

# Techno-Economic Analysis of Deployment Options for Converged 5G Wireless-Optical Access Networks

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**Abstract** - Currently, a lot of efforts are put in place to design and implement a high-capacity, flexible and highly efficient 5G network infrastructure. A very important consideration that should be kept in mind when designing future 5G networks is developing an adequate network architecture and high-capacity and future-proof backhaul and fronthaul links. Especially novel network concepts such as the cloud radio access network (C-RAN) set very high requirements on the backhaul and fronthaul connectivity and call for a solution that ensures high-capacity, flexibility, practicability and future readiness while providing an easy and economical migration path.

This paper examines deployment options for converged optical-wireless access networks in urban areas regarding their cost efficiency and implementation flexibility. It presents results of a case study for a coordinated planning of optical fixed access and wireless backhaul solutions for 5G networks by considering following options: i) roll-out of a converged fiber-to-the-home (FTTH) network infrastructure that provides both fixed internet access and integrated cellular backhaul, ii) use of the existing fiber-to-the-curb (FTTC) network infrastructure to provide the backhaul for cellular networks, and iii) deployment of a dedicated optical fiber network to act as backhaul of cellular networks. A techno-economic study was carried out to compare the economic viability of the three deployment options under realistic assumptions.

**Keywords** - *Wireless-Optical Convergence; Network Planning; Techno-Economic Analysis; Access Networks; 5G*

## I. INTRODUCTION

In the age of digitalization and with the advent of 5G, a powerful and flexible optical-wireless access network is needed. 5G will be capable of providing enhanced mobile broadband coverage (eMBB) and ultra-reliable low-latency communications (URLLC) to meet the requirements of future applications and use cases. To support the requirements, 5G will soon use additional frequency spectra including the mm-wave band. This makes significantly higher bandwidths available. However, millimeter wavelengths do not provide the same coverage as low-frequency radio waves. For this reason, a densification of the radio access network by using small cells is necessary, which will require a roll-out of more fiber-optic network infrastructure to connect the large

number of base stations to the network core. Traditionally, fixed and mobile access infrastructures has mostly been planned and implemented separately. The implementation of a new infrastructure is very cost-intensive, so that in the future, a fixed and mobile convergence in the access network could be a solution to reduce both the capital expenditure (CAPEX) and the operational expenditure (OPEX) by a common fiber access [1]. Indeed, many telecommunications operators have started to follow the combined network planning approach and implement technologies such as cloud radio access network (C-RAN) to reduce the CAPEX and OPEX of a modern mobile access network [2].

In this paper, we present results of a techno-economic study that analyses the CAPEX of three deployment options for fiber-based access infrastructure for future 5G networks.

## II. RELATED WORK

In recent years, telecommunications operators have massively deployed fiber-to-the-home (FTTH) or intermediate solutions such as fiber-to-the-curb (FTTC) or fiber-to-the-building (FTTB) in the fixed access network. Provision of FTTH network access for residential users is mostly based on passive optical network (PON) technologies - a point-to-multipoint (P2MP) architecture with optical splitters. In contrast, dedicated point-to-point (P2P) fibers are still often implemented for both the fixed network access and backhauling of the mobile network [1,3].

Due to the broad penetration of point-to-multipoint FTTH networks, especially in urban areas, PON access has become increasingly common. The next generation PON solutions, such as the NG-PON2, are capable to deliver much higher capacities by using higher data rates and wavelength-division multiplexing (WDM), making this technology attractive for implementing a converged network that can be used to transport both fixed and mobile traffic over a common physical network [1,4].

