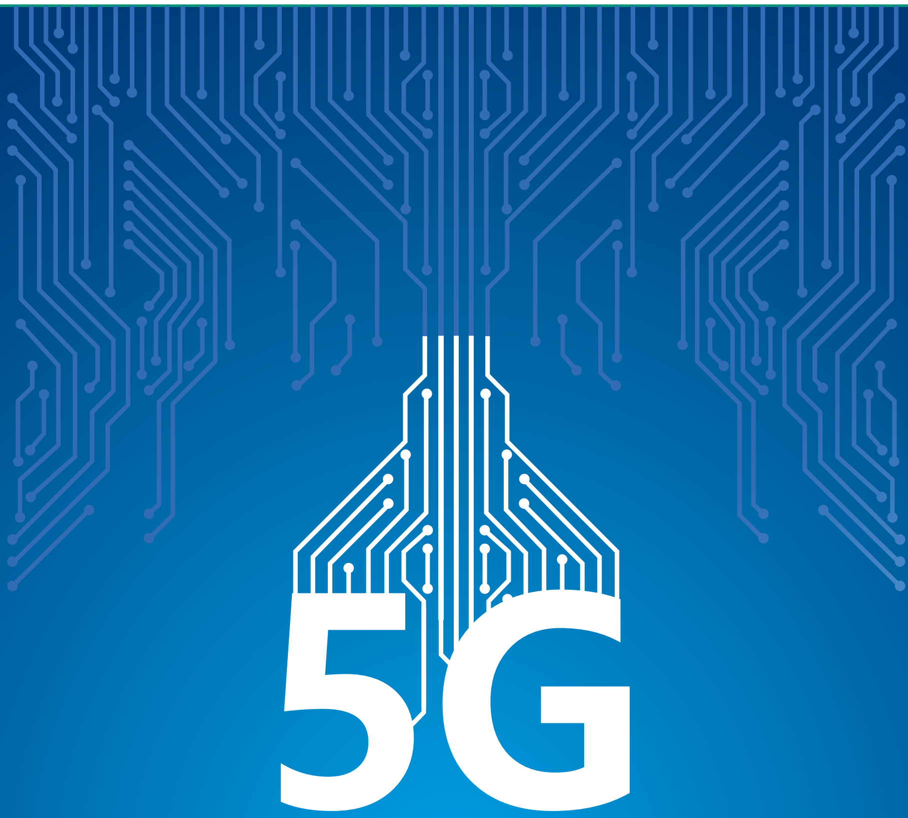
OPINION PAPER

Unleashing PON full potential – connectivity for all use cases

Integrated planning for 5G and NG-PON2

Content



Unleashing PON full potential

In this paper we investigate the potential synergies between integrated planning in the fixed access domain to serve both mobile and fixed network use cases. Traditionally the mobile network is separated from the fixed network in the sense that mobile backhaul is a transmission service utilizing partially some physical resources from fixed access network (dark fiber, copper line). We are going further compared to traditional approaches because we consider the possibility to deliver mobile connectivity from functional and capacity point of view while leveraging the same fiber optical fixed access network (PON).

By doing so we show that it is feasible to combine fixed and mobile services over the same underlying physical network infrastructure resulting in a more efficient utilization of resources. In turn this approach potentially has higher and faster return on investments. Such integrated approach can foster the faster deployment of fiber optic infrastructure and contribute to growth in both public and private sectors.

Finally, we believe the integrated planning and deployment approach will facilitate the 5G rollouts by offering highly reliable, high capacity and low latency infrastructure.

Introduction

End of 2017 was a crucial milestone for the telecommunications industry. LTE technology became number one in terms of number of connections worldwide. At the same time 3GPP standardization organization agreed and froze the first of the much anticipated and talked about next generation wireless standard – 5G. The so-called non-standalone (NSA) part of the standard heralded the next evolutionary step in high-speed data communications.

The first significant deployments of 5G technology are planned for end of 2018 and beginning of 2019. Major telecom operators around the world are issuing on weekly basis all type of 'firsts' milestones. Abstracting from the hype it is important to put the arrival of the new technology into the perspective of required basic resources to be able to deliver on the promises of: massive connectivity, ultra low latency and 10Gbps + speeds.

The key resources (as usual) are spectrum, site locations and transmission connectivity. Spectrum is a hot topic being addressed at various levels (international, government, industry groups, regulators, users). Gradually over time spectrum used for other technologies will be made available to 5G, indeed the standard already assumes LTE as one of the technologies under its umbrella. The situation with site locations is less clear. Adding all new spectrum bands on existing sites is very likely not to work – while 3.5GHz with massive MIMO antennas could still be feasible that will not be the case for higher bands. In that context, it is expected that small cells will finally play the crucial role the industry has hoped for years and deployment cases will sharply rise.

That brings to the last major resource needed (and the main topic of this paper) – site connectivity. Connectivity requirements will grow in at least two dimensions – high capacity (10Gbps and more) and high quality (reliability, availability and low latency). That leaves few candidates capable to deliver – fiber – you guessed it, is the most likely suspect. While in LTE a hybrid (fiber, microwave, even in some cases copper) transport network is still quite a common practice today, for the 5G networks of tomorrow that would most likely shift to a hybrid albeit fiber only network (dark fiber, passive fiber, active fiber).

The development of fiber technologies have been significant, however, less glamorous compared to their mobile counterparts. In the backbone level, speeds of 100Gbps and 400Gbps are common, with bundling methods speeds can reach Tbps. In the aggregation level, a multiple of 10Gbps is already common and moving towards the 100Gbps mark. The situation rapidly changes moving towards the backhaul domain. Connections of 10Gbps are rare, majority are 1Gbps or less. Many countries (more developed or less developed) still lack a significant penetration of fiber in the fixed access networks. There the most of the work will have to be done to enable the availability of resources.

Synergetic approach for covering the 5G connectivity demand together with evolution of fixed access networks to next generation PON technology have to be explored. Converged planning and implementation is beneficial from several aspects - cost savings, efficient use of infrastructure, fiber push, and lead the path to full-fledged mobile and fixed access convergence. NG-PON2 technology appears to be a legitimate PON candidate to provide connectivity for both, fixed and wireless users.

Fronthaul – Description and Requirements

The high user data rates 5G is aiming for are a challenge for the transport network. This is especially true for fronthaul where the baseband processing is located at a central site. Even in a classical backhaul scenario, the requirements for the transport network require a redesign or at least a re-dimensioning.

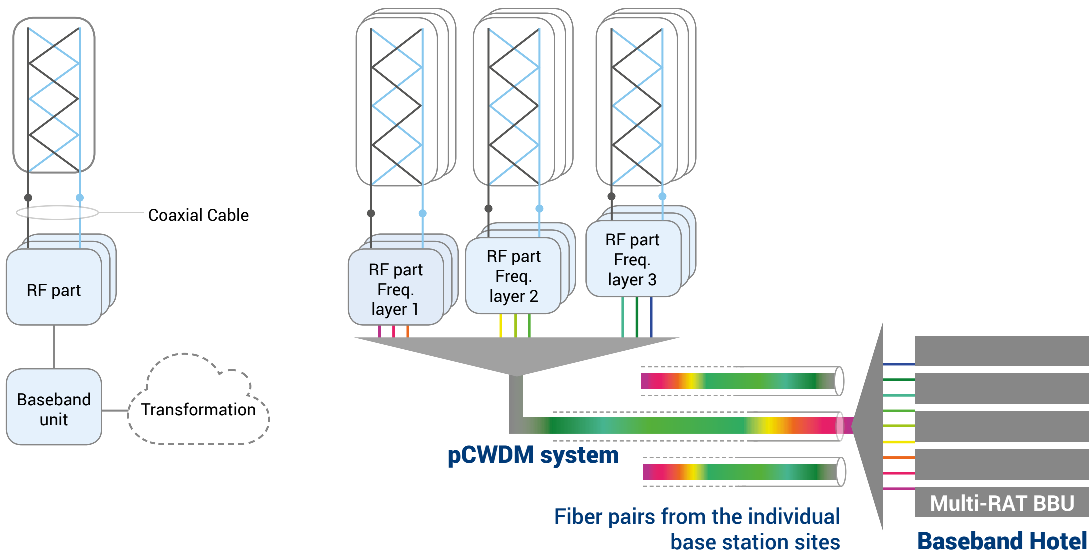
Fronthaul versus backhaul
The classical RAN (Radio Access Network) architecture is shown on the left part of Figure 1 for a single sector. The main building blocks are:

Antenna
- The antenna radiation and reception of the electromagnetic waves
- Most often (always in LTE), two polarizations are implemented, at least for the reception
- The antenna is frequency (band) dependent, multiband antennas are available

Radio Frequency (RF) part
- Up-converts and amplifies the transmit signal, amplifies and down-converts the receive signal
- The RF part is frequency (band) dependent
- Is often called **Remote Radio Unit, RRU**
- Interface between the RF part and the BBU is not standardized

Baseband unit (BBU)
- Modulation of the transmit signal and demodulation of the receive signal, both user traffic and signaling
- Used to be RAT (Radio Access Technology) specific; Multi-RAT BBUs are now available (the BBU supports more than a single air interface technology, e.g. 2G, 3G, 4G and upcoming 5G)
- Interface to the transmission network and via the transmission network to central controllers
- Implements the Radio Resource Management in LTE and 5G

Figure 1: Classical RAN architecture with backhaul (left) and centralized RAN with Fronthaul (right)



Source: Detecon

Transport network

- Provides the connection of the radio base station to the central controllers
- This connection is called "backhaul"

As a rule of thumb, the backhaul traffic is the sum of the peak data rate offered by the mobile radio system (and marketed by the mobile operator) plus, in case of multiple sectors, n times the mean data rate of a sector in the busy hour.

