The Cost of Nationwide Fibre Access in Germany

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Abstract: It is common knowledge that Next Generation Access (NGA) networks require significant investments and that for many regions, especially in more rural areas, there is no viable business case. In this paper a bottom-up cost modelling approach is applied to determine the investment and cost of deploying and operating a FTTH network in Germany on a national level. The monthly cost per subscriber at various levels of penetration is compared with the Average Revenue Per User (ARPU) to determine the penetration level or the required revenue for profitable operation in a steady market state. Those regions for which there is no business case are analysed with regard to the level of required subsidies. The modelling is based on differentiated geotypes reflecting urban and rural areas. The basic cost model used has been applied to numerous case studies before and was adapted to determine different forms of subsidies.The research questions addressed are (1) What is the area of profitable FTTH coverage in Germany? (2) What is the level of prices, internal subsidisation or investment subsidy necessary to increase the coverage of FTTH in Germany? These results inform policy makers and operators of the relevant investment deltas and/or price levels needed to increase the coverage of next generation broadband access infrastructure.

Key words: next generation access, FTTH, cost modelling, GPON, P2P, broadband strategy.

■ Goal and methodology

It is common knowledge that Next Generation Access (NGA) networks require significant investments and that for many regions, especially in more rural areas, there is no viable business case. In order to increase the profitable coverage of Germany with fibre access networks some options are conceivable and addressed here: 1) End users can pay a higher monthly price. 2) The operators can use profits from profitable areas to subsidise deployment in non-profitable areas. 3) The network investment could be subsidised to the point that makes network operation profitable for the investor. Such subsidisation could e.g. be one-time connection fees from end-users or funds from the state budget.

The objective of this paper is to analyse the investment requirements for rolling out fibre networks nationwide in Germany, to determine the area of profitable operation and to assess the level of subsidies needed for extending the range of profitable operation. To this end, a bottom-up cost model was applied to determine the investment and cost of deploying and operating a FTTH network in Germany on a national level. The model assumes a steady state in the future where the existing copper network has been completely substituted by the new fibre network. This is a long-term view towards market structure and neither incorporates the additional cost of parallel operation of fibre and copper networks nor the cost of migration.

Previous research by the authors for Germany did not incorporate geodata or the determination of subsidy requirements (see ELIXMANN *et al*., 2008; DOOSE *et al*., 2009). Subsidy requirements were already calculated by the authors in a 2009 cost study for Switzerland (see ILIC *et al*., 2009).

For this exercise detailed geodata of Germany was available, such as the location of Main Distribution Frames (MDF), location of buildings, georeferenced road networks and statistical data of households and businesses. The work was conducted in four steps:

- Extensive processing of geodata: at the end of the process geo-coded data for MDFs, buildings, streets etc. was prepared as input into the model.
- Delineation of access areas, determination of distribution point locations and trench lengths: the MDF locations were considered as given ("scorched node"). The model endogenously determined the trenches and distribution point locations to connect all customers (~43mn lines). For each of the 7731 MDFs trench lengths, customers, buildings, distribution points, etc. were determined.
- Aggregation of MDF data into 20 clusters: for simplifying the calculations MDFs were aggregated to 20 clusters of equal size in terms of number of customers defined by customer density. Investment, cost and profitability are determined for each cluster.
- Determination of subsidies for loss-making clusters.

Three FTTH architectures were analysed: Ethernet Point-to-Point (P2P), GPON and GPON over P2P. A brief description of these architectures is included in the assumptions section in the following chapter.

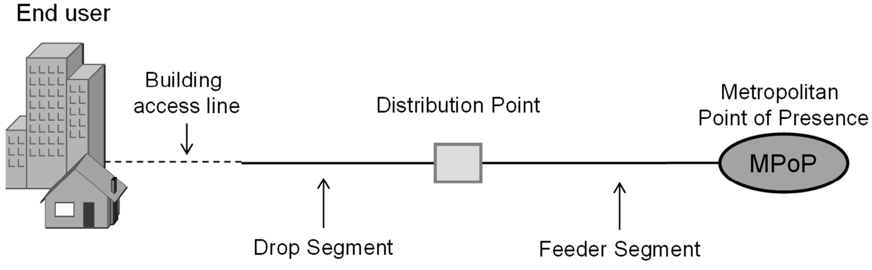
■ Key assumptions

Geo-data processing

Structural input data was obtained from the federal ministry of economics, federal and state statistic offices, the federal agency for cartography and geodesy as well. The road network used was sourced from TeleAtlas. MDF-locations of the German incumbent operator (taken from the Ministry of Economics' "Broadband Atlas") have been treated as scorched node and transformed to MPoPs (Metropolitan Point of Presence) of the Next Generation Access network. Delineation of access areas was conducted with the bottom-up model that associated all 10 mn German street segments to the nearest MDF and determined access area polygons on top of the street layer. The algorithm was configured to respect distance criteria. MDF locations are those of the German incumbent but MDF areas and distribution point number and location have been determined in the model (i.e. they are not identical to the incumbent's network). The model differentiates between the following network segments (see figure 1):

- The feeder segment extends from the MPoP to the distribution point (street cabinet).
- The drop segment extends from the distribution point to the street in front of the building.
- The building access line segment extends from the street in front of the building to the building entry point.