Much of the research on converged networks, e.g. [4,5,6,7,8,9], focuses on a converged infrastructure that assume 5G mobile network with an optical backhaul. A

recent study by the FTTH Council Europe [4] as well as a webinar by CommScope [9] has underlined the attractiveness of the convergence of fixed FTTH and mobile transport networks for minimizing CAPEX and OPEX. A special focus of many research works is placed on the migration path, which is a complex, strategic problem of network planning. There exist several approaches proposed to minimize the migration complexity and costs [10]. Independently of the approach chosen, the use of powerful planning tools is essential. Modern network planning tools support optimized and automated planning processes to achieve a high-capacity and future-proof design that ensures an easy migration path while minimizing costs. Most of these tools are based on either geometric or geographical models [11]. While geometric models are well suited for theoretical studies and are easy to use, they, however, can lead to inaccurate results because of their inability to take into account geographical and operational constraints as well as location dependent variation of the distribution of demand points and data traffic. Geographical models, on the other hand, ensure realistic results due to the availability of exact geographical and operational data as well as constraints at the street and building level. For the case study presented in this paper we used a tool based on a geographical model in order to estimate the required equipment and installation effort to cover a particular urban area. Three deployment scenarios for a converged wireless-optical access network have been considered and analyzed on the basis of realistic assumptions. The scenarios are compared with each other regarding their economic viability.

### III. MODELLING APPROACH

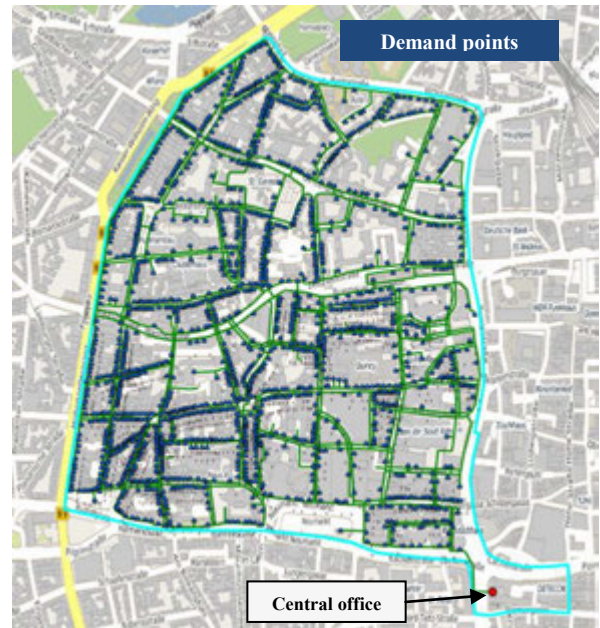
The planning tool "NetWorks Fixed Access" from Detecon International GmbH is used to determine the effort required for the roll-out of the converged network infrastructure. For this case study, we consider a network roll-out in an urban development area with a high cell density. The number of demand points (see Figure 1 a)) results from the locations of the buildings. The locations of macro and small base stations are determined such that an adequate coverage of the exemplary development area within the city of Cologne is provided (see Figure 1 b)).

For an automated planning procedure, a uniform material concept is necessary and decisive for the implementation of cable infrastructures. It should be pointed out that we assumed that costs are based on approximate but realistic values and only passive infrastructure is considered for the cost calculation.

The first step in planning the passive infrastructure for optical access networks is to identify the demand points for the deployment options as well as potential routes for civil engineering works. The required demand points were grouped together to form a distribution area according to the capacity of the distributor as can be seen in Figure 2. The planning tool applies optimization algorithms to calculate the ideal size and shape of the distribution area. Cable protection duct routes and cable connections were then determined based on the placement and the size of the distribution areas. After the first step in planning, a

balance of the planning was made from the Bill of Quantities (BoQ).

a)



b)

