [5], [21]. Next to offering a practical methodology to calculate the value of real options, it also indicates three conditions which are necessary to perform this analysis. First, there must be an uncertain factor in the project to meet the first condition. It was already indicated that in the FttC case, customer uptake was a factor of uncertainty. Secondly, a project must possess some kind of flexibility. With the 7S framework, these flexibilities can be easily identified, as has been done for the FttC case. The last condition covers the timing aspect. While uncertainty might exist at the start of the project, in the future, with more information, the flexibility can be used to act against this uncertainty to optimize the payoff of the investment project. Therefore, a real option analysis can only be performed if the project consists of two (or more) phases. In Fig. 2, this timing aspect is shown for the operator.

With these three conditions met, a real option analysis (ROA) can be performed for the investment project. Here, the methodology proposed in [5] is used. The first step consists of a standard NPV analysis, while step two and three are closely linked to the first two conditions. The conditions and methodology are summarized in Fig. 3.

V. Business Case Analysis of an FttC Rollout

The previous section introduced the framework to perform a ROA, but for the standard NPV analysis, such a large infrastructure project also requires a standardized approach. In [22], a structured approach to perform techno-economic evaluation was introduced. The first step, setting the scope of the project, requires collecting data about the market situation, the targeted area and the technologies. This data serves as input for the second step, where the different cost and revenue aspects of the project are modelled. Thirdly, the economic assessment of the project is made using a standard NPV analysis. In the last step, the extended economic evaluation is performed, for example to analyse the impact of competition or flexibility on the project outcome.

A. *Market situation and adoption of the FttC service*

The current market situation for FttC in the UK predicts a market potential around 20% [23]. However, next to the total expected uptake, a timing aspect of this uptake is also required. Several mathematical models exist to estimate the timing of the adoption of services [24–26], but [27] indicated the Gompertz curve as the most appropriate approach to model the adoption of telecom business cases (1). In the Gompertz model, three parameters are required, point (a), slope (b) and market size (m). For telecom cases, values of 4 (a) and 0.3 (b) have been found realistic [2] (Fig. 4).

