2009 IEEE Globecom Workshops

30 November – 04 December 2009

Hawaii, USA

IEEE Workshop on Network Operation Cost Modeling

(This is an excerpt from the 2009 2009 IEEE Globecom Workshops)

Celebrating 125 Years
of Engineering the Future

IEEE COMMUNICATIONS SOCIETY

CFP0900E-PRT

2009 IEEE Globecom Workshops

IEEE Catalog Number	CFP0900E
ISBN	978-1-4244-5626-0
Library of Congress	2009910926

Printed copies of this publication are available from:

Curran Associates, Inc
57 Morehouse Lane
Red Hook, NY 12571 USA
Phone: (845) 758-0400
Fax: (845) 758-2633
E-mail: curran@proceedings.com

Produced by the IEEE eXpress Conference Publishing
For information on producing a conference proceedings and
quotations, contact conferencepublishing@ieee.org
http://www.ieee.org/web/publications/pubservices/confpub/index.html

A Model-based Techno-Economic Comparison of Optical Access Technologies

Stefanus van der Merwe[1], Claus G. Gruber, Yelena Grigoreva, and Thomas Kessler

Detecon International GmbH, Bonn, Germany

***Abstract*— The need for broadband Internet services requires the deployment of high-capacity access networks. In the next years, network operators will invest high amounts of money to deploy new fiber-based systems. In this paper we present a techno-economic calculation model and case-study results to compare three diverse access technologies: GPON, Active Optical Networking, and Point-to-Point optical networks.**

***Index Terms*—Cost models, CapEx, OpEx, GPON, AON, AE, Pt2tP, FTTH**

I. Introduction

Telecommunication operators around the world are facing the challenge of highly competitive markets. Regulation, new market entrepreneurs and constantly increasing demand for new, and innovative broadband services are the key drivers of this competition. For those operators that have a focus on providing competitive data transport services to connect their residential and business customers to the Internet or to other networks, one major requirement is to run future-prove technology in a strongly cost optimized environment.

Due to well designed, high capacity packed-based backbones the predominant bottleneck of an end-to-end connection today lies in access networks. Based on the current technology development it can be presumed that future fixed-access networks will rely on optical access technologies to overcome this bandwidth bottleneck. However, for many network operators one major question still has to be answered: Which optical access network technology to deploy?

This paper presents a techno-economic cost model as well as case-study results to compare technology options for optical access networks. The model is designed to enable interested parties (e.g. telecommunication operators) to compare given technology options and to support fast but profound deployment decisions. Based on operator specific market information and together with benchmark data per technology option, capital expenditures and operational costs for each technology in different, configurable scenarios can be deducted. As result, the user of the model can identify technology options that provide the best match between market requirements, service offering and cost. For further analysis benchmark information can be replaced by specific information to refine the analysis e.g. as part of a feasibility study or tender evaluation.

The document is organized as follows: Section II gives a short overview about promising optical access network technologies. Following this, Section III introduces an operational and capital cost model for these technologies. Consequently, Section IV presents case-study calculations and cost comparison results applicable to a typical large city in Europe. Finally, Section V summarizes the key findings.

II. Optical Access Network Technologies

Optical access networks can be deployed in quite a large number of varieties [1]. Passive optical networks (PONs) enable point-to-multipoint fiber access networks based on unpowered (passive) optical splitters. A PON consists of an optical line terminal (OLT) at the service provider's central office, optical splitters and optical fibers that form the optical distribution network (ODN) and optical network units (ONU) at the end user sites.

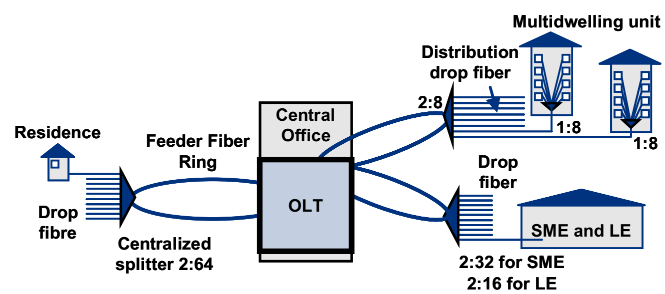

Figure 1: A passive optical network using a ring feeder fiber.

When multiplexed in the time domain (TDM-PON), one single optical signal can be used to serve multiple premises concurrently (typically 32 to 128 premises). With this, the required amount of fibers in the access network can be reduced and pure passive elements can be used in the distribution area. An overview architecture illustration is shown in Figure 1.

Active optical networks (AONs) use electrically powered equipment such as switches, routers or multiplexers to amplify and forward a signal towards the ONUs that are located at the customer premise [2]. Unicast signals that leave the central office are directed only to the customer for that they are intended and are not duplicated or split in-between.

[1] Corresponding author: Stefanus.vanderMerwe@detecon.com

978-1-4244-5626-0/09/$26.00 ©2009 IEEE

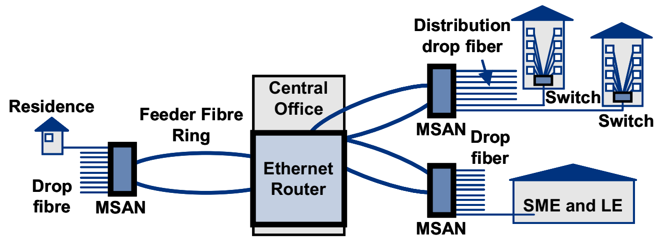

Figure 2: Active optical network example.

The AON variant that uses Ethernet switching in the distribution network or inside multi dwelling units is often also called Active Ethernet (AE). An illustration of an AON architecture is shown in Figure 2.

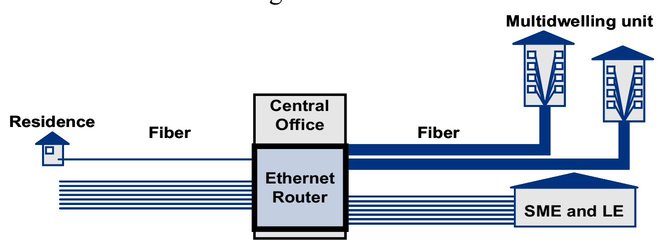

Figure 3: Pt2Pt optical access network example.

Finally, point-to-point (Pt2tP) optical access networks can be used in the areas where customers are connected directly using own dedicated fibers for up- and downstream [3]. Similarly to PON, Pt2Pt network architectures require no intervening electronics.

III. Cost Model

We assume a green field deployment of a fiber access network and present a model to calculate the required equipment and operational expenditures for the three analyzed fiber technology architectures. The central office areas are assumed to be circular with the central office located in the center of each area.

A. General Model Building Blocks

The building blocks of the proposed cost model are depicted in Figure 4. The model receives three kinds of inputs: market related, design and technology specific input as well as prices for operational tasks and capital. Operational and capital price books can be deducted from operator specific market information and available benchmark data [4,5,6,7].

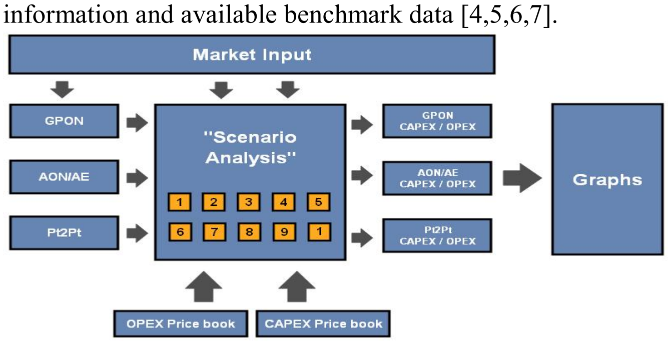

Figure 4: Overview of the CapEx and OpEx cost model.

B. Market Input

Market input models the amount of subscribers and the area over that these subscribers are distributed. We distinguish between four different subscriber types: residential and multi-dwelling unit subscribers and small-to-medium (SMEs, up to 1000 employees) and large enterprises (LE, more than 1000 employees). We assume an average of eight flats per multi-dwelling unit. Four different subscriber density classes are taken into account, which are listed in Table 1.

Table 1: Subscriber associated with four density areas.

Name	Subscribers per km^2
Dense urban	2000 +
Urban	1100-2000
Suburban	200-1100
Rural	0-200

Subscribers are distributed over the city area according to these four classes. Inside one area that belongs to one density class we assume a random distribution of subscribers.

C. *Technical Input - Required Hardware and Fiber Infrastructure*

Dependent on the analyzed FTTx architectures (GPON, AON and Pt2Pt) different technical input parameters are modeled.

1) GPON Design

One significant design parameter is the number of central offices that supply one density area (N_{CO} *(A)*). This parameter directly yields to an area value per central office and density class (A_{co} *(A)*). Additionally, the number of feeder fiber rings per central office can be chosen. The length of a feeder fiber is dependent on the number of rings ($N_{Rings}(A)$) and the area of the central office ($A_{CO}(A)$) as depicted in Figure 5.

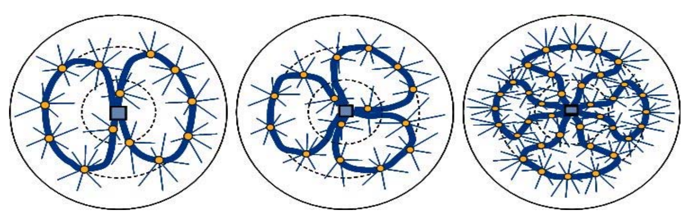

Figure 5: Feeder fiber rings using two, three and four rings.

$$R_{CO}(A) = \sqrt{\frac{A_{co}(A)}{\Pi}} \quad (1)$$

$$L_{ff-ring}(A) = \pi \sqrt{2 \cdot \left[\left(\frac{R_{CO}(A)}{3} \right)^2 + \left(\frac{R_{CO}(A)}{N_{Rings}(A)} \right)^2 \right]} \cdot P_{street} \quad (2)$$

The feeder fiber length of each ring can be estimated according to Equations 1 and 2. Each feeder fiber forms an elliptical structure. Its circumference can be calculated using the Euler approximation method. The horizontal radius of a feeder fiber equals to 1/3 of the central office radius (R_{CO} *(A) / 3*). The vertical radius of a feeder fiber diminishes with the number of feeder fiber rings and is approximated by (R_{CO} *(A) /* $N_{Rings}(A)$). Additionally, the feeder fibers lengths are multiplied by a correction factor (P_{Street}) to take detours due to the deployment of fibers along existing street layouts into account.