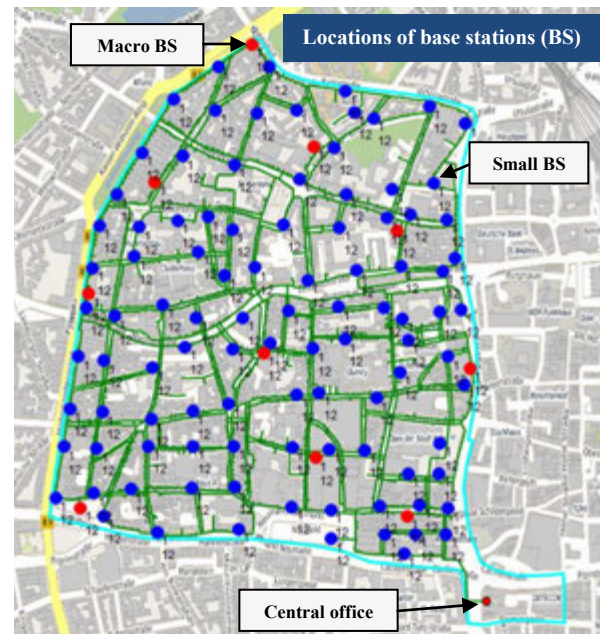


Figure 1. Demand points (a) and locations of base stations (b) in the considered exemplary urban coverage area.

The cost assumptions for various components and working processes are shown in Table I. Note that the cost values for the underground work and the installation of cables and ducts are given per meter, while all other values represent the total costs of a component or a subsystem.



Figure 2. The main steps carried out during the planning procedure.

TABLE I. COST ASSUMPTIONS

Component	Unit	Cost
Central Office		€ 60,000
House feed		€ 300
Fiber Distribution Hub		€ 1,500
Construction work	[m]	€ 100
Micro-Duct 12x10mm	[m]	€ 8
Micro-Duct 7x16mm	[m]	€ 10
LWL-Cable 144F/288F	[m]	€ 3/ € 5
LWL-Cable 12/24F	[m]	€ 0.5 /€ 1
APL-24F		€ 50
Optical Distribution Frame (ODF)		€ 15,000
Optical Splitter 1:32		€ 50

#### IV. DEPLOYMENT OPTIONS

In this section, the considered deployment options are presented. The roll-out of new network infrastructure has always been very expensive and time-consuming. Since telecommunications operators have already put a lot of effort to roll-out fiber optic networks to various extents and using different technological options, a flexible expansion strategy is being sought to realize the backhaul for 5G. This strategy should be as cost efficient and future-oriented as possible. In this study, we consider the following three deployment options, which we examine for their flexibility and economic viability.

##### A. Converged optical-wireless network with FTTH as a cellular backhaul (C-FTTH)

In the first deployment option, we consider an area-wide FTTH deployment that includes both fixed access and backhaul for cellular network. Here, fiber-optic cables reach all buildings in the residential and business areas. The distribution hubs are supplied from the central office

(CO) in a star configuration. The buildings are then directly connected to the fiber optic distribution hubs. Additionally, the FTTH network infrastructure also provides direct links to mobile base stations. Each fiber optic connection is implemented in a P2P manner to provide maximum flexibility.

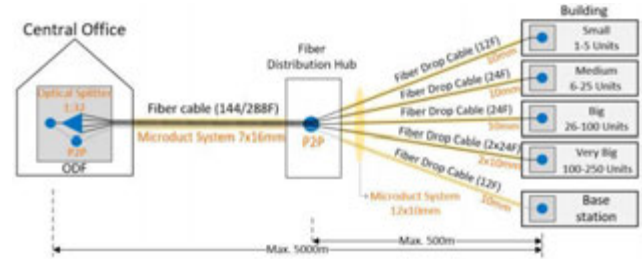


Figure 3. Schematics of the C-FTTH deployment option (P2P: Point-to-Point, ODF: Optical Distribution Frame)

##### B. Use of the existing FTTC network infrastructure to provide the backhaul for cellular networks (E-FTTC)

The second deployment option assumes the use of an existing FTTC network to connect mobile stations to the core network. In this scenario, mobile base stations are directly connected by optical cables to the existing FTTC distribution hubs (see Figure 4). We assume here that the distribution hubs have sufficient capacity, enough space and free ports to connect base stations.