$$S(t) = m * e^{-e^{-b(t-a)}} \qquad (1)$$

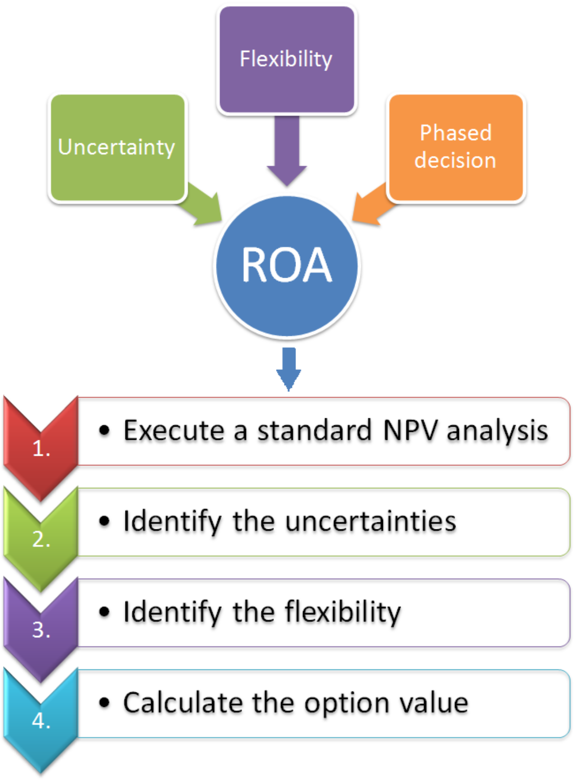


Figure 3. Practical framework to perform a real option analysis

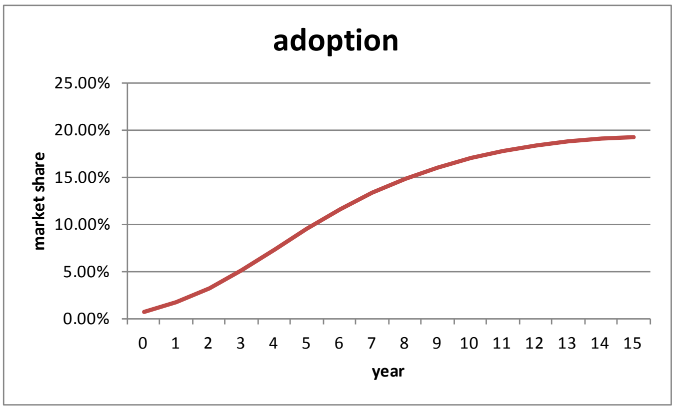


Figure 4. Gompertz adoption curve applied to an FttC based service

B. Dimensioning of the necessary network investments and revenues

To perform the business case analysis, a detailed cost and revenue model is required. The input for these models is based on the geotype classification as used in [12], [13], which results in a network dimensioning for a representative LEX. The costs to deploy and operate this network are divided in capital expenditures (CapEx) and operational expenditures (OpEx). CapEx are incurred when a company spends money to buy fixed assets or upgrade existing fixed assets. In case of the FttC rollout, these are subdivided in duct and cable costs, costs related to the installation of new street cabinets, and equipment in the LEX, street cabinet and at the customer's premises. OpEx are recurring and ongoing costs to keep the business going. Recurring costs, related to sales and administration and research and development fall in this category.

1) Capital expenditures

An important part of the CapEx is the initial investment in the passive network infrastructure. Based on the geotype classification used in [12], [13], thirteen representative LEX were identified (Table 1). This input is used to calculate the rollout costs of the FttC passive network infrastructure in the business case. When the rollout of an FttC network is considered, fibre is deployed between the LEX and the street cabinet. In Fig. 1, two sections can be identified, namely a shared section and a dedicated section per cabinet. Based on the duct and cable length and installation costs, the total initial deployment cost can be calculated. The specific parameters can be found in Table 2 and Table 3. The initial installation of cables and ducts is based on the initial uptake assumptions and rollout scenario. In case of the small cabinet installation, fibre is deployed for an uptake of 30%, and 60% in the large cabinet scenario, since this is to upper level of expected uptake. Additionally, the operator expects that 80% of the ducts can be reused when deploying the fibre in the ground.

TABLE I. OVERVIEW OF THE UK GEOTYPES [12]

Geotype	#exchanges	#lines per exchange	#cabinets	#lines per cabinet	#distribution points (DP)	#lines per DP
London	86	16812	2892	500	172118	8.4
>500k pop	204	15512	6329	500	376721	8.4
>200k pop	180	15527	5590	500	332713	8.4
>20k lines (a)	167	17089	6008	475	365886	7.8
>20k lines (b)	167	10449	4362	400	223708	7.8
>10k lines (a)	406	10728	9679	450	604925	7.2
>10k lines (b)	406	3826	4142	375	215740	7.2
>3k lines (a)	1003	2751	13355	205	493569	5.6
>3k lines (b)	1003	3181	22227	144	570745	5.6
>1k lines (a)	1230	897	5974	185	246555	4.5
>1k lines (b)	1230	935	9343	123	257043	4.5

TABLE II. AVERAGE SEGMENT LENGTH PER GEOTYPE [12]

Geotype	A segment	B segment	C segment	D segment	E segment	F segment	Total
London	258	775	166	29	4	4	1236
>500k pop	359	1076	280	49	7	8	1779
>200k pop	354	1062	314	55	7	9	1801
>20k lines (a)	294	881	265	47	6	8	1501
>20k lines (b)	778	2335	579	102	13	20	3827
>10k lines (a)	250	749	327	58	7	10	1401
>10k lines (b)	475	1425	889	157	20	30	2996
>3k lines (a)	119	358	205	36	5	9	732
>3k lines (b)	521	1562	586	103	16	37	2825
>1k lines (a)	48	144	346	61	7	16	622
>1k lines (b)	176	528	1099	194	23	70	2090
<1k lines (a)	16	48	349	62	11	32	518
<1k lines (b)	205	615	1093	193	32	126	2264

