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# Valuation of Flexibility in Optical Layer Network Planning: a case study for a Belgian network

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This paper discusses the economic evaluation of different fiber deployment scenarios on the optical network layer, based on dark fiber and wavelength lease. Upfront planning based on predicted traffic leads to a network expansion plan which is probably not optimal for the actual traffic evolution. Real Options valuation determines the value of choosing a certain network deployment scenario, taking into account the ability to switch to another scenario based on information that is unknown upfront, but becomes available during the course of the planning horizon. Based on realistic assumptions for equipment and lease contract costs in a case study for a Belgian network, we show that dark fiber lease provides the most cost efficient solution. An Indefeasible Right of Use on dark fiber allows to cope with growing traffic without the need to update the contract immediately, however, its long contract term is little flexible and therefore in general not beneficial in case of uncertain traffic evolutions. Lambda lease was shown to benefit from its flexibility switch fast to another network scenario in case of uncertain traffic evolutions.

## 1. Introduction

The current telecom market remains very uncertain. Changes are observed in the number of customers as well as in the type of the services demanded. Although the growth for network traffic is not expected to stop, future traffic demands are not precisely known in advance, therefore predictions have to be used. Within this uncertain environment, network operators are often a bit reluctant to make big investments. The presence of multiple telecommunication providers and their past investments in optical layer capacity, have led to a wide availability of dark fiber throughout Europe. Therefore, for a network operator planning to deploy a new network, there is no need to acquire all physical capacity. Leasing capacity gives more flexibility and is therefore considered an attractive solution. This paper describes several capacity leasing

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scenarios on the optical network layer and indicates useful approaches to evaluate the associated investment decisions.

Real Options valuation was introduced in 1977 [1] and was applied to a variety of domains. During the last decade, it also gained a lot of interest in the field of network planning. De Miranda [2] describes a theoretical model to find the optimal time to open a new segment in an already existing network (not necessarily a telecom network). D'Halluin and Forsyth [3] study the application of the problem of optimal timing of investment into new capacity in a telecom network, presenting a mathematical model. The milestone paper of Kenyon and Cheliotis [4] values lighting decisions on dark fiber based on Real Options tree valuation. It considers the option to light the fiber at any time during the owners' Indefeasible right of use, further options to upgrade this lighting lateron could be studied as an extension. It shows that optimal lighting timing and capacity decisions depend on many factors, such as lighting cost, rate of lighting cost decrease, price volatility, etc.

In this paper, we focus on the choice of the appropriate capacity leasing scenario for optical network layer capacity from the perspective of the user of the lease. Scenarios include the lease of dark fiber versus the lease of lit wavelengths. The lighting timing question itself is not addressed. We focus on the evaluation of the different scenarios in an actual network deployment scenario, given the flexibility to switch between them as well as the relation between future traffic uncertainty and network flexibility, using Real Options thinking. In this paper, we want to demonstrate the ease to apply Real Options within a common network planning problem.

## 2. Dark Fiber versus Leased Wavelengths

Transmission capacity is put into place in a series of steps [4]: after obtaining the legal right to put the fiber along the intended path (right-of-way), a duct is put in place in order to protect the actual physical optical fiber, then the optical fibers are blown or pulled into the ducts and finally the transmission equipment is installed at both ends and connected to the fiber. This final stages is called lighting of the fiber. Dark fiber is sold or leased unlit, whereas leased wavelengths concern lit fibers (transmission equipment is in place and part of the leasing contract).