The right part of Figure 1 shows the architecture of centralized RAN for a radio base station with three frequency layers and three sectors per frequency layers. The main difference to the classical RAN architecture is that the BBU (most often a Multi-RAT BBU) is now located at a central hotel site. Typically, around 10 to 30 cells are connected to the BBU at the hotel site.

So far, the interface between the RF units (RRUs) and the BBU is not fully standardized. However, there is the CPRI (CPRI: Common Public Radio Interface, promoted by Ericsson, Huawei, NEC and Nokia; for more information please refer to http://www.cpri.info) industry standard that specifies this interface up to layer 2. There are very tight requirements for delay and jitter on this interface. The typical implementation of the physical layer is a passive CWDM system that multiplexes the signals of the various RF units at the radio site on a dark fiber.

The required transport bandwidth on the interface between a RF unit and the BBU depends on the air bandwidth of at mobile air interface and on the number of antenna ports; e.g. around 5 Gbps for a single LTE sector in a 4T4R configuration with 20 MHz air bandwidth.

The main advantages of centralized RAN are:

- Best user experience at the cell borders as centralized RAN provides the best performance of the interference mitigation features; achieved by coordinated scheduling
- No need for a (big) operating room at the radio site which may result in OPEX savings
- Baseband Pooling (with multiplexing gain) may result in CAPEX savings

The special case of Small Cells in a HetNet environment

Small Cells within the coverage area of a macro cell may need a tight coordination of the radio resource management between the macro cell and the small cell(s), unless the small cells use a dedicated frequency layer. Such a tight coordination can only be achieved with coordinated scheduling.

There are two options for this:
1. Both the macro cells and the small cells are implemented as centralized RAN with BBUs at a central hotel site
2. At least the small cells have a connection to the BBU at the macro site in the coverage area of which the small cells are located.

Small Cells within the coverage area of a macro cell may need a tight coordination of the radio resource management between the macro cell and the small cell(s), unless the small cells use a dedicated frequency layer.

The figure 2 shows the second option. The BBU of the macro cell can be considered as a small hotel site; the small cell consists only of a RF part (plus power supply and transport)

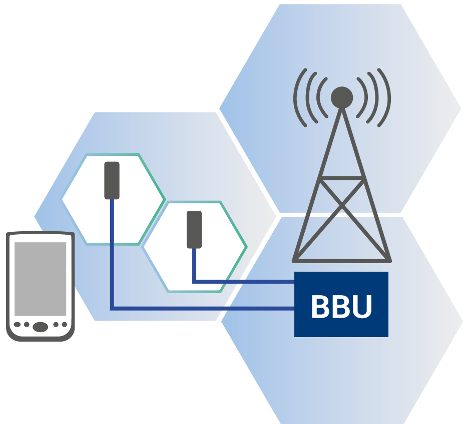
In this case, utilization of unused fiber resources (dark fibers) can be considered. Dark fibers are reserved fibers kept in feeder network and terminated at distribution points. Those capacities are currently not planned for use further in the distribution network.

Again, the required transport bandwidth of such a connection depends on the air interface bandwidth and on the antennas configuration. However, because of the intrinsic limitations of Small Cells

- Reduced space for the antenna, i.e. no high order MIMO possible (at least in the frequency bands below 5 GHz
- Limited EIRP for reasons of the EMF, i.e. reduced number of frequency layers

the required transport bandwidth is significantly lower than in case of fronthaul for a macro site, e.g. 2.5 Gbps for LTE in a 2T2R configuration with 20 GHz air bandwidth.

Figure 2: Small Cells in a HetNet environment with a connection to the BBU of the macro cell



Source: Detecon

The impact of 5G

As already mentioned before, 5G is aiming for a user data up to 10 Gbps.
To achieve this, the key technologies are:

- Massive MIMO and beamforming
- Significantly more spectrum than currently used in 4G

Significantly more spectrum is only available in the frequency bands above 3.5 GHz; even the higher GHz range as 28 GHz or 80 GHz (E-band) is under discussion. It should be noted that, in these frequency ranges, the propagation conditions are far away from optimum which results in a very limited inter cell distance.

On the other hand, the antenna size becomes smaller in the higher GHz range, which could allow the implementation of massive MIMO or beamforming at small cells. Consequently, the required transport bandwidth to connect a small cell would increase correspondingly. However, the EMF limits have to be taken into account as well. The latter could lead to a situation in which beamforming cannot be used to increase the received signal level at a mobile but only as a means to reduce the interference.

Therefore, in our opinion there still is a high uncertainty how a 5G network will look like:

- Will the higher frequency bands that allow massive MIMO be deployed at macro cells as well?
- If not, the transport bandwidth of the macro cell will not significantly increase.
- Will 5G lead to the massive deployment of small cells, which has been forecasted since several years, but has not become reality so far?
- If so, the cost efficient connection of the small cell sites is the key factor to success
- Which configurations are possible at small cell sites in terms of air interface bandwidth and massive MIMO and/or beamforming under the EMF constraints?

Despite this uncertainty, in some publications figures for the transport requirements of 5G macro cells fronthaul are given: 100 Gbps in [1]. The CPRI industry initiative did an estimation of the required fronthaul transport bandwidth: 236 Gbit/s for a radio air bandwidth of 100 MHz duplex and 64 antenna ports [2]. It is obvious that such transport bandwidths are a big challenge for optical networks in the access domain.

1 *"Huawei Launches Full Range of 5G End-to-End Product Solutions", February 26, 2018; http://www.huawei.com/en/press-events/news/2018/2/Huawei-Launches-Full--Range-of-5G-End-to-End-Product-Solutions*

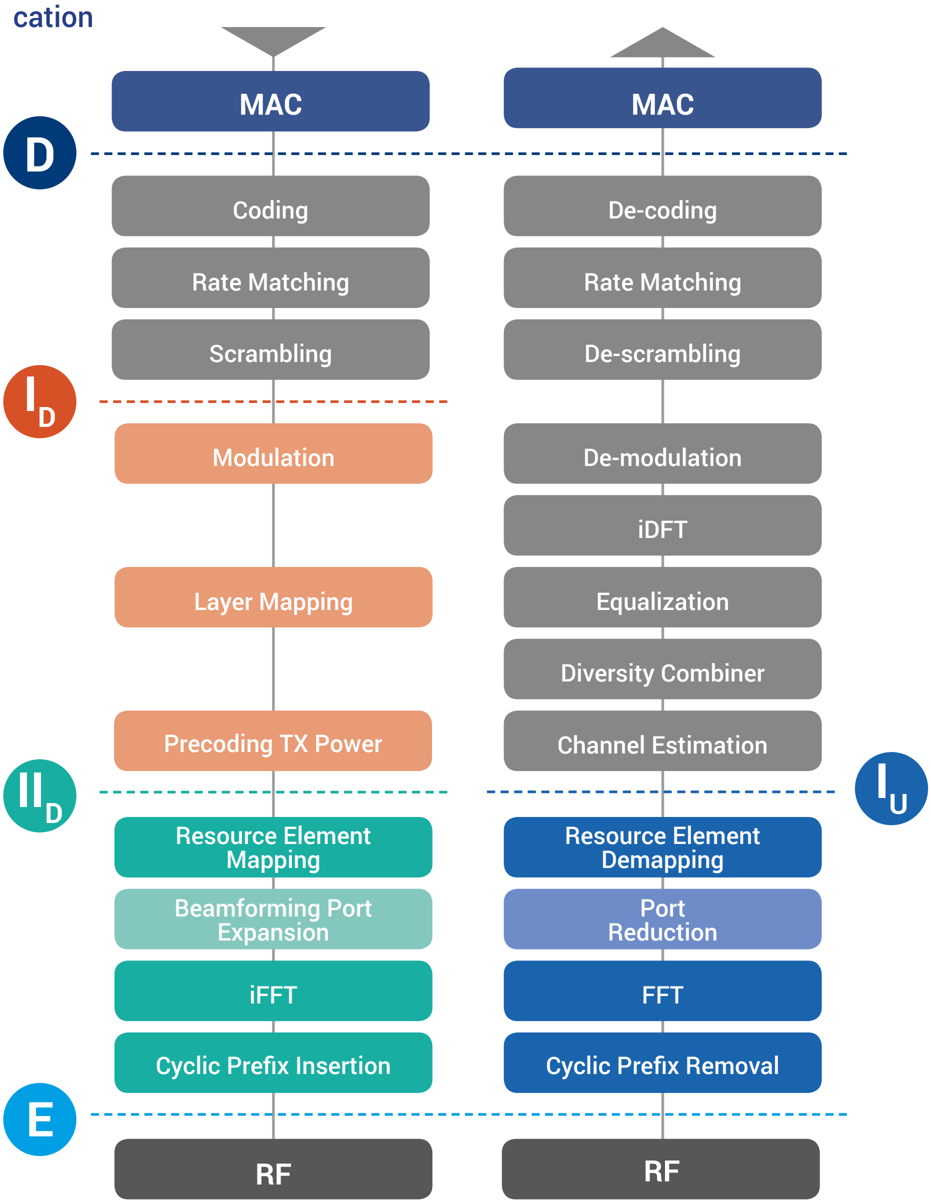
2 *"Common Public Radio Interface – eCPRI Specification", January 2018; http://www.cpri.info/downloads/eCPRI_Presentation_for_CPRI_Server_2018_01_03.pdf*

New functional Splits to reduce the Requirements for the Transport

In order to reduce the requirements for the transport both in terms of the required bandwidth and in terms of the acceptable delay and jitter, several initiatives are aiming for a new functional split between the radio unit located at the radio site and the baseband unit located at a central hotel site.