Figure 1 - Access network segments



It was assumed that the feeder and drop segment were deployed for 100% of potential customers (independent of penetration) while the building access line over (partly) private ground and the inhouse fibre were only deployed for active subscribers. All trenches were deployed along the German road network.

All MDF with less than 2000 customers (about 1650 locations, about 20% of all MDF) were modelled as passive nodes to reap scale benefits. The only investment in this case is a large manhole (no plant room setup and rental, no active equipment and power that is considered in the Greenfield setup of the active MPoP locations). Customers of these MDF were connected to the nearest remaining active MPoP respecting a maximum distance of 30km. A detailed analysis of the optimal number and location of MDFs/MPoPs has not been conducted and is a field for further research. In this interpretation and for the architectures considered the MPoP is the first point where active equipment lights the fibre towards the end user.

Cluster aggregation

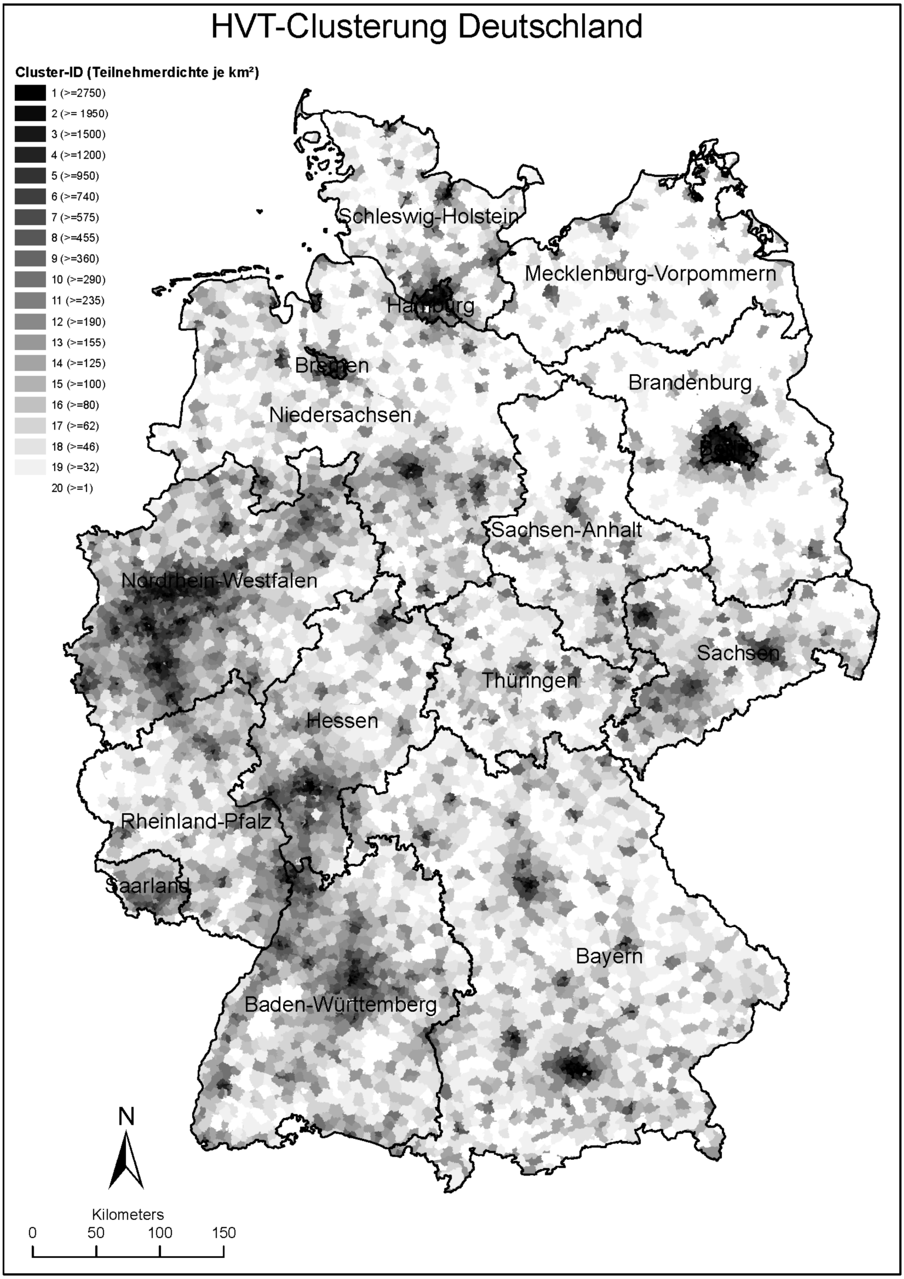
MPoPs were sorted by customer density in descending order. Then MPoPs were grouped in 20 Clusters by first aggregating 5% of all customers per cluster and readjusting for even customer density thresholds. Therefore, clusters (~ "geotypes") roughly include 2.1mn customers or 5% of the total national customer base (about 43mn potential customers composed of about 40mn households and about 3mn business users).