For an operator wanting to deploy a new optical communication network, we distinguish the following scenarios:

- acquisition of an Indefeasible Right of Use on dark fiber (IRU on DF)
- leasing of dark fiber (DF lease)
- leasing of wavelengths (lambda lease)

Leasing is a well-known concept where the *grantor* grants the use of the asset to the *user* for the duration of the lease. A *lease* usually applies for a relatively short term, e.g. one to five years. An

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*Indefeasible Right of Use (IRU)* is similar to a lease. In telecom, an IRU is a type of long term lease of capacity on someone else's network. For instance, assume operator X aggressively builds a worldwide fiber-optic network. If another operator Y is building a network but not in the same places as operator X, to expand its reach, operator Y might buy an IRU for two fibers in operator X's network for 20 years [5]. In most cases, an IRU applies to longer terms than a traditional lease contract, e.g. 15 or 20 years. In the remainder of this paper, we are going to consider both IRU and lease of dark fiber, assuming a duration of 15 years for the former and 5 years for the latter. For the contract of leasing wavelengths, we assume a duration of one year. A summary of the fiber and wavelength scenarios is given in Tab. 1. The link prices mentioned are in line with values found in the literature [6]. The absolute cost for an IRU on dark fiber equals the cost for a fiber lease contract for 5 years, so that the annual cost for the lease is three times that of the IRU. For the sake of simplicity, we assume lump sum payments for all contract types at the beginning of the contract.

Tab. 1. Overview of fiber and wavelength scenarios

| | IRU on DF | DF lease | lambda lease |
|---|---|---|---|
| duration (years) | 15 | 5 | 1 |
| linkprice (euro/meter/duration) | 6 | 6 | 1.5 |

## 3. Network and technology under study

In the nodes on the optical network layer we consider Optical Add-Drop Multiplexers (OADMs) allowing to transit fibers on the optical layer, which contain several wavelengths using the Wavelength Division Multiplexing (WDM) technique. An OADM allows to provide a direct optical connection between a number of node pairs in the optical network, which is called a light path [7]. Some wavelengths coming into the OADM are transmitted on the optical layer to the next node on their path. Other wavelengths are dropped at the considered node (going up to the electrical layer). Some new wavelengths coming from the electrical layer can be added to the outgoing optical signal as well. Fig. 1 illustrates how some transit wavelengths can be switched on the optical layer, whereas tributary traffic (add/drop, denoted by different λs) is sent through the electrical layer (the Digital Cross Connect (DXC) in the figure). In our study we refer to the network node configuration of Fig. 1, where the cost of the DXCs is not considered, as this cost is present in both leased wavelengths and dark fiber scenarios. We focus on the cost differences between the distinguished scenarios. We don't refer to any vendor-specific equipment, but rather assume a simplified node model with the base cost assumptions of Tab. 2. For the sake of simplicity, in case of growing traffic demands, we assume several identical OADMs can be combined, without dealing with interconnection between them.

Both a dark fiber and a wavelength network are based on wavelength infrastructure in the network nodes. Several candidate node configurations can be distinguished, depending on the physical topology at hand and the requirement to have grooming capabilities (packing low capacity traffic in high capacity streams). More information on possible node configurations can be found in [8]. In a dark fiber network, the multiplexers and the transponders are owned by the network operator acting as the user of the lease or IRU, whereas in a leased wavelength network this transmission equipment is owned by the external service provider (grantor of the lease). We study the cost of the optical layer for the user of the lease/IRU. In case of a leased wavelength network, this cost is entirely constituted of the cost of the leasing contracts. In case of a leased (or IRU) dark fiber network, apart from the cost of the leasing contract, we need to include the costs of the optical amplifiers, the transponders, the (de)multiplexers and the OADMs.

In the remainder of the paper, we consider a network on the Belgian scale (32,545 km$^2$) consisting of 3 interconnected rings with a total link length of 1488 km. We consider a planning horizon of 15 years, with an annual traffic growth of 60%. The reference traffic described in [8] was assumed to be obtained in the fourth year of the period studied.