TABLE III. FTTC INSTALLATION COST PARAMETERS [12]

Cost parameter	Cost (GBP per m)
Duct installation • Road • Footpath • Grass • Aerial/Final drop	 100 60 40 15
Fibre cable installation	8
Fibre cable cost	1 – 8

TABLE IV. CAPEX FOR THE DIFFERENT COMPONENTS IN THE FTTC CASE [12]

Hardware component	**Cost (GBP)**
Street Cabinet • Small (144 subscribers) • Large (336 subscribers)	 1250 1375
ODF (1440 subscribers)	935
GigE card (24 DSLAMs)	3500
Chassis (16 cards)	6000
DSLAM • Cost per port in small cabinet • Cost per port in large cabinet	 60 120
CPE	200
Installation cost CPE	100

Next to the passive infrastructure, there is also a need for equipment: in the LEX, street cabinets and at the customer premises. It was already indicated that in the LEX, an ODF is provisioned, together with a chassis to host the Gigabit Ethernet (GigE) cards towards the cabinets and the core network. Every GigE card has 24 ports, and can thus support 24 connections to a DSLAM. In turn, a DSLAM line card can host 32 connections to separate households. In the initial installation, the existing cabinets are replaced with VDSL cabinets, each containing one DSLAM line card to host the first connection. With rising adoption, extra line cards are installed when necessary. At the customer side, the CapEx comprises of the hardware cost for the customer premises equipment (CPE) and its installation cost. The cost figures can be found in Table 4.

2) Operational expenditures

Several approaches can be taken to quantify the recurring OpEx, from a fractional approach to a detailed quantification [28], [29]. In order not to overcomplicate the analysis, the fractional approach is chosen. The total OpEx is broken down in two categories, namely electronics and other operations. Each category is quantified as a percentage of the related CapEx. The OpEx for electronics is estimated at a 10 percent fraction of the total CapEx for all installed electronic equipment, while a one percent fraction of the non-electronic CapEx is taken into account for the other operations.

3) Revenues from the FttC service

The yearly revenues from the FttC service are based on the adoption model introduced in 5.1. An adoption curve is modelled for every street cabinet connected to the representative LEX for all geotypes. Based on the number of lines connected to each cabinet, the yearly number of customers is calculated. The average annual revenue per user (ARPU) is estimated at 500 GBP.

C. A standard business case evaluation of the FttC rollout

With the input and models from the previous section, the business case analysis for the FttC rollout can be conducted. Based on the geotype information and adoption percentage, the network dimensioning was performed for the representative LEX in the small and large cabinet scenario. For a period of 15 years, the required quantities of equipment were calculated. Additional parameters, e.g. cost erosion on optical and electronic equipment were added. For discounting the cash flows, a discount factor of 10% was used.

In Fig. 5, the payoff for both the large and small cabinet scenario is shown for the six largest geotypes. For the London geotype, both options result in a payoff over 5 million GBP (€5.8 million). When taking a closer look at the results, it is clear that the both options result in a highly profitable project, but the installation of a small cabinet turns out to be the best choice. Taking into account the geotype information and cabinet sizes, this is of course a logical conclusion. With the expected uptake of 20%, the small cabinet is dimensioned large enough to host all future connections, while being a cheaper choice than the large cabinet. If this would be the final step of the techno-economic analysis, the operator would choose to install small cabinets everywhere to offer FttC based services to its customers.

