Costs and Revenues Models for Optical Networks Architectures Comparison

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Abstract. Network operators are receiving high pressure to increase networks' bandwidth capacity providing faster access to distributed applications and media contents. At the same time, the hard competition for opportunities in the telecommunications market forces them to cut prices for the provided services at the risk of reducing turnovers. In consequence, costs must be carefully evaluated and kept under control. Therefore, any network investment must be evaluated from an economic perspective. In finance, the Net Present Value (NPV) is the most extended criteria to compare among investments. NPV allows comparing long-term projects as it measures the generated cash flows in present value terms, thus relating revenues, and costs. In this paper, we present costs and revenues models in the context of optical networks. Those models are afterwards related using the NPV expression. Regarding costs, not only technology or cable infrastructure is considered but also human resources and energy consumption thus allowing comparison among network architectures. Illustrative numerical results show how variations in the cost of the different elements affect total costs and finally the NPV.

Keywords: OPEX, CAPEX, Net Present Value, Optical Networks

1 Introduction

In financial crisis times network operators are carefully evaluating any network investment to cope with the everyday increasing bandwidth demand. Although internet-based applications, media contents, or the emerging real-time multimedia applications exchanging 3D contents [1] are putting pressure to operators to increase networks' bandwidth capacity, customers are willing to pay inexpensive rates at the risk of reducing operator's turnover. Thus, costs must be carefully evaluated and kept under control. Total expenditures of a network operator can be divided into Capital Expenditures (CAPEX) and Operational Expenditures (OPEX). CAPEX is related with purchasing and installing fixed infrastructure such as buildings, equipment, cables, etc., whereas OPEX represents the costs of keeping the company operational and includes personnel costs, rented infrastructure, external services, etc.

The optical technology based on Wavelength Division Multiplexing (WDM) allows transporting huge amount of data by multiplexing different data flows on different optical wavelengths, reducing thus the cost per transmitted bit. A WDM-based network is a network composed by optical nodes which are connected through optical fibers. The information is transmitted in the optical domain and the signal can be treated optically or converted to the electrical domain in the network nodes. The introduction of intelligence to optical networks using a Generalized Multiprotocol Label Switching (GMPLS) control plane [2] allows setting up, configuring and releasing optical connections in an automatic and dynamic manner, drastically reducing provisioning costs related with legacy Synchronous Digital Hierarchy (SDH) technology.

Some works have proposed methodologies and models for calculating OPEX and CAPEX costs in optical networks (e.g. see [3], [4]). However, those models are only a partial view. As an example, authors in [4] present an activity based approach to quantify the cost part of the operational processes, those related with repair and provisioning. Non event-driven processes, such as preventive maintenance, or other related with the used technology or the amount of served traffic, such as power consumption, are, however, omitted. Moreover, although costs can be used directly to compare among network alternatives, it is important consider also the generated revenues.

A great part of core network operators' revenues comes from the provisioned connectivity services. Being the core business, it is critical to perform a detailed analysis of the profitability of any investment project. In finance, the Net Present Value (NPV) is the most extended criteria to compare among investments [5]. NPV allows comparing long-term projects as it measures the generated cash flows in present value terms, thus relating revenues, OPEX, and CAPEX.

The reminder of this paper is organized as follows. Section 2 shortly overviews WDM-based networks focusing on the study of the architecture of optical nodes and links. Next, section 3 develops models for CAPEX, OPEX, and Revenues which are all related through NPV. The derived models are applied to different reference network topologies in section 4. Finally, section 5 concludes the paper.

2 Background on Optical Networks

The WDM technology allows transmitting different data flows on different optical wavelengths. Light emitters (usually semi-conductor lasers) are key components in any optical network since they convert the electrical signal into a corresponding light signal, on a single wavelength, that can be injected into the fiber. Besides lasers, a WDM system uses a multiplexer at the transmitter to multiplex the different wavelengths together into a WDM bundle, and a de-multiplexer at the receiver to split them apart.

