

# Impact of network reliability on network costs in next generation access networks

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## ABSTRACT

Today's access networks are still mainly based on copper cable infrastructure in the first mile. The geographic extension of conventional access service areas and with this also the structure of the access/aggregation network is mainly defined by the resistance of the copper lines – and thus the copper loop length – as well as by the switching capacity of the electro-mechanic telephone exchanges in the past. The evolution towards next generation optical access networks will provide a new degree of freedom in network design due to the higher reach of optical transmission. This will potentially lead to much larger service areas serving several thousands of customers from a single location. This increased concentration of customers will have a significant impact on network reliability and service availability in next generation access networks.

In this paper we will review the impact of network reliability and availability on network costs in next generation optical access networks. The results show that there is a significant cost impact in all consolidation scenarios depending on the aspired failure penetration.

**Keywords:** Optical Access Networks, Passive Optical Networks (PON), Techno-Economic Analysis, Capital Expenditures (CapEx)

## 1. INTRODUCTION

Conventional fixed access networks of incumbent network operators rely on a structure and topology inherited from the analogue telephone network era: They are usually based on the existing copper-based infrastructure. The area of a whole country is subdivided in a number of service areas each belonging to a Central Office (CO). The size of these services areas is determined by two main limiting factors, copper cable length and switching capacity of the Local Exchange (LEx) equipment installed in the CO.

With the trend towards optical fiber transmission in access networks for increased access bit rates [1], [2], [3] new opportunities for a potential restructuring of the network arise due to the superior transmission characteristics – low attenuation and high bandwidth – of optical fibers. This could lead to the definition of larger service areas with much more customers within one service area than in today's scenarios. From a network operators point of view re-designing the access network structure and reducing the number of COs are expected to lead to a lower total cost of ownership (TCO). In [4] different next generation optical access (NGOA) network scenarios with network node consolidation and hence larger access service areas were studied and compared in terms of capital expenditures, power consumption and power costs.

Not only physical related parameters like necessary fiber length, bit-rate per customer, and aggregate capacity will change but also the influence on network quality and the impact of a failure scenario in terms of number of affected customers and frequency of occurrence of a failure needs to be reconsidered. In this contribution, a systematic analysis of feasible failure scenarios in NGOA networks encompassing larger service areas is presented and different resiliency options based on infrastructure changes are studied with respect to associated capital expenditures.

## 2. NEXT GENERATION OPTICAL ACCESS NETWORK STRUCTURE AND MODEL

### 2.1 Optical Distribution Network in traditional service areas

The present structure of telecommunication networks of incumbent network providers is based on the historical subdivision into several thousand local telephone networks mainly due to political and administrative reasons. Technical limitations and economic considerations caused a further partitioning of the local telephone networks into service areas. The structure of a traditional service area is depicted in the left part of Figure 1: A CO building is usually installed in each service area and all subscriber lines are terminated in the CO. Due to the length limitation on copper the lengths of the subscriber lines are typically much shorter than 5 km. For economic reasons copper access networks are usually subdivided into two sections: The main cable section and

the distribution cable section. While in the distribution cable section – which is directed to the customer premises – the copper cables were installed for 100% coverage already at the time of the first network installation, the main cables – which are directed to the CO and which are usually much longer than the distribution cables – have been installed according to the customer demand. The main cables and the distribution cables can be connected flexibly in street cabinets. Since the structure of the cable duct networks and the right of way in the access networks – which are substantial assets of incumbent network operators – reflect the structure of the copper network, this structure will be also the basis for the Optical Distribution Network (ODN) for Fiber-To-The- Home (FTTH). In this context the street cabinet location may be a good candidate for installing active or passive multiplexers in point-to-multipoint optical access network architectures.

## 2.2 Next generation optical access network model

In case of reducing the total number of COs when deploying optical access network technologies new service areas (NGOA service areas) have to be identified according to a number of boundary conditions:

- Economic considerations: A cost-optimal cut of service areas has to be identified.
- Maximum reach of access network technologies.
- Limitation of the number of fibers which can be terminated in the remaining – surviving – CO buildings. This refers mainly to the available capacity of the house lead-ins and the feeding trunks as well as the available floor space for the optical distribution frame and the active equipment, mainly the Optical Line Termination devices (OLT).
- Resilience requirements: The maximum number of subscribers connected to a certain CO may be limited.