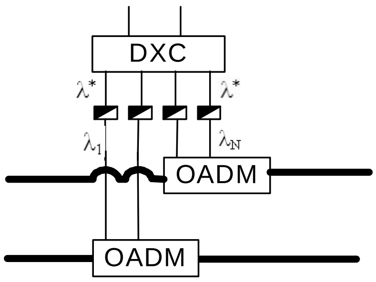


Fig. 1. Considered node configuration

Tab. 2. Considered network costs

| Equipment | cost (euro) |
|---|---|
| OADM | 17000 |
| MUX dwdm | 37500 |
| transponder 10G | 23000 |
| optical amplifier | 20000 |

## 4. Analysis of Upfront Decision to Deploy a Single Scenario under Traffic Uncertainty

In this section, we study the impact of an uncertain traffic evolution. We consider the situation

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where the choice between the three network deployment scenarios is made at the beginning of the planning interval and based on the predicted traffic evolutions. Within a certain network deployment scenario, there is some flexibility to easily increase or decrease the capacity at the end of the lease contract, indicated by the dots on the lines within a certain scenario (e.g. release a wavelength on a yearly basis in case of lambda lease or increase the amount of dark fiber leased after 5 years) in Fig. 2. The full lines represent IRU on DF, the dashed lines represent DF lease and the dotted lines lambda lease. In this section, we assume that it is impossible to switch from one to another scenario.

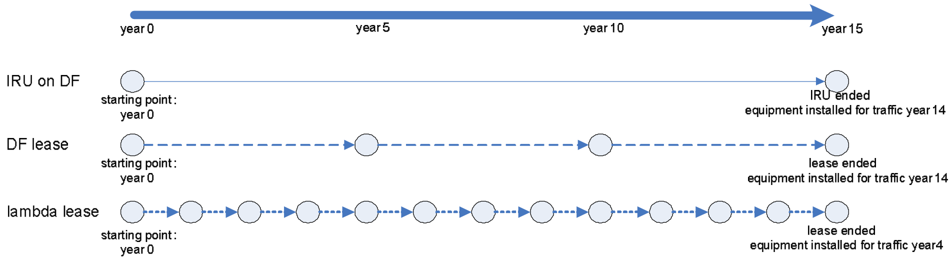


Fig. 2. Limited flexibility within the different scenarios

The discounted cost over 15 years for the three scenarios when the traffic indeed evolves as predicted is shown in the left column of Fig. 3. The DF lease scenario is the cheapest. However, when we experience an unpredicted, abrupt traffic growth with a factor 10 in year 6, the situation changes. Now the IRU on DF scenario benefits from the fact that there is some room for growth within the available dark fiber capacity, so that it is not required to upgrade capacity immediately. In case of the DF lease on the other hand, the available dark fiber capacity is insufficient, so that additional expenses need to be made (e.g. the leasing contract needs to be extended to include more dark fibers) in order to cope with this unexpected additional traffic demand. This results in the situation depicted in the right column of Fig. 3, where the IRU on DF is the most cost-efficient solution. This observation learns that upfront planning based on the predicted traffic evolution can easily lead to a network which is not optimal for the actual traffic evolution.

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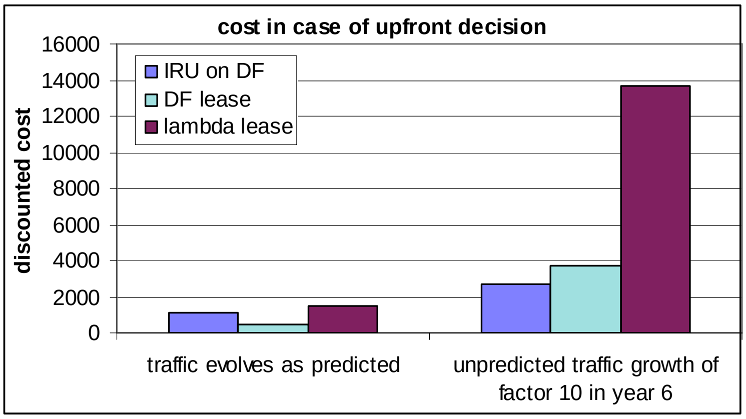


Fig. 3. Discounted cost over 15 years in case of upfront decision with limited flexibility under traffic uncertainty

## 5. Analysis of Upfront Decision with Flexibility to Switch Scenarios under Traffic Uncertainty

Apart from the limited flexibility to increase or decrease capacity within a certain scenario (at the end of a contract term) indicated above, in practice, there is also the flexibility to switch between the scenarios considered at the end of the contract term, this means after 15 years for the IRU on DF, after 5 years for the DF lease and yearly for the leased wavelengths. Note that, in real life, there is also the possibility to prematurely end the contract, e.g. end the IRU before the end of the 15 year period by paying a kind of penalty fee, but this is not considered here.