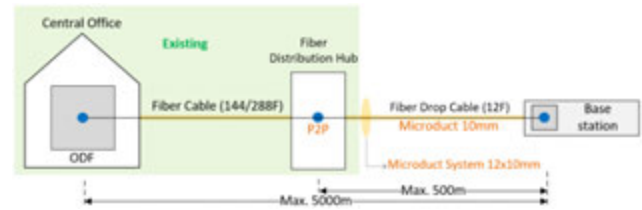


Figure 4. Schematics of the E-FTTC deployment option (P2P: Point-to-Point, ODF: Optical Distribution Frame)

##### C. Dedicated optical network as a backhaul for cellular networks (D-FTTH)

For the purpose of comparison with the converged deployment options, a dedicated optical network for the mobile base stations is considered and modeled. We assume here direct fiber connections of mobile station to a dedicated fiber network. The fixed internet access is provided through a different FTTH network. It is of particular interest to determine whether a converged infrastructure or dedicated networks is more preferable regarding both the implementation flexibility and cost-efficiency.

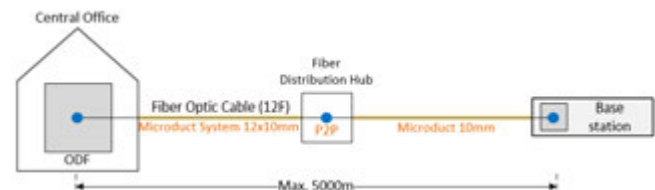


Figure 5. Schematics of the D-FTTH option (P2P: Point-to-Point, ODF: Optical Distribution Frame)

## V. RESULTS AND DISCUSSION

### A. Analysis of the roll-out of the converged wireless-optical network (C-FTTH)

We first analyze the roll-out of a converged P2P-FTTH network infrastructure. The modeled network has 41 distribution hubs within the considered development area that provides certain flexibility in planning fiber connections. The feeder network between the central office and the distribution hub comprises 47 pipes. The length of the feeder section is estimated to be about 38 km, which requires putting a large effort in construction work to lay fiber cables. Consequently, the main cost of the FTTH roll-out is related to the construction work and contributes by 66.8% to the overall implementation cost as indicated in Figure 6. Other significant cost factors are the cost of optical cables with 14.6%, the ducts costs with 12.1% and that of implementing ODFs with 2.8%. The residual components account for additional costs that lie below 1%, giving that they have no potential for eventual cost savings. Assuming 13,833 demand points within the coverage area, the estimated total implementation cost is €5.94 million so that the cost per subscriber accounts to €430.

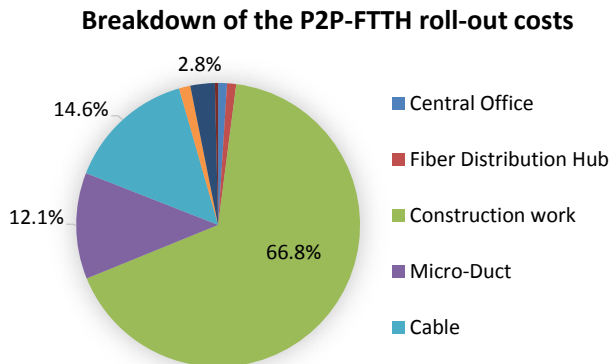


Figure 6. Cost breakdown of the converged P2P-FTTH roll-out

Although an area-wide roll-out of a converged P2P-FTTH network can potentially offer maximum flexibility and performance because dedicated fibers are used, this implementation option requires a high management effort in the CO. As an alternative to the P2P-FTTH network, we also modeled a P2MP FTTH-Network using optical splitters with a 1:32 split ratio. The use of optical splitters in distribution hubs has proven to be more efficient and a certain level of flexibility can still be kept in the distribution network. As a result, the relative cost of ODFs can be reduced to less than 1%. The cost breakdown of the P2MP-FTTH roll-out is shown in Figure 7. The use of optical splitters has a strong effect on the number of required ducts and cables in the feeder network. The cost of the ducts can be consequently reduced from 12.1% to 7.1% and that of the cables from 14.6% to 4.7%. The cost of the construction work remains the same, but now it accounts for 83.3% of the total cost.