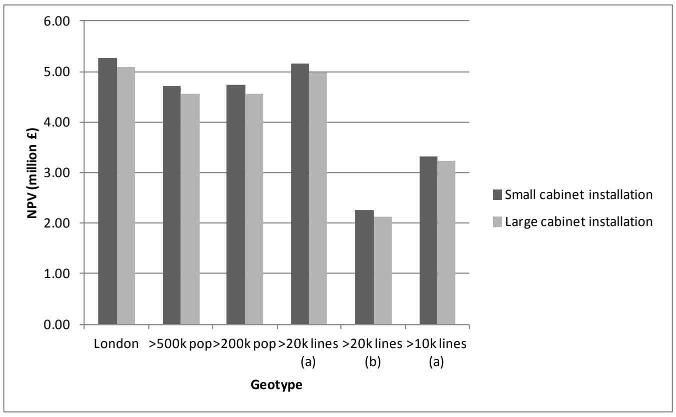


Figure 5. NPV result for large and small installation scenario

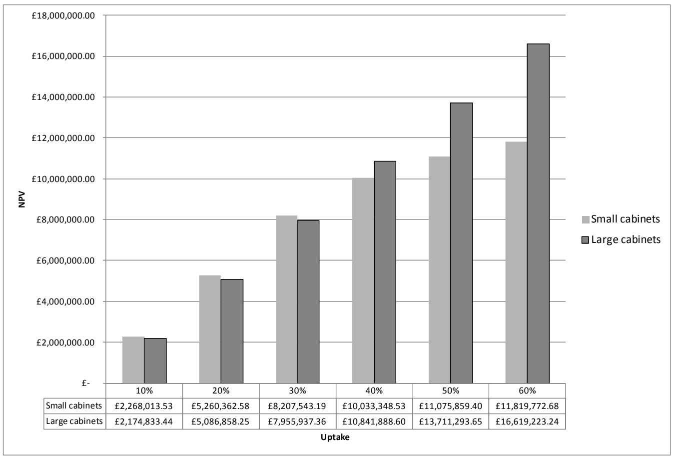
VI. Introducing Flexibility – An Extended Techno-Economic Analysis

It was already indicated that this case is subject to high levels of uncertainty. The initial assumptions on customer adoption and duct reuse can largely impact the outcome of the different installation scenarios. Therefore, the standard economic analysis should be extended to assess the impact of this uncertainty on the final decision. The different extensions to the traditional NPV analysis will be performed. First, a scenario analysis comparing scenarios of lower and higher consumer uptake will be assessed, which will be extended towards a sensitivity analysis. Secondly, to include the value of managerial flexibility, a ROA is conducted using the methodology described in section 3. This paper will only discuss the results for the London geotype in detail, but the model allows making the same analysis for the other geotypes.

A. Impact of uncertainty on the final decision

The standard NPV analysis concluded that the small cabinet installation is the most profitable option for the operator, since it is dimensioned large enough to host all future connections. However, customer uptake is one of the most uncertain parameters in an investment analysis, while it has a major impact on the revenues of the product or service [19]. Mathematical adoption models typically show a good fit with the observed adoption ex-post, but making an ex-ante estimation of the different parameters usually results in "guesstimates". An appropriate scenario analysis would thus be to compare the different cabinet sizes under different market scenarios. The NPV for six different uptakes has been calculated and is shown in Fig. 6 for the London geotype. As long as the uptake of the FttC service is under 30%, the small cabinet is the most profitable option. Above 30% uptake, these street cabinets are no longer large enough and without flexibility for the management, no extra cabinets are installed. This results in lost revenues for the extra customers and as such the large cabinet installation results in the largest payoff.

However, such a scenario analysis only compares some fixed total market potential scenarios. Additionally, for a larger area, like the London geotype, the average market potential usually will be a good approximation, but the uptake per street cabinet can show large differences between cabinets. For example, one cabinet could have an FttC uptake over 40%, while another cabinet only has a final uptake potential of 5%. Using a sensitivity analysis, this uncertainty can be studied in more detail, by adding an uncertainty distribution on the total market potential for every cabinet (Fig. 7). Each cabinet has a potential following a triangular distribution between 0 and 60 percent, with 20 percent as the most likely.