Absolute values were summed up over all MPoPs of a cluster (e.g. total number of MPoPs, distribution points, customers, buildings, and trench meters). Relative values were determined as average for this cluster (e.g. customers per MPoP equals total customers divided by total number of MPoPs in a cluster).

A comparison of the spatial distribution of customers reveals a strong concentration: the 80% densest concentration of customers (clusters 1-16) inhabit about 1/3 of Germany. The next three clusters 17-19 also account for 1/3 of the area and the last cluster alone accounts for another third.

The overall concentration of customers can also be noted from the relatively small dark patches of high customer density compared to the dominant low density light grey or white on the map of Germany in figure 2.

Figure 2 - MDF area clustering in Germany (*)



(*) "HVT Clusterung Deutschland" = MDF clusters Germany

"Teilnehmerdichte pro km²" = customer density per km²

Investment, cost and profitability determination

A bottom-up cost model for fibre based access networks was applied (the "WIK NGA model"). It determines investment of the access network components in detail while approximating the cost of concentration and core network through cost functions. A Greenfield fibre deployment was assumed.

The large majority of cables are deployed underground and all of these are deployed ducted. We assumed a small part of aerial cabling (5% each in the last 5 clusters) for which lower investment but higher OPEX is required. CPE investment is considered at 100€ for P2P Ethernet and 115€ for GPON (lifetime 5 years). 1000€ investment per GPON OLT port and 120€ per P2P Ethernet switch port is considered (lifetime 7 years). Civil works cost (trenching, duct and cable) are considered from 120€ in cluster 1 to 40€ in cluster 20.

The model converts investment [1] into monthly cost (CAPEX) by taking account of asset lifetime and Weighted Average Cost of Capital (WACC, 10% in this study). Accordingly, the cost determined includes the risk-adjusted weighted average cost of capital. Profits are therefore profits that exceed the return on interest of capital.

Operating Cost (OPEX) is primarily determined through mark-ups on investment (8% for active equipment, 0.5% for passive infrastructure). Some positions such as floorspace rental and MPoP energy costs are also calculated bottom-up as direct cost. Common Cost is also considered as a mark-up on CAPEX and OPEX (10%). In addition to the access network investment in an IPTV platform and retail costs for customer acquisition, marketing, billing etc. is accounted for (5€ per subscriber and month) [2].

The monthly cost of the nationwide concentration network that connects MDF locations to core network nodes was assumed to be 22.5mn€ fixed cost and 0.7€ per subscriber. Similarly, monthly core network cost was considered as a cost function with 6mn€ fixed cost and 1.08€ per subscriber.

The model assumes a steady state in the future where the existing copper network has been completely substituted by the new fibre network.

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[1] In addition to the direct investment determined bottom-up, indirect investments for assets such as buildings, vehicle fleet, workshops etc. is calculated as mark-up on direct investment.

[2] This figure is probably at the lower end.

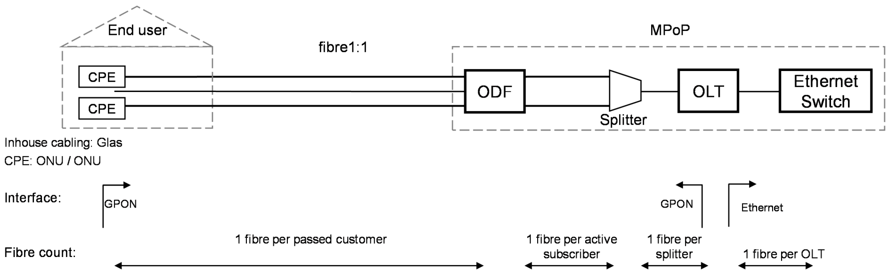
This is a long-term view towards market structure and incorporates neither additional cost of parallel operation of fibre and copper networks nor the cost of migration. The latter also includes the cost of running the network at low penetration rates, i.e. at high costs per user, initially. It should be noted that the cost of migration is likely to be significant and as such would reduce the profitability deduced in this paper. On the other hand, having a large customer base that can be migrated is probably a very important asset when it comes to quickly realising high penetration rates.

When checking for profitability the monthly Average Revenue per User (ARPU) is compared with the monthly cost per user. The maximum take-up of the NGA is assumed to be lower than 100% of homes passed since a share of all potential customers for which the network is deployed will select cable or mobile-only services (or not use telecommunication services at all). Today the fixed network penetration in Germany is about 80%. In this analysis a maximum penetration of the fibre access network or the market share of the fixed network (without cable networks!) within a given cluster is assumed to be 70%.