As a consequence, the total cost of the converged FTTH roll-out can be reduced from €5.94 million to €4.76 million by using optical splitters in the distribution hubs.

Thus, a total savings potential of 20% can be achieved as indicated in Figure 8.

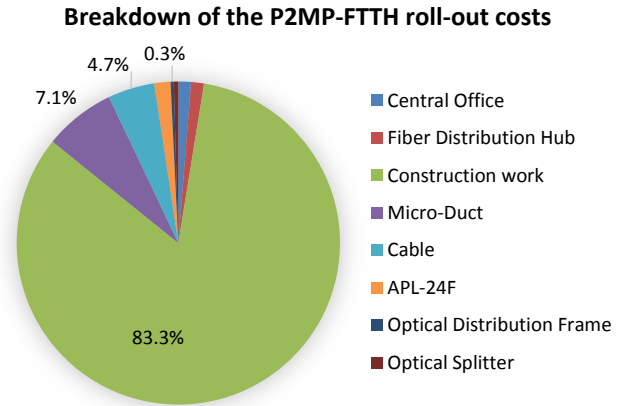


Figure 7. Cost breakdown of the converged P2MP-FTTH roll-out

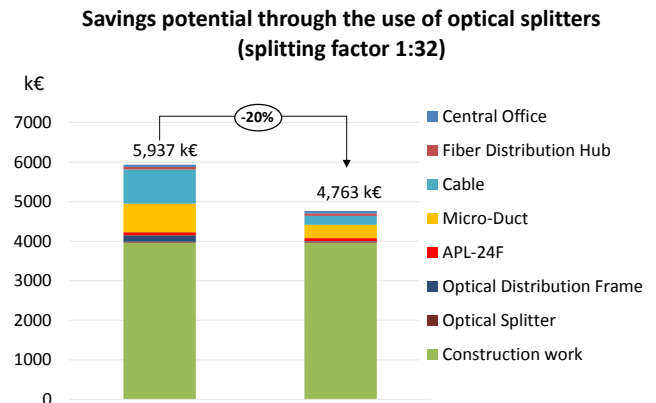


Figure 8. Total savings potential of the converged P2MP-FTTH roll-out in comparison to the P2P-FTTH.

### B. Comparison between C-FTTH, E-FTTC and D-FTTH options

As already mentioned above, in a traditional network planning, the fixed and mobile access infrastructures has mostly been planned and implemented separately. To investigate whether the combined planning of fixed and mobile network infrastructure has potential to reduce the CAPEX of a common fiber access, we analyzed the deployment options for fiber-based access networks in separate and combined manners and considering an implementation of optical backhaul for future radio access networks deploying both macro and small cells

The results show that using the combined planning approach instead of a separate deployment the implementation of the backhaul for macro cells promises a cost reduction of 8% and for small cells 19% (see Figure 9). As expected in both cases, the highest costs are those of the construction work. It becomes clear that in the converged network, there is less need for construction work because the infrastructure is already available almost everywhere through the fixed network. This becomes clearer as the number of demand points increases.

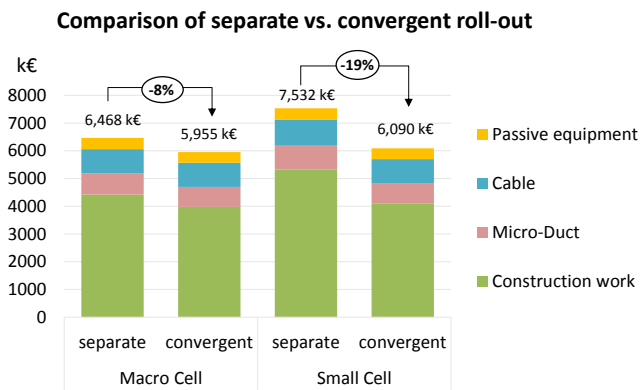


Figure 9. Comparison of the separate and convergent roll-out of FTTH networks considering the backhaul for macro and small base stations.