In order to keep the problem comprehensible, we split the planning horizon in two parts. We assume the predictions for the first 5 years to be more or less reliable and therefore consider the case where the traffic evolves as forecasted for the first 5 years and has an uncertain evolution during the last 10 years. We consider year 5 to be the only point which allows flexibility, which is a simplification of the realistic situation. The flexibility to change the network scenario based on the uncertain evolution assumed in this section is illustrated in Fig. 4.

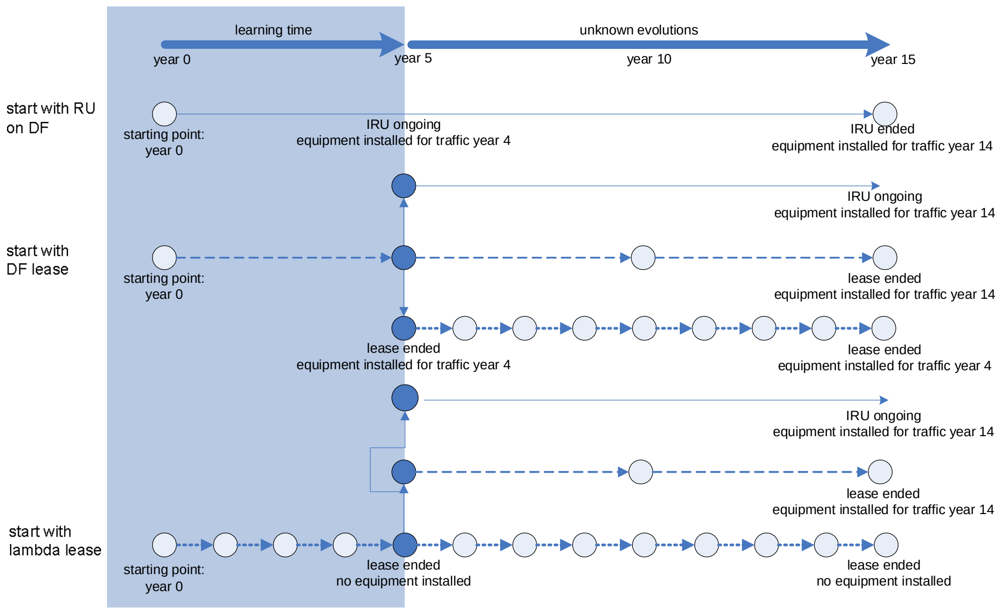


Fig. 4. Considered flexibility to switch between scenarios

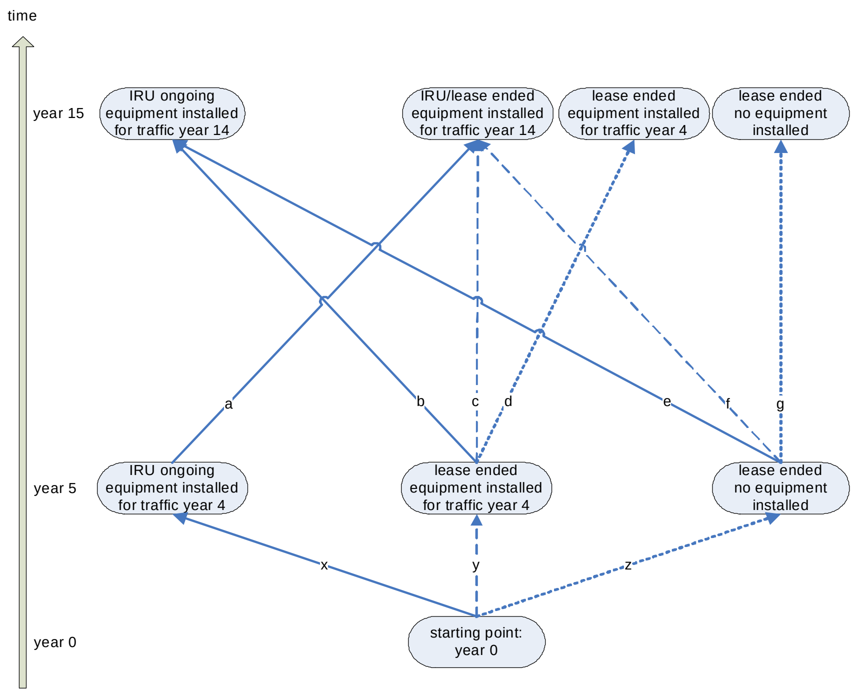


Fig. 5. Network migration tree

The situation of Fig. 4 is mapped to the network migration tree of Fig. 5, where the bottom part reflects the first *5* years, the top part the last *10* years. Again, the full lines indicate the IRU on DF scenarios, the dashed lines indicate the DF lease scenarios and the dotted lines the lambda lease

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scenarios. The nodes in the network migration tree of Fig. 5 indicate the situation concerning acquired network equipment and status of the lease contracts, this explains why the edges *a*, *c* and *f* all end in a situation where the lease or IRU contract is finished and equipment is installed to cope with the traffic of year 14. As we do not consider the possibility to prematurely end the contracts, there is only 1 arrow starting from the "IRU ongoing" node. For the DF lease and lambda lease scenarios, the contract is ended in year 5, so that all scenarios are possible for the second planning interval.

The costs for the first five years are easy to calculate since it concerns the static case and are shown in Tab. 3. In case of the IRU on DF there is an end value after the first 5 years, as the dark fiber can still be used for 10 more years in that case. Note that the end value is not taken into account when considering the costs for the entire 15 years planning horizon (as the end value of the fibers will be used in the last 10 years).

Tab. 3. Discounted cost over first 5 years for different scenarios for traffic evolutions as expected

| | cost | end value | adjusted cost for the first 5 years |
|---|---|---|---|
| x | 944 | 385 | 559 |