- The CPRI industry initiative of the big vendors Ericsson, Huawei, NEC and Nokia; **www.cpri.info**
- The xRAN initiative of leading mobile operators (AT&T, Deutsche Telekom, Telstra, Verizon and SK Telecom) plus technology suppliers and research leaders including: Intel, Texas Instruments, Aricent, Radisys, Mavenir, Cisco, Altiostar, ASOCS and Stanford University. There is a dedicated working group “xRAN Fronthaul Working Group” within the xRAN initiative; **www.xran.org**

Figure 3: Functional decompositions considered in the eCPRI specification



Source: Common Public Radio Interface – eCPRI Specification

- The OpenAirInterface™ software alliance ("5G software alliance for democratising wireless innovation") actively participates in the definition of the Next Generation Fronthaul Interface (NGFI); Orange as an operator, some industry partners as Fujitsu and Cisco, and several universities and research bodies; **http://www.openairinterface.org/?page_id=83**
- The OpenRAN and vRAN fronthaul initiatives as part of Telecom Infrastructure Project driven by Facebook, Vodafone and Telefonica; **https://telecominfraproject.com/openran/**

As an example, figure 3 on the left shows the various functional decompositions considered in the eCPRI specification.

Table1 summarizes the corresponding transport bandwidths in the downlink and in the uplink direction. The abbreviation "eREC" in the table stands for "eCPRI Radio Equipment Control", and "eRE" for "eCPRI Radio Equipment". The configuration of the radio interface is as given in [2].

Table 1: Resulting transport bandwidths for the functional decompositions considered in the eCPRI specification

	Split D		Split I_D		Split II_D		Split E
	User Data [Gbit/s]	Control [Gbit/s]	User Data [Gbit/s]	Control [Gbit/s]	User Data [Gbit/s]	Control [Gbit/s]	User Data [Gbit/s]
Downlink (eREC > eRE)	3*)	<< 1	< 4	< 10	≈ 20	< 10	236
	Split D		**Split I_U**				**Split E**
Upink (eREC > eRE)	1.5	<< 1	≈ 20	< 10			236

**) assumptions*

2 *"Common Public Radio Interface – eCPRI Specification", January 2018; http://www.cpri.info/downloads/eCPRI_Presentation_for_CPRI_Server_2018_01_03.pdf*

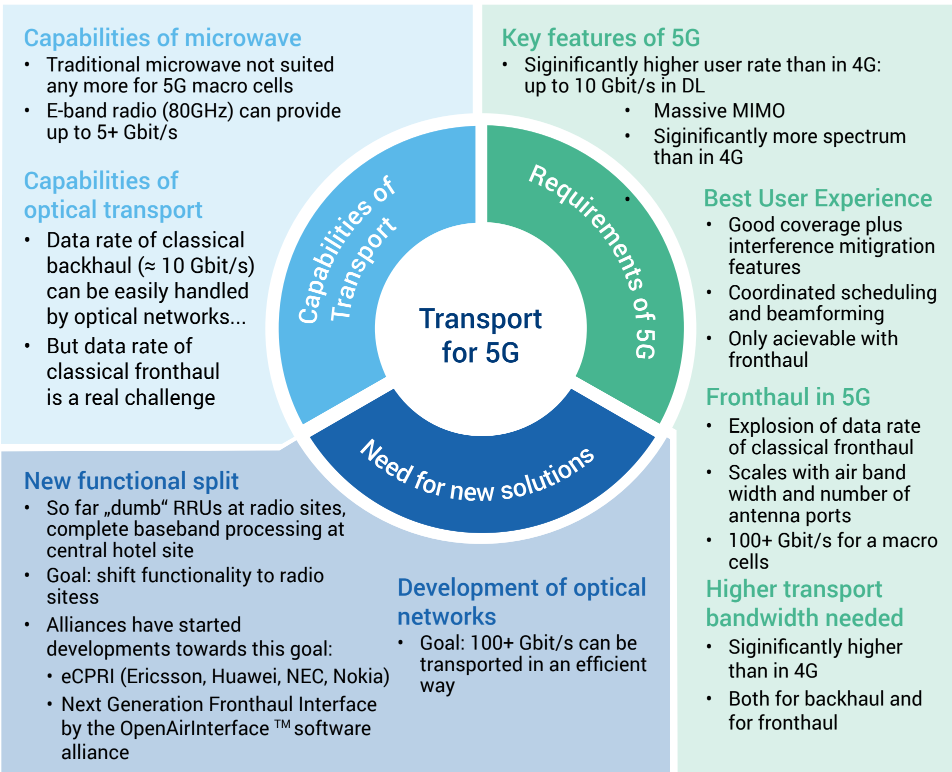
It is obvious that, the more functionality is put in the eRE, the lower becomes the required transport bandwidth. The functional decomposition E is the conventional fronthaul. In any case, the new functional decompositions lead to a signification reduction of the required transport bandwidth. However, the required transport bandwidth is only one key requirement for the transport; the other key requirement is the allowed latency. Table 2 shows the maximum one-way packet delay and the maximum one-way Packet Loss Ratio for the functional decompositions E and ID, IID, IU.

Table 2: Maximum one-way packet delay and the maximum one-way Packet Loss Ratio for the functional decompositions E and ID, IID, IIU considered in the eCPRI specification

CoS Name	Example use	One way maximum packet delay	One way packet Loss Ratio
high	User Plane	**100 µs**	10^{-7}
medium	User Plane (slow), C & M Plane (fast)	1 ms	10^{-7}
low	C & M Plane	100 ms	10^{-6}

It is worth to note that the packet delay requirements for the functional decompositions ID, IID, and IU are not relaxed compared to the classical fronthaul (functional decomposition E). Especially, the 100 µs packet delay for high CoS user traffic is challenging.

Figure 4: Transport network capabilities and 5G requirements



Source: Detecon

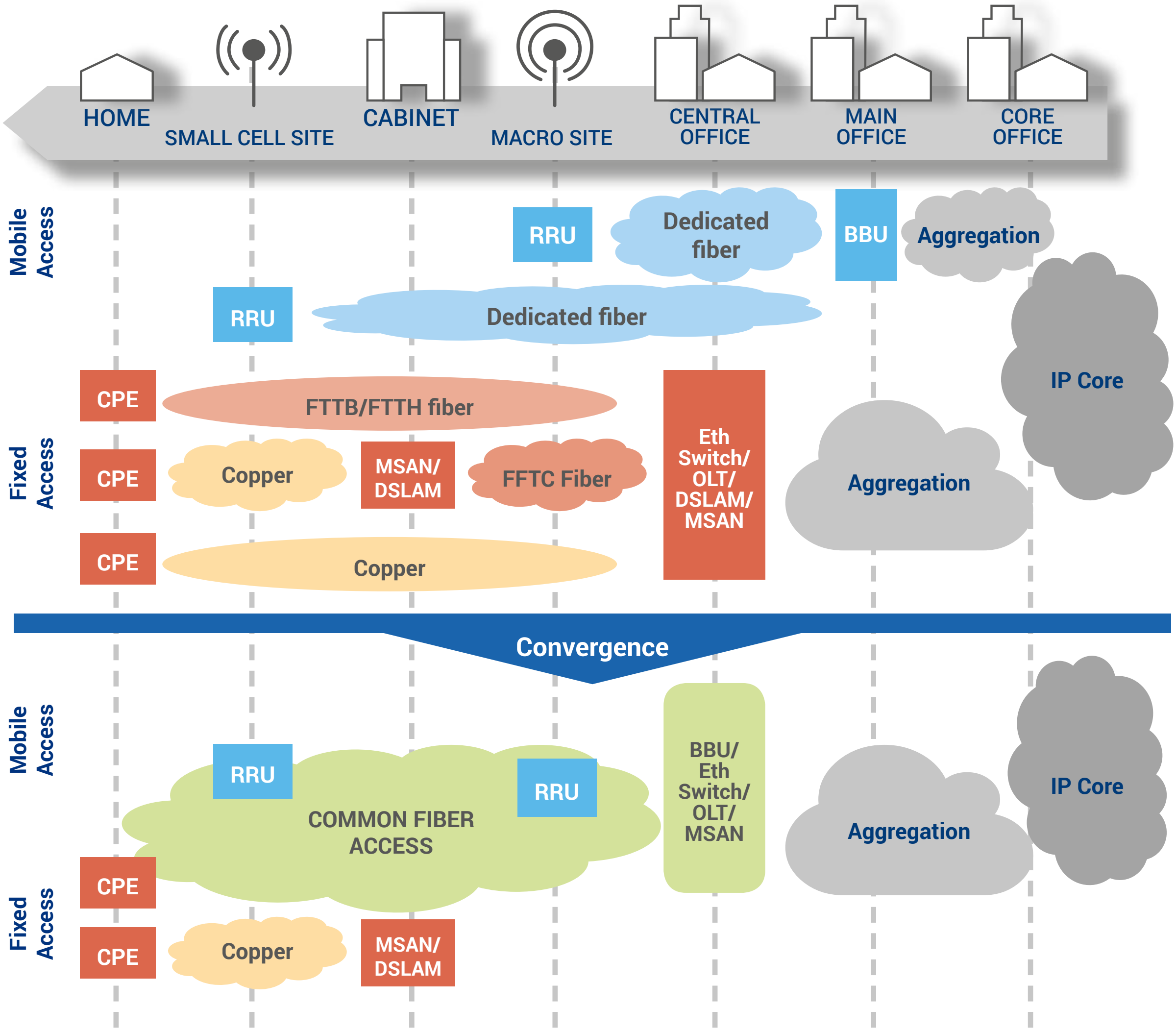
Evolution of fixed access technologies to support fixed mobile convergence