	10%	20%	30%	40%	50%	60%
Small cabinets	£2,268,013.53	£5,260,362.58	£8,207,543.19	£10,033,348.53	£11,075,859.40	£11,819,772.68
Large cabinets	£2,174,833.44	£5,086,858.25	£7,955,937.36	£10,841,888.60	£13,711,293.65	£16,619,223.24

Figure 6. Market potential based scenario analysis

Using a Monte Carlo analysis, the impact of this uncertainty on the two installation scenarios is analysed. At the start of the project, the operator has to choose between the small or large cabinet rollout, but it has no future options. Once the cabinet is full, no expansion options are possible, which results in a loss of potential revenues if the small cabinet reaches its full capacity. In contrast with the scenario analysis, where the project was compared on five fixed market potentials, a sensitivity analysis results in two probability distributions, each for one rollout scenario (Fig. 8). It is clear that the large cabinet installation is the most profitable option, since it results in a higher average return and a lower risk on a low return. On average, the large cabinet scenario outperforms the small cabinet scenario with over 260.000 GBP (+3.88%). This contrasts with the result from the static analysis, which put the small cabinet installation forward as the most profitable rollout scenario. This clearly indicated the added value of performing an analysis checking for the impact of uncertainty on the business case evaluation. However, no managerial flexibility was present in this analysis. Once the small cabinet was full, it was assumed that the operator took no action, which resulted in a loss of potential revenues. This assumption does not hold in reality, since the operator will exercise his options when they are profitable. The value of these options will be assessed in the following section using a ROA.