The average length for the remaining drop-fiber section can be calculated according to Equation 3. The average distance from a splitter to a subscriber is calculated as a fraction of the central office radius R_{CO} *(A)*. This fraction ($R_{Fraction}$) is assumed to be *1/6* in the following. Similarly to the calculation of the feeder-fiber length the additional correction factor (P_{Street}) can be applied.

$$L_{drop-fiber}(A) = R_{CO}(A) \cdot R_{Fraction} \cdot P_{Street} \quad (3)$$

Since many fibers can be put into the same duct, the overall required duct length (L_{Duct}), from which civil works expenses can be calculated, is much shorter than the total fiber length. The duct sharing factor (S_{Duct}) is dependent on the fiber routes (typically along existing streets) and the distance of subscribers relative to each other. For an average distance between houses of around 20 to 25 m and typical European street layouts in urban areas, around 93% of fiber kilometers can be placed into shared ducts (S_{Duct} = 7%)

$$L_{Duct} = \sum_{Area\ Types}\left[L_{ff-rings}(A) + L_{drop-fiber}(A) \cdot S_{Duct}\right] \quad (4)$$

Different splitter types have to be used for different subscriber types in order to adapt to their bitrate needs. The following splitter types are used in the model: 2:64 splitters for residential subscribers (39 Mbps), a combination of a 2:8 splitter followed by 8 times 1:8 splitters for multi-dwelling unit subscribers (39 Mbps), 2:32 splitters for SME subscribers (78 Mbps) and 2:16 splitters for LE subscribers (156 Mbps).

The number of subscribers per central office and density area type (*A*) can be calculated according to Equation 5. To calculate the number and type of subscriber per feeder fiber ring, the number of subscribers per central office can furthermore be divided by the number of rings per central office (Equation 6).

$$N_{SubPerCO}(A) = \frac{N_{Sub}(A)}{N_{CO}(A)} \quad (5)$$

$$N_{SubPerRing}(A) = \frac{N_{SubPerCO}(A)}{N_{Rings}(A)} \quad (6)$$

The number of required splitters ($N_{x:y}$) can be calculated by dividing the number of subscribers per ring with the respective split factors. These numbers need to be multiplied by the number of rings per central office ($N_{Rings}(A)$) as well as the number of central offices ($N_{CO}(A)$) to calculate the number of splitters required in the specific area (Equations 7 to 11).

$$N_{2:64}(A) = \frac{N_{ResSubPerRing}(A)}{64} \cdot N_{CO}(A) \cdot N_{Rings}(A) \quad (7)$$

$$N_{2:8}(A) = \frac{N_{MDUSubPerRing}(A)}{8 \cdot 8} \cdot N_{CO}(A) \cdot N_{Rings}(A) \quad (8)$$

$$N_{1:8}(A) = N_{MDU}(A) \quad (9)$$

$$N_{2:32}(A) = \frac{N_{SMESubPerRing}(A)}{32} \cdot N_{CO}(A) \cdot N_{Rings}(A) \quad (10)$$

$$N_{2:16}(A) = \frac{N_{LESubPerRing}(A)}{16} \cdot N_{CO}(A) \cdot N_{Rings}(A) \quad (11)$$

The number of fiber cores that are required in the feeder fiber sections can then be calculated based on the number of splitters per feeder fiber ring. Each splitter requires one fiber in the feeder section. An additional number of fibers (N_{Extra}) can also be added for future expansion planning. The number of fibers in the feeder fiber section is given in Equation 12. This number has of course to be rounded up according to fiber-bundle availabilities (typically 192, 144, 96, or 36 fibers per cable).

$$\begin{aligned} N_{FeederFibers}(A) = {} & N_{2:64}(A) + N_{2:8}(A) + \\ & + N_{2:32}(A) + N_{2:16}(A) + N_{Extra} \end{aligned} \quad (12)$$

The hardware requirement is calculated and dependant on the number and type of subscribers. The number of required ports per area type can be calculated according to Equation 13. Additionally, a certain percentage of redundant ports for protection purposes can furthermore be modeled per area and subscriber type (*P(A,T)*).

$$N_{Ports}(A) = N_{FeederFibers}(A) + P(A,T) \quad (13)$$

The number of required Optical Distribution Frames (N_{ODF}), the number of GPON line-cards (N_{LC}), shelves (N_{Shelf}), chassis ($N_{Chassis}$) and the number of switching (N_{SC}) and controller cards (N_{CC}) can be calculated with Equations 14 to 19 according to available hardware specifications (e.g. $N_{PortsPerLC}$ = 4, if line-cards with four GPON ports are available).

$$N_{ODF}(A) = N_{CO}(A) \cdot N_{ODFPerCO} \quad (14)$$

$$N_{LC}(A) = \lceil N_{Ports}(A) / N_{PortsPerLC} \rceil \quad (15)$$

$$N_{Shelf}(A) = \lceil N_{LC}(A) / N_{LCPerShelf} \rceil \quad (16)$$

$$N_{Chassis}(A) = \lceil N_{Shelf}(A) / N_{ShelvesPerChassis} \rceil \quad (17)$$

$$N_{SC}(A) = N_{Shelf}(A) \cdot N_{SCPerShelf} \quad (18)$$

$$N_{CC}(A) = N_{Shelf}(A) \cdot N_{CCPerShelf} \quad (19)$$

2) AON/AE Design

The architecture design for an Active Optical Network is very similar to GPON considering the calculation of required fiber and duct lengths. Therefore, Equations 1 to 6 can be used for the calculation of fiber and duct lengths of AON networks as well. However, different hardware has to be deployed for AONs. Ethernet equipment called Multi-Service Access Nodes (MSANs) is used in the cabinets to connect multi-dwelling units, SMEs and LEs subscribers with higher bitrates (typically 1 Gbps ports) and residential subscribers with lower bitrates (typically 100 Mbps ports). In addition, 10 Gbps and 1 Gbps uplink ports to the central office are required. Each multi-dwelling unit furthermore requires an Ethernet switch that provides 100 Mbps ports to the subscribers as well as 1 Gbps uplink ports to the MSAN. Oversubscription factors can additionally be selected for the MSANs to exploit the multiplex gain. In order to have comparable bitrates to GPON the following oversubscription factors are used: 1:2 for residential subscribers and 1:4.5 for multi-dwelling units, SME and LE subscribers. This calculus results in a bill of required quantity for AON/AE equipment.

3) Pt2Pt Design

For Pt2Pt technology the number of central offices is identical to the other design architectures. However, each subscriber is connected with one dedicated fiber to the central office. For practical reasons and to reduce civil work expenses the individual fibers will also be placed in shared ducts as long as possible forming a structure similar to that illustrated in Figure 6. Feeder ducts are targeting in $N_{Pt2PtFD}$ directions.

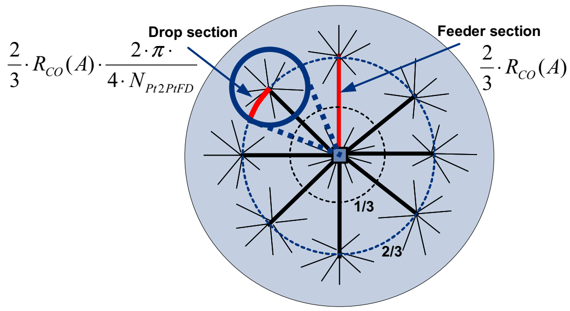

Figure 6: Model for Point to Point fiber distribution in a central office area using eight duct directions.

The majority of subscribers of the area ($N_{Pt2PtFD}$ / ($N_{Pt2PtFD}$ +*1*)) will be connected to the central office using a fiber that is routed along a shared duct part (*2/3* of $R_{CO}(A)$) and an individual drop fiber part. Subscribers close to the central office will only be connected with individual fiber parts (drop-fiber). The average drop fiber part can be calculated by taking the circumference of the circle with a radius of *2/3* of $R_{CO}(A)$ divided by four times $N_{Pt2PtFD}$ as highlighted in Figure 6. With this, the average fiber length per subscriber can be calculated according to Equation 20. Similarly to the feeder-fiber calculation, the correction factor (P_{Street}) can be applied. In the feeder fiber sections the fiber cores can be bundled and rounded up according to fiber-bundle availabilities (typically 192, 144, 96, or 36 fibers per cable).

$$\begin{aligned} L_{Pt2PtFiber}(A) &= \left[\frac{N_{Pt2PtFD}}{N_{Pt2PtFD}+1} \cdot L_{Pt2PtFeeder} + L_{Pt2PtDrop} \right] \cdot P_{Street} = \\ &= \frac{N_{Pt2PtFD}}{N_{Pt2PtFD}+1} \cdot \left(\frac{2}{3} \cdot R_{CO}(A) \right) \cdot P_{Street} + \\ &+ \left(\frac{2}{3} \cdot R_{CO}(A) \right) \cdot \frac{2 \cdot \pi}{4 \cdot N_{Pt2PtDFD}} \cdot P_{Street} \end{aligned} \tag{20}$$

Ethernet switches are required in the central office with FE and GE ports. The required number can directly be calculated using the subscribers per central office. This calculus results in a bill of quantity for AON equipment.

D. Cost Model

The CapEx and OpEx for each technology option can be obtained by multiplying the individual prices of the OpEx and CapEx price books with numbers and lengths calculated in the previous technical sections.

1) Capital Expenses

The capital expenses to build up the access network can further be decomposed into capital cost for hardware (C_{HW}), capital cost for software (C_{SW}), capital cost for civil work (C_{CW}) and capital costs not related to the former categories (C_{Other}) as shown in Equation 21.

$$CapEx = C_{HW} + C_{SW} + C_{CW} + C_{Other} \tag{21}$$

Hardware cost (C_{HW}, Equation 22) is a sum of cost for networking hardware and cost for general support hardware (C_{GenHW}). Networking hardware consists of hardware for the OLT or switching equipment, fibers, splitters, cabinets and shelves as well as the customer premises equipment. General hardware costs consists of costs for air-conditioning systems and power equipment as well as other tools and instruments required at each central office.

$$C_{HW} = C_{NetHW} + C_{GenHW} \tag{22}$$

For software expenses (C_{SW}) a one-time payment is assumed. However, also regular payments dependent on the number of connected customers or deployed areas are conceivable.

The expenses for civil work (Equation 23) consist of installation costs for central offices, street and splitter cabinets, home entries as well as costs for the fiber deployment (feeder, distribution, outdoor and indoor drop section).

$$\begin{aligned} C_{CW} &= N_{CO} \cdot C_{CO-Inst} + N_{StreetCab} \cdot C_{StreetCab-Inst} + \\ &+ N_{SplitCab} \cdot C_{SplitCab-Inst} + N_{HE} \cdot C_{HE-Inst} + \\ &+ L_{Duct} \cdot C_{Ducts} + \sum_{FiberType\ t} \left(L_{Fiber}(t) \cdot C_{Fiber-Inst}(t) \right) \end{aligned} \tag{23}$$

Civil work costs per meter (C_{Ducts}) are heavily dependent on the type of fiber deployment. Different civil work options are possible: Installation of the optical fiber cables in already existing ducts (used ducts); deployment of new fiber ducts including ground-work, and recovery of the surface (direct bury); deployment of the optical fiber cables via aerial lines (aerial); construction of the optical fiber cables in sewage pipes (sewage) or to use micro trenching techniques to place the optical fibers in the ground (micro trenching).