Fixed and mobile convergence on structural level

Historically, fixed access and mobile access infrastructure has mostly been planned and deployed separately. Until now, fixed access technologies have been developed to address needs of residential customers and offices. Convergence, if any, is done only in the aggregation, IP Core and transport domain. With densification of the RAN network (small cells and C-RAN), many advantages of converging the access network become obvious:

- Existing fiber infrastructure can be reused
- With increasing fiber rollout in the fixed domain, a number of Central offices can be consolidated for fixed and mobile access
- A common fiber access would reduce CAPEX and OPEX

Figure 5: Converged infrastructure in the access domain [3]



3 Combo research: http://www.ict-combo.eu/

Source: Detecon, based on Combo research: http://www.ict-combo.eu/

Fixed access technologies assessment to support fronthaul

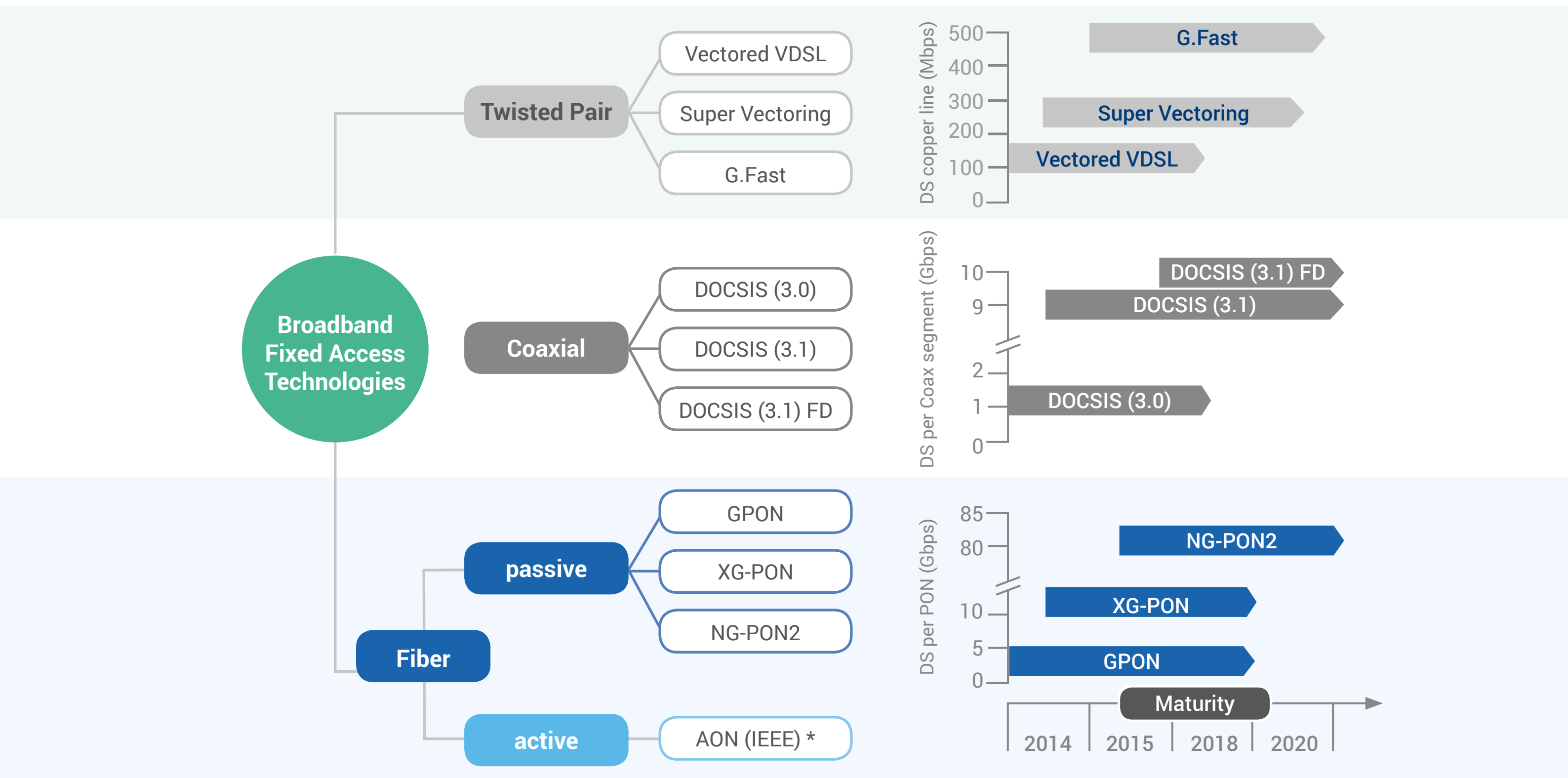
Fixed access technologies are developing into following directions:

- Copper technologies are increasing bitrates to prolong the lifetime of legacy copper in the last mile
- Coax technologies are increasing bitrates per coax segment utilizing a wider frequency band and improving coding techniques
- Fiber-based PON technologies are evolving to increase reach and provide more bandwidth to the end-user, while reusing existing passive fiber infrastructure.

The following illustration gives an overview of mature and emerging fixed access technologies over different access media. While backhauling applications over existing mature fixed access (e.g. GPON) technologies exist, fronthauling imposes new challenges in terms of bitrates and delays. It is evident that current mature and widely deployed fixed access technologies, such as Vectored VDSL, GPON or DOCSIS are not able to support these strict requirements. Therefore, it is worth exploring the possibilities of emerging fixed access technologies:

Copper twisted pair – G.Fast and beyond: G.Fast offers bitrates of up to 500 Mbit/s downstream and upstream in real deployment scenarios over a dedicated copper pair at short distances of up to 100 m. Further developments of G.Fast aim to achieve even higher bitrates of up to theoretical 10 Gbit/s, but further reducing the length of the last mile copper pair. Its application to support fronthauling was successfully tested [4], but can however be seen as limited for special use cases (e.g. for covering small cells inside buildings). Apart from that, a possible application of G.Fast for fronthauling will require a flexible split of functions between the BBU and RRU.

Figure 6: Fixed access technologies overview and evolution



** Not considered in this assessment, all technologies w/o „(IEEE)" are recomended by ITU.*

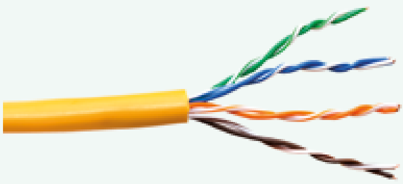
Coax – DOCSIS 3.1/FD: The emerging DOCSIS 3.1 technology will offer a throughput of 10 Gbit/s downstream and 1-2 Gbit/s upstream per Coax segment, with its full duplex flavor will offer 10 Gbit/s in both up- and downstream by simultaneously utilizing the spectrum in both directions. However, neither technology is suited to provide support for fronthauling, since the available bandwidth is shared between multiple end-users and the rigid latency requirements of CPRI cannot be met.

Fiber – NG-PON2: NG-PON2 is the evolution of PON technologies which increases available bitrates over one passive optical network. With TWDM it provides 40 Gbit/s downstream and 10 Gbit/s upstream over one PON. In addition, up to 4 point-to-point overlay wavelengths can be utilized over the same fiber, each offering up to 10 Gbit/s down- and upstream. Alternatively, up to 8 point-to-point wavelengths of 10 Gbit/s down- and upstream can be utilized, if TWDM is not used on the PON. With these overlay wavelengths, NG-PON2 is able to support fronthauling, up to CPRI option 8 [5]. It thus allows connecting of up to 4 RRUs over one PON in a brownfield scenario, or up to 8 RRUs in a greenfield scenario.

4 *"BT researchers show how G.fast technology could hasten arrival of 5G", February 15 2016: https://www. btplc.com/Innovation/Innovationnews/5G/index.htm*

5 *ITU-T G.989.2, August 2017; https://www.itu.int/rec/T-REC-G.989.2-201708-I!Amd2/en*

Figure 7: Assessment of fixed access technologies for fronthaul application

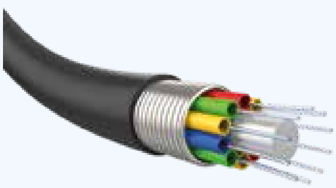


G.Fast and beyond

- Application limited only to special use-cases, e.g. in brownfield scenario to cover small cells inside buildings
- Requires flexible split of functions inside BBU and RRU

DOCSIS 3.1 / FD

- Neither DOCSIS 3.1 nor its full duplex flavor are suitable for fronthauling applications, as the available bandwidth is shared
- Furthermore, rigid latency requirements for CPRI cannot be met.