To identify potential new service areas by consolidation of some existing traditional service areas we used a clustering algorithm for developing four exemplary network scenarios differing in the number of NGOA service areas. We used a reference model for Germany and in all scenarios we started from 8000 COs and reduced the remaining number to 500, 1000, 2000 and 4000  $CO_{new}$ , respectively. It is obvious that other related parameters like the number of households connected to a certain access node or the covered area per NGOA service area vary in the different scenarios too. Figure 1 depicts the structure of such a new service area of an NGOA network.

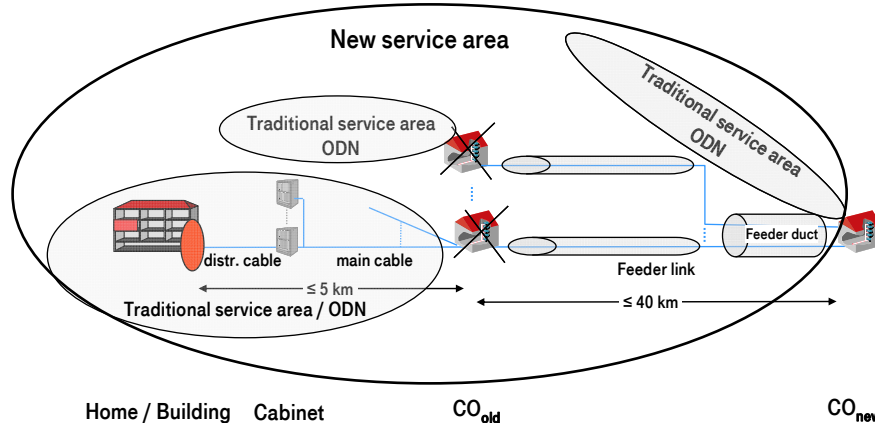


Figure 1: Access network model showing traditional and new service area (NGOA service area).

The whole area is served by the  $CO_{new}$  which, however, now comprises several traditional service areas, one directly linked to the  $CO_{new}$  and the others remotely linked to the  $CO_{new}$  by feeder links. The feeder links are interconnecting the former COs in the remote service areas to the  $CO_{new}$ . The distance for this feeder fiber depends on the number of  $CO_{new}$  and with this on the degree of CO consolidation and is up to about 40 km in most cases (Figure 2). Several of these feeder fibers may be bound to the same duct structure for a certain length of the feeding section.

More details of the model can be found in [5].

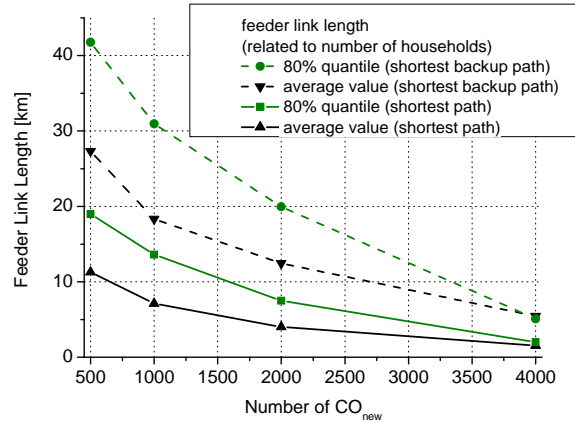


Figure 2: Feeder fiber length on working and backup path (single homing) in exemplary NGOA service area

### 2.3 Network quality and impact of failure scenarios

An important criterion for network and service quality is availability. This aspect is twofold: From the customer perspective the service quality is mainly determined by the failure probability and the mean outage time of the individual services. From a network operators and an economic point of view the impact of a failure in terms of the number of customers getting simultaneously affected by a failure, called failure penetration range, is also very important.

To evaluate the failure penetration range and the probability of particular failure scenarios in the NGOA network model a systematic investigation of the number of customers sharing a particular network element and the outage probability of the network elements is needed.

Figure 3 shows the customer concentration at different points within a future NGOA service area. Inside the customer premise the Optical Network Termination (ONT) or in multi-dwelling units the Optical Network Unit (MDU-ONU) is typically used for connecting between 1 and 15 customers, depending on the network architecture (FTTB/FTTH) and the size of the building. In the distribution cable section the failure penetration range of a single cable is usually up to 50 customers but several distribution cables can share a particular cable duct. A cabinet typically serves up to 200 customers and a main cable is usually connected to several cabinets (like a pearl necklace) and connects typically up to 2000 customers. Again, several main cables can be installed in a single duct.