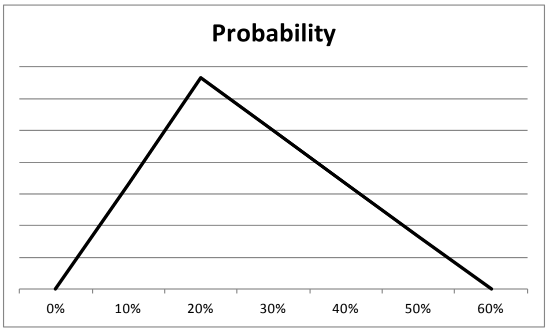


Figure 7. Uncertainty on the per cabinet market potential

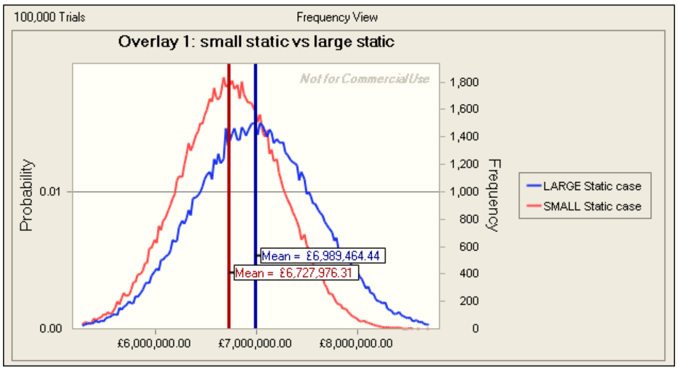


Figure 8. Comparison of the small and large cabinet scenario under sensitivity

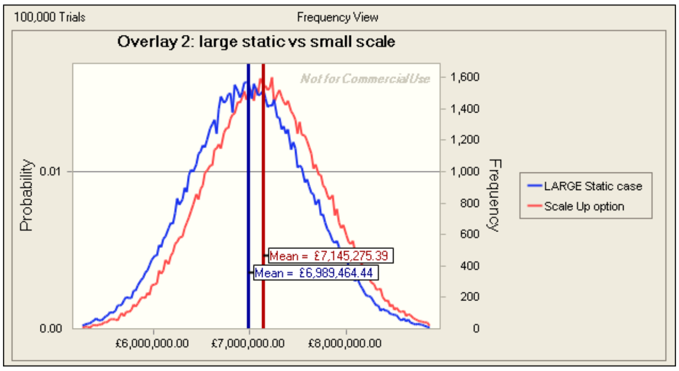


Figure 9. Comparison of the scale up option case and the large cabinet

B. *How managerial flexibility impacts the results – a real option analysis*

It was indicated that three conditions should be met before a ROA can be performed. The first condition, uncertainty, is clearly met and has been elaborated on in the previous section. The second condition requires flexibility present in the project. Based on the 7S framework [14], three different flexibilities were identified. Once a small cabinet is full, the operator can follow different expansion paths, as indicated in Fig. 2. The first flexibility consists of installing a second small cabinet on the same location to host the additional connections. Such an option is typically categorised as a scale up option. The second flexibility is upgrading the network to connect the extra customers on an FttP based solution, a switch up option. However, the operator not only has the opportunity to extend his customer base using these two options, he can also decide to increase the ARPU by offering extra services to the existing customers, for example by offering IPTV services, which is a typical scope up option. These three options will be investigated in more detail separately. In addition, the combination of different options, a so-called compound option, is introduced. The last condition, the timing aspect, is also present, since the operator does not need to decide if he exercises the options now.

1) Scale up: installing extra small cabinets

When the operator rolled out small cabinets, he has the option to install extra cabinets when the first cabinet is full. This extra installation comes with additional capital expenditures for a cabinet and DSLAM line cards, but the extra revenues for the previously unconnected customers are now included in the business case. Since the option is only executed when profitable, the option case is a simple maximisation of the static case and the scale up case. The value of this option is again assessed via a Monte Carlo analysis and compared with the static case under uncertainty. It is very interesting to compare the payoff of the case with the option included with the case of installing large cabinets from the beginning, which was the most profitable under a sensitivity analysis (Fig. 9).

An interesting result shows up in this figure. The value of the flexibility in the small cabinet scenario is large enough to outperform the large cabinet scenario with 2.23%. The scale up option offers the operator the possibility to initially install the cheaper small cabinets and only invest in additional capacity when necessary. Large cabinets offer enough capacity to host all connections, but in most cases this capacity is never used. While this difference between the large static scenario and the scale up option on the small cabinets might seem small, when the total extra gain for the operator in the London geotype alone is calculated, the scale up option offers him an extra gain of almost 13.5 million GBP.

2) Switch up: additional capacity through a more future proof network

Instead of installing extra small cabinets, the incumbent could also opt to start with the migration of his network towards a more future proof solution, namely FttP, for the extra customers. Of course, this has a larger impact on the static business case. The remaining copper last mile needs to be upgraded for these customers towards a fibre network and extra Gigabit capable passive optical network (G.PON) equipment needs to be provided in the last mile. Instead of active DSLAM equipment in the cabinets, passive splitters now ensure connectivity. The cost parameters are based on industry insight and can be found in Table 5.

The impact of this option, shown in Fig. 10, is smaller compared to the scale up option. The option still offers considerable value, but not enough to outperform the static large cabinet case. This is mainly caused by the higher CapEx required for the FttP installation.

TABLE V. COST PARAMETERS FOR AN FTTH DEPLOYMENT [12]

Hardware component	**Cost (GBP)**
G.PON card (256 customers)	6.000
Cost per G.PON port	500
Passive splitter	210
CPE	80
CPE installation cost	100