An optical fiber transmit optical signal through long distances. However, the power of the signal is reduced when it propagates over distance, this is called attenuation. The receiver sensitivity indicates the minimum power required to detect the incoming signal. In order to compensate for the effect of attenuation, the optical signal can be amplified within the optical domain. When the optical signal travels through an optical fiber it is also distorted by the effect of dispersion, which modifies the optical pulse duration. This may lead to inter-symbol interference. However, dispersion may be compensated using dispersion compensators. In our models, we assume optical amplifiers composed in three stages: optical pre-amplifier, dispersion compensation, and optical post-amplifier or booster. Fig. 1 shows an example of an optical link with a number of intermediate optical amplifiers.

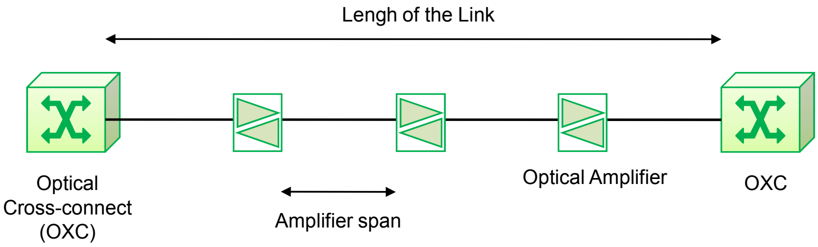

Fig. 1. Example of an optical link

The introduction of sophisticated optical devices such as Wavelength Selective Switches (WSS) made possible to build optical cross-connects (OXCs), the key element to build optical mesh-based networks. In this regard, the nodal degree (*d*) of an optical node is the number of WDM links incident on the node. Fig. 2 shows the architecture of an OXC with *d*=5. This architecture is consistent with that presented in [6] for colorless nodes.

As shown, an OXC node is composed by four blocks: first, WSSs which depending on the direction can be used to add or to drop wavelengths to/from the WDM bundle; second, optical amplifiers to amplify optical signals which can also include dispersion compensators; third, optical splitters to split one input optical signal into several identical output signals; and finally forth, optical transponders to adapt client signals to the optical domain and vice versa, so they include one WDM laser and a photo-detector.

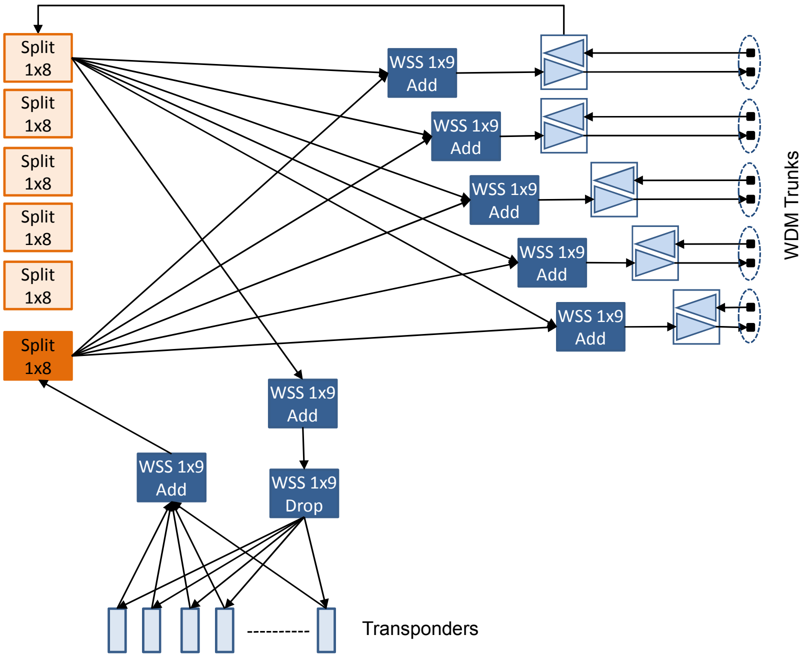

Fig. 2. OXC architecture with *d*=5. Scalable up to *d*=8.