NG-PON2

- Standard developed to support up to CPRI option 8 (10 Gbps) over dedicated lambdas
- Allows different use-cases: brownfield (up to 4 RRUs on one fiber) and greenfield (up to 8 RRUs on one fiber)

Source: Detecon

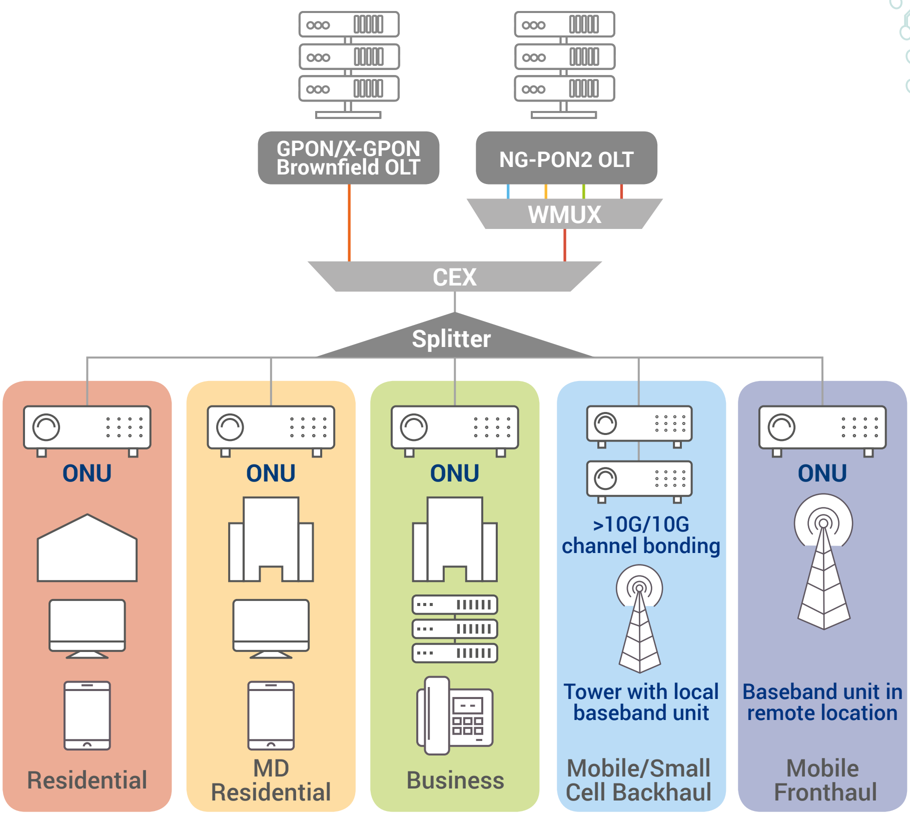
NG-PON2 Technology as enabler of fixed mobile convergence in the access domain

NG-PON2 technology is standardized under the ITU-T G.989.x standards. Time and Wavelength division multiplexing (TWDM) is selected as the primary technology solution for residential services offering 40 Gbit/s in the downlink and 10 Gbit/s in the uplink on one PON, which is achieved via multiple wavelengths using a Coexistence element (CEX) at Central location. In addition to this, symmetrical point-to-point links can be implemented over the same PON with overlay WDM and bitrates up to 10 Gbit/s per wavelength. The standard defines colorless ONUs with wavelength tunable SFPs. The ONUs are equipped with tunable transmitters and receivers in order to dynamically tune to provisioned downstream/upstream wavelengths, which reduces OPEX.

NG-PON2 is backwards compatible with both, XG-PON and GPON by utilizing different wavelengths. While deploying NG-PON2 on existing legacy PON network, no modification on passive infrastructure is required.

NG-PON2 was developed to support CPRI over the overlay point-to-point wavelengths. Currently bitrates of up to CPRI option 8 are defined in the standard [9]. This makes it possible to use the same PON for providing services to residential customers, businesses, as well as for backhaul and fronthaul applications. All of the aforementioned leads to the conclusion that NG-PON2 is the true enabler for convergence in the access domain.

Figure 8: NG-PON2 technology architecture [6]



6 Broadband forum: https://www.broadband-forum.org/standards-and-software/major-projects/ng-pon2

Source: Broadband forum

FTTH/B deployment challenges

Current state of FTTH/B deployment

Many developed countries in Europe currently lag behind the EU average when it comes to FTTH/B deployment e.g., as of September 2017, Germany had only 2,3% penetration of FTTH/B [7]. Other developed countries such as Austria, Ireland or Italy have similar penetration rates, as shown in the picture below.

Even though the FTTH/B Homes passed figure has been growing steadily in the past years, the growth rate in the EU28 countries is still slow, as the picture below shows, based on IDATE FTTH/B Panorama [8].

7 *IDATE FTTH/B Panorama, September 2017: http://www.ftthcouncil.eu/documents/IDATE_European_FTTH_B_panorama%20_at_Sept_2017_VF.pdf*

8 *FTTH Council, FTTH/B Ranking, September 2017. http://www.ftthcouncil.eu/documents/FTTH%20GR%2020180212_FINAL.2.pdf*

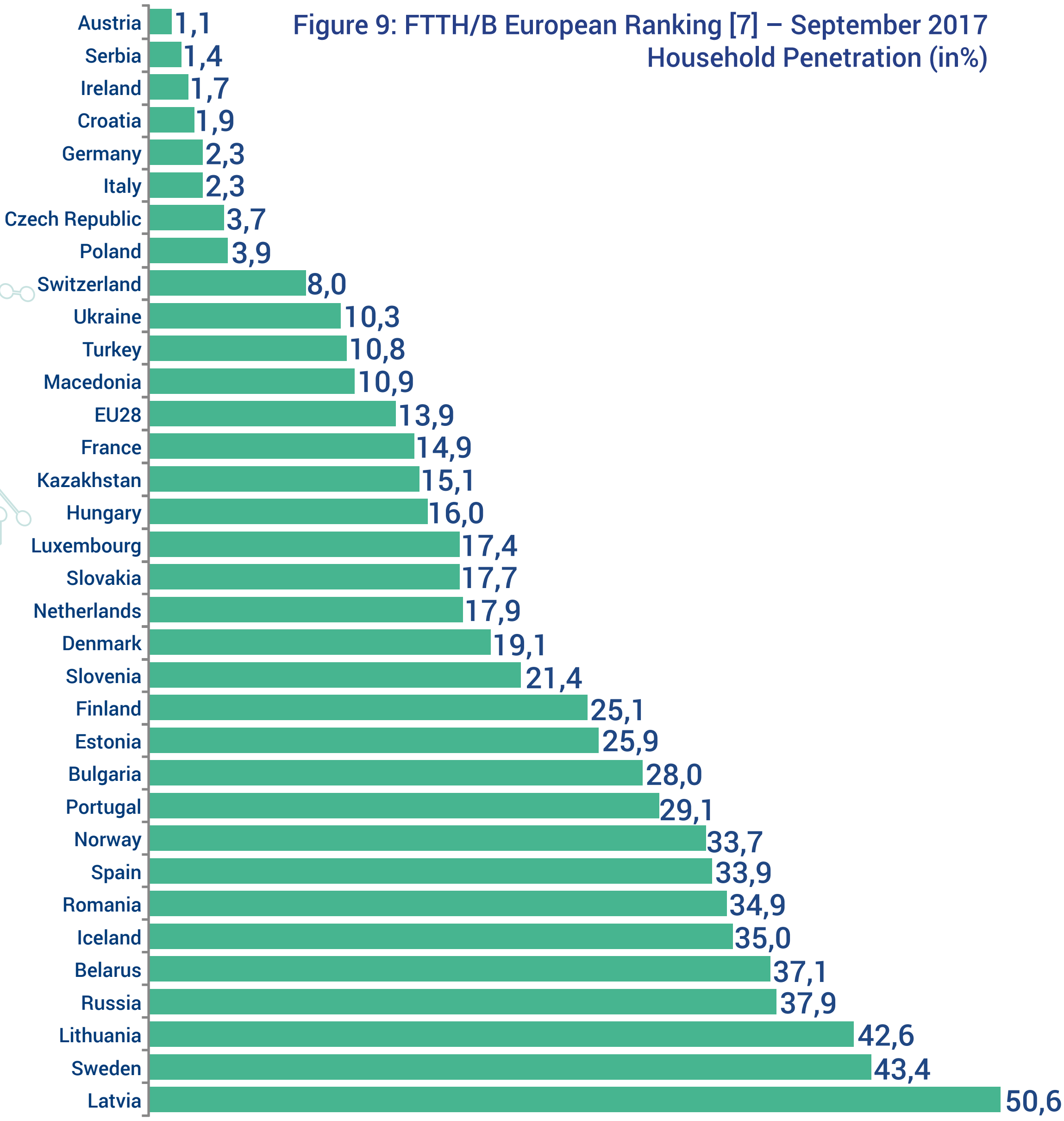


Figure 9: FTTH/B European Ranking [7] – September 2017
Household Penetration (in%)

Source: IDATE FTTH/B Panorama

When compared to regions worldwide, European countries are lagging behind even more. Regions with highest FTTH/B penetration are Middle East (Qatar, UAE) and East Asia (Singapore, South Korea, Hong Kong, Japan).

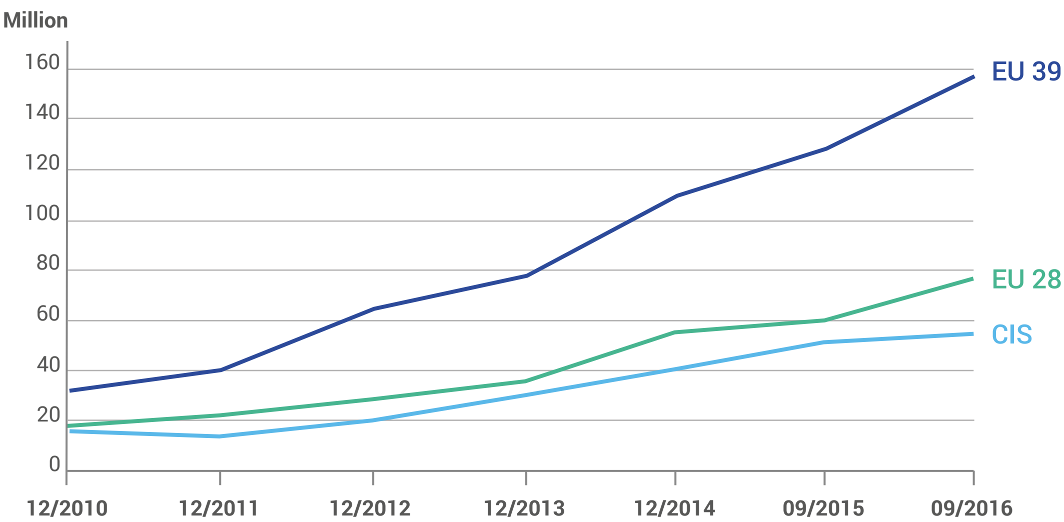
Challenges

The main reasons for limited FTTH/B deployment growth are:

High CAPEX is needed to deploy FTTH/B networks, especially in the developed countries, due to:

- **High deployment costs.** The most significant portion of CAPEX consists of the cost for deploying the passive infrastructure. The labor costs in developed countries are significantly higher than in the developing world especially when it comes to OSP works and fiber installation works.
- **Stricter implementation regulations in the OSP.** In developed countries, especially in urban areas, the regulations often allow only underground deployment of FTTx networks. The less costly aerial deployment, which is frequently used in developing countries, is often not allowed. While some other underground fiber deployment techniques, such as mini- and micro-trenching have been developed, they still remain CAPEX-intensive and time-consuming.
- **In-House Cabling challenges.** Traditionally, during a building planning or construction project, mandatory telecommunication media was copper and/or coax cabling, mainly utilized by xDSL and cable providers. Non-existent fiber in-house cabling disrupts potential FTTH investments, due to a significant additional impact on overall CAPEX, as well as ownership, legal and technical challenges while deploying fiber in-house cabling in a brownfield environment.