Finally, other costs such as required cars at each central office and additional project management costs (assumed to be a percentage (P_{PM}) of network hardware costs) are modeled according to Equation 24.

$$C_{Other} = C_{Car} \cdot N_{CO} + P_{PM} \cdot C_{NetHW} \tag{24}$$

2) Operational Costs

The operational costs are divided into two parts: Fixed and variable OpEx (Equation 25). Equation 26 models the fixed operational cost (OpEx) per year, which is composed of costs for site rental ($O_{SiteRental}$), costs for salaries of operational personnel ($O_{Salaries}$) as well as other fixed operational cost parts ($O_{OtherFixed}$) such as network security, insurance, regular license fees, administration fees, marketing and distribution, training, maintenance, operations, spare parts and service, freight and insurance and income tax.

$$OpEx = OpEx_{Fixed} + OpEx_{Variable} \tag{25}$$

$$OpEx_{Fixed} = O_{Site\,Rental} + O_{Salaries} + O_{OtherFixed} \quad (26)$$

Energy costs (O_{Energy}) per year are variable operation expenses and can be calculated (Equation 27 and 28) by multiplying the energy costs per kWh (O_{kWh}) with the number of installed hardware ($N_t(A)$) and the individual power consumption of the hardware (P_t).

$$OpEx_{Variable} = O_{Energy} \quad (27)$$

$$O_{Energy} = O_{kWh} \cdot 365 \cdot 24 \cdot \sum_{Areas\ A} \sum_{HW\ Types\ t} \left(N_t(A) \cdot P_t\right) \quad (28)$$

IV. CASE STUDY

We apply the techno-economic model to a realistic scenario and will use characteristics for the city of Munich, Germany, a typical large European city with about 1.4 million inhabitants and an area of around 342.1 km^2. The assumed market input values are given in Table 2. The used capital and operational price values are based on benchmark data and information acquired from different network operators.

TABLE 2: SUMMARY OF MARKET INPUT.

	Dense urban	Urban	Suburban
Area in km^2	12.4	102.3	227.4
Subscribers	43.025	127.864	213.974
Subscriber density per km^2	3470	1250	940
Residential subscribers	0	63.732	213.504
Multi-dwelling subscribers	40.325	63.732	350
SME subscribers	2.700	400	120
LE subscribers	0	0	0

For the dense urban area two central offices are used each supplying 6 km^2 and about 20 000 subscribers. For the urban area six central offices are used resulting in a central office area of 17 km^2 and about 21 000 subscribers per central office. For the suburban area ten central offices are used each having an area of 22 km^2 and about 21 000 subscribers. Choosing less central offices results in longer fiber distances per subscriber and an increase in CapEx. Having too many central offices, however, is also not favorable since it also drives up the operational and site rental cost resulting in higher OpEx.

The effect of changing the number of rings around the central office does not have that big effect on the total CapEx since fiber-cost and overall duct length will be changed only slightly. For the GPON and AON/AE technology options in the dense urban we choose three rings around each central office. The feeder fiber ring length ($L_{ff\text{-}ring}$) is 3.8 km and the drop distance per subscriber ($L_{drop\text{-}fiber}$) is 0.3 km. In the urban area we choose three rings which results in 6.3 km each. The drop distance per subscriber in the urban area is 0.5 km. In the suburban area, also with three feeder fiber rings, the feeder fiber ring length is 7.3 km and the drop distance is 0.6 km per subscriber. For Pt2Pt technology, eight feeder fiber links are used with a length of 1.2 km in the dense urban area, 2.0 km in the urban area and 2.3 km in the suburban areas. The total duct and fiber lengths for the different technologies and sections are given in Table 3.

TABLE 3: SUMMARY OF DUCT AND FIBER LENGTHS.

	GPON	AON/AE	Pt2Pt
Duct length feeder section	357 km	357 km	227 km
Fiber length feeder section	40 716 km	191 617 km	693 674 km
Duct length drop section	11 429 km	11 429 km	11 973 km
Fiber length drop section	163 266 km	163 266 km	211 952 km

The duct lengths of GPON and AON/AE in both sections are equal since the feeder fiber rings and drop section rings are identical for both technologies. However, more fiber kilometers are required in the feeder section of AON/AE due to different bitrates per fiber and different multiplex ratios for AON/AE and GPON. The feeder fiber duct length of Pt2Pt is smaller than AON/AE and GPON due to the different feeder structure (links instead of rings). However, due to dedicated fibers the total fiber length is much longer for Pt2Pt than for the other technologies.

Table 4 shows the required ports per network location for the three architectures. AON/AE requires 69 times more ports than GPON. Pt2Pt requires 63 times more ports than GPON.

TABLE 4: SUMMARY OF ACTIVE PORTS.

	GPON	AON/AE	Pt2Pt
COs	6 066	26 412 GE 760 10GE	381 630 FE 3 220 GE
street cabinets	0	227 230 FE 42 690 GE 760 10GE	0
multi-dwelling units	0	104 400 FE 13 058 GE	0

1) *CapEx comparison of the three Access Technologies*

The CapEx values for the case-study design are depicted in Figure 7. For the dense urban area, GPON technology is the most CapEx friendly solution. Due to similar duct lengths, expenses for civil works - the most expensive part of FTTH rollout - is almost identical in all density areas. The reason for GPON being the cheapest is the low number of ports and required feeder fiber km. AON in dense urban areas is expensive due to high volume of active hardware required. In urban and suburban areas Pt2Pt is the highest due to the large number of fibers required as seen in Figure 8.

More than twice as much capital expenses have to be invested per subscriber in urban and suburban areas. The less dense the area the more similar the cost for GPON, AON/AE and Pt2Pt become.

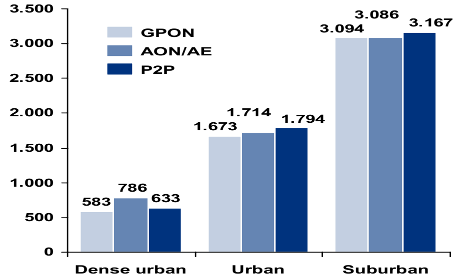

Figure 7: CapEx in € per subscriber
for the roll out of a fiber based access technology.

CapEx for Pt2Pt, however, is still more expensive and the reason for this is twofold: long distances and the large number of fibers for the Pt2Pt technology. Figure 8 depicts the CapEx breakup over all density areas. For all architectures, the CapEx is dominated by civil works and network installation (around 77%). For GPON capital expensed for passive network hardware is the second dominating factor, due to high costs for splitters today. AON/AE requires more active hardware resulting in 9% of the overall CapEx. Although a large number of active hardware is also required for Pt2Pt the large quantity of passive hardware (fibers) dominates the active hardware.

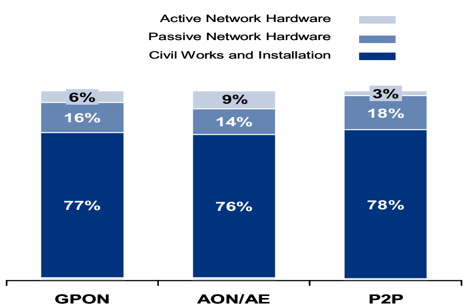

Figure 8: CapEx breakup.

2) OpEx comparison of the three Access Technologies

When looking at operational expenses, the results are dramatically different. Figure 9 shows the calculated operational expenses for the operation of a fiber based access technology. GPON is by a factor of 5 in dense urban areas and by a factor of 15 in suburban areas less OpEx intensive than AON/AE or Pt2Pt technologies. The variable part of OpEx is dependent on the port numbers and therefore also subscriber numbers. For a small number of subscribers the OpEx is higher but as the subscriber number increase, the OpEx per subscriber decrease. In the AON case the differences in operation costs are pretty strong but in the Pt2Pt case are almost the same in urban and suburban areas.

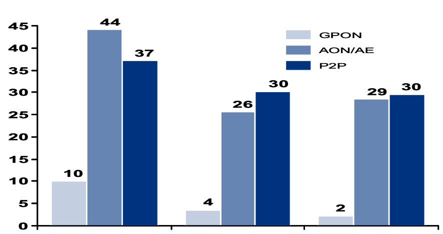

Figure 9: OpEx in € per subscriber and year.

The reason for the low OpEx in GPON becomes obvious when analyzing the OpEx breakup as shown in Figure 10. In GPON power consumption contributes to only 6% of the total OpEx. For the AON/AE and Pt2Pt cases the power consumption consists of 86% of total OpEx.

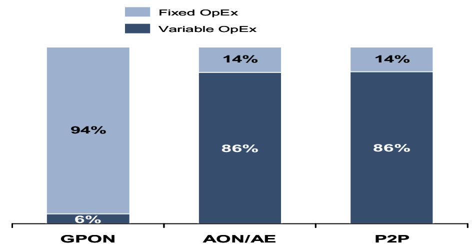

Figure 10: OpEx breakup.

V. Conclusion

This paper presented a techno-economic model with the flexibility to calculate capital and operational expenses for three promising FTTH technologies. The results show that FTTH rollout in dense urban areas is economically feasible but is quite capital cost expensive for less dense areas. GPON technology can reduce the operational costs significantly. Thus, operational as well as capital expenses have to be analyzed concurrently to allow a cost-minimizing deployment of future access networks. Detailed network design will bring more insights in the costs estimations and will also allow bringing costs down by clever combining the different access solutions. The presented model certainly can only estimate the costs since actual street maps and with that precise information about duct lengths are not modeled. However, the presented cost model is extremely flexible and can be used for various applications including vendor comparison, civil works comparison and subscriber number comparison and yields as a basis for quick technology decisions. As further steps, sensitivity analysis will be performed and CapEx and OpEx costs for different city types around the world with different types of market input will be investigated.

References

[1] ITU-T 984.1.x, “Gigabit-capable Passive Optical Networks (GPON): General characteristics, ITU-T, March 2003

[2] KEYMILE Report, “AON vs. PON – A comparison of two optical access network technologies and the different impact on operations", KEYMILE International GmbH, 2008

[3] Heavy Reading Report, “FTTH Wordwide Technology Update & Market Forecast”, Heavy Reading, Vol.6, No.1, February 2008

[4] B. Rao, “FTTH Architectural Choices”, online, http://www.lastmileonline.com/index/webapp-stories-action?id=301

[5] S. Azodolmolky and I. Tomkos, “Techno-Economic Study of a Modeled Active Ethernet FTTB Deployment” 6th International Symposium on Communication Systems, Networks and Digital Signal Processing, 2008. CNSDSP 2008, July 2008, pp 496-499.