It is worth mentioning that the OXC architecture in Fig. 2 can be scaled up to a maximal nodal degree of 8 WDM trunk links. However, this restriction does not limit our study since the optical networks under consideration do not reach those nodal degrees.

3 Costs and Revenues Models

In this section we present models to compare among network designs in economic terms using the Net Present Value (NPV) [5]. It calculates the value in present time of future cash flows originated by an investment. The methodology consists on evaluating in current time (updating with an interest rate) all the future cash flows generated by each of the alternatives. Comparing these values we are able to choose the scheme providing the highest profitability.

The expression to calculate the NPV of an optical network described by a graph G (N, E), where N is the set of nodes and E the set of links, is:

$$NPV=\sum_{\forall y \in Y}\left[\frac{REVENUES_y - OPEX_y}{(1+r)^y}\right]-CAPEX \tag{1}$$

Where $REVENUES_y$ represents the annual income obtained by the commercialization of connectivity for every year (y), $OPEX_y$ are the network operation and maintenance costs for every year, r is the interest rate, and finally CAPEX is the investment or the capital necessary for the initial network deployment. In the following subsections we describe a model to calculate both the income and the costs that have just been defined.

3.1 Revenues Model

In our models we assume dynamic traffic, where connections arrive to each OXC according to a Poisson process with a predefined mean inter-arrival time (*iat*). The connections holding time is exponentially distributed with a predefined mean (*ht*). The destination of each connection is uniformly distributed. Thus, the average traffic intensity in Erlangs departing each node is therefore: $I=ht/iat$.

Annual revenues are obtained from selling optical connectivity, for a given traffic intensity per node, and thus can be computed as follows

$$REVENUES_y = |N| \cdot I \cdot \Delta t \cdot C \tag{2}$$

where Δt represents one year in service hours, and C is the price per service hour.

3.2 Capital Expenditures (CAPEX)

To compute the CAPEX we can distinguish two differentiated costs: first, the cost of the optical nodes, which depends on the traffic intensity by node, and on the node degree, and second, the link cost which depends on the link length.

On the one hand, the optical node cost can be shown as the summation of three factors: a) the base cost, C_{BASE}, which includes the subrack, a set of common cards and the installation; b) the cost for each of the optical interfaces of the node. This cost directly depends on the optical node degree (d) and on the cost of each WDM trunk card, C_{Trunk}; c) the cost of accessing the network (optical transponders) $C_{Transponder}$. This cost will depend on the traffic intensity that the network will transport. Then, the cost of an optical node can be computed as:

$$C_{BASE} + C_{Trunk} \cdot d + maxPaths \cdot C_{Transponder} \tag{3}$$

where *maxPaths* represents the maximum number of optical connections that will begin or end on each current node, i.e., the number of transponders to be installed in each of the network nodes. Under uniform traffic conditions, *maxPaths* can be dimensioned as the double of the traffic intensity, *maxPaths* = ceil(2**I*).

On the other hand, the cost of a link includes: a) the optical fiber cost C_{FO}, which is a function of the total link length in km (L). At this point it is worth emphasizing that we consider optical fibers as being already installed, so neither cable installation costs nor civil work costs are considered; b) the cost of the optical amplifiers C_{OA} and other necessary elements, such as dispersion compensators, which allow to convey information between optical link end points. Thus, the optical link cost becomes:

$$L \cdot C_{FOKm} + \left\lfloor \frac{L}{SA} \right\rfloor \cdot C_{OA} \tag{4}$$

where SA is the amplifier span.