Considered NGA architectures

Three FTTH architectures were considered in our calculations. FTTH/P2P uses Ethernet technology to light a Point-to-Point passive network topology. It provides one fibre for every customer between the customer and the MPoP. FTTH/PON uses GPON technology to light a Point-to-Multipoint passive network topology with remote splitters in the field. The topology has individual fibres in the drop segment and shared fibres in the feeder segment (splitting factor 1:64). GPON over P2P uses GPON technology to light a Point-to-Point passive network topology with splitters located centrally at the MPoP. The combination of a Point-to-Point topology with GPON active technology in the MPoP is visualised in figure 3. The advantage of this architecture is that it has a high degree of flexibility regarding customer bandwidth management. By adjusting the splitting ratio customers can be provided with different levels of (guaranteed) bandwidth and GPON active electronics can always be run on high levels of efficiency independent of the actual penetration. The investor can also provide individual customers with P2P Ethernet links. In addition, this retains the option of unbundling individual customers at the MPoP location. A more detailed description of these FTTH architectures can for example be found in HOERNIG *et al*. (2010).

Figure 3 - GPON over P2P



For every FTTH architecture scenarios with and without inhouse cabling cost were calculated as both home-owners and operators might have to bear this cost.

■ Investment, cost and limits of profitability

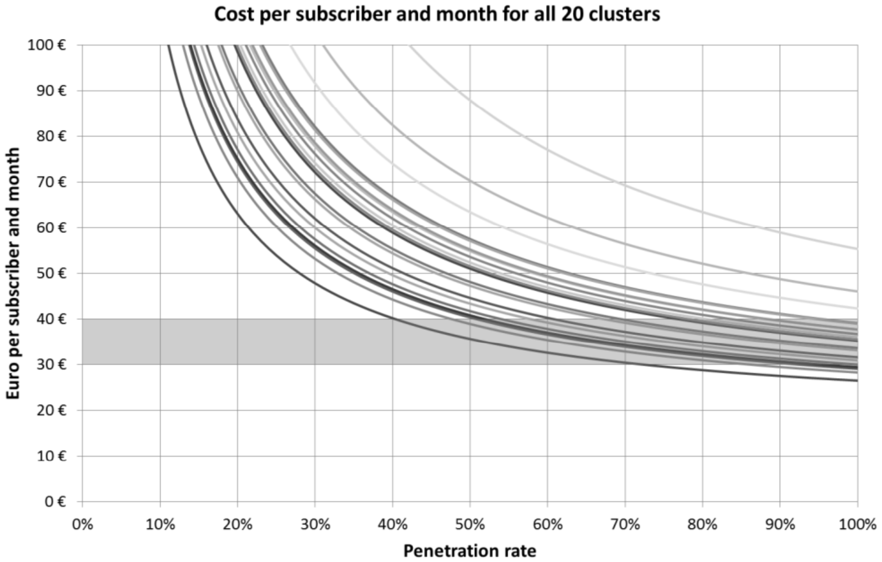
In this chapter investment, cost and profitability of rolling out NGA to all of Germany through 20 clusters is determined. The analysis is conducted in detail for one architecture (FTTH/P2P without considering the cost of in-house cabling) but results for all scenarios are shown.

Impact of penetration on cost per customer

The total monthly cost per subscriber is strongly dependent on the take-up rate because of the high degree of fixed cost in the access network. This is shown clearly in figure 4 in which every line represents one cluster with cluster 1 (most dense) being bottom left and cluster 20 (least dense) top right. The cost shown here is the total cost including the passive access network, the active equipment, concentration and core network cost, marketing, customer support etc.

The level of current averaged revenues in Germany is estimated to lie between 30€ and 40€ which has been visually highlighted in figure 4. This allows two different analyses: first, one can fix an ARPU level and analyse the necessary penetration required to operate profitably, i.e. with lower cost than revenues per user. Second, one can fix a penetration level and determine the necessary ARPU that allows profitability at this level of penetration.

Figure 4 - Monthly total cost per subscriber
(example FTTH/P2P without considering the cost of inhouse cabling)



Considering for example the 40€ mark as ARPU, figure 4 shows that Cluster 1 needs at least 40% penetration, Cluster 2 a little bit less than 50% and so on. Notably, clusters 18-20 always have a cost per user that is above 40€ per month. At 30€ per month only some of the densest cluster ever break even.

At penetration rates below 40% revenues would need to be very high to sustain profitable operation. Considering the maximum penetration of 70% for the NGA suggested by the authors, prices of many clusters lie above the perceived 30-40€ range. Clearly, the penetration has a strong impact on cost per customer and profitability (see following section).

Investment and profitability

For the following results penetration was fixed at 70% reflecting a situation in which the copper network was completely replaced by fibre and other access platforms (such as mobile and broadband cable) as well as non-users make up 30% of the market. With the penetration set at this level the total investment to deploy and operate a nationwide fibre access network is in the range of 70-80 bn€. The first nine clusters require only 33% of investments but contribute 45% of customers. The last 5 clusters also require 33% of total investments but contribute only 25% of customers. As expected, less dense clusters contribute relatively more to the overall investment volume. If one only covered clusters 1-15 (the 80% densest customers that make up only 1/3 of Germany's space) the investment reduction is about 30%.