| y | 28 | 0 | 28 |
| z | 113 | 0 | 113 |

The top part of Fig. 5 shows the situation for the last 10 years. Within the network migration tree of Fig. 5, the optimal path over the total 15 year period (the cheapest path calculated from the root node to one of the nodes on the top level, calculated by Dijkstra's algorithm [9], taking the costs of the scenarios as edge weights) may be different for different traffic evolutions. The costs of all edges of the tree for the second part of the planning horizon (year 5 till 15) are given in Tab. 4. If we assume that the traffic growth stays constant at 60% a year, the costs of the arrows in the top part of the figure are given by the values of the first column of Tab. 4. The dashed edges (*c* and *f*) have the lowest costs for the last 10 years. Combined with the information for the first 5 years, this shows that in case the traffic grows as predicted during the entire planning interval, the dark fiber lease leads to the most economical solution. The cheapest path in the tree of Fig. 5 is given by the straight path from the root node to the "IRU/lease ended, equipment installed for traffic year 14" node in this case. On the other hand, in case of an important unexpected traffic increase (we assume, traffic growing a factor 10) in year 6 of our planning horizon (at the beginning of the uncertain traffic period), the situation is different, as shown in the last column of Tab. 4. In this case the solution with the IRU on DF starting in year 6 has the lowest cost (edges *b* and *e* in the figure). Note that in this case the end value of the fibers in year 15 is taken into account, which has a positive impact on the overall cost of this solution (the fibers can indeed still be used for 5

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more years after the end of year 15). The shortest path is now given by edge *y* followed by edge *b*. As no network equipment needs to be bought by the operator in case of the lease wavelength scenario, the costs of edges *d* and *g* are equal to each other for all network scenarios, see Tab. 4 for some examples. The small cost difference between the edges *e* and *b* and *f* and *c*, respectively, is the cost for the additional equipment required for the DF lease from year 5, because no equipment was available in year 5 in case lambda lease was used up to that time.