Figure 10: FTTH/B Growth in Europe – IDATE for FTTH Council Europe



Source: IDATE for FTTH Council Europe

Utilization of copper in the last mile. Incumbents in developed countries are investing in copper-based technologies, such as in Vectored VDSL and Super Vectoring, while Cable operators are upgrading their networks to DOCSIS 3.0 and 3.1. These technologies are capable of providing 100 Mbit/s and more to the end customer with FTTC deployment in urban areas, which can mostly cover current customer demand. Access network providers thus do not always have the immediate pressure to invest in FTTH/B networks. As a result, FTTH/B investments are being postponed and operators are prolonging the lifetime of legacy copper / coax infrastructure in the last mile. The benefits of this strategy are mostly limited to urban and suburban areas. Rural areas, with low population density and longer copper cable lengths, which usually do not profit from FTTC deployment, remain undeveloped when it comes to broadband access.

Public funding for NGA Broadband Networks

The EU set the target of 50% of households receiving above 100 Mbps and 100% of households receiving above 30 Mbps broadband by 2020 in their Digital Agenda of Europe (DAE) [9]. It is evident that market-driven rollout of FTTH/B networks will not cover many unprofitable, mostly rural areas. Therefore, these areas will rely on government funding in order to receive a state-of-the-art broadband infrastructure. The European commission, as well as some state governments (e.g. Germany) have developed plans to fund the deployment of FTTx networks in such areas, defining the rules on which areas are eligible for funding, as well as technical guidelines and regulations the funded networks have to fulfill.

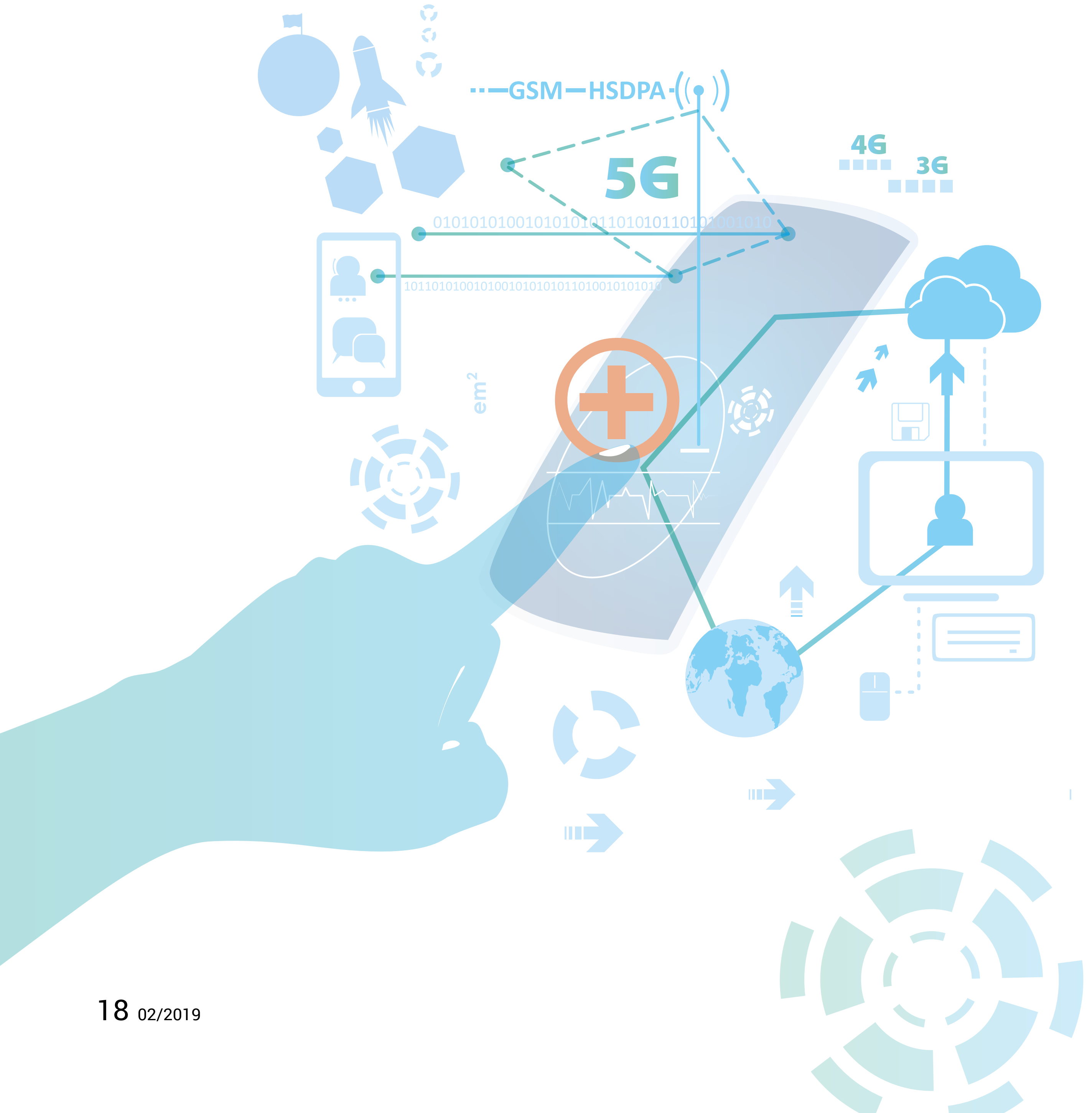
While these funds will help increase the deployment of fiber networks and to a certain extent bridge the digital divide between rural and urban areas, they will not be able to ensure full FTTH/B coverage unless deeper cooperation between private and public sector is stimulated.

9 *European Commission: EU Guidelines for the application of State aid rules in relation to the rapid deployment of broadband networks, January 2013: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52013XC0126(01)&from=EN6. FTTH Council, FTTH/B Ranking, September 2017. http://www.ftthcouncil.eu/documents/FTTH%20GR%2020180212_FINAL.2.pdf*

5G as possible driver for fiber investments

An additional driver for fiber investments can be the upcoming next generation wireless communication standard 5G, together with the expected densification of the RAN network and the migration from distributed to centralized RAN.

The strict bandwidth and latency requirements of C-RAN for fronthaul and backhaul can be achieved only via fiber optic cables as physical medium. Having this in mind, advantages of using fixed access infrastructure for front-hauling /backhauling become obvious in order to reduce investments. Fixed operators need to consider fiber demand of RAN networks when planning investments in new FTTx networks, while for mobile operators fiber fronthaul and backhaul will become an increased cost driver for deploying 5G. An integrated planning and synergic deployment of fixed / radio networks would reduce overall implementation costs. Optimizing CAPEX with a converged planning while at the same time increasing revenue from 5G is a factor worth considering when investing in fiber.



Case Study

Overview

Having in mind the considerations outlined in the previous chapters, Detecon conducted a case study aiming to compare CAPEX implications of joint versus separate deployment of fixed access network and backhaul/fronthaul network. For this purpose we analyzed an urban residential area in western Europe. For the modelling of the passive network Detecons own network planning tool NetWorks fixed access is used.

The figure below shows the considered area covered with fixed and mobile end-locations for the purpose of our case study.