Finally, the CAPEX equation becomes:

$$CAPEX = \sum_{\forall n \in N} \left(C_{BASE} + d_n \cdot C_{Trunk} + \lceil 2 \cdot I \rceil \cdot C_{Transponder} \right) + \sum_{\forall e \in E} \left(L_e \cdot C_{FOKm} + \left\lfloor \frac{L_e}{AS} \right\rfloor \cdot C_{OA} \right) \tag{5}$$

3.3 Operational Expenditures (OPEX)

Network operation and maintenance annual costs can be divided into four components: first, alarm surveillance and network monitoring cost necessary to detect alarms and anomalies, so that they can be solved in time to prevent service cuts or other major problems. This cost depends on the number of employees monitoring the network that also depends on the number of nodes. We consider that one person can supervise up to 10 nodes of the network and *Team24* (e.g., four) employees are needed to cover 24 hr a day / 7 days a week. Then, the monitoring cost can be computed as

$$C_{MYear} \cdot Team24 \cdot \left\lceil \frac{|N|}{10} \right\rceil \tag{6}$$

Second, provisioning costs which are costs of providing the required service over the network such as connectivity verification. This cost is calculated based on the volume of traffic to be established. To calculate the traffic volume, we compute the number of arrivals in a period of time (e.g., one year), as ($\Delta t * I$)/ht. Let CX_{hr} be the average number of new connections per hour that one employee can verify and *WTime* the number of working hours per year, provisioning costs can be computed as

$$C_{MYear} \cdot \left\lceil \frac{\Delta t \cdot I}{ht \cdot CX_{hr} \cdot WTime} \right\rceil \tag{7}$$

Third, failure repair cost which represents the cost to repair systems failures, e.g., equipment failures and fiber cuts. The mean time to failure (MTTF) of each of the components is known, and therefore it is possible to estimate the number of failures per year. We consider the following failures:

- Optical node, which fails principally due to software failure. There are |*N*| optical nodes in the network.
- Optical transponder. Every node has been equipped with *maxPaths* transponders, and then there are |*N*|* *maxPaths* transponders in the network.
- WSS. It is the basic component of a WDM trunk card. The number of WSS can be calculated as double of the number of links in the network, 2*|*A*|.
- Optical fiber, which fails principally as a consequence of civil work involving the use of machinery. The amount of fiber in the network is the summation of the length of every link.
- Optical amplifiers. An optical amplifier is installed every *SA* km of optical fiber. The number of optical amplifiers in a given link is calculated as ceil(*L*/*SA*).

Table 1 Algorithm to compute the number of failures per year

```
INPUT: MTTF, number of years
OUTPUT: Number of failures on each year

Compute Weibull’s distribution for the given MTTF

For each year i do
   Compute failure probability for year i
   Elements in year i = 0
   Failures on year i = 0
End

Elements on the first year of life = Total number of elements
Total element failures = 0

For each year i do
   Failures on year i = 0
   For each year j ≤ i do
       Failures on year j =
                 Failure prob. for year j * Elements on year j
       Failures on year i += Failures on year j
   End

   For each year j ≥ 2,j ≤ i do
        Elements in year j =
                 Elements in year j-1 – Failures on year j-1
   End
   Elements on the first year of life = Failures on year i

End
```

To compute the number of failures of each system, we consider that they follow a Weibull distribution with mean MTTF, and a shape parameter equal to 2. Therefore the distribution function can be calculated as D(x)=1-exp(-($x/\lambda)^2$), where x is an interval of time (e.g., Δt), and the scale parameter can be calculated as λ=2*MTTF/sqr(π).

The probability of failure of the elements in one year y, is the probability of failure of the year and minus the probability of failure of the previous year y-1. The number of failures of a given type per year can be computed using the algorithm in Table 1. It is worth noting that failed elements are repaired thus being considered as new for failure probability considerations.

To repair the failures we assume that a team of employees covers an area 24 hr per day / 7 days per week. Each team can repair up to *MaxFailTeam* failures per day, considering both trip and repair times. Then, the reparation cost can be computed as

$$C_{Team24} \cdot N_{areas} \cdot \left\lceil \frac{F_y}{365 \cdot MaxFailTeam \cdot N_{areas}} \right\rceil \tag{8}$$

where F_y is the total number of failures in the year y, and N_{areas} is the number of repair areas defined.