In traditional service areas the number of customers is typically up to 10.000. Hence, also the number of customers sharing a single feeder link in the NGOA scenario will be in this order of magnitude. Furthermore several feeder cables may be installed in a particular cable duct, especially near by the CO<sub>new</sub> building, leading to a failure penetration range of the cable duct of up to several 10.000 customers. Since the failure probability of cables and ducts is correlated with its length the failure probability of the feeder links in an NGOA service area will increase with increasing level of CO consolidation. The number of customers connected to a CO<sub>new</sub> building can be up to 100.000 or even above, also depending on the level of CO consolidation. The failure penetration range of the fiber distribution frame is in the same order of magnitude like for the whole CO<sub>new</sub> but it can be decreased by installing multiple fiber distribution frames inside different fire compartments. The failure penetration range and the system availability of the active equipment installed in the CO<sub>new</sub> (mainly the (OLTs) and the Heating, Ventilation and Air-Conditioning (HVAC) devices) can be adapted by the system design (limitation of the number of customers served by a single device, redundant switch architecture, redundant HVAC systems, power backup etc.)

In traditional service areas the failure penetration ranges of the elements in the copper distribution network are similar to the numbers mentioned for the ODN. A redundant connection of the subscriber lines in copper access networks is typically not applied mainly for the following reasons:

- The exclusive use of passive elements in the distribution network which typically have very small failure probabilities
- The small numbers of customers sharing a particular network element
- The short length of the subscriber lines: The probability of a cable outage is correlated with its length.
- The probability of an outage of the distribution frame inside the CO, where all subscriber lines are terminated, is very low (this is typically a purely passive element) and also the probability of an event where the whole CO building is deconstructed is very low.

- Optimized design of the active equipment installed in the COs (limited number of customers served by a single device, redundant switch architecture, redundant HVAC systems, power backup etc.).

Most of these statements are also valid for the ODN and, as mentioned above, the failure penetration range of the different elements installed in the ODN is approximately the same like in copper access networks. The failure probability of the optical cables in the ODN will also be in the same order of magnitude like for the copper cables. Redundant subscriber lines should therefore also not be required in FTTH networks. Regarding the splitter design in point- to-multipoint optical access networks two different options exists: in Passive Optical Networks (PON) it is implemented as a passive device (power splitter or wavelength splitter) and in Active Optical Networks (AON) it is implemented as an active device (typically outdoor Ethernet switches). Since the failure probability of active devices is significantly higher compared to passive splitters (Table 1) a redundant design of the outdoor switches could be needed in AONs. Nevertheless, the number of customers connected to an outdoor switch is typically similar to the number of customers connected to a copper cabinet (< 200) and with this the failure penetration range of the active splitters is still very low.

Regarding the failure penetration range of the feeder fiber links and the CO<sub>new</sub> buildings (including the fiber distribution frame) the picture is different in NGOA service areas compared to traditional service areas. In present networks this part of the network belongs to the aggregation network. The highest availability requirements are demanded for voice services since this is the basic service. Hence, the Public Switched Telephone Network (PSTN) platform interconnections are typically redundantly implemented in present networks and each CO is redundantly connected to the aggregation network at least for the PSTN switches. In FTTH networks voice services will also be IP based and the whole broadband service must fulfill the availability requirements of the voice service. With this the failure penetration range and the failure probability of the feeder links, the fiber distribution frames inside the CO<sub>new</sub> and the CO<sub>new</sub> buildings becomes very important and a redundant feeder link design may be necessary. Two principal design options for a redundant feeder link are feasible: firstly redundant feeder cables can be installed via disjoint ducts towards the same CO<sub>new</sub> building (single homing) and secondly the redundant feeder cables can be terminated in different CO<sub>new</sub> buildings (dual homing). In both cases protection against feeder link failures is realized. Protection against outages of the fiber distribution frame and the CO<sub>new</sub> building itself is only guaranteed with the dual homing concept.

But besides the number of customers affected it is also important to have a look to the failure frequency at the different locations. For active equipment the Mean Time Between Failure (MTBF) for an ONT or OLT is roughly in the order of 10 to 30 years (Table 1), so that the influence on a single customer is limited. Passive components, e.g. splitters, can be considered as almost not influencing the availability (MTBF >100 years modeled).

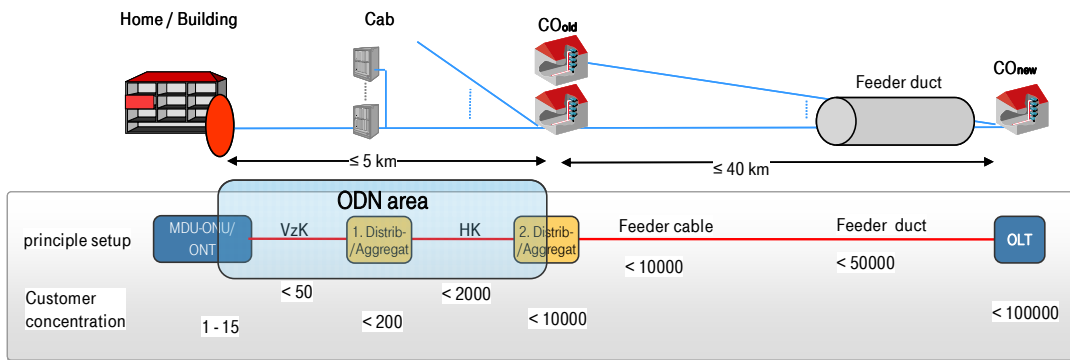


Figure 3: Customer concentration at different points within a NGOA service area.

From these considerations one may conclude that a major impact of a failure can be expected for the segment going from the former central offices to the CO<sub>new</sub>. On these segments the customer concentration is extremely high compared to traditional service areas. Therefore the resiliency concept focuses on this area.

Table 1: Estimated MTBF values for passive and active components in optical access networks.

| Location                                | Typical MTBF value / years |        |
|---|----------------------------|--------|
|   | passive                    | active |
| MDU ONU/ONT                             | -                          | 10     |
| First aggregation / distribution point  | >> 50                      | 10-30  |
| Second aggregation / distribution point | >> 50                      | 10-30  |
| OLT                                     | -                          | 10-30  |

### 3. Case Study: Impact of maximum tolerable failure penetration range on network costs

A case study analyzing the dependency between the failure penetration range of the fiber connections used by the feeder links, the level of CO consolidation and the associated feeder link and OLT interfaces costs is presented in the following.

We use a network model of Germany with approximately 8000 traditional service areas interconnected via a partly meshed fiber graph. A clustering algorithm was used to develop four NGOA network scenarios with 500, 1000, 2000 and 4000 CO<sub>new</sub> with minimized overall feeder fiber demand on the working paths (see chapter 2.2). Following the routing of the feeder link working paths the failure penetration range of each fiber graph link can be calculated as the sum of the number of subscribers in the traditional service areas whose related feeder links are routed via the respective fiber graph link. The maximum tolerable failure penetration range is a parameter in the case study and varies between 0 (full protection of all subscriber lines in the feeder link section), 2.000, 5.000, 10.000 subscribers and infinite (all feeder links are unprotected). If the failure penetration range of a particular fiber link is above the maximum failure penetration range, the feeder links routed via the fiber link becomes successively protected by allocating respective fiber resources on the redundant backup path (single homing), starting with the feeder link with the highest number of respective subscriber lines. We do not assume the possibility of partially protecting the feeder link fibers belonging to a particular traditional service area.

On the right hand side of Figure 4 the relative feeder fiber demand for the different NGOA network scenarios and the different levels of the maximum failure penetration range is shown. It is obvious that in case of an infinite maximum failure penetration range all feeder links are unprotected and the feeder fiber demand is lowest. When decreasing the maximum failure penetration range the additional required feeder fiber demand is different in the different NGOA network scenarios: If the maximum failure penetration range is between 5.000 and 10.000 subscriber lines, the smallest increase of the feeder fiber demand is observed in the scenarios with lowest level of CO consolidation (4.000 and 2.000 CO<sub>new</sub>). For the majority of traditional service areas the number of subscribers is below 5000. With this mostly fiber links used by more than one feeder links will exceed a maximum failure penetration range of 5000 subscribers. The number of feeder links sharing a particular fiber links is smaller in the scenarios with high number of CO<sub>new</sub> since routing is more distributed.

If the maximum failure penetration range is between 0 and 2.000 subscriber lines the relative feeder fiber demand in the scenarios with 2.000 or 4.000 CO<sub>new</sub> is above the feeder fiber demand in the scenarios with 500 and 1000 CO<sub>new</sub>. Now the share of the protected feeder links is similar in all network scenarios, since the failure penetration range is below the number of customers in a remotely connected traditional service area in most cases and with this approximately all feeder links are protected. Furthermore the relative length of the feeder link backup paths compared to the working paths increases with increasing number of CO<sub>new</sub> (Figure 2) leading to higher relative feeder fiber demand in the scenarios with 2.000 or 4.000 CO<sub>new</sub>.

The relative number of required OLT tributary interfaces in the different scenarios is shown on the right hand side of Figure 4. We assume that redundant OLT tributary interfaces are needed for feeder link protection. The number of OLT tributary interfaces is lowest in the scenarios with highest number of CO<sub>new</sub> if the tolerable failure penetration range is limited. As mentioned in the previous paragraph, more feeder links have to be protected in the scenarios with small number of CO<sub>new</sub>. Furthermore, the share of subscribers in traditional service areas, directly connected to the CO<sub>new</sub>, increases with increasing number of CO<sub>new</sub>. Since the subscribers in the traditional service areas directly connected to a CO<sub>new</sub> are not connected via feeder links they also do not contribute to the failure penetration range of the feeder links and with this redundant OLT tributary interfaces are not needed for these subscribers in our case study scenario.

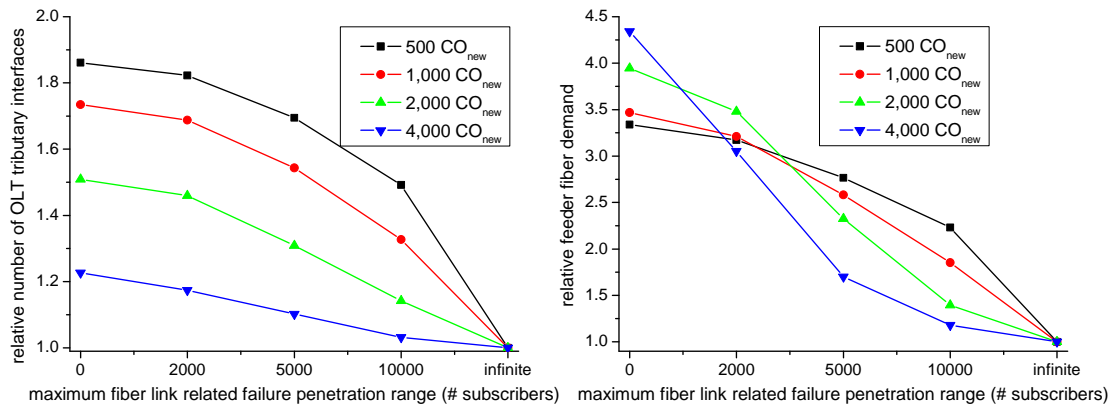


Figure 4: Relative feeder fiber demand and relative number of OLT tributary interfaces in different NGOA network scenarios according to different levels of the maximum failure penetration range.

#### 4. CONCLUSIONS

From an operator point of view it is essential to understand the chances and challenges of next generation fiber based access networks. Due to the lower loss of optical fibers compared to copper potentially much longer reach can be achieved and thus a restructuring and repartitioning of an NGOA network with lower total cost of ownership is possible. However, increasing the service area in an NGOA network will also lead to an increased number of customers potentially affected by a network failure. In this study we analyzed the impact of resilience on the feeder fiber segment in NGOA network scenarios with different level of node consolidation and different tolerable failure penetration ranges with respect to the relative feeder fiber and OLT tributary interface demand. The results show that there is a significant cost impact in all consolidation scenarios on the feeder fiber segment by varying the failure penetration range. Particularly, for a large number of  $CO_{new}$  there is a strong dependence on the failure penetration range and thus on the costs associated with the aspired resilience.

The need for redundant feeder paths in NGOA networks is also an important system design requirement and must be taken into account by the vendors and the standardization bodies.

Further research on that topic is necessary and is intended to be conducted in the framework of the OASE project.

#### ACKNOWLEDGEMENTS

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