Finally, we investigated how much additional effort is needed to implement the backhaul for mobile base stations in comparison to an implementation of a fixed FTTH access only. Our results have shown that the cost of connecting not only macro cells but also small cells using the C-FTTH option is much lower in comparison to the two other options (E-FTTC and D-FTTH). As can be seen from Figure 10, all cost factors can be reduced by a combined planning of the FTTH infrastructure. The converged infrastructure also provides high flexibility and is future ready. It is open for upgrades to higher capacities and a potential efficient operation that can be achieved through an easier reconfiguration and resource allocation between the fixed and mobile parts as well as different distribution areas.

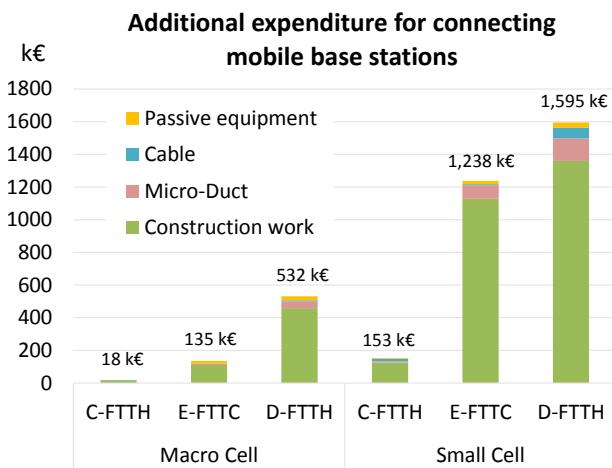


Figure 10. Comparison of the additional expenditure for connecting mobile base stations

## VI. SUMMARY AND CONCLUSION

This paper examines deployment options for converged optical-wireless access networks. The analysis is based on the results of a case study for an exemplary urban development area within the city of Cologne. Although some other studies have already considered converged networks and combined planning of fiber-to-the-home (FTTH) and 5G radio access infrastructures, extended fiber-to-the-curb (FTTC) networks and

greenfield deployments are not sufficiently investigated. For this reason, we considered three different deployment options including i) a converged optical-wireless point-to-point (P2P) and point-to-multipoint (P2MP) FTTH network, ii) an extension of an existing FTTC network to connect 5G base stations, and iii) a dedicated FTTH network as a backhaul for 5G radio access network. These three deployment options were analyzed with each other with regard to their economic viability and keeping in mind the requirements of 5G applications.

The results show that the convergence in future access networks has the potential to reduce both CAPEX and OPEX. Convergence also provides an improvement in flexibility. Traditionally, cost-effectiveness has always been a primary goal in planning and deploying access networks. However, current trends such as the high requirements for capacity and flexibility driven by novel network technologies and concepts such as network virtualization and softwarization, network programmability, edge networking, and cloud radio access network (C-RAN) as well as the continuous increase of the number of base stations have led to the need for many new fiber optic connections and more flexibility of the fiber optic infrastructure. For this reason, fiber-optic access networks must be dimensioned in a flexible and future-oriented manner, as passive network infrastructures will need to provide not only cost-efficiency but also maximum flexibility to support future developments in order to make the high investments worthwhile.

The additional costs for connecting mobile base stations are lowest in the C-FTTH option, especially if the number of demand points increases. This becomes clear when considering the case of connecting small cells, in which the additional costs are only 3%. This means that a high CAPEX is not to be expected in the future when implementing additional services such as smart city with a converged FTTH network, as there will be the need for relatively little construction work and this is a major cost driver. Furthermore, the infrastructure can be used by several operators and applications so that the CAPEX can be divided among several cost units. To further increase the flexibility of the network, the additional cost of approx. 20% for a throughout P2P infrastructure may be considered. This would provide absolute flexibility to implement arbitrary network configuration or application in the future and would eventually enable a significant long-term reduction in the OPEX of the network infrastructure.

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