Figure 11: Case study area scope with fixed and mobile end-locations

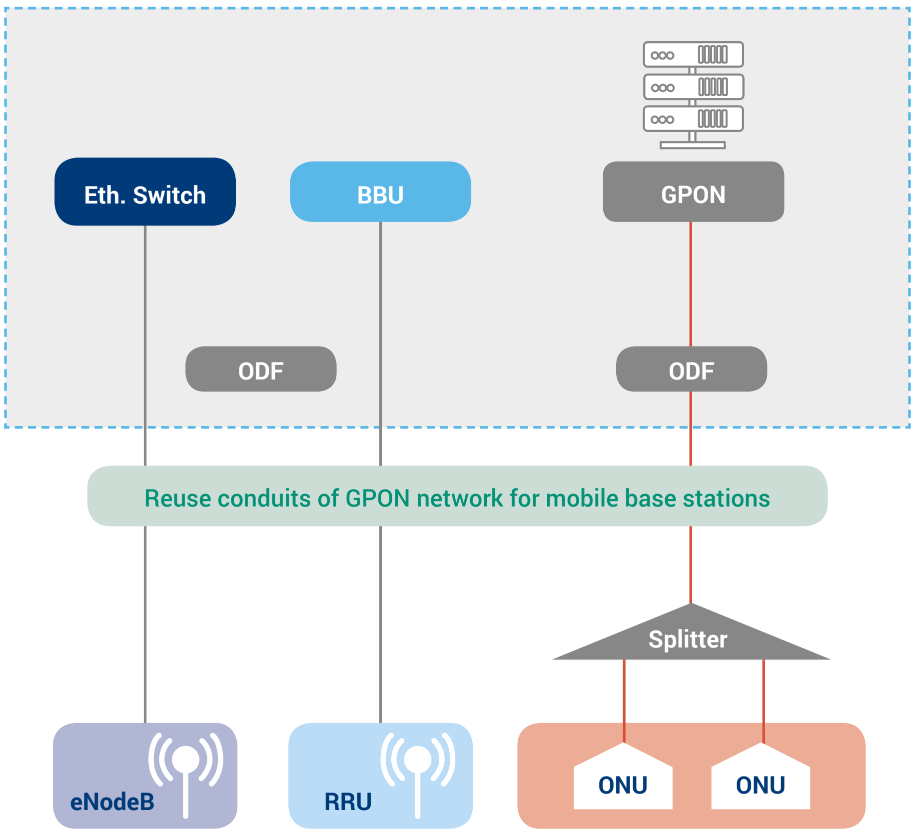
Following scenarios were considered:

Scenario 1 – Separate greenfield deployment of fixed access network and 4G/5G network

In scenario 1 of the case study, separate planning / deployment of FTTH GPON network for the fixed customers and fiber backhaul / fronthaul network for 4G/5G customers is modelled. The main assumptions are:

- Fixed Access Network planning / deployment is done for 1162 buildings using GPON technology with 1:32 splitting ratio
- 4G/5G Network planning / deployment is done for 50 5G small cells and 10 4G sites connected using both, backhaul and fronthaul. Locations are connected via point-to-point fibers from central location (PoP)
- Separate planning / deployment is done for active equipment, cables, etc., while utilizing same central location (PoP) for both the mobile an fixed networks.
- Performing civil works (greenfield) is assumed, while reusing of conduits of the FTTH/B network for 4G/5G network.

Figure 12: Scenario 1 architecture — Separate deployment



Source: Detecon

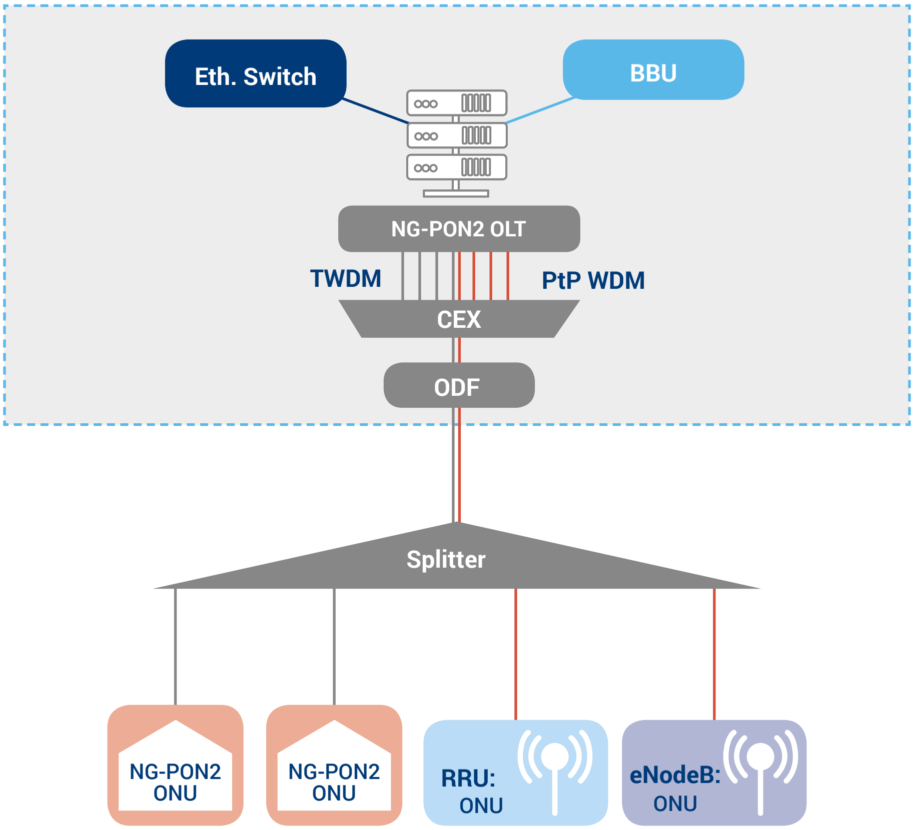
Scenario 2 – Converged greenfield deployment of fixed access network and 4G/5G network

In scenario 2 of the case study, converged planning / deployment of FTTH network for the fixed customers and fiber backhaul / fronthaul network for 4G/5G customers using NG-PON2 technology is modelled. The main assumptions are:

- Fixed Access Network planning / deployment for both, fixed and 4G/5G locations using NG-PON2 technology
- Common planning / deployment of NG-PON2 active equipment, cables, splitters, conduit systems, trenches etc. is considered.
- Up to 96 fixed (3 wavelengths), 8 mobile backhaul (1 wavelength) and 4 mobile fronthaul (point-to-point overlay) connections per NG-PON2 active port are considered, using 1:128 overall splitting ratio (1:4 in PoP and 1:32 in a field).

The placement of RAN nodes (macro cells or small cells) was done considering the topography of the area. While macro cells were placed on building rooftops small cells were dispersed across the area covering street junctions, open space between buildings as well as indoor placement in buildings.

Figure 13: Scenario 2 architecture — Converged deployment



Source: Detecon

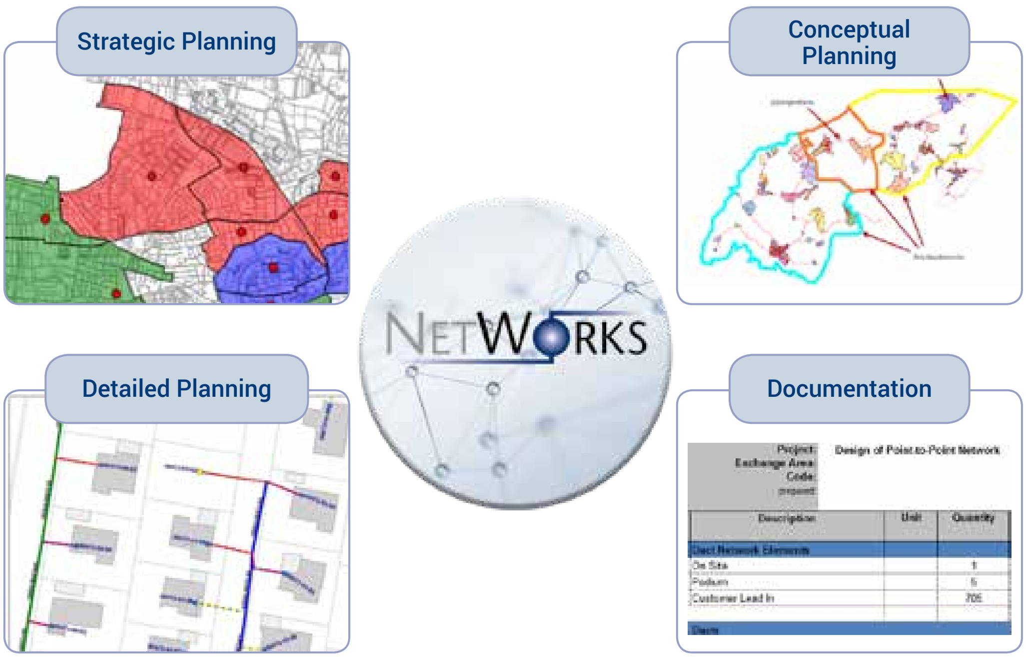
Used tools – Networks Fixed Access
NetWorks Fixed Access, the network planning tool developed by Detecon, is used for the purpose of network modelling in the case study. NetWorks planning software is based on a comprehensive technical expertise of the development team and the experience gained from a large number of international consulting projects. The result is efficient, tailor-made and reliable tool for daily work in the analysis, planning, optimization and documentation of telecommunication networks. The NetWorks software is developed and maintained exclusively by Detecon's competence team in Dresden. Detecon offers several NetWorks products for planning of different types of telecommunication networks. The software is developed and updated for more than 25 years already.