[6] K. Casier, S. Verbrugge, et al., “Techno-economic evaluations of FTTH roll-out scenarios”, Proceedings of the 13th European Conference on Networks and Optical Communications (NOC), Krems, Austria, 2008

[7] S. Kulkarni, B. Polonsky et M. El-Sayed, “FTTH Network Economics: Key Parameters Impacting Technology Decisions”, 13th International Telecommunications Network Strategy and Planning Symposium (Networks), Budapest, Hungary, 2008

Cost Comparison of Optical Distribution Network – Flexible or Fixed Architecture?

Erik Weis, Ralf Huelsermann, Christoph Lange and Dirk Breuer
Deutsche Telekom AG, Laboratories
Goslarer Ufer 35, 10589 Berlin, Germany
{erik.weis; ralf.huelsermann; christoph.lange; d.breuer}@telekom.de

***Abstract*— In this paper a cost comparison of flexible and fixed fiber access network designs is presented. Different cost types are analyzed over a period of time and the impact of different penetration scenarios is investigated. The results show, that a fixed Optical Distribution Network design has significant cost advantages compared to a flexible design.**

Keywords- Fiber to the Home, Optical Distribution Network, Techno-Economic Evaluation

I. Introduction

Digital subscriber line (DSL) technologies utilizing the existing copper access networks are dominating today's broadband access market. The growing number of broadband users and the increasing demand for triple play services – requiring increasing bit rates – drive these DSL technologies to their limits. In particular bit rates on copper lines are limited by the copper wire frequency characteristics and crosstalk between adjacent wire pairs [1]. Manuel switching is often necessary for changing between different DSL technologies as well as for reducing the impact of interferences and thus increasing the network operational expenditures (OpEx).

Fiber-to-the-Home (FTTH) networks are promising candidates for overcoming the bandwidth limitations of current copper based DSL broadband access networks. At the same time they are expected to lead to significantly lower OpEx. However, in order to establish FTTH access networks high capital expenditures (CapEx) for network rollout will arise in advance.

There are different optical distribution network (ODN) design options for establishing FTTH broadband access networks with Passive Optical Network (PON) technology available. On the one hand the ODN can be designed as a flexible network with flexibility points in the field (e. g. in the street cabinet) to connect the customers on demand. On the other hand the ODN can be realized as a fixed ODN network where all fiber connections will be established in advance. Each of these alternatives will have different impact on CapEx and OpEx.

In this paper, we present a cost based assessment of flexible and fixed ODN design of PON based FTTH networks. Our analysis is basing on a numerical evaluation, taking into account major cost drivers for CapEx and OpEx. Furthermore the impact of different FTTH service penetration scenarios is investigated.

This article is organized as follows: Chapter II introduces some basic design principles of optical access networks followed by a brief qualitative comparison of flexible and fixed ODN design. Assumptions and methodology of the numerical cost evaluation as well as the numerical results are described in chapter III. Conclusions are given in Chapter IV.

II. Optical Distribution Network Design Concepts

A. *Passive Optical Networks*

There are two basic design principles for optical access networks: point-to-point networks and point-to-multipoint networks. The first option relies on a dedicated Optical Line Termination (OLT) port per customer and implies therefore a dedicated fiber connection from the Central Office (CO) location to the customer. In the latter case parts of the access network infrastructure are shared between multiple customers.

PON technologies are point-to-multipoint transmission concepts based on passive multiplexing points. In contrast to point-to-point networks a number of *n* distribution fibers are connected via a passive optical multiplexer (optical power splitter or wavelength filter, in short splitter) to one main cable fiber. Therefore the main cable fibers and OLT PON cards are shared by *n* customers. The OLT equipment at the CO is responsible for coordinating the access of the customer equipment to the shared resources [2].

PONs are promising candidates for FTTH networks since they have significant cost advantages compared to active optical networks and optical point-to-point networks [3].

B. *Flexible ODN Design*

In the flexible network option the ODN is installed as illustrated in Fig. 1. As a customer subscribes to the network services, the access line of the customer is connected to the splitter by a patch cord and step by step the splitter gets "filled" – and hence the associated OLT PON card. Thus, splitters and OLT PON cards get installed as driven by the service penetration and an optimum PON system utilization is achieved realizing low CapEx. On the other hand frequent switching operations are necessary implying high OpEx.

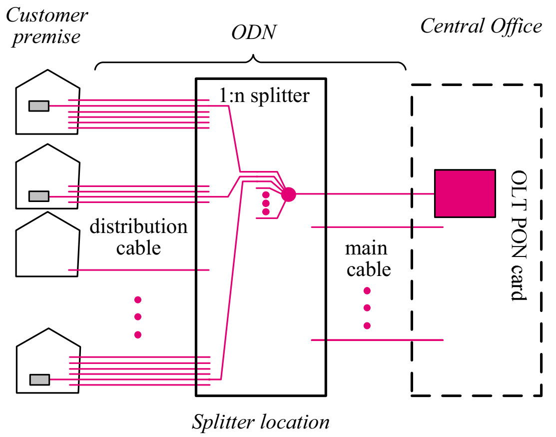

Figure 1. Flexible FTTH-ODN design based on PON technology

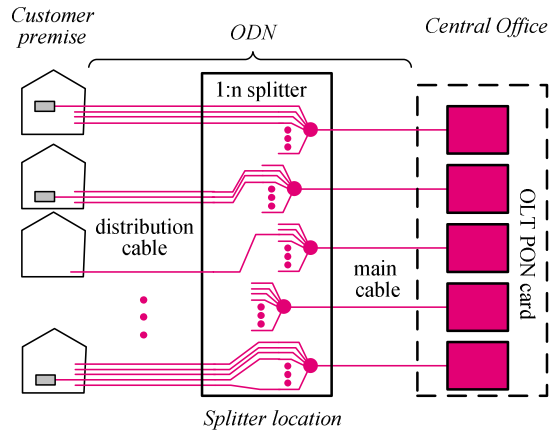

Figure 2. Fixed FTTH-ODN design based on PON technology

The flexible ODN design requires an easy accessible splitter location (e.g. street cabinet), which is designed to hold the splitter modules as well as the distribution and main cable termination modules. The fiber strands as well as the splitter ports have to be prepared for easy handling with connectors. For an 1:n splitter there are 2(n+1) splices, 2(n+1) pigtails and n+1 patch cords necessary.

C. Fixed ODN Design

In contrast to the flexible design the fixed network design option aims at a "Zero Touch" network without manually switching a fiber connection by a technician. With the initial deployment all splitters have to be placed in the field and spliced to distribution and main cable fiber strands (Fig. 2). For an 1:n splitter there are n+1 splices required. The number of splitters required at a splitter location depends on the number of customers covered by the splitter location. Given the number of customers with C then the number of splitters S can be calculated by using (1).

$$\lceil S = C / n \rceil \tag{1}$$

Provided that all customers are equally attracted by FTTH services and the customer's preferences are not known in advance the following situation will occur: Already at the beginning of the service rollout, when the FTTH service penetration rate is still very low, a high number of OLT PON cards have to be installed since a small number of FTTH customers are fragmented over a high number of PONs. This bears the risk that if the penetration curve is flat over long time or the forecasted customer potential will not be reached in time the OLT PON cards will be badly utilized.

D. Comparison of Concepts

The fixed network is deployed for 100%, i.e. the whole anticipated CapEx has to be invested in advance. There is an enduring over-dimensioning of the PON, i.e. 100% splitters and OLT PON cards are installed even in case 100% FTTH service penetration rate is not achieved. However, it is expected, that the number of manual switching operations will be very small, leading to lower OpEx. The fixed network therefore has advantages in case of a steep penetration slope leading to a high FTTH service penetration rate very rapidly.

In the flexible network a high advance payment for connector terminations is required. However, this strategy avoids over-dimensioning of the network in case of a low FTTH service penetration rate leading to lower CapEx for splitters and OLT PON cards. An additional interest profit due to time-shifted deployment of splitters and OLT components may be achieved. Since every subscription of new customers requires manual switching operations, higher OpEx is expected than in the fixed network case. Therefore it can be advantageously in case of a relatively light penetration slope.

In summary it can be stated, that there is a trade-off between CapEx and OpEx when comparing both of the aforementioned scenarios. Therefore in the following sections an exemplary numerical evaluation is performed based on typical network and cost data.

III. Techno-Economic Analysis

A. Penetration Scenarios

As mentioned above the penetration rate of FTTH services, i.e. the acceptance of FTTH services by the customers, will have a major impact on the cost effectiveness of a fixed versus a flexible ODN design. In order to investigate this dependency systematically we analyze several penetration scenarios. All scenarios presume a completed FTTH fiber rollout in advance covering 100% of all living units. With this all customers have equal possibility to order FTTH. The penetration scenarios differ regarding the saturated ratio of customers which can be addressed by FTTH services in total (100%, 60%, 40%) and regarding the length of the period before the penetration rate will be saturated (10 years, 15 years, 20 years).

We model the FTTH service penetration rate over time by using the logistic function with parameters A and B (2). The logistic function provides a progression from small beginnings that accelerates and approaches a climax over time. It is often used for modeling learning curves or growth processes and can also be applied for approximating the penetration rate of broadband telecommunication services over time [4].

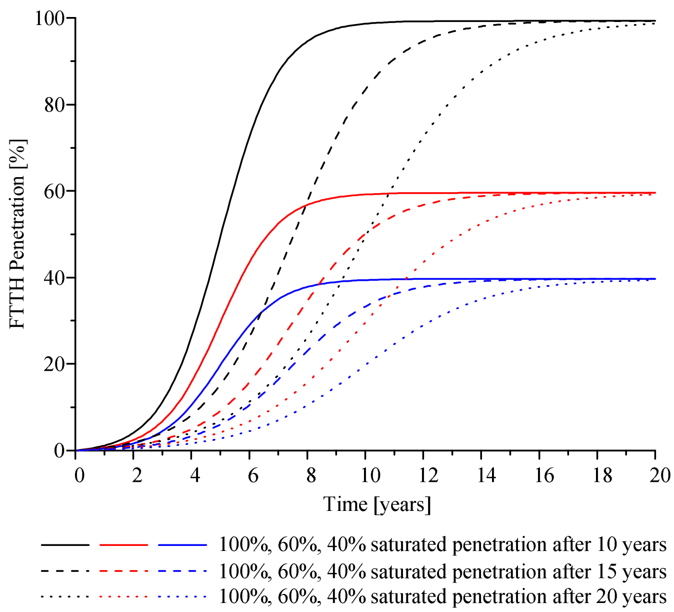

Figure 3. Penetration scenarios

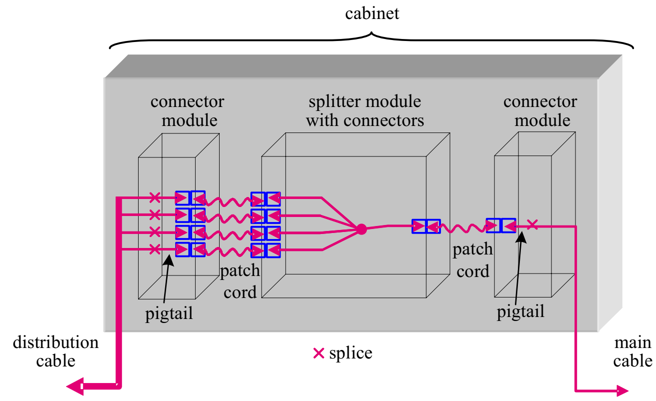

Figure 4. Flexible splitter installed in a cabinet

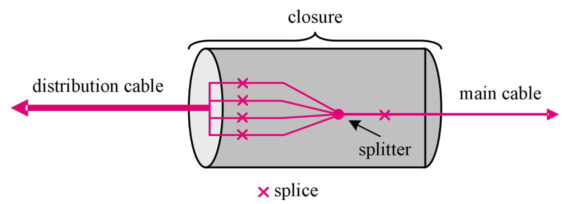

Figure 5. Fixed splitter installed in a closure

Parameter *A* defines the time period before the penetration rate equals 50% of the climax. Parameter *B* affects the gradient of the curve and is set to *A/5* in all scenarios.

$$P(t) = \frac{1}{1 + e^{\frac{A-t}{B}}} \tag{2}$$

The resulting penetration curves are depicted in Fig. 3.