Comparing investments per customer, these range from about 1.300€ in dense areas to 4.800€ in less dense areas. Table 1 details investment components that together account for 97%-99% of total investments. It is immediately evident that the passive network from the ODF-port at the MPoP to the sleeve at the street in front of the building accounts for by far the largest share of total investments (at least 2/3). The building access accounts for about 15% and inhouse cabling (where applicable) for about 7% of total investments. Together the passive network detailed here (FTTR - Fibre to the Road [3], building access, inhouse cabling) accounts for roughly 80%-90% of total investments.

There are relatively small differences in investment, considering e.g. P2P and GPON the difference for a nationwide roll-out and operation at 70% penetration in Germany is only 5%. The reason is that most items of the dominant investment positions are identical for all architectures in a Greenfield deployment. Inhouse cabling, building access and the drop segment between the building's street and the distribution point are identical for all FTTH networks. The differences between point-to-point and point-to-multipoint topologies lie in the distribution point, the feeder segment and the ODF at the MPoP which are all part of the line FTTR in table 1. The splitter at the distribution point is only required for the PON case. In the feeder segment PON requires fewer fibres. However, in most cases this does not lead to smaller trenches so civil works cost remains comparable in a Greenfield deployment. In a Brownfield environment where existing ducts can be used the situation is a little different. The most favourable case would be the free access to ducts. [4] In this case one can consider the different probability that ducts exist in a desired location and that they have enough free space and sufficient remaining asset lifetime to host the fibre cables of the FTTH network.

[3] Fibre to the Road: drop network, distribution point, feeder network, customer sided ODF-ports at the MPoP and associated floorspace.

[4] If duct access was priced at cost, access charges would probably be at a similar level as that of deploying new ducts.

Table 1 - Key investment components for nationwide rollout in 20 clusters at 70% penetration

	P2P	*P2P + inhouse*	*PON*	*PON + inhouse*	*GPON over P2P*	*GPON over P2P + inhouse*
Total invest (bn €)	72.78€	77.82€	69.31€	74.35€	70.86€	75.90€
FTTR	73% 52.78 €	68% 52.78 €	76% 52.95 €	71% 52.95 €	74% 52.78€	70% 52.78€
Building access line	15% 11.18 €	14% 11.18 €	16% 11.18 €	15% 11.18 €	16% 11.18 €	15% 11.18 €
Inhouse cabling		6% 5.04 €		7% 5.04 €		7% 5.04 €
CPE	5% 3.31 €	4% 3.31 €	5% 3.81 €	5% 3.81 €	5% 3.81 €	5% 3.81 €
Active equipment at MPoP	5% 3.99 €	5% 3.99 €	2% 1.12 €	2% 1.12 €	1% 0.68 €	1% 0.68 €
Rest [(*)]	2% 1.52 €	2% 1.52 €	0% 0.26 €	0% 0.26 €	3% 2.41 €	3% 2.41 €

[(*)] Network sided ODF ports, space for active equipment at the MPoP, central splitter for GPON over P2P, IPTV platform

This probability will be the same for all architectures in the drop segment but differ between Point-to-Point and Point-to-Multipoint topologies in the feeder segment due to the difference in fibre count. In this study it was assumed that the degree of ducted cabling of the German copper infrastructure (which is assumed to be the basis of potential existing ducts) depends on the cluster and that in less dense clusters the degree of ducted copper cabling is very low. This leads to Brownfield results that do not change the profitable reach very much but only make the business case more attractive in those dense clusters that are profitable anyway. Total investments of PON are reduced by about 3% when considering all clusters (2% for P2P). When considering only the first ten clusters the investment reduction for PON is about 7% (5% for P2P). If other infrastructures were available (e.g. utility assets) this could increase the reduction and ultimately the level of subsidies required.

Expectations about the willingness to pay of end users are another critical pillar of the profitability analysis. It is fair to say that it is quite uncertain how much end users might be willing to pay for services on future broadband networks. So far analysis has been conducted in a band between 30€ and 40€ where German revenues would likely be. [5] For the following

[5] Confirmed by a survey of German retail prices in August 2011.

calculations a mix of single, double, triple play and business customers was chosen that leads to an ARPU of 38€ per subscriber per month as a reference point. For the German market this is probably at the upper end of achievable revenues and could be interpreted as including a certain willingness to pay more for high speed broadband services. Such a willingness to pay for bandwidth above 16Mbps was measured as about 5€ in a recent study by HOFFMANN (2010).

The intersection of cost curve and ARPU (see figure 4) leads to the minimum penetration required for profitability. These critical penetration rates are shown for all architectures in table 2. Critical penetration rates can implicitly be interpreted as being the aggregate of retail and wholesale business even though the analysis has strictly speaking only been conducted on the basis of retail revenues.

Instead of fixing the maximum penetration at 70% one may consider a different maximum penetration rate such as 60% and check the critical penetration rates cluster by cluster to determine the limits of profitability likewise, e.g. at 60% maximum achievable penetration P2P only reaches 5 clusters.

