

Assessment Framework and evaluation of state of the art technologies

Executive Summary of the Deliverable

The COMBO project will propose and investigate new integrated approaches for Fixed Mobile Convergence (FMC) for broadband access and aggregation networks. Besides the improved user experience, a key driver for convergence is the reduction of cost and energy consumption. WP5 is responsible for the techno-economic assessment of the candidate and proposed FMC network architectures.

Deliverable 5.1 is summarizing the activities of the first year for all tasks within WP5. The document is therefore an “intermediate” report of ongoing work, with focus on preliminary activities for the techno-economic assessment of FMC proposals of COMBO in the next two years.

From an architectural point of view, the starting point was the definition of state-of-the-art **network scenarios** (in line with Deliverable D2.2 from WP2). These were used for testing the assessment framework, and to provide initial cost and energy assessment results.

The main focus was on the **Assessment Framework**: the set of tools was identified, and several software components were implemented, including the communication or interfaces between the different tools. The first numerical results about state of the art fixed and mobile access networks are included in the deliverable, with the purpose of demonstrating the abilities of the tools and the Assessment Framework.

The **cost assessment** activity began with determining the scope of cost assessment, i.e. the network segments/elements, and cost factors considered. The methodology for calculating CAPEX and OPEX costs were addressed, and a cost database was created for the considered network elements. Finally, a preliminary cost assessment of state-of-the-art network scenarios was carried out.

Besides “pure” cost evaluation, as a higher level aspect, the **business ecosystems** were analysed. In the first phase of Task 5.3, existing business ecosystem for fixed, mobile, Wi-Fi and current FMC networks were evaluated, which will serve as the basis for the analysis of ecosystems corresponding to FMC proposals of the COMBO project.

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The **energy efficiency** aspects were considered by Task 5.4, addressing power consumption aspects of the considered network architectures. D5.1 lays the foundations of this activity: the methodology and scope for energy consumption assessment was defined, a power