NetWorks Fixed Access – Overview
With the help of NetWorks Fixed Access Module, Detecon offers fast and efficient planning of FTTx networks. All network development phases are covered: from strategic and conceptual planning to detailed planning and documentation. NetWorks tools can significantly increase the efficiency and quality of planning activities. Using NetWorks Fixed Access results in following benefits:

- Use of an integrated software solution for the entire planning process from design to operation
- Comprehensive support and mapping of passive network components to active devices
- Professional network design with review of planning rules / design guidelines
- Reduced planning effort, based on the automatic fiber cables and conduit systems layouts
- Automatic planning of interconnection for active and passive components
- Coordinated, simultaneous daily work of several users on one project
- Comprehensive and detailed network documentation

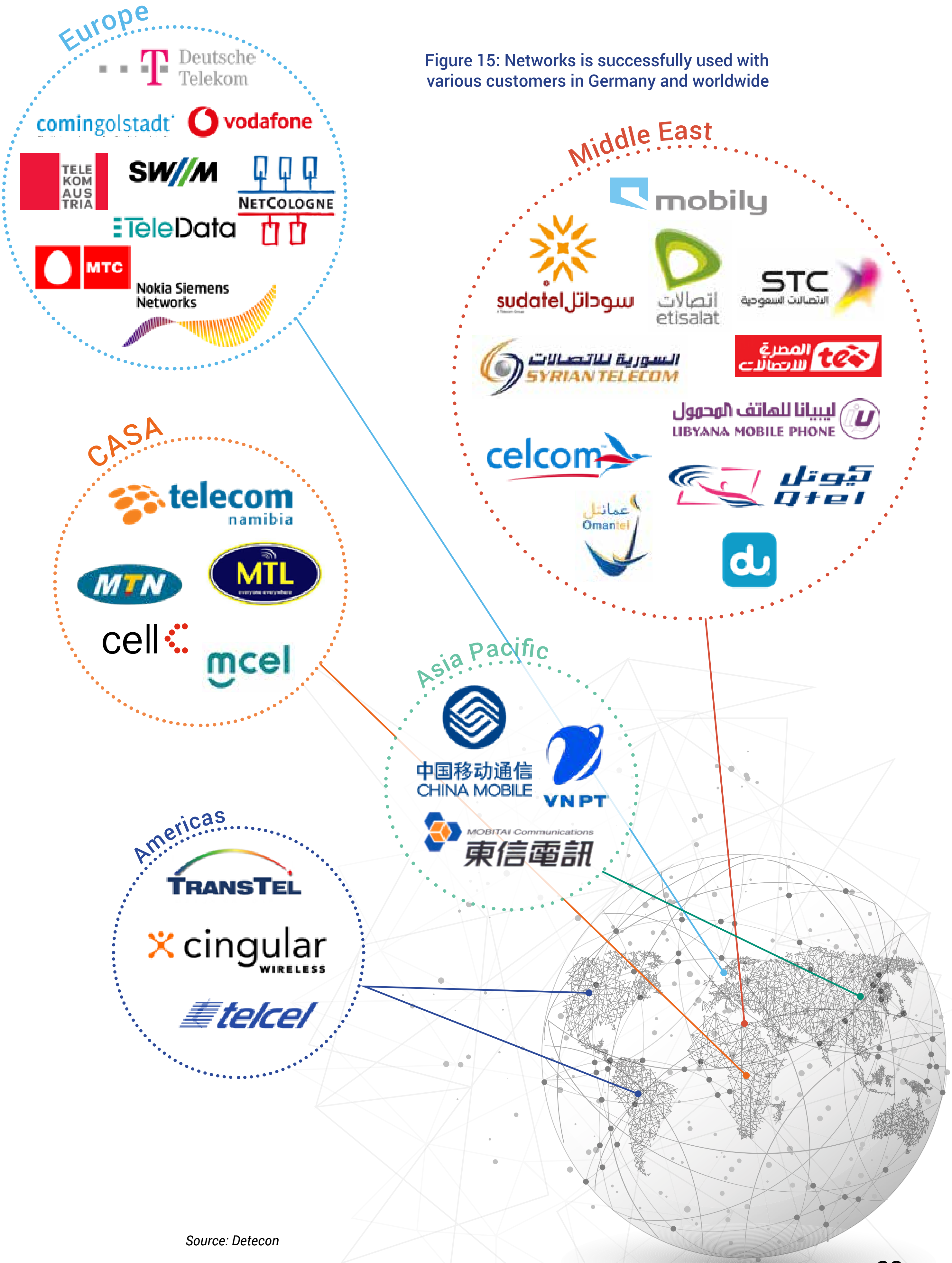
Detecon uses NetWorks in numerous projects for customers in Germany and worldwide. Our customers include numerous leading telecommunication companies, as well as city carriers, municipalities and other users.

Figure 14: Overview of NetWorks Fixed Acces Software



Source: Detecon

Figure 15: Networks is successfully used with various customers in Germany and worldwide



Source: Detecon

NetWorks software solution allows us to perform fast and efficient network planning because it has the following characteristics:

- Direct import of planning-relevant data from different sources
- Interfaces to popular GIS and WMS systems
- Integrated test functions for optimal planning results
- Automatic detailed quantity and cost calculation
- Automatic creation of various reports, diagrams and network plans

Figure 16: NetWorks Tool covers all phases of network planning and documentation

Source: Detecon

Results and Conclusion

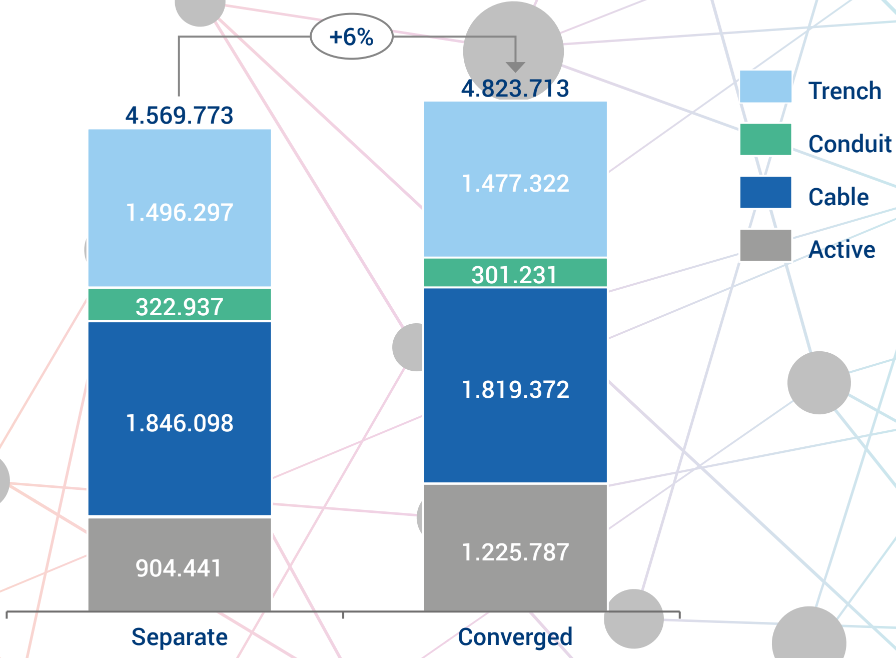
Modeling was conducted for the separate (Scenario 1) and converged (Scenario 2) deployments. The total CAPEX and its breakdown to different cost categories can be seen in the following pictures.

As to date, there are still no significant commercial deployment of NG-PON2 active components, NG-PON2 equipment CAPEX calculations for comparison results between “converged” vs. “separate” are estimated. Once sufficient market data on NG-PON2 active equipment is available, Detecon will make updated calculation with real market figures.

From the results we can see:

- There is a slight increase in the total CAPEX in the Converged deployment scenario (Scenario 2) than in the scenario of separate deployment.
- This increase comes from the anticipated higher cost of Active NG-PON2 equipment in Scenario 2, compared to GPON in Scenario 1.
- The cost of passive infrastructure is lower in Scenario 2 than in Scenario 1.
- Incremental CAPEX to connect the mobile base stations as a share of the total CAPEX is small to moderate due to high household density in the rollout area.

Figure 17: Case study results with BoM (Scenario 1 vs. Scenario 2)



Source: Detecon

Based on these results we can conclude that a converged deployment of an NG-PON2 network, as opposed to implementation of separate fiber infrastructure for mobile networks and GPON for fixed access customers is worth considering for the following reasons:

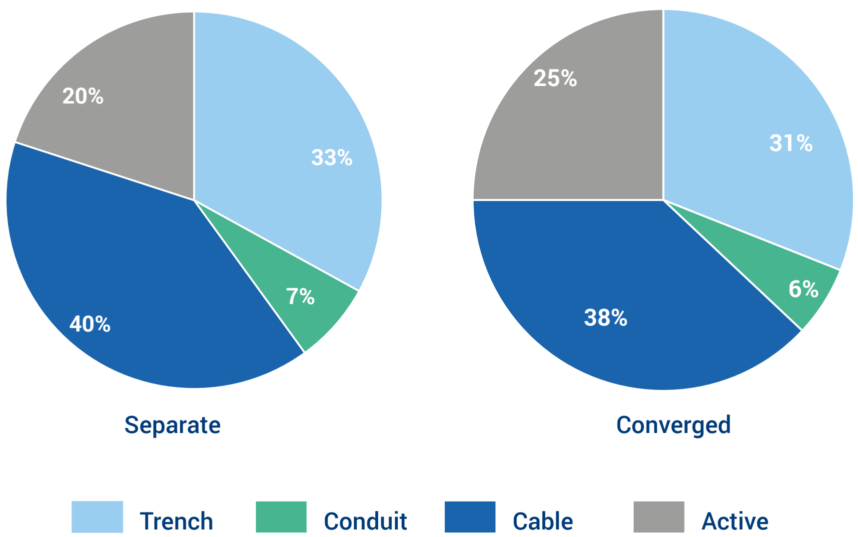
- While the CAPEX is slightly higher, the deployment of NG-PON2 allows for significant increase of the available bitrates per PON.
- Through the reuse of fibers of the PON network to connect the mobile base stations the cable and duct infrastructure is used more efficiently.
- The revenues from the connected mobile base stations could positively impact the overall business case.

Further Studies

For future studies, the modelling should be extended to cover the following points:

- Sensitivity analysis by varying the small cell density
- Analysis for different type of rollout areas (dense urban, urban, suburban, rural)
- CAPEX analysis with NG-PON2 market figures
- Modelling of different scenarios, such as different brownfield deployments

Figure 18: Case study results with BoM (Scenario 1 vs. Scenario 2)



Source: Detecon

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The Company

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We build the bridge between business and ICT perspectives. With this ability, we guide our customers through the digital transformation. Detecon is a subsidiary of T-Systems International, the corporate customer brand of Deutsche Telekom

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