Table 2 - Critical penetration rates at 38€ ARPU

Cluster	*Cumulate share of customers*	*FTTH/P2P*	*FTTH/P2P + inhouse*	*FTTH/PON*	*FTTH/PON + inhouse*	*GPON over P2P*	*GPON over P2P + inhouse*
1	5%	45%	54%	40%	47%	40%	48%
2	10%	53%	63%	47%	55%	48%	56%
3	15%	56%	67%	50%	58%	51%	59%
4	20%	58%	67%	51%	58%	52%	60%
5	25%	60%	70%	54%	61%	54%	62%
6	30%	64%	75%	57%	65%	58%	66%
7	35%	68%	78%	59%	67%	61%	69%
8	40%	75%	86%	66%	73%	67%	76%
9	45%	77%	88%	68%	75%	69%	78%
10	50%	86%	96%	75%	82%	77%	85%
11	55%	87%	97%	76%	83%	78%	86%
12	60%	90%	100%	78%	86%	80%	88%
13	65%	93%		81%	87%	83%	91%
14	70%	99%		85%	91%	88%	95%
15	75%	99%		86%	93%	88%	96%
16	80%			91%	94%	95%	99%
17	85%			91%	94%	95%	99%
18	90%						
19	95%						
20	100%						

While the three architectures have all been analysed for profitability with the same ARPU they have in fact differences (not only) related to the peak and sustained bandwidth per user. Accordingly, if these differences are valuable to customers, they should also have a different level of willingness to pay. This was not considered in this study but elaborated in HOERNIG *et al*. (2010).

Comparing P2P and GPON, GPON has lower critical penetration rates than P2P (or any other architecture) in every cluster because it is overall the cheapest concept. Assuming the 70% threshold, GPON's profitable reach is 9 clusters of Germany which represents 45% of all customers. P2P only reaches 7 clusters (35% of customers). Interesting to note is that GPON over P2P has very similar requirements regarding the critical penetration rate as GPON. When comparing the total investments of GPON and GPON over P2P in table 2 the investment requirements are also very similar (2% difference). Considering that the latter architecture is much more flexible regarding future bandwidth requirements and in addition enables unbundled access to fibre at the MPoP this appears to be a strong argument in favour of such a hybrid concept.

Results show that NGA deployment in Germany can only be profitably realized for less than half of all customers. If the investor bears the cost of inhouse cabling without raised revenues the profitability is reduced to about 25% to 35% of the densest customers.

The primary key issue for profitability is the penetration rate. Network operators must realise high penetration rates, e.g. in order to produce a total cost below 40€ per customer per month the penetration has to be higher than 50% even in the most dense areas (see figure 4).

Especially the passive access network is characterized by high fixed cost that is driven purely by coverage requirements and not by the number of actual subscribers (usually more than 70-80% of total cost is related to the passive access network). In the Greenfield investment situation assumed here the cost difference between architectures is therefore relatively small.

All results shown here are based on the assumption that the investor passes all customers with the network in any given cluster. However, an investor could also select his roll-out area on the basis of street segments with a preference (among other factors) for multi-dwelling units with a high willingness to pay. Such an investor which "cherry picks" areas and therefore does not pass 100% of the customers in a cluster will produce at significantly lower cost per customer. He will therefore also be able to operate profitably at lower critical penetration rates and might be able to extend the limits of profitability to less dense clusters, too.

Still the assumption of full coverage reflects requirements of the market. At least in denser clusters operators will have to strive for copper network substitution in the long run in order to reduce the cost of parallel network operation and to be able to apply marketing as homogenously as possible. Furthermore, the primary goal of public broadband strategies is the area-wide rather than the spotted availability of broadband access.

Benchmark of results with other studies

Only very few publicly available cost modelling exercises are comparable with the one used in this paper. Among those only ANALYSYS MASON (2008) contains an explicit cost model differentiating between costs for P2P and GPON. Analysys Mason also conclude that the difference between GPON and P2P is relatively moderate, although the difference is more pronounced than the results in this paper. According to their study GPON is on average about 15% cheaper than P2P when considering a national roll-out (at a take-up of 31%). This value varies between about 10% and 30% depending on geographical area and take-up rate. These geographical differences between GPON and P2P are similar to the results in this paper. The difference in investment between the densest and least dense geotypes is about factor 4 in the Analysys Mason study which still fits well with results presented here. It is also comparable with results presented in HOERNIG *et al*. (2010) where the same cost model as in this paper was applied.

FISCHER (2009) distinguishes between three scenarios regarding duct availability and impact on the cost difference between P2P and GPON: with plenty of ducts and only little civil works required for P2P and GPON the difference in cost is only 5%. In case there are only limited ducts that require more civil works for P2P than for GPON the cost difference is 25%. When there are no ducts available and civil works have to be conducted for both architectures (Greenfield) the cost difference is only 2%. This compares well with findings in this paper.