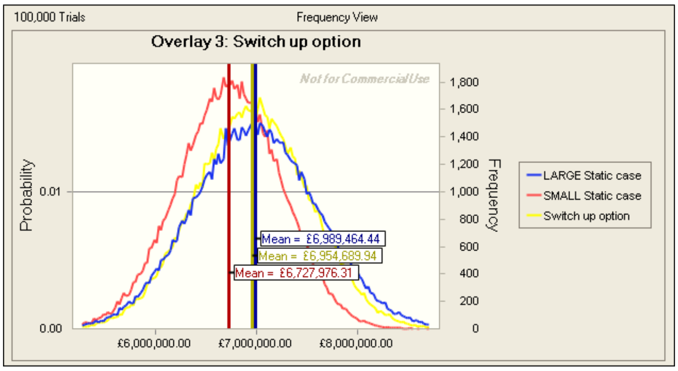


Figure 10. Impact of a switch up option on the business case

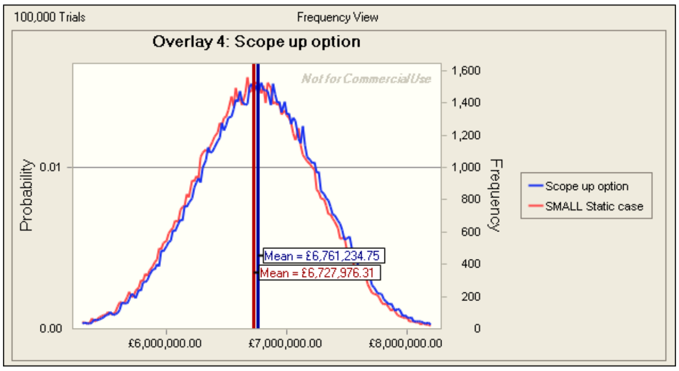


Figure 11. Scope up option result

3) Scope up: offering IPTV services over the existing infrastructure

The two previous options focussed on increasing the yearly revenues by enlarging the existing customer base. However, the operator also has the option to increase these revenues by raising the ARPU, which has already been observed in reality. Most incumbent operators now have, next to telephone and internet services, a television offer, resulting in triple-play offers. In this section, the extension of the product portfolio towards triple play is investigated. Expanding your product portfolio towards new areas is a typical example of a scope up option, the third category within the growth options of the 7S framework.

In order not to overcomplicate the current model, the implementation of this option has been simplified. The operator only has the option to extend his portfolio with IPTV in the fourth year of the project. The extra equipment to offer video services is added as a fixed cost for a video server and other equipment. At the customer's premises, a new CPE is required, together with an installation cost (Table 7). The adoption of the new service is modelled using the Gompertz model. Historic adoption percentages of IPTV have been fitted to this model, resulting in the parameters shown in Table 7 [30].

The ROA results can be found in Fig. 11, but the scope up option generates only marginal extra value compared to the static case.

TABLE VI. COST PARAMETERS FOR THE IPTV INSTALLATION

Component	**Cost (GBP)**
Video server	20.000
CPE	200
CPE installation cost	100
Extra ARPU	100

TABLE VII. GOMPERTZ CURVE PARAMETER ESTIMATES FOR IPTV ADOPTION

Parameter	a	B	m
Value	4.667	0.366	0.405

4) Combining options: scope and switch up combined

Until now, the impact of single options on the business case was studied. However, typical investment projects possess a wide spectrum of possibly interacting options. When the three options discussed above are considered, it is clear that the scale up and switch up option are mutually exclusive. Installing an extra cabinet in an area makes the switch up option redundant. On the other hand, the scope up option can be easily combined with both of these options.

In the scope up option, abstraction was made of the extra network investments required to offer IPTV services. In reality, such services require extra capacity, which cannot be offered by the FttC network. This means that only when the customers are connected via the FttP network, the incumbent can offer IPTV services. This is a so-called compound option, or an option on an option. In this case, the model for the FttP rollout was extended with the scope up option, where the adoption curve for IPTV was only applied to the FttP customers. In contrast with the single scope up option, the option is now not executed in the fourth year, but dynamically in the first year with FttP customers. Additionally, the installation cost for the new CPE at the customer's premises for the IPTV service no longer applies, since this installation concurs with the FttP installation. The total NPV for this case results in an even larger payoff compared to the small cabinet scenario with the scale option (Fig. 12), outperforming the large cabinet scenario by 3.56%.