B. Network and Operation Model

It is assumed, that in both ODN design scenarios the costs of the cable infrastructure (distribution cable and main cable) will be equal and thus can be ignored in this comparison, although they will be the major part of the total costs. Thus, equipment modeling is focused on the design of the splitter location and the OLT PON cards.

Fig. 4 shows the main building blocks of a flexible splitter installed in a cabinet. All fibers are equipped with pigtails and are connected to connector modules. The splitter ports are also equipped with pigtails and connectors. If a customer requests an FTTH connection, the distribution fiber belonging to the customer can be simply connected with the splitter via a patch cord. But of course this requires manual switching of the patch cord and a technician has to drive to the street cabinet. If there are no free splitter ports left, a new splitter has to be installed. In this case the splitter must also be connected to the main cable fiber and a new OLT PON card, serving this new splitter, must be installed at the CO.

In case of fixed ODN design all splitters are installed in advance and all distribution cable fibers and main cable fibers are connected to the splitter ports via splices. Since the splitters must not be accessible for later manual switching operations they may be installed in underground closures (Fig. 5). Regarding the installation of OTL PON cards two different strategies are feasible in the fixed ODN scenario: Firstly the installation of all OLT PON cards in advance (Fig. 2) and secondly on-demand installation of OLT PON cards. In the latter case an OLT PON card gets installed when the first customer out of all customers connected to a specific splitter requests an FTTH connection.

In our network model we presume that one cabinet or one closure serves 150 customers on average and 1:32 splitting ratio is used exclusively.

C. Cost Model

According to the equipment model described above equipment costs in both ODN scenarios can be subdivided into upfront costs, which arise in advance and on-demand costs, which arise during network operation.

The equipment cost model (CapEx) in the flexible ODN scenario covers the costs for

- Cabinets including connector modules (upfront costs)
- Flexible splitters (equipped with pigtails) (upfront costs)
- Pigtails and splices for main and distribution cable fibers (upfront costs)
- Patch cords (on-demand costs)
- OLT PON cards (on-demand costs)

Furthermore we have taken into account costs for splitter and OLT PON card installation (on-demand costs).

The equipment cost model (CapEx) in the fixed ODN scenario covers the costs for

- Underground closures (upfront costs)
- Splitters (upfront costs)
- Splices for main and distribution cable fibers (upfront costs)
- OLT PON cards (upfront or on-demand costs depending on the OLT PON card installation strategy)

OLT PON card installation costs are again taken into account, if they get installed on-demand.

The costs of an underground closure are assumed to be 33% of the costs of a cabinet. In the same way it is assumed that the costs of the fixed splitter device (equipped with plain fibers) are about one third of the costs of a flexible splitter (equipped with connectors).

Regarding the costs for network operation (OpEx) the following parts are taken into account:

- Manual switching operations (flexible ODN only)
- Reparation of splitter configuration failures caused by manual switching (flexible ODN only)
- Power consumption and cooling of OLT PON cards.

In the flexible ODN scenario it is assumed, that 2% of all manual switching operations lead to splitter configuration failures. The costs for repairing a splitter configuration failure are assumed to be equal to the costs of a normal manual switching operation.

In order to make cost calculation more realistic changes in cost over time are also taken into account: Regarding the equipment costs a decrease of 5% per year is assumed due to learning curve effects [5]. Regarding the costs of manual operations and electrical power and cooling we presume an increase of 3% per year.

D. Cost Comparison

On-demand equipment costs and operational costs depend on the number of FTTH connection requests and the number of installed OLT PON cards. Both are a function of time according to the time-dependent FTTH service penetration rate and they are estimated by performing a discrete event based simulation.

Fig. 6 shows the number of installed OLT PON cards over time according to two selected penetration scenarios. It is obvious that in case of a fixed ODN design and installation of all OLT PON cards in advance the number of installed OLT PON cards is independent of time and is always 100%.

In case of a fixed ODN design and on-demand installation of OLT PON cards the number of installed OLT PON cards increases approximately linearly up to 100%. In the worst case scenario all PON cards would be installed in this scenario even

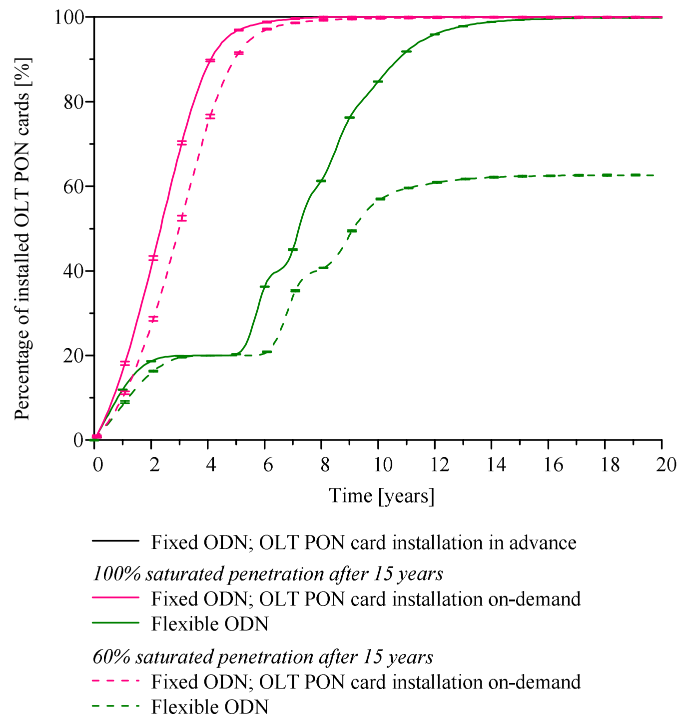

Figure 6. Number of installed OLT PON cards over time

if only one customer per splitter requests FTTH. In our scenario (1:32 splitters, 94% PON utilization) this would be the case if the FTTH service penetration is ≈3.3% (≈2.7 years in scenario "100% saturated penetration after 15 years"; ≈3.3 years in scenario "60% saturated penetration after 15 years"). Since the occurrence probability of the worst case scenario is very little the expectation of the time at which 100% OLT PON cards are installed is later than in the worst case scenario. But nevertheless, even in the scenario with 60% saturated penetration 100% OLT PON cards must be installed in total leading to an effective PON utilization of 56% on average.

In the flexible ODN scenario the number of installed OLT PON cards grow stepwise according to the increase of the FTTH service penetration rate over time. Since the penetration rate grows very little in the beginning the steps are more pronounced during this period. In the scenarios with small saturated FTTH service penetration rate over-dimensioning of OLT PON card capacity will be avoided and the PON utilization is optimized.

$$NPV = \sum_i \frac{\sum \text{costs}(year_i)}{(1+p)^i} \quad (3)$$

From a cost point of view a major difference between the flexible and the fixed ODN network scenario is that different cost portions arise at different points in time: e.g. in the fixed ODN scenario there is a high upfront invest for splitters and OLT PON cards while in the flexible ODN scenario costs for manual switching operations arise every time a customer requests a FTTH connection. In order to make the costs over time comparable we have performed a discounted cash flow

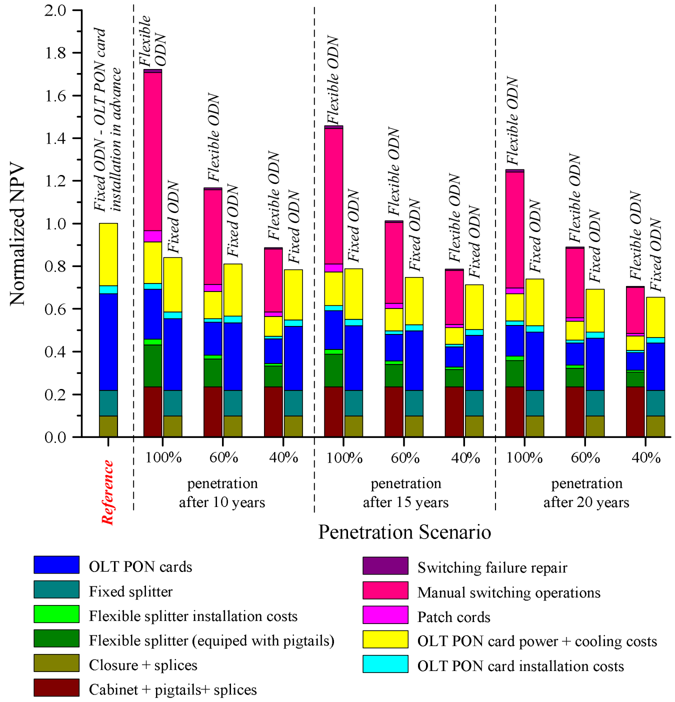

Figure 7. Normalized NPVs of costs in different ODN design scenarios

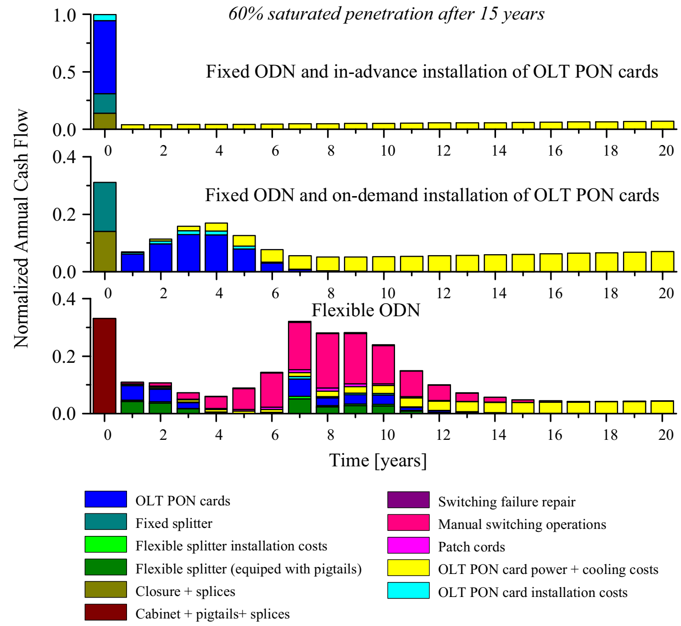

Figure 8. Annual cash flows in different ODN design scenarios

analysis over a period of 20 years. For this the cumulated costs arising in year *i* get *i*-times discounted taken into account the same annual interest rate *p*. The net present value (NPV) is defined as the sum of all discounted annual cash flows (3) [6]. The NPV is used for scenario comparison.