And forth energy costs. Let us define $W_x = Cwh{*}P_x{*}\Delta t$, as the energetic cost because of the power consumption of the system type x, where Cwh is the price of the kilowatt-hour and P_x is the power consumption of x. Then, similarly to CAPEX, energy costs can be computed as

$$\sum_{\forall n \in N} \left(W_{BASE} + d_n \cdot W_{Trunk} + \lceil 2 \cdot I \rceil \cdot W_{Transponder} \right) + \sum_{\forall e \in E} \left\lfloor \frac{L_e}{AS} \right\rfloor \cdot W_{OA} \tag{9}$$

Finally, adding expressions (6)-(9), the equation to compute OPEX costs at year y becomes:

$$\begin{aligned}
\mathbf{OPEX}_y \quad = \quad & C_{MYear} \cdot Team24 \cdot \left\lceil \frac{|N|}{10} \right\rceil \\
+ \quad & C_{MYear} \cdot \left\lceil \frac{\Delta t \cdot I}{ht \cdot CX_{hr} \cdot WTime} \right\rceil \\
+ \quad & C_{Team24} \cdot N_{areas} \cdot \left\lceil \frac{F_y}{365 \cdot MaxFailTeam \cdot N_{areas}} \right\rceil \\
+ \quad & \sum_{\forall n \in N} \left(W_{BASE} + d_n \cdot W_{Trunk} + \lceil 2 \cdot I \rceil \cdot W_{Transponder} \right) \\
+ \quad & \sum_{\forall e \in E} \left\lfloor \frac{L_e}{AS} \right\rfloor \cdot W_{OA}
\end{aligned} \tag{10}$$

Illustrative numerical results

Aiming to illustrate the models presented above we evaluate the NPV on two network topologies with different average link length, the 16-node European Optical Network (EON) and the 14-node Deutsche Telecom (DT) network (Fig. 3).

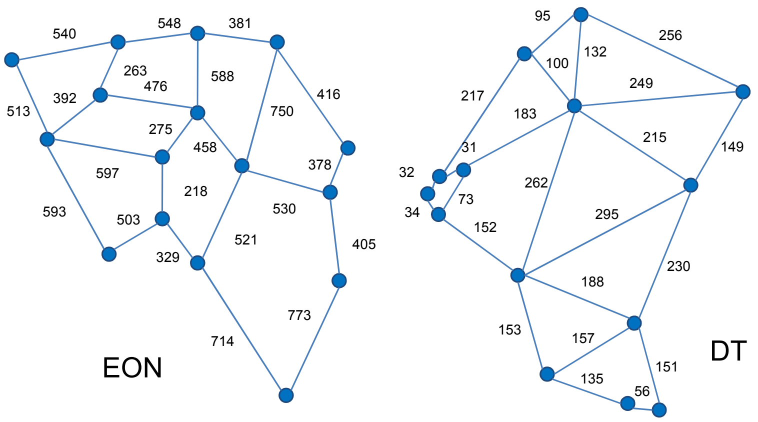

Fig. 3. Sample transport network topologies used in this paper. Each link is labeled with its length in km

Table 2 presents the value of above models' parameters while Table 3 presents specific values for MTTF, cost and power consumption [7] for each network component. For each sample topology we study the influence of changing one of the parameters from the value specified with respect to the base case, i.e., the scenario resulting from apply the values depicted in Table 2 and Table 3. Studied cases are: a) cost of optical fiber ($C_{FO} = 2$ k€); b) cost of technology (25% off); c) cost of personnel (C_{MYear} = 60 k€); d) cost of energy (Cwh = 0.2 €/kWh).