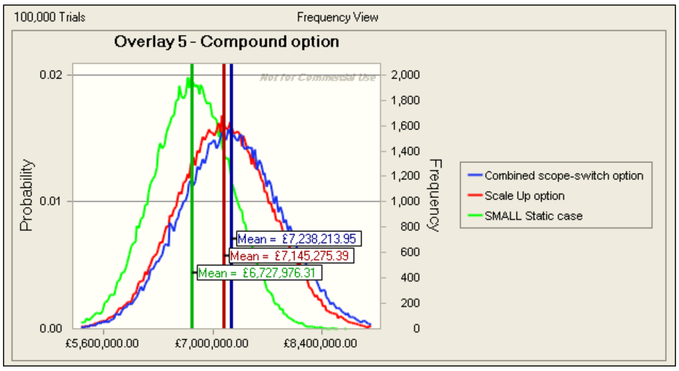


Figure 12. Compound options: IPTV services over an FttP network

VII. MIGRATION TOWARDS AN FTTC NETWORK – CASE CONCLUSION

In this paper, the migration of the traditional copper network towards a more efficient FttC network in the UK was evaluated. Initially, the incumbent operator was offered two choices, either rolling out for full coverage, or a demand driven infrastructure investment. When a traditional NPV analysis was executed, the demand-driven rollout resulted in a higher payoff. However, the limitations of the NPV analysis for this case were clearly indicated. The uncertainty surrounding the input parameters could have a significant impact on the results.

A scenario and sensitivity analysis were performed, both showing the extra value of a full rollout under uncertainty, contradicting the initial results. Although these methods allow analysing the impact of uncertainty, managerial flexibility is not assessed with these methods. Indeed, based on the course of the project, the operator can react against unforeseen evolutions. In the demand-driven rollout scenario, he can install extra cabinets, deploy a more future proof network or offer extra services to his customers. The impact of such options is typically assessed using a ROA.

To indicate the strength of real options, the different options were implemented in the static model, after checking the three conditions necessary to perform a ROA. In case of a migration towards FttC, the scale up option was found to be the most profitable, outperforming even the full rollout scenario under uncertainty. It generated an extra value of over 150.000 GBP per LEX compared the installation of large cabinets. The switch up option also offered extra value compared to the demand-driven scenario without options, but it the installation of large cabinets remained more interesting. Offering an IPTV service as a scope up option was also investigated, but this turned out to offer almost no extra value. However, in realistic business cases, options never occur in isolation. Therefore, a compound option was introduced, where the extra service option (scope up) required the more future-proof network (switch up). When using the proposed methodology, this remains a straightforward exercise.

In conclusion, this case study shows the importance of real options in telecom infrastructure projects. While the NPV analysis and several of its extensions offer insight in the profitability of the project and its main drivers, only a ROA offers a quantitative evaluation of both the uncertainty and managerial flexibility on business cases. When the migration towards more future-proof fixed access networks is considered, it has been shown that the intermediate step towards FttC is economically viable, but more interesting in demand-driven scenarios. However, with growing bandwidth demand put on the network due to extra services, like IPTV, operators should take into account that FttC could not suffice in the (near) future. This has been taken into account in this paper with a compound option approach, showing that exercising this option also results in extra return on investment. In future work, the next network migration steps can be taken into account in this model. This would allow assessing the viability of the complete migration path towards FttH on a real option basis.

ACKNOWLEDGMENT

The work leading to these results has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 249025.

This research was partially supported by the IBBT TERRAIN project. This project is co-funded by IBBT, IWT and Acreo AB, Alcatel-Lucent, Comsof, Deutsche Telekom Laboratories, Digipolis, FTTH Council Europe, Geosparc, Stad Gent, TMVW, TE Connectivity, UNET and WCS Benelux BV.

This research was carried out as a collaboration between BT and IBBT.

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