The normalized NPVs relating to the different ODN design scenarios and the different penetration scenarios are depicted in Fig. 7. In case of a fixed ODN design with on-demand installation of OLT PON cards the NPV is always below the NPV in the flexible ODN design scenario. The cost advantage decreases with decreasing saturated FTTH service penetration rate and with increasing length of the time period until the saturated FTTH service penetration rate will be reached. But even in the scenario with 40% saturated FTTH service penetration rate after 20 years a flexible ODN design would be more expensive. The main reason for the higher costs in the flexible ODN scenario is the cost share for manual switching operations. Only in case of in-advance installation of OTL PON cards in the fixed ODN scenario a flexible ODN design would outperform the fixed one if the saturated FTTH service penetration rate is low (<60%).

Fig. 8 provides more details about the annual cash flows in the different ODN design scenarios. Here the annual cash flow is defined as the sum of all costs arising in a specific year. In the fixed ODN scenario with in-advance installation of OLT PON cards all equipment costs arise in advance and during network operation only power costs have to be considered in our model. Expenditures for OLT PON cards are more distributed over time in case of a fixed ODN scenario with OLT PON cards installed on-demand. In case of a flexible ODN design high upfront invests for cabinets and fiber equipment (pigtails, connectors) are needed and high costs for manual switching operations arise during the period with highest penetration increase.

IV. CONCLUSIONS

In this paper we assessed two different ODN scenarios with respect to capital and operational expenditures, one with a fixed connection from the very beginning of network deployment and the other one with a flexible connection, allowing to add customers to the network as requested.

Analyzing the scenarios we found that a major difference between the flexible and the fixed one is that different cost portions arise at different points in time. Even if in the fixed ODN a significant portion of the investment has to be done in the beginning the numerical investigation has shown that this approach is superior compared to a flexible approach where high cost of manual operation arise during the network life time.

REFERENCES

[1] J. A. C. Bingham, “ADSL, VDSL, and Multicarrier Modulation”, New York: Wiley, 2000.

[2] G. Keiser, “FTTX Concepts and Applications”, Hoboken, New Jersey: John Wiley & Sons, 2006.

[3] C. Lange, J. Preuschaft, M. Braune, N. Gieschen, “Migration from Current DSL-Based Architectures to Future-Proof Pure Optical Access Networks”, in: 13th European Conference on Networks & Optical Communications (NOC). Krems (Austria), 01.–03. July 2008, pp. 152–159.

[4] H. Hishinuma, “ICT Policy in Japan – Broadband and Mobile”, http://www.soumu.go.jp/main_sosiki/joho_tsusin/eng/presentation.html

[5] T. Olsen, K. Stordahl, “Models for forecasting cost evolution of components and technologies”, Telektronikk, vol. 4, 2004, pp 138-148.

[6] http://en.wikipedia.org/wiki/Net_present_value

Qualitative OPEX Analysis for Multidomain Carrier Ethernet

Sascha Kallin, David Berechya, Ilya Vershkov, Dominic A. Schupke, *Senior Member, IEEE*

Abstract—**Automated service provisioning is crucial for efficient interdomain networking. Using the Business Process Modeling Notation (BPMN), two automation-based interdomain architectures for Carrier Ethernet transport are compared with traditional approaches, in order to identify main Operational Expenditure (OPEX) differences.**

Index Terms—**Interdomain, Multi-domain, Techno-Economic Analysis, TCO, OPEX, BPMN.**

I. Introduction

THE project "Ethernet Transport Networks and Architectures (ETNA)" proposes interdomain Carrier Ethernet transport network architectures [1]. The key to success for such architectures is the substantial reduction of the Operational Expenditure (OPEX). In a first step, this paper models a qualitative analysis of the proposed architectures. To describe the processes and how they interact with each other, we use the Business Process Modeling Notation (BPMN) [2], which is one of the standard tools for business process modeling [3]. A great benefit of BPMN is the graphical implementation that enables the user to create intuitive graphical process diagrams. The composition of the elements of BPMN is described in [3].

The paper is organized as follows. In Section II, a basic technical introduction of the interdomain architecture is given and the relevant roles, peering models, and services are described. Section III presents the process structure for interdomain networking in the traditional way and for two ETNA-based approaches. As we investigate a carrier as a company, those affected roles are put forward that are responsible for processes, the processes itself to accomplish the service management, and possible continuous and recurring processes. Service management comprises offering, provisioning, monitoring, ceasing, moving, and changing the services. Section IV analyzes the different approaches qualitatively by focusing on the differences regarding the task duration, necessary roles, and process coordination. Section V concludes the paper and provides an outlook.

This work has been performed in the framework of the ETNA project, which is partly funded by the European Union (ICT-215462). The authors would like to acknowledge the contributions of their colleagues, although the views expressed are those of the authors and do not necessarily represent the project. This information reflects the consortium's view, the Community is not liable for any use that may be made of any of the information contained therein.

S. Kallin was with Nokia Siemens Networks, Munich, Germany; he is now with Telefonica O_2, Munich, Germany. D. Berechya and I. Vershkov are with Nokia Siemens Networks, Hod HaSharon, Israel. D. A. Schupke is with Nokia Siemens Networks, Munich, Germany (phone: +49 89 636 43518; fax: +49 89 636 45814; e-mail: dominic.schupke@nsn.com).

II. Interdomain Transport Network Architectures

As new services demand (i) quickly available, (ii) abundant, and (iii) cheap bandwidth from the network, the interdomain transport network architecture needs special attention. ETNA's architecture enables automatic provisioning of interdomain transport services, especially intercarrier services. It is agnostic to the transport technology at hand (e.g. MPLS-TP, MPLS, PBB, PBB-TE) and can reduce the intercarrier service provisioning from days or weeks to minutes.

In this document, a carrier is defined as a network operator that can operate several domains of its own. Interdomain transport networks are in general assumed to be hosted by different network operators.

After the introduction of the general idea of the interdomain transport network architecture introduced by ETNA, we will define the important roles in interdomain transport networks, prioritize relevant future peering models and describe the appeal of ETNA's approach according to the market relevancy of services introduced by the Metro Ethernet Forum (MEF).

A. Roles in Interdomain Transport Networks

As detailed in [1], there are different roles collaborating with each other while using ETNA's interdomain network architecture. The most important roles for this document are the Customer, the Administrative Owner (AO), and the Element Owner (EO).

Customers request services provided by an AO. An AO delivers services for retail to the customers. An AO represents a service provider that is responsible for all administrative issues to provision a service (e.g., setup, management, monitoring, ceasing). An AO is in contact with the EOs. An EO is also a service provider with its own infrastructure that participates in the delivery of a service. An EO provides transmission paths through its domain. According to ETNA's interdomain approach the EO has to publish its services via *service templates* to let peered service providers know the provided service types.

To evaluate the effect of ETNA's interdomain approach, the Customer and AO roles are investigated. We also introduce inner-company roles of an AO, to help understand the differences regarding workflows and business processes.

B. Relevant future Peering Models

To describe the commercial relationship between carriers that provide interdomain transport services, ETNA introduced

978-1-4244-5626-0/09/$26.00 ©2009 IEEE

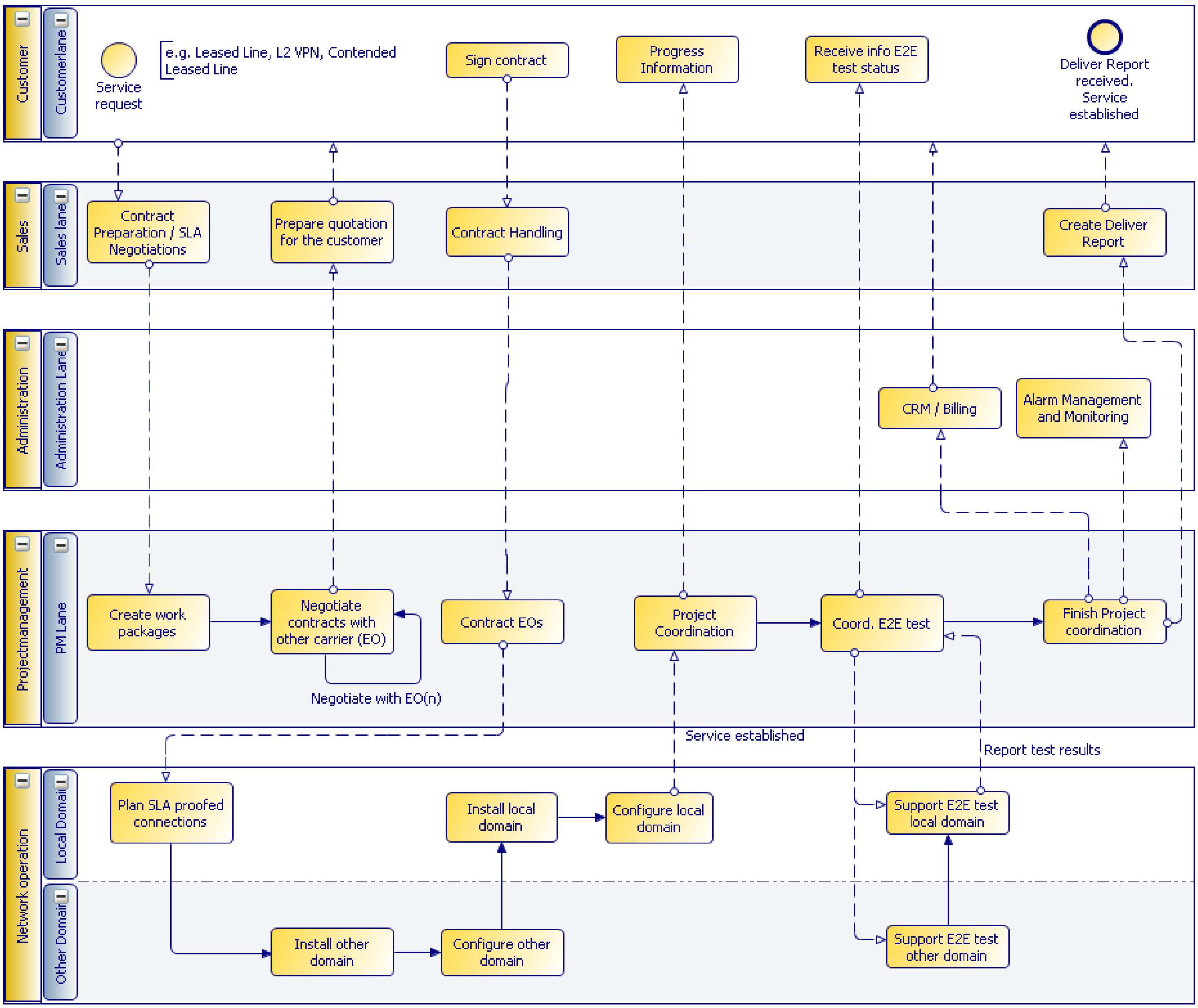

Fig. 1. Traditional process of interdomain service provisioning.

several different peering models. Out of these, we selected alliance peering and neutral exchange peering. The reason for this is the higher number of differences we observe between them compared with other model pairs.