Measures for increasing the profitable coverage

In order to increase the profitable coverage of Germany with fibre access networks three options are addressed here. 1) End users can pay a higher monthly price. 2) The operators can use profits from profitable areas to subsidise the fibre roll-out in non-profitable areas. 3) The network investment could be subsidised (externally) to the point where the network can be operated profitably by the operator. Such subsidisation could e.g. be a one-time connection fee from end-users or subsidised funds from the state.

The calculation is shown in detail exemplarily for FTTH/P2P without cost of inhouse cabling. Results for all architectures are described in JAY *et al*. (2011).

Prices

The basis for identifying the price level required for profitability is the cost per customer and month in the 20 clusters. If prices were set regionally differentiated they would lie between 30€ and 70€ per customer per month at 70% penetration. If prices would be set at that individual cluster-specific value there could be nationwide coverage of a fibre network without any internal or external subsidy. If a single national price was to be set based on the average cost of all customers this price would have to be about 43€ per customer per month. At 40€ ARPU monthly prices need to be subsidised by between 2€ (Cluster 10) and 29€ (Cluster 20). At an ARPU of 30€ no cluster remains profitable.

With an ARPU of 38€ the total loss in non-profitable clusters (Clusters 8-20) is divided by all subscribers to identify the premium all customers would have to pay to support the non-profitable clusters while leaving profits in profitable areas to the operator. This leads to a premium of about 6€ which increases the uniform end-user price to about 44€ per customer per month at 70% penetration.

Internal subsidy between profitable and non-profitable clusters

So far the investment decision has been based on a profit maximising investor. Such an investor will maximise his profits by deploying the network as long as a profitable return (in this calculation in excess of return on capital) is achievable. Cluster 7 still shows a slight profit while cluster 8 is the first loss making cluster. Accordingly, the profit maximising investor would invest only in clusters 1-7.

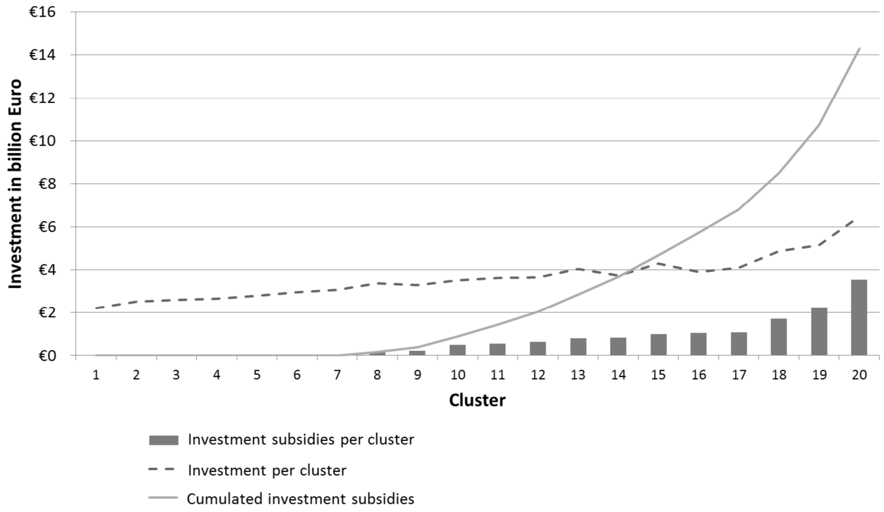
Now, it is hypothetically assumed that operators would be willing to use profits in excess of return on capital to subsidise clusters that are non-profitable. This assumes a welfare-maximisation goal in the sense that higher coverage with fibre access is welfare enhancing. Since the sum of all profits is smaller than the sum of all losses across all clusters one cannot achieve national profitability this way. If one used all the profits from clusters 1 to 7 to subsidize losses in the next best cluster, the profitable reach could be extended to cluster 13 and losses in cluster 14 could be reduced by about half. The situation in clusters 15 to 20 would not change.

One-time investment subsidy

To increase the profitable reach of fibre access networks in Germany investment subsidies are conceivable, e.g. in the form of investment sharing with the building owner. The total investment per customer for FTTH/P2P (without considering the cost of inhouse cabling) ranges from about 1.500€ in cluster 1 to about 4.300€ in cluster 20. In clusters 8 to 13 moderate investment subsidies of up to 500€ per fibre access line would be sufficient to make the case for the investor profitable. In the last cluster, however, subsidies would need to be in the range of 2.300€ per customer.

Figure 5 shows total investment per cluster (dashed line), the required subsidies per cluster (columns) and the cumulated subsidies at 70% penetration and 38€. The line of cumulated subsidies shows e.g. at cluster 15 that the investor needs around 5 bn€ from other sources to make the investment in clusters 8 to 15 also profitable. In the same way the value for cluster 20 shows that a national roll-out would require about 14 bn€ subsidies to make all clusters profitable at 70% penetration and 38€ ARPU. The figure also reveals that the last three clusters account for over half of all required subsidies. Hence, if the state was to make funds available for extending the NGA roll-out to all customers in Germany it would have to provide at least 14bn€.