Table 2 Value of models' parameters

NPV	**REVENUES**	**OPEX**	
$r = 6\%$	$C(EON) = 15$€	$C_{MYear} = 40$ k€	$Team24 = 4$
$Y = 10$ years	$C(DT) = 8$€	$C_{Team24} = 160$ k€	$CX_{hr} = 4$
$\Delta t = 365*24$ h	$I = 3$ Erlangs	$Cwh = 0.1$ €/kWh	$MaxFailTeam = 2$
	$ht = 48$ h	$WTime = 11*22*7$ h	N_{areas}=3(DT)/4(EON)

Table 3 MTTF, cost and power consumption per network component

Component	**MTTF (hours)**	***Cx* (k€)**	***Px* (kW)**
Optical Fiber (km)	263,000	1	-
OXC (BASE)	200,000	200	0.2
Transponder	400,000	3	0.05
Trunk card (WSS)	500,000	20	0.13
Optical Amplifier	250,000	8	0.05

Before start analyzing NPV, we need to obtain the number of failures per year using the algorithm presented in Table 1. Fig. 4 illustrates the evolution of the number of failures versus time aggregating failures in optical fibers and equipments (OXC, WDM trunks, transponders, and optical amplifiers). It is worth highlighting the huge difference between the number of failures in both cases, as a consequence of the large amount of deployed fiber; 3,545 and 11,161 km in DT and EON networks, respectively. In light of this numbers, recovery mechanisms at the optical networks become a necessity.

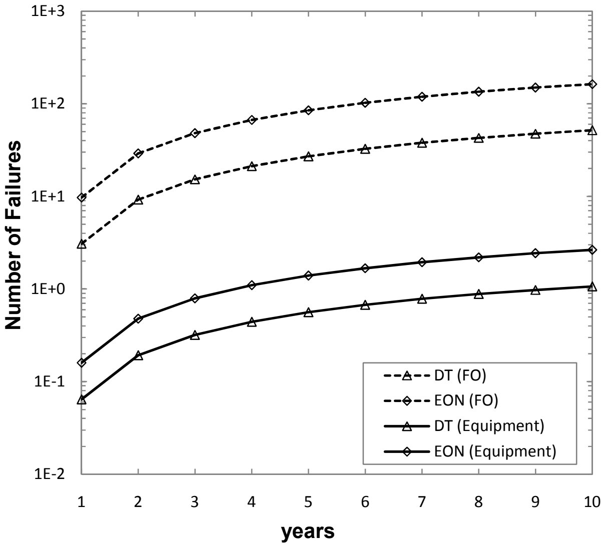

Fig. 4. Evolution of the number of failures for DT and EON networks.

Fig. 5 and Fig. 6 show the evolution of the NPV on the DT and EON networks, respectively for the five cases studied. In addition, Table 4 shows the values of the CAPEX, and the annual values of OPEX and REVENUES. In light of equation (8) and (10), the only element variable in time is the distribution of failures, F_y. However, for the network sizes under study, equation (8) is constant with time (ceil() function is equal to 1 for each network). Therefore, OPEX costs become constant. Regarding revenues, they are also constant as was argued in the previous section.

Table 4 Results for de DT and EON network (k€)

	DT			**EON**		
	CAPEX	**OPEX(*y*)**	**REVENUES(*y*)**	**CAPEX**	**OPEX(*y*)**	**REVENUES(*y*)**
BASE	7,765	852.73	2,943.36	16,585	1,017.81	6,307.20
FO	11,310	852.73	2,943.36	27,746	1,017.81	6,307.20
Technology	6,710	852.73	2,943.36	15,229	1,017.81	6,307.20
Man Costs	7,765	1,272.73	2,943.36	16,585	1,517.81	6,307.20
kWh	7,765	865.46	2,943.36	16,585	1,035.62	6,307.20

In the base case, we observe the break-even point between 4th and 5th years for the DT network, and between the 3rd and 4th years for the EON network.