In *alliance peering*, bilateral business agreements exist not only between adjacent but also between non-adjacent carriers. On the basis of mutual agreements such as pricing, service exclusivity, etc. they have partnerships for intercarrier transport service provisioning. In *neutral exchange*, the participating EOs can add services they want to publish including the necessary information like price, infrastructure capabilities, etc. By using neutral exchange peering, the AO that normally retails services to end customers and EOs that provide services through their domains can use a neutral platform to trade. Through this neutral exchange, an AO has a business partnership with several EOs to provision the service intercarrier-wide.

We have created BPMN diagrams for these two most relevant peering models to show the differences for the interdomain transport service provisioning.

III. Process Structures

On the basis of [5], we show the different interdomain process structures modeled with BPMN. In our study we also regard (i) service management processes and (ii) continuous and recurring processes. The service management processes are mostly affected by an automatic way of interdomain service provisioning.

As given before, a company in this paper corresponds to the carrier itself, which might be in our case an AO or EO. We outline different departments or roles within a company, which process customer requests for service provisioning.

A. *Traditional Structure*

The traditional structure of today's interdomain service management is a very complex and, thus, time-consuming and

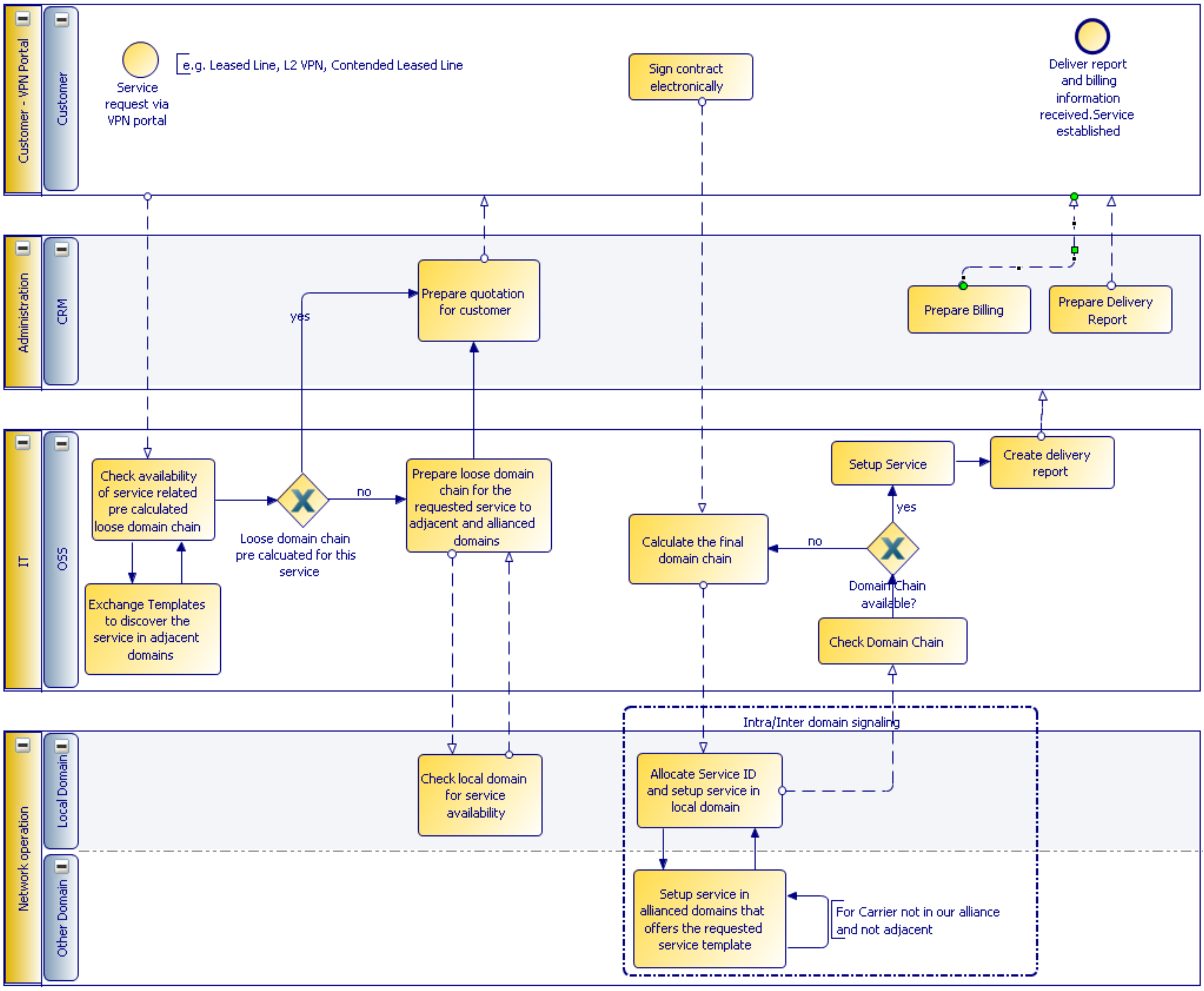

Fig. 2. ETNA approach for interdomain service provisioning by using the alliance peering model.

inefficient process related to the total cost of ownership (TCO) of a carrier. If a customer today wants to get a service that traverses through different domains which are administered by different carriers, days or even weeks are often involved until the service is established. There are several reasons for this, e.g., manual intervention, poorly defined processes of intercarrier communication (especially on the legal side), and the lack of efficient control plane techniques. The next chapters will describe the roles that are necessary for a company to establish a service, as well as the service management and continuous and recurring processes that contribute to OPEX.

The Roles within a Company:

In today's traditional interdomain service management we see different roles in a company [4]. These roles might also be regarded as the company's departments that accomplish the task of service provisioning, which starts with the customer request and includes the service establishment itself. We regard the roles of a customer, sales team, administration, project management, and network operation.

The customer requests a service under a contact with the sales department of the company. The sales department is the interface between the customer and the project management, which is responsible for work packages that are defined to accomplish the task of provisioning of the requested service. The administration department is responsible for creating delivery reports, billing issues, and other customer relationship management (CRM) issues.

Finally, we have the network operation department that is responsible for the technical realization of the service provisioning. Here we have two different “domains:” Since we investigate the interdomain service establishment, we have to model the different companies that act as a service provider or a carrier. Therefore we introduce “local domain” and “other domain” as areas of responsibility.

Service Management Processes:

As shown in Fig. 1 we created a process diagram to show the interaction of the different roles in a company to ac-

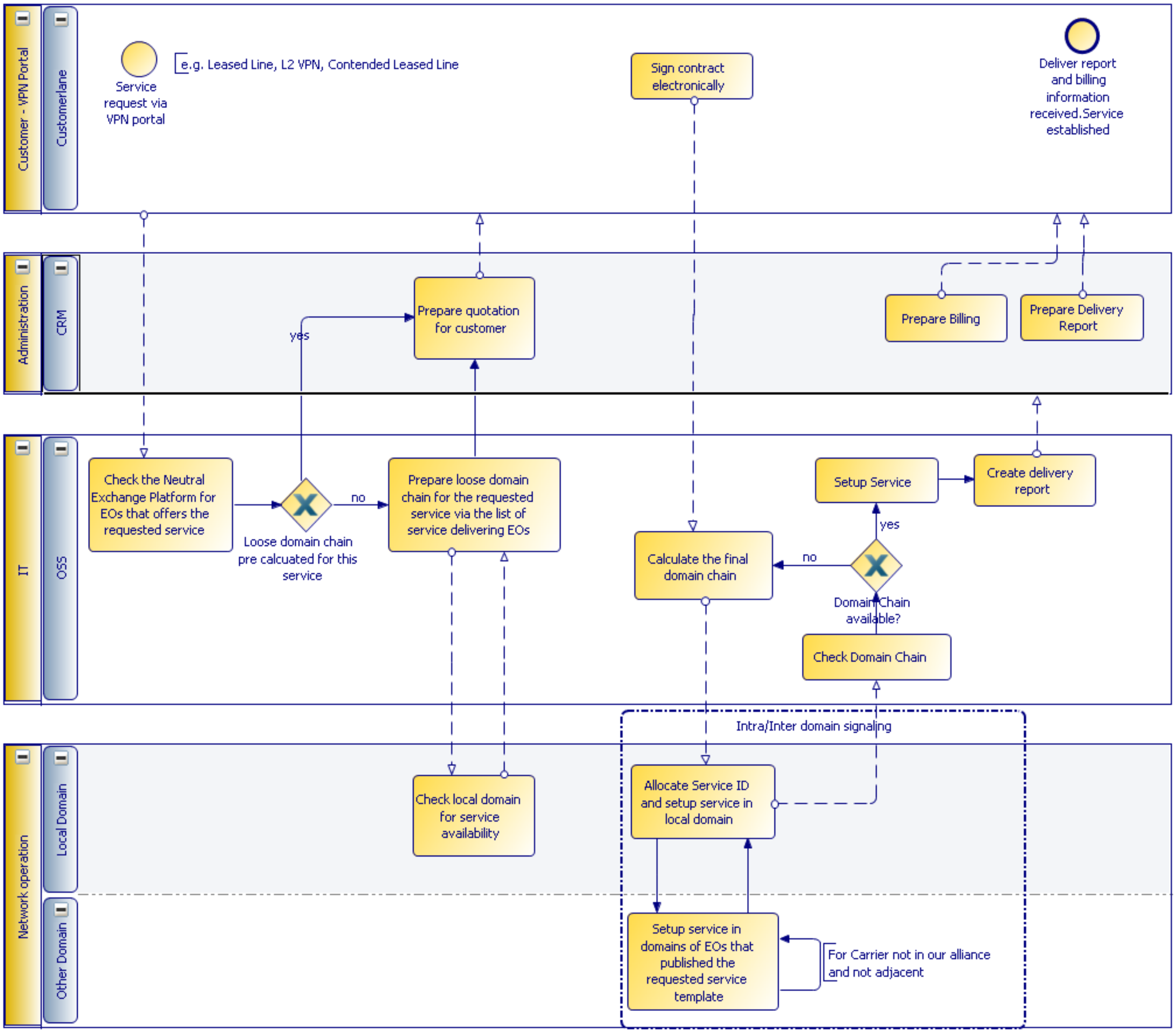

Fig. 3. ETNA approach of interdomain service provisioning by using the neutral exchange peering model

complish the task of interdomain service provisioning. The whole diagram can be divided into two main parts. As in [4], we assume the service offer and the service provisioning to be the main parts describing the interactions between the different roles. Service cessation is out of this paper's scope, since the influence of manual and automatic intervention is analogous to the service offer and provisioning process.

The service offer part describes the interaction of the customer with the sales team. Contract conditions, prices, Service Level Agreements (SLAs), etc. have to be negotiated. In cooperation with the Project Management team the first quotation is sent to the customer to finish the contract handling. There is a lot of negotiation work necessary between the different EOs of the domains, which is handled by the Project Management. This makes the whole process particularly slow and results in long service provisioning time and high cost. After the negotiations, the Network Operation department installs and configures the connection for the later service transmission. As mentioned before, until we reach the stage of delivery of the service and of the billing etc., we have a lot of intermediate processes to accomplish due to the manual character of today's interdomain service management.

Continuous and Recurring Processes:

We assume the same continuous and recurring processes as presented in [4]. This approach has practical reasons since the mentioned processes are rather common to transport networks. The necessary continuous and recurring processes are continuous cost of infrastructure, routine operations, reparation, operational network planning, and marketing. These processes cover expenses like cost of power, cooling, service, monitoring, diagnosis, technicians travelling, planning upgrades, and customer acquiring. These costs are essentially directly influenced by the number of used network elements and are only indirectly influenced by new established services.

Therefore, in this study we emphasize the OPEX values caused by service provisioning processes to show the benefits of automatic interdomain transport network architecture.

B. General ETNA based Interdomain Structure

By using the ETNA based approach, interdomain service provisioning becomes automatic. Consequently, the flexibility is enhanced compared with the traditional approach. Additionally, the various peering models give different results in flexibility, time consumption, and cost, for establishing an interdomain service.

There are some roles necessary in a company to accomplish the interdomain service provisioning task. The responsibilities even differ with respect to the peering models introduced in [3]. Due to the fact that the ETNA approach solves the problem of interdomain service provisioning automatically, the traditional inner structure of a carrier changes.

The Roles within a Company:

As a first result, the role of the project management is not considered as necessary anymore. The cases, where manual intervention is necessary to realize interdomain service provisioning, are not part of ETNA. Therefore, we introduce the IT department, which is responsible for the tasks related to the Operation Support Systems (OSSs). OSSs are the automatic processes replacing the manual intervention.

Generally, the role of the administration becomes a combination of the traditional necessary roles of sales and former administration. At this point, some cost savings are obtainable. Since the customer is able to request a list of the services and the service itself via a VPN portal, frequent interaction with sales teams are not necessary anymore. Although the sales department continues to be the first contact between the customer and the carrier, automatic interdomain service provisioning takes over its responsibility. Now, the administration department is responsible for the most important customer related issues (CRM, quotation, etc.).

Service Management Processes:

a) Processes for Alliance Peering

In Fig. 2, the BPMN diagram of the process chain with the introduced Alliance Peering Model is shown. In this diagram, the influence of automation onto the processes and the roles should be noted. Instead of having a sales team for the interaction with the customer, we can decrease the labor cost by letting the customer request services through the VPN portal where all services are published. The OSS, which is under the responsibility of the IT department, decides if the service is provisionable or not via a precalculated loose domain chain. If not, it calculates a loose chain separately; otherwise, it sends a quotation automatically to the customer. The CRM part is assumed to be under the responsibility of the administration department. As in the traditional process, it interacts later at time of preparing the billing and other CRM related interactions. The network operation department is responsible for the same processes as for the traditional scenario, though without manual interference. The control of the service availability and the setup of the interdomain services are done by ETNA's template and signaling techniques automatically. The particularity of alliance peering is to stay in contact with allied carriers for the automatic service provisioning. As a result we can see fewer processes and fewer necessary departments (no sales team, no project management for the task of service provisioning itself). This leads to a much leaner staffing, which results in time saving due to intercommunication delays and cost reduction due to the smaller amount of staff.

b) Processes for Neutral Exchange Peering

Fig. 3 shows the processes related to neutral exchange peering. It exhibits the advantage that there is no need to contact the carriers of the other domains directly. In spite of the fact that in the case of the alliance peering, this contact is very simple and flexible, it consumes additional time. This additional time can be saved by participating in a neutral exchange point that represents a market place for services. Each carrier can publish its services there and put additional information that describes the service in more detail.

As we can see in Fig. 3 we have the same roles as introduced for alliance peering. Additionally, we can disburden the network operation department by using only the neutral exchange platform instead of automatically triggering the carriers in an alliance. The rest of the processes are quite the same. The administration department is responsible for the creation of the delivery report, billing preparation and other customer relationship related interactions.

Continuous and Recurring Processes:

Here we still have the continuous cost of infrastructure, routine operations, reparation, operational network planning, and marketing.

Table 3: Cost development by using ETNA's approach

Continuous Cost of Infrastructure	Routine Operations	Reparation	Operational Network Planning	Marketing
increase	*decrease*	*decrease*	*equal / increase*	*decrease*

Regarding the automatic character, we assume different developments for the cost values as listed in Tab. 3. The section of continuous cost of infrastructure is related to the network keep-alive costs, e.g., power, cooling, and equipment cost itself. ETNA will have impact on these cost values, since it will result in more expensive network elements due to increased functionality even if it is only applied in the border nodes. By contrast, the cost included by routine operations will decrease since operations like monitoring, reparation, and publishing of services are automatically handled. Hence, it avoids time-consuming and therefore cost-intensive manual interventions. Costs regarding network failure reparation will also decrease since the interdomain Operation, Administration, and Maintenance (OAM) can lower the reparation OPEX. However, operational network planning is expected to be equal or slightly increased by using ETNA's approach. Network planning is part of the network operation that includes the design phase of the network, in which it is decided where to place the network elements, which links should be replaced with higher bandwidth links, and how to make the load balance of the network. Network planning is based on network performance monitoring and load forecast.

It seems that ETNA will demand additional network planning due to unexpected ad hoc transport services. Another point is the need to plan the partitioning of the network between legacy and new services. All of these issues can lead to a slight increase of the cost in that area. Above all, the pure marketing will decrease. Acquiring new customers, for example, is not related to the technical realization of interdomain service provisioning and therefore ETNA's approach cannot influence it directly.

IV. Qualitative Analysis

First differences and valuations have been already discussed in the previous sections and this section gives more details about the differences, advantages and disadvantages of all structures qualitatively.

With an automatic technique for interdomain network architecture we definitely save in OPEX since we do not need to interfere with manual interactions. Although automated systems will also have an OPEX, we can assume that it will be lower. As expected, ETNA's interdomain approach will have a high impact on the cost and duration of the provisioning of a service. The cost savings in OPEX are directly related to the effects of ETNA's approach on the internal situation of a company. As we have shown in the different process diagrams, by using ETNA's approach we are able to have a leaner department structure in a company due to fewer manual interactions. We will certainly need e.g. the role of a sales department and/or project management in the future to be able to react properly in case of emergency. The necessity of these roles though will be definitely lower in situations of ordinary day to day service provisioning. In our diagrams about the service provisioning process, these roles are even negligible therefore we have not mentioned them individually. Furthermore, there are some differences in the process chains between the discussed peering models. The neutral exchange peering needs less effort than the alliance peering regarding the necessary processes and the cost because the neutral exchange peering is a business entity, which has its own OPEX. We still have to consider legal negotiations, even if these negotiations are just necessary at the beginning of a peering. In this case, after they have been processed once, a carrier does not need to become active again for every new service request.

Within this study we consciously emphasized the service offer and provisioning process. The service offer process will be handled also automatically at the VPN Portal due to the flexible service template technique of ETNA. SLA negotiations, i.e. some aspects like bandwidth, QoS, legal issues etc., are more or less solved at the beginning of the different peering establishments. The customer can use the results of these negotiations via the VPN Portal, where he or she can select options for his or her service request.

We assume that the CAPEX values will be marginally influenced by ETNA's approach. The expenditure of network elements itself will rise due to the additional functionalities. We also have to consider the additional cost that ETNA will cause regarding the update of NMS and OSS systems by some new features in order to be able to work together with the ETNA approach.

The advantages of using ETNA's interdomain network architecture are not limited to some special types of carriers. As introduced in [4], we can think about different carriers like incumbent carriers and new entrant carriers. We assume that both will benefit from ETNA's interdomain network architecture. For incumbent carriers, it is a question of migration how to extend their working platform with updates of software and/or hardware to be able to deliver the discussed features introduced by ETNA. Questions regarding the creation of a parallel ETNA featured network platform or the iterative extension of an available platform should be answered. For new entrants, the decision could be easier since they do not have a big network infrastructure and thus an extension of their network is mandatory.

V. Conclusion and Outlook

This document has set out, qualitatively, the techno-economic advantages of the Interdomain Network architecture introduced by the ETNA project. We have addressed the process structure of the traditional interdomain communication and its disadvantages in contrast to ETNA's approach. We also considered the advantages of ETNA's interdomain network architecture for two different peering models.

The qualitative character of this study presented the applicability of the interdomain network architecture in practice. In particular, the BPMN diagrams are a useful way to visualize the processes, responsibility of the roles and how they communicate with each other.

As an overall conclusion, this document has indicated that ETNA's interdomain network architecture provides opportunities to decrease the cost and the needed time for interdomain service provisioning. The next step is a quantitative analysis based on these opportunities, since each process requires different cost factors.

References

[1] ETNA, "Ethernet Transport and Networks, Architectures of Networking," Deliverable D2.1 Issue 2.1, Dec. 2008, http://www.ict-etna.eu/documents/ETNA%20WP2%20Network%20and%20Service%20Architecture%20-%20D2.1%20R2%20-%20Issue%202.pdf

[2] OMG, BPMN 1.2 - Final Adopted Specification, http://www.omg.org/docs/formal/09-01-03.pdf, Jan. 2009.

[3] J. Recker, P. Wohed, and M. Rosemann, "Conceptual Modeling," Springer, Berlin/Heidelberg, 2006.

[4] S. Pasqualini et al., "Influence of GMPLS on Network Privoders' Operational Expenditures: A Quantitative Study," IEEE Communications Magazine, July 2005.