Planung eines landesweiten passiven optischen Netzes: Optimierung der Anzahl und Standorte aktiver Knoten.
Nation-wide deployment of (long-reach) passive optical networks: Computing the location and number of active nodes.

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Kurzfassung

Abstract
For the European project DISCUS, we study the deployment of active nodes to connect all customers in different countries via (long-reach) passive optical networks. In particular, we investigate design parameters such as the resilience strategy, the maximum node size, and the maximum signal reach. We evaluate the resulting node distributions and survivable fiber route connections using different cost models.

1 Introduction
Global IP traffic has increased by a factor of 4 in the past 5 years and will surpass the zettabyte threshold by the end of 2017 [4]. It is commonly agreed that any future architecture able to handle this tremendous traffic growth has to be based on optical technology also in today’s access networks, including the last mile towards the end-user. Consequently, nowadays, telecommunication networks all over the world are in a transition phase of pushing fiber technology closer to the customers premises. This process and the resulting architectures are referred to as FTTx (fiber-to-the-home, fiber-to-the-building, etc.).

Once optical fibers are available already at the network edge, distance constraints known from copper technology and DSL protocols become obsolete. In principle, the first active nodes could be moved far away from the customers. This observation strongly questions today’s end-to-end architectures, where customer signals are terminated within a distance of at most a few kilometers (and typically already within a few hundred meters) at one of several thousand local exchanges (LE) in a typical European country.

1.1 The DISCUS architecture
The EU FP7 project DISCUS [12] revisits the classical divide between access, metro, and core networks for a new future proof end-to-end network architecture for next-generation communication networks. The DISCUS architecture is based on three three major design principles:

- A long reach passive optical access network (LR-PON) that bypasses today’s local exchange (LE) sites and also eliminates today’s metro transmission networks.
- The metro/core (MC) nodes which are the first active nodes marking the edge between the access and the core network.
- A flat optical core network with a small number of large scale MC nodes organized in so-called optical islands. An optical island is as a full mesh of optical connections.

Central to the DISCUS LR-PON is a dual-homing architecture, see Fig. 1. The optical signal is supposed to pass a three-stage splitting hierarchy from the MC node to the customer. The first stage 4x4 splitter, located at a local exchange site, is used to provide a redundant connection to a second MC node. In consequence, every LR-PON bypasses an LE site and is connected with two different MC nodes.

The design limit for the DISCUS LR-PON reach, that is, the longest path length from a customers ONU (optical network unit) to a metro-core node is 100 km, see [8]. Also 125 km are under consideration, see [7]. Clearly, due to the quadratic scaling of connections in the full mesh of the optical island a small number of MC-nodes is indispensable for this architecture to be cost-effective and scalable.

1.2 Contribution
In [3] we showed how to solve optimization problems related to the minimization of the number of MC nodes under distance and dual homing constraints stemming from the DISCUS LR-PON design. We also presented compu-
The DISCUS LR-PON architecture: A multiple splitting hierarchy between customer and LE and dual-homing between LE and MC. The MC node acts as the access optical line termination as well as a core router with L1/2/3 switching and routing functionality.

In this paper we build on and improve the results from [3] by incorporating two major practical requirements: (i) First of all, we observe that simply minimizing the number of active nodes may lead to huge nodes with several millions of connected customers. We show how to avoid this situation within the same modeling paradigm by introducing a maximum customer constraint. (ii) Secondly, to improve on the resource sharing (cables, ducts) we optimize the fiber routes studying two opposed solutions, one that minimizes the fiber kilometers and one that minimizes trail kilometers. This is done without violating the required disjointedness and distance constraints.

Using the resulting enhanced LR-PON optimizer we close with a study that reveals how nation-wide cable and duct cost is influenced by the studied parameters: (i) the maximum LR-PON reach and (ii) the maximum number of customers connected to an MC node, and the (iii) the fiber routing strategy.

In addition to the central design concepts mentioned above we make the following assumptions throughout the paper:

- We start from existing LE sites with connected DSL customers. That is, every customer has a designated LE site.
- Due to the lack of more detailed data, we assume a (maximum) distance of 10 km between a customer and its designated LE site.
- A customer will be assigned to an LR-PON that bypasses its designated LE site.
- The design of the LR-PON (splitter hierarchy and fiber routing) in the optical distribution network, that is, between customer an LE, is not subject to optimization.
- We will vary the assignment of LR-PONs to MC nodes only.
- MC nodes are only opened at existing LE-sites.