Figure 5 - Total investment and required subsidy per cluster as well as cumulated subsidies in bn€: FTTH/P2P without inhouse cabling at 70% penetration and 38€ ARPU



■ Conclusions

The coverage of all German customers with FTTH and the operation of the network at 70% penetration requires Greenfield investments in the range of 70 to 80 bn€. The differences in investment between the architectures are relatively small in the range of a few per cent. The reason is that most investments into the passive access network that make up 80-90% of total investments are identical for the considered architectures (inhouse cabling, house access line, drop cable segment). Even in the feeder segment between distribution point and MPoP GPON only has limited cost savings in a Greenfield environment because civil works have to be conducted anyway and do not scale much with the observed fibre count.

Sensitivities show that even with free access to ducts of the old copper network the profitable reach cannot be significantly extended because especially the rural areas of Germany were assumed to have limited ducted copper infrastructure in the first place. However, with (free) access to other infrastructures (e.g. other telecom networks, electricity, gas, etc.) the potentials of Brownfield could be increased. Here, initiatives such as infrastructure registers could help in identifying potentials and increasing the profitable reach.

Anyway, nationwide coverage with fibre is not economically possible without a form of subsidy since results have shown that the limits of profitability are about 20 to 45% of the densest German customers at the considered ARPU. The profitability of fibre access is critically dependent on the penetration. Investors must realize high penetration rates for ubiquitous deployments (all homes in a cluster are passed) such as assumed in this study. In this case penetration rates have to be above 40% and often above 60% even in the more dense areas. On the other hand, investors that do not roll out the network to all customers of a given cluster but only focus on e.g. 80% of all potential customers of that cluster will very likely be able to save (much) more than 20% of the cost of deploying the network to all customers. This is because in practice it becomes increasingly expensive to pass more customers. An investor which "cherry-picks" on a street segment base should therefore be able to produce at lower cost, would require lower critical penetration rates and potentially extend his reach to other clusters. In this study however, the fibre network is rolled out to the road in front of the customer buildings for all customers, so there is no "cherry-picking". This approach was necessary for the goal of this study even though it does not reflect the initial deployment phase of a real life investor. It is still valid though for analysing the long-term competitive situation of the fibre access network.

Two aspects follow from the finding that penetration rate is so critical: first, wholesale business is important to increase the load of the network (quickly). Second, it appears next to impossible to realize ubiquitous coverage at the required high penetration levels in a parallel operation of the old copper and the new fibre network. In the long-run the substitution of the old copper infrastructure is therefore a key requirement for the fibre investor. However, in reality opportunity cost - cannibalization of copper profits - reduces the incentives for investing into fibre (see HOERNIG *et al*., 2011).

But even at the high end of penetration rates (70% was assumed to be the maximum achievable penetration level for the new fixed network) in many clusters the cost is too high to be profitable at current price levels. Accordingly, users would have to pay a higher price in order to bring broadband to less dense areas of Germany. In the last cluster customers would have to pay an average price of 70€ per month. Alternatively, users could participate in the investment to connect their home. Depending on the degree of losses occurred in a non-profitable cluster this would range between a few hundred€ and over 2,000€ in the last cluster. The total volume of such one-time investment subsidy is between 11 and 17 bn€.

In most of the detailed results shown the cost of the inhouse cabling was allocated to the sphere of the building owner. If the investor has to bear it himself this will increase the total investments by at least 5 bn€. This value is probably conservatively low since the deployment not only includes the technical realisation that was considered here but also the legal and administrative cost of preparing the deployment. The latter were not considered in this calculation and would reduce the profitable reach of fibre access. In all scenarios the investor fully paid the building access line. If building owners were to bear this cost the investor would be relieved of a volume of around 11 bn€ so this could potentially be an important starting point for sharing the investment as it is already common practice in new building areas.

To realize nationwide coverage with fibre access regionally differentiated prices and investment subsidies were discussed. Finally, all NGA customers could also pay the same price including a broadband premium that is sufficient to cover the losses incurred in the non-profitable clusters. The level of such a premium critically depends on the penetration and the base line ARPU because they define the level of profitability throughout all clusters.

The critical success factors of fibre access are therefore primarily the achievable penetration rate and the willingness to pay of end users. Furthermore, the willingness of end users to bear parts of the investment determines to what extent the profitable coverage can be extended further. Due to the additional cost of parallel network operation and the necessity of high penetration rates the speed of migrating from copper to fibre is another important factor. Establishing wholesale products quickly and activating demand from the market will therefore be another pillar in realizing profitable coverage with fibre access networks, not only in Germany.

Further research should be dedicated to the relevance of FTTC with VDSL which has not been addressed in this study. While it would generally cut investments by reusing the existing copper drop network it will not allow uniform bandwidth provision due to the dependency of bandwidth on line lengths. Especially in less urban areas the long sub-loop lengths might require extension of fibre (or microwave links) to other locations than the existing distribution points.

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