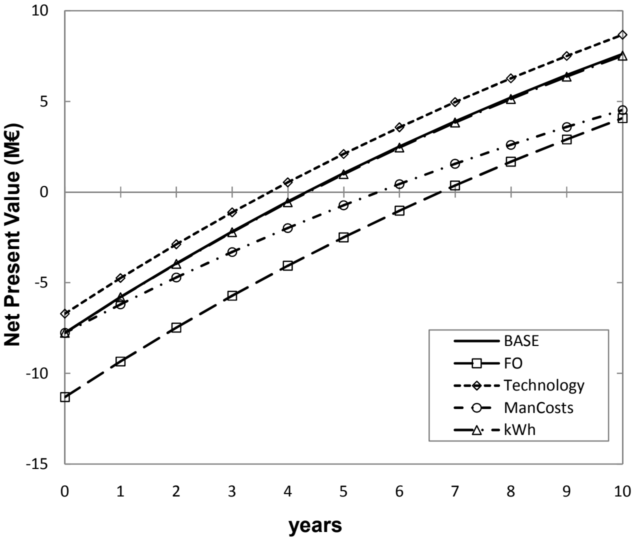

Fig. 5. Evolution of NPV for the DT network.

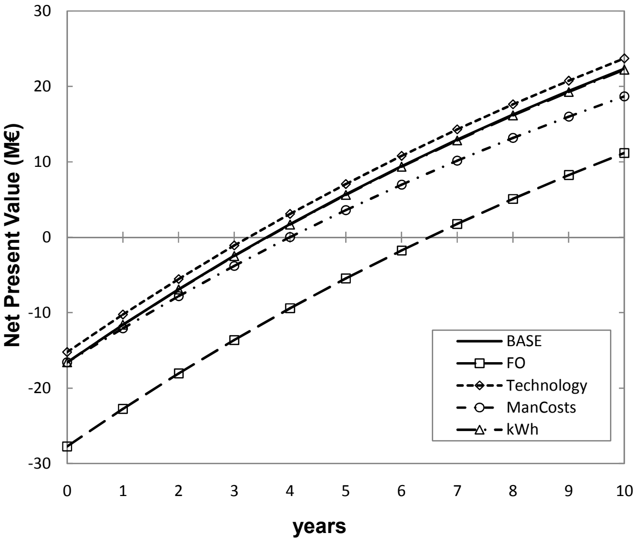

Fig. 6. Evolution of NPV for the EON network.

Second and third cases modify costs related with CAPEX. In the second case FO costs are doubled. As illustrated, these costs increment CAPEX between 46% and 67% for DT and EON networks, respectively. These increments move the NPV function in parallel placing break-even points between 6th and 7th years. In the third case we assume a 25% off in the price of the equipments. As shown, these costs reduce CAPEX costs between 14% and 8% for DT and EON networks, respectively. The discount in technology moves forward break-even points less than 6 months in all cases.

Fourth and fifth cases modify costs related with OPEX. In the fourth case, we increment personnel costs to 60 k€ (50%). As revealed, these costs increment OPEX about 49% in both networks and they slightly reduce the NPV function with the time. Finally in the last case, energy costs are doubled. As illustrated, energy-related costs can be neglected in optical networks as they increase no more that 1.7% OPEX costs.

Conclusions and future work

In this paper, costs and revenues models to be used in optical networks have been presented and NPV was proposed to relate them. Revenues come from selling optical connectivity. Dynamic traffic was assumed, thus revenues are proportional to the offered traffic intensity. CAPEX costs were computed adding node costs, intermediate optical amplifiers, and optical fiber use. To compute OPEX, four different costs have been considered: alarm surveillance and network monitoring, provisioning costs, failure repair cost, and energy costs.

Models were used over two network topologies and important results can be highlighted. First, it is important to maintain under control fiber costs to limit CAPEX, especially in long haul networks, and personnel costs to limit OPEX. Cost of technology is also an important issue but with a limited influence in long haul networks. In contrast, energy costs have a negligible influence in OPEX and thus in NPV.

We plan to eventually use these models to compare among network architectures within the framework of the FP7 STRONGEST project.

Acknowledgments

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