1.3 Reference Network and Data

Only a realistic nation-wide reference network reflecting a potential fiber topology allows to properly analyze the influence of topological connectivity (e.g. for resilience issues) and technological restrictions (e.g. maximal distances). Such data is typically highly confidential!

Similar to [3], which was based on an Italian reference network with central offices from TELECOM ITALIA, in this study we work with a data-set provided by BRITISH TELECOM. It contains coordinates of their current local exchange locations in the UK, a total of 5,578 locations, together with the current number of connected (residential) DSL customers. This data-set has been anonymized in the sense that the coordinates of the local exchanges have been slightly shifted. We hence worked with a realistic amount and distribution of locations but not with the real coordinates.

To come up with a realistic fiber topology, connecting the local exchanges, we decided to combine the available non-confidential operator-specific key-information with public available data, namely with data from open street maps OSM [11]. Such geo-referenced data from street networks...
2 Facility location and disjointedness

In [3] we showed how to solve the MC node placement problem using facility location models that assign given clients (local exchanges and their customers) to facilities (metro core nodes) while balancing the cost for opening the facilities and the cost for assigning the clients. A central binary programming model for our problem can be written as follows:

\[
\begin{align*}
\min & \quad \sum_{l \in L} \sum_{k \in K} c_{lk} x_{lk} + \sum_{m \in M} c_m x_m \\
(DFL) & \quad \sum_{k \in K_l} x_{lk} = 1 \quad \forall l \in L \\
& \quad x_{lk} \leq s_m \quad \forall l \in L, k = \{m,n\} \in K_l \\
& \quad x_{lk} \leq x_n \quad \forall l \in L, k = \{m,n\} \in K_l \\
& \quad x_{lk} \in \{0,1\} \quad \forall l \in L, k \in K \\
& \quad x_m \in \{0,1\} \quad \forall m \in M 
\end{align*}
\]

In this model, L, M, and K denote the set of local exchanges with connected customers, the set of potential MC locations, and the set of all pairs of potential MC locations, respectively. Not all pairs of MCs have to be considered, but only pairs that can be reached from an LE within the given distance via a pair of disjoint fiber routes. The set \(K_l\) denotes all such feasible pairs for every local exchange \(l \in L\). Equation (2) assigns each LE location to one pair of MC nodes. Whenever a pair is chosen, inequalities (3) and (4) guarantee that the corresponding MC locations are opened.

The objective (1) balances facility opening and assignment cost. By setting \(c_m := 1\) and \(c_{lk} = 0\) for all \(l \in L, m \in M,\) and \(k \in K\) we minimize the number of necessary MC nodes.

In our computations, every LE location is a potential MC location if it lies in a (bigger) biconnected component of the UK reference network, that is, it has a degree of at least two and can be reached from (many) other locations with at least 2 disjoint paths. In case of the UK reference network we have 4888 such locations (out of 5449 LE sites).

Model (DFL) selects the MC-locations whereas the problem of finding disjoint paths (a difficult optimization problem in itself) is handled in the generation of input-data when building the sets \(K_l\). For the computation of (disjoint) paths we use variants of Dijkstra’s algorithm \([5]\) and Suurballe’s algorithm \([10,13]\) while properly handling the required length restriction.

Path disjointedness from the mathematical point of view cannot always be guaranteed in practice for many reasons. We use the notion of maximally disjoint paths using an assignment policy that favors node-disjointedness over edge-disjointedness and if mathematical disjointedness is not possible (within the given distance) minimizes the number of commonly used nodes or edges, see [3] for details.

3 Distributing active nodes

Table 2 shows the results of our initial computations stating the number of MC nodes that are necessary if all customers...
in the UK are connected to LR-PONs assuming the mentioned disjointedness and distance principles. The number of necessary nodes clearly decreases when increasing the allowed reach. In the extreme case of a customer to MC distance of 120 km only 75 active nodes are necessary to connect all customers to LR-PONs (compared to nowadays more than 5,000 active local exchanges).

In Table 2, we report on the influence of the resilience strategy on the number of required MC nodes. As expected when requiring dual homing instead of single homing the number of MC nodes roughly doubles. Additionally requiring maximally disjoint fiber routes increases the number of MC nodes by further 40% and 53% for maximal distances 100 km and 125 km, respectively.