Tab. 4. Edge costs for second planning interval in the tree of Fig. 5 (mio euro)

| source node | edge | edge cost | |
|---|---|---|---|
| | | traffic growth according to predictions: annual growth rate 60% | 60% annual growth, plus abrupt traffic growth factor 10 in year 6 |
| IRU ongoing, equipment installed for traffic year 4 | a | 1.38E+02 | 1.79E+03 |
| lease ended, equipment installed for traffic year 4 | b | 5.12E+02 | 2.16E+03 |
| | c | 3.91E+02 | 3.66E+03 |
| | d | 1.38E+03 | 1.36E+04 |
| lease ended, no equipment installed | e | 5.19E+02 | 2.17E+03 |
| | f | 3.98E+02 | 3.67E+03 |
| | g | 1.38E+03 | 1.36E+04 |

The example discussed in this section shows that the flexibility to switch between scenarios can add value (i.e. reduce cash out-flows), e.g. in our case it is beneficial to switch from DF lease towards IRU on DF in case of abrupt traffic growth. This flexibility cannot be taken into account in traditional planning schemes that are entirely based on the predicted evolutions.

## 6. Analysis of Flexible Upfront Decision under Traffic Uncertainty

A solution to the problems described above (where the planning is entirely based on predicted evolutions) could be to identify several possible future traffic evolutions instead of a single prediction. We consider the following uncertain traffic evolutions for the last 10 years of the planning horizon, which are simulated using Monte Carlo simulation, performed by Crystal Ball [10].

- *abrupt traffic change in year 6*: the traffic is supposed to follow the forecasted traffic growth of *60%* a year, except from an abrupt change in that trend in year 6 (beginning of second

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planning period). The abrupt change is modelled as a traffic increase or decrease somewhere between 0.01 times its current size and 10 times is current size. A continuous variable with uniform distribution is assumed.

- *abrupt traffic decrease at unknown time*: the traffic change is supposed to be a decrease to a fraction of 0.05 till 1 of its current size, modelled as a continuous uniform random variable. The timing of the occurrence of the abrupt change is modelled as a discrete variable with uniform distribution over the second part of the planning horizon (year 6 till 15).
- *abrupt traffic increase at unknown time*: similar to abrupt traffic decrease at unknown time, but with a traffic increase of *1* till *10* times its current size.

We distinguish between two methods to use these future traffic evolutions in order to find the most suitable network deployment plan:

- We could perform a simulation analysis of a set of future evolutions and choose the network scenario (IRU on DF, DF lease or lambda lease) which leads to the cheapest network, on average over the considered future traffic evolutions. This means that we calculate the average of the costs of the edges in the second part of the planning horizon (*E[a], E[b], E[c], E[d], E[f], E[g]*) and choose the edges with the lowest cost amongst those originating from a single node in the network migration tree (*min(E[b,c,d])* and *min(E[e,f,g])*).
- If we assume that some information concerning the future traffic evolutions becomes available in year 5 (which is not known in year 0), we need to recognize the fact that only one outgoing edge of the nodes in year 5 will be selected, namely the one with the lowest cost given the actual traffic situation at that time (not based on the average of all possible scenarios). This means that we take into account the fact that our strategy can be changed in year 5, *based on the additional information available by that time*. This is represented by choosing the average of the minimum of the outgoing edges of the nodes in year 5 (*E[min(b,c,d)]* and *E[min(b,c,d)]*) and reflects the idea of Real Options thinking.

Whereas the traditional technique of scenario analysis explained in the first bullet aims at maximizing the value given the information available in year 0, based on the expected evolutions, the Real Options approach aims at maximizing the value given the information available today and later, where the information becoming available later can and will be used for revising the network migration strategy during the course of the planning horizon. In case there is no uncertainty involved, both approaches lead to the same solution as the deterministic solution described in the previous paragraph.

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## 7. Real Options valuation through simulation

In this study we applied a simulation based [11][12] to the tree of Fig. 5, as explained below. The fact that the best edge out of the nodes “lease ended, equipment installed for traffic year 4” and “lease ended, no equipment installed” can be chosen in year 5, taken into account any additional information available by that time, gives an additional value to those nodes. This flexibility is not present in the “IRU ongoing, equipment installed for traffic year 4”, as this node has 1 outgoing edge (out-degree = 1). The value of the flexibility to switch to another network scenario (the option value) should be taken into account already at year 0 when deciding on the solution for the first 5 years. Indeed, choosing the IRU on DF solutions limits our options in year 5. Therefore, the actual cost of the different network scenarios for the first *5* years is calculated as the sum of the actual costs in the first 5 years and the minimum of the costs in the last 10 years.

Tab. 5. Costs for second planning interval in the graph of Fig. 5, in case of uncertain traffic evolution

| | | abrupt traffic change in year 6 | abrupt traffic decrease at unknown time | abrupt traffic increase at unknown time |
|---|---|---|---|---|
| IRU ongoing, equipment installed for traffic year 4 | E[a] | 5.70E+02 | 8.73E+01 | 6.80E+02 |
| lease ended, equipment installed for traffic year 4 | E[b] | 8.09E+02 | 5.06E+02 | 9.02E+02 |
| | E[c] | 1.87E+03 | 2.95E+02 | 1.20E+03 |
| | E[d] | 6.92E+03 | 9.37E+02 | 6.38E+03 |
| | E[min(b,c,d)] | *7.80E+02* | 2.95E+02 | *6.98E+02* |
| | min (E[b,c,d]) | *8.09E+02* | 2.95E+02 | *9.02E+02* |
| lease ended, no equipment installed | E[e] | 8.16E+02 | 5.13E+02 | 9.09E+02 |
| | E[f] | 1.88E+03 | 3.02E+02 | 1.21E+03 |
| | E[g] | 6.92E+03 | 9.37E+02 | 6.38E+03 |
| | E[min(e,f,g)] | *7.87E+02* | 3.02E+02 | *7.05E+02* |
| | min (E[e,f,g]) | *8.16E+02* | 3.02E+02 | *6.38E+03* |

In Tab. 5, we study the impact of traffic uncertainty on the solution concerning the best network scenario. In case of the “abrupt traffic decrease at unknown time”, the most economical situation is given by the DF lease scenario as the cost for edge *a* is lower than that of all other edges in this case. In case of the “abrupt traffic change in year 6” and the “abrupt traffic increase at unknown time”, on the other hand, the average of the minimum of the edge costs is lower than the minimum of the individual averages per traffic evolution path. This is the difference between the value determined by traditional scenario analysis and the value indicated by Real Options. It shows that, e.g. in case of the “abrupt traffic change in year 6”, the lease DF scenario is not always (i.e. not for all possible future scenarios) the best solution. This was already shown in the right most column of Fig. 3, were IRU on DF was more economical in case of a factor 10 traffic increase. The difference between $min(E[a,b,c])$ and $E[min(a,b,c)]$ is exactly the value associated with the flexibility in the node “lease ended, equipment installed for traffic year 4”. This is the value of the option to switch between network scenarios. Note that in option terminology the option value is defined as the difference between the value of the flexible situation (in our case, change the network scenario according to the actual traffic evolution) and the static situation (in our case, stay with the same network scenario). However, as we assume equal revenues for all scenarios, the difference in cash-out flows equals the difference in value.

The results of Tab. 5 indicate that the use of Real Options valuation succeeds in taking into account the flexibility to change the network migration strategy during the course of the planning interval (shown in the shaded rows in the table), which is not possible with traditional approaches. In order to determine the most suitable network scenario to start deploying in year 0, taking into account all types of flexibility described above, we need to add the value for the second part of the planning horizon (based on Real Options) to the value for the first 5 years, which was supposed to be static. Referring back to Fig. 5 the costs to be compared at the beginning of the planning horizon are given by the formulae below.

$$cost\ IRU\ on\ DF = x + a$$

$$cost\ DF\ lease = y + E[min(b,c,d)]$$

$$cost\ lambda\ lease = z + E[min(e,f,g)]$$

The results can be calculated from Tab. 3 and Tab. 5 and are given in Fig. 8. The results indicate that, for all uncertain evolutions considered in this paper, the best scenario to start deploying in year 0 is the DF lease scenario. Dependent on the actual traffic evolution, it might be useful to switch to another scenario later on. In case future traffic evolves as expected, wavelength lease proves to be a very expensive scenario. However, in case of uncertain evolution, the inherent flexibility from this scenario gives additional value, whereas the inflexible IRU on DF scenarios gets less interesting. Considering the entire range of uncertain traffic evolutions, DF lease and lambda lease prove to outperform IRU on DF for the case study at hand.

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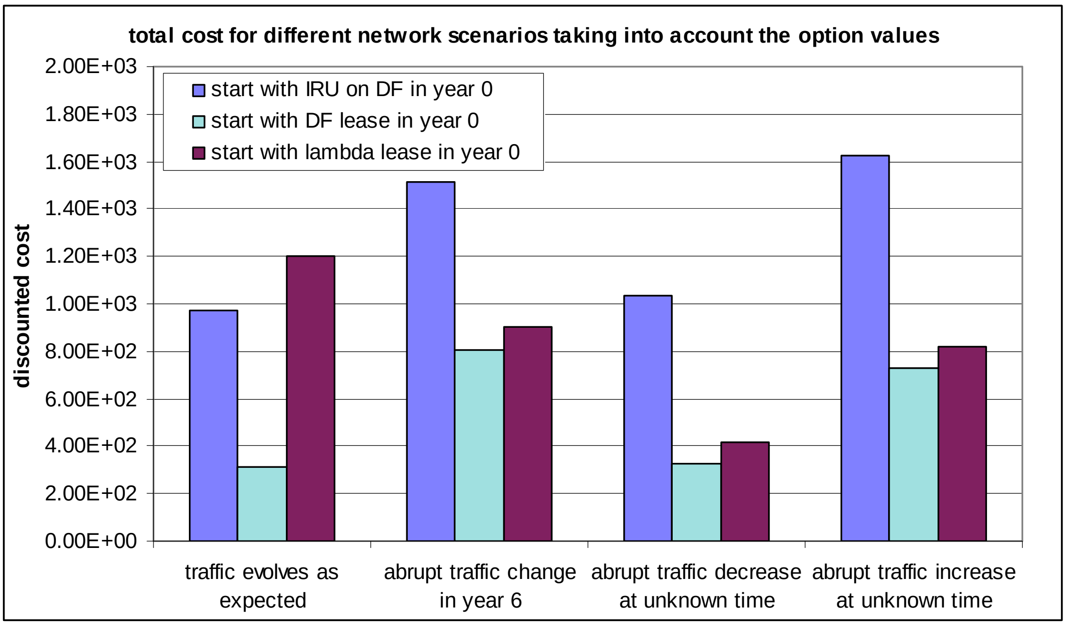


Fig. 6. Total costs for the different network scenarios taking into account the option values

## 8. Conclusions

In this paper, we have studied long term network planning decisions, comparing wavelength lease to dark fiber lease with different contract durations. We have focused on the economic evaluation of the different scenarios. Based on some realistic assumptions for equipment and lease contract costs, we have shown that the dark fiber lease provides the most cost efficient solution.

We have studied the different forms of flexibility inherent to the network deployment scenarios under study. We applied Real Options valuation to evaluate the flexibility to switch between the scenarios, taking into account that information becoming available during the course of the planning horizon might influence the strategy followed. This approach can easily be used in any real network deployment problem in order to evaluate the value of inherent flexibility of the different strategies. Using a realistic network deployment case study, it was shown that the long contract term of an Indefeasible Right of Use on dark fiber is little flexible and therefore in general not beneficial in case of uncertain traffic evolutions. On the other hand, lambda lease was shown to benefit from its flexibility switch fast to another network scenario in case of uncertain traffic evolutions.

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