Table 2: Active nodes necessary to connect customers to LR-PONs using the DISCUS architecture of disjoint dual homing: Different reach constraints.

<table>
<thead>
<tr>
<th>region</th>
<th>80 km</th>
<th>100 km</th>
<th>120 km</th>
</tr>
</thead>
<tbody>
<tr>
<td>England</td>
<td>65</td>
<td>42</td>
<td>40</td>
</tr>
<tr>
<td>Scotland</td>
<td>54</td>
<td>37</td>
<td>24</td>
</tr>
<tr>
<td>Wales</td>
<td>13</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>N. Ireland</td>
<td>10</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>UK</td>
<td>142</td>
<td>95</td>
<td>75</td>
</tr>
</tbody>
</table>

A resilience strategy for the LR-PON becomes necessary as by decreasing the number of active nodes an increasing number of customers connects to a single node. In the case of 75 nodes and 120 km maximum distance we have 15 MCs with more than 1 Mio connected customers (primary and secondary) and 5 with more than 3 Mio. The two biggest locations are in London with 5.4 and 5.6 Mio connected customers. In fact most of the local exchanges and their current customers are connected to these two nodes in this extreme solution, see also [4].

This might not be desirable both from the resiliency and also from the operational perspective. However, we can easily include customer bounds into model (DFL). If we denote by \( \text{max}_\text{cut} \) the maximum number of customers that might be assigned to an MC node \( m \in M \) and by \( n_l \) the number of current DSL customers at local exchanges \( l \in L \) then inequalities

\[
\sum_{l \in L, k \in K_l} n_l x_{lk} \leq \text{max}_\text{cut}, \quad \forall m \in M
\]

limit the size of the MC nodes. Table 3 shows how such constraints with \( \text{max}_\text{cut} \in \{ 2 \text{Mio}, 1 \text{Mio}, 200\text{K} \} \) influence optimal MC distributions for the UK reference network. For a maximum distance of 120 km the number of necessary MC nodes increases to 106 if we force at most 1 Mio customers connected to the same MC. In this case we get 7 MCs sharing the connections in and around London, see [4]. In fact, in this example the distribution of customers across the MCs becomes much more uniform. More than 50% of all MCs connect between 500K and 1Mio customers.

Table 3: Influence of resiliency strategy on the necessary number of MC nodes. SH = single homing, DH = dual homing, DHD = dual homing with maximally disjoint paths

<table>
<thead>
<tr>
<th>region</th>
<th>SH 100km</th>
<th>120km</th>
<th>DH 100km</th>
<th>120km</th>
<th>DHD 100km</th>
<th>120km</th>
</tr>
</thead>
<tbody>
<tr>
<td>England</td>
<td>15 28 42</td>
<td>21 42</td>
<td>14 27 42</td>
<td>19 37 24</td>
<td>3 6 27</td>
<td>5 10 24</td>
</tr>
<tr>
<td>Scotland</td>
<td>14 11 28</td>
<td>21 42</td>
<td>14 9 27</td>
<td>19 37 24</td>
<td>3 2 6 4</td>
<td>5 10 24</td>
</tr>
<tr>
<td>Wales</td>
<td>3 2 6 4</td>
<td>4 6 4</td>
<td>3 2 6 4</td>
<td>5 10 24</td>
<td>3 2 6 4</td>
<td>5 10 24</td>
</tr>
<tr>
<td>UK</td>
<td>35 68 49</td>
<td>49 75</td>
<td>35 24 49</td>
<td>49 75</td>
<td>35 24 49</td>
<td>49 75</td>
</tr>
</tbody>
</table>

In Table 4, we report on the influence of the resilience strategy on the necessary number of MC nodes. inf refers to the results without any size constraint.

Table 4: Influence of customer restrictions on the necessary number of MC nodes. inf refers to the results without any size constraint.

<table>
<thead>
<tr>
<th>instance</th>
<th>80 km</th>
<th>100 km</th>
<th>120 km</th>
</tr>
</thead>
<tbody>
<tr>
<td>UK, –</td>
<td>142</td>
<td>95</td>
<td>75</td>
</tr>
<tr>
<td>UK, 2 Mio</td>
<td>148</td>
<td>98</td>
<td>86</td>
</tr>
<tr>
<td>UK, 1 Mio</td>
<td>163</td>
<td>114</td>
<td>106</td>
</tr>
<tr>
<td>UK, 200K</td>
<td>345</td>
<td>324</td>
<td>308</td>
</tr>
</tbody>
</table>
Resource sharing denotes by (the number of common nodes is used as a tie breaker). We greater disjointedness, that is, less common trail kilometers paths connecting the same LE to the same pair of MCs with we say that two paths conflict if there exists another pair of precisely, following the notion of maximal disjointedness p E we write m MC P lating distance and disjointedness constraints. That is, there is a trade-off between between the two opposed objectives. In fact, independent of the actual cost model (see also the next section) it is of interest to understand the structure of the solutions stemming from these two opposed extreme strategies: minimizing fiber kilometers and minimizing trail kilometers.

To obtain a solution following the second strategy we start from an existing solution with a fixed distribution of MC nodes and a fixed assignment of customers to MC nodes and modify the fiber routing such as to minimize the used trails kilometers. Clearly, this has to be done without violating distance and disjointedness constraints.

Let \( M(l) \) be the pair of MC nodes selected for LE \( l \in L \) and \( \mathcal{P}(l,m) \) a set of paths feasible for connecting LE \( l \) to MC \( m \) under the given distance constraint. We further denote by \( \mathcal{P} \) the set of all paths and for a given path \( p \in \mathcal{P} \) we write \( E_p \) to denote all trail edges in \( p \). We say that two paths \( p_1, p_2 \) are in conflict if they cannot be used together, that is, if they violate the disjointedness principle. More precisely, following the notion of maximal disjointedness we say that two paths conflict if there exists another pair of paths connecting the same LE to the same pair of MCs with greater disjointedness, that is, less common trail kilometers (the number of common nodes is used as a tie breaker). We denote by \( \mathcal{C} \) the set of all path conflicts.

\[
\text{(PC) } \min \sum_{e \in E} \text{length}(e) \cdot u_e
\]

\[
\sum_{p \in \mathcal{P}(l,m)} z_p = 1 \quad \forall l \in L, \forall m \in M(l) \tag{8}
\]

\[
z_{p_1} + z_{p_2} \leq 1 \quad \forall (p_1, p_2) \in \mathcal{C} \tag{9}
\]

\[
u_e \geq \sum_{p \in \mathcal{P}} u_e \quad \forall e \in E_p \tag{10}
\]

Model (PC) improves on the LE to MC assignment by choosing new fiber routes in such a way that the total length of commonly used trail edges is minimized. Equations \( 8 \) chose one path for every LE \( l \) and MC \( m \). Inequalities \( 9 \) avoid path conflicts and inequalities \( 10 \) are used to count the used trails whose length is minimized by \( 7 \).

Due to its exponential size it is not feasible to generate all possible paths as input to (PC). However, we use the following two path generation strategies two provide a reasonable large set of alternative paths for each of the LE, MC combinations:

- **Alternative Shortest Paths**: For each relevant (LE,MC) pair calculate the shortest path, add it to the set of paths, increase the weight of the path-edges, recalculate the shortest-path, etc. Repeat this for a limited number of iterations.

- **Steiner-Tree**: For each MC node \( m \) calculate a Steiner-Tree \( T \) connecting \( m \) and all \( l \) in \( L(m) \). Test all paths \( p = (l,m) \) in \( T \). If the path length \( d \leq d_{\text{max}} \) add path \( p \). Update the edge-weights, i.e., increase weight for used edges and repeat this a limited number of iterations.

<table>
<thead>
<tr>
<th>Inst</th>
<th>MCs</th>
<th>Trail km</th>
<th>Fiber km</th>
<th>Trail km</th>
<th>Fiber km</th>
</tr>
</thead>
<tbody>
<tr>
<td>UK 100km</td>
<td>95</td>
<td>68,534</td>
<td>8,357,047</td>
<td>-2.6%</td>
<td>+13.8%</td>
</tr>
<tr>
<td>UK 100km</td>
<td>98</td>
<td>68,774</td>
<td>7,834,669</td>
<td>-3.1%</td>
<td>+16.7%</td>
</tr>
<tr>
<td>UK 100km</td>
<td>114</td>
<td>69,232</td>
<td>6,891,754</td>
<td>-4.3%</td>
<td>+18.9%</td>
</tr>
<tr>
<td>UK 100km</td>
<td>324</td>
<td>68,813</td>
<td>4,714,023</td>
<td>-8.7%</td>
<td>+23.6%</td>
</tr>
<tr>
<td>UK 120km</td>
<td>75</td>
<td>68,617</td>
<td>8,324,820</td>
<td>-1.8%</td>
<td>+10.4%</td>
</tr>
<tr>
<td>UK 120km</td>
<td>86</td>
<td>69,032</td>
<td>8,979,285</td>
<td>-1.5%</td>
<td>+10.6%</td>
</tr>
<tr>
<td>UK 120km</td>
<td>106</td>
<td>69,010</td>
<td>8,437,198</td>
<td>-3.1%</td>
<td>+11.0%</td>
</tr>
<tr>
<td>UK 120km</td>
<td>308</td>
<td>69,385</td>
<td>6,297,866</td>
<td>-7.0%</td>
<td>+15.5%</td>
</tr>
</tbody>
</table>

Table 5 shows how the two extreme solutions differ in the total fiber length and the total trail length. Obviously, the used trail kilometers decrease by the fiber routing algorithm while the fiber kilometers increase. The trail length decrease is between 1 K and 6.5 K kilometers (between 1.5% and 9.7%) while the fiber length increase is between 0.8 Mio and 2 Mio kilometers (between 10% and 33%). Interestingly, we start from solutions (Table 5(a)) where the trail kilometers are relatively independent of the instance, that is, independent of the number of MC nodes (compare with Table 4). However, trail length minimization (Table 5(b)) is most effective for instances with more MC nodes, in particular for the 200K instances. With a restrictive customer bound at the MC nodes (200K) there is a trend towards shorter routes (even shorter than the distance constraints), which gives optimization more path alternatives within the distance constraint. In contrast, having only few MC nodes, many connections are close to the distance
constraint with few possible alternatives. For the extremest solution with only 75 MC nodes (Inf, 120km) there is not a big difference between minimizing fiber length or trail length.

5 Cost considerations

So far we have ignored the notion of cost. There is clearly a trade-off between the cost for the flat core network interconnecting the MC nodes and the cost for connecting LR-PONs to the core (fibers, cables, ducts). Computing the cost-optimal number of MC nodes from an end-to-end perspective is beyond the scope of this paper as the above approach concentrates on the LR-PON.

However, we have computed different solutions for MC node distributions in the UK plus different fiber routing strategies. These can be evaluated with different cost models to get some cost estimates.

The cost for the DISCUS network will be mainly driven by the cost for deploying the LR-PONs on a nation-wide scale and the cost for the flat optical core network. The solutions we wish to compare do not with respect to the optical distribution network between the customer and the LE, see Fig. 1 such we may ignore the cost for the corresponding fiber/cable/duct deployment, the cost for fiber drop and termination at the customers, the cost for splitters, ONU, etc., Regarding the LR-PON cost we can concentrate on the cost for fiber/cables/ducts on the stretch between the LE and the MC. Table 6 provides the DISCUS cost model for these network elements.

The main cost driver in the flat optical core is to provide a full mesh by optical channels between all MC nodes. The number of necessary transponders clearly increases quadratically with the number of MC nodes. We estimate a lower bound on the cost for the flat core by assuming a single 40G channel between any pair of MC nodes. The cost for the necessary 40G transponder (fixed grid) is also stated in Table 6. A similar value is used as a reference in the IDEALIST project [1].

Let us first of all compute a cost for the solutions in Table 5 considering the core network. We start with a simple cost model assuming the deployment of only cables with 240 fibers, that is the number \( n_{240} \) of such cables on a trail is computed as \( n_{240} = \left\lceil \frac{\text{count}}{240} \right\rceil \), where \( f \) is the number of fibers routed on that trail. We further assume that we need to provide duct build in 5% of all cases. That is, the cost for duct and trenching on a trail amounts to 3,315 € per km.

![Table 7](https://example.com/table7.png)

(a) Minimizing fiber route distance opposed to (b) Minimizing total trail kilometers. Cost in Mio € assuming cables with 240 fibers and 5% duct build cost.

The resulting total cost values for the nation-wide deployment are reported in Table 7. As expected the values based on the solution where trail kilometers are minimized are smaller (Columns (b)). However, the cost difference is surprisingly small between the two options of fiber routing. There is a notable difference only for the 200K solutions (5-9%).

![Table 8](https://example.com/table8.png)

(a) Minimizing fiber route distance opposed to (b) Minimizing total trail kilometers. Cost in Mio € assuming a cable model that depends on the fiber count and a duct model that depends on the cable count.

In fact it turns out that the difference strongly depends on the applied cost model. For the evaluation in Table 8 we applied more fine-grained assumptions on the cable and duct cost. First of all we deploy different sizes of cables depending on the actual fiber count on the trail. We ignore very large (> 240 fibers) and very small cables (< 48 fibers). If the fiber count is less than or equal to 48 (96, 144, 192) we install the corresponding cable and only if the count is at least 240 we use the same formula as for (7). This way the fiber count on the trails does not change but we do not over-estimate the cost by using big cables for small fiber counts as in Table 7. Notice that the cable cost in Table 8 decreases by 40-60%. Similarly, for the duct build probability we assume that it actually depends on the number of deployed cables and apply the function indicated in Fig. 6.

In this function the duct build probability starts with 3% for 1 cable and increases by 3%, 7%, 10% for cable counts

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Table 6 Cable and duct build cost as defined within the DISCUS project, see [6, 9].

<table>
<thead>
<tr>
<th>Type</th>
<th>Provides</th>
<th>Cost in €/Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duct</td>
<td>Duct-Space</td>
<td>66,300 Kg</td>
</tr>
<tr>
<td>Cable</td>
<td>276 fibers</td>
<td>7,859 Kg</td>
</tr>
<tr>
<td>Cable</td>
<td>240 fibers</td>
<td>7,145 Kg</td>
</tr>
<tr>
<td>Cable</td>
<td>192 fibers</td>
<td>6,145 Kg</td>
</tr>
<tr>
<td>Cable</td>
<td>144 fibers</td>
<td>5,145 Kg</td>
</tr>
<tr>
<td>Cable</td>
<td>96 fibers</td>
<td>4,145 Kg</td>
</tr>
<tr>
<td>Cable</td>
<td>48 fibers</td>
<td>3,145 Kg</td>
</tr>
<tr>
<td>Cable</td>
<td>24 fibers</td>
<td>2,716 Kg</td>
</tr>
<tr>
<td>Cable</td>
<td>12 fibers</td>
<td>2,430 Kg</td>
</tr>
<tr>
<td>Transponder</td>
<td>1x40G Port</td>
<td>24,000 Piece</td>
</tr>
</tbody>
</table>
2-5, 6-10, > 10, respectively, with a maximum of 90%. Also the duct cost decreases from Table 7 to Table 8 which means that there are many trails in the field with only a small fiber count for both fiber routing strategies. Surprisingly, comparing the two strategies in Table 8, it turns out that minimizing the trail kilometers does not improve on the overall cost for almost all instances. The cable cost increases from (a) to (b) because strategy (a) leads to many small cables, which are cheaper. The resource sharing does not pay off. Moreover, assuming to have duct build only in case of many cables also leads to an increase in the duct cost from (a) to (b) simply because strategy (b) forces fibers (and thus cables) to share common ducts. Again the decrease in the kilometer cost does not pay off the increase in the resources on these trails.

Optical Island Cost

We conclude with the observation that the total cost does not significantly differ among the different MC node distributions. Clearly, as expected it is cheapest with respect to cable and duct deployment to have many MC nodes as the fiber distances from customer to MC is smallest. For the solution with 345 active nodes we get a total cost of 680 Mio € (436 Mio €) with the cost model Table 7 (Table 8) while for the solution with only 75 nodes we pay 856 Mio € (628 Mio €) which is a difference of only 185 Mio € (192 Mio €).

However, the difference in the flat core cost is significant, even if we assume a lower bound with only one 40G link everywhere. For 75 nodes we pay 133.2 Mio € (5550 transponders) while a 345 node solution costs already 2,848 € (118,680 transponders). Clearly, one may argue that a flat core is not optimal. However, a simple calculation yields that also solutions with smaller interconnected optical islands of size at most 50 nodes leads to cost differences of more than 200 Mio € and these solutions are not as simple and do not scale as well with increasing traffic volumes as a single optical island.

6 Conclusion

Connecting all customers in the UK via (long-reach) passive optical networks to so-called metro-core nodes following the DISCUS [12] architecture, we studied the consolidation and distribution of these nodes under different side constraints such as resiliency strategies, the optical reach of the PONs, the maximum node size, an the fiber routing algorithm. We also elaborated on the deployment cost with different assumptions on the used cables and the duct build.

Acknowledgment

The authors would like to thank Andrew Lord and Paul Wright from BRITISH TELECOM for many fruitful discussions and the detailed data they were able to provide to us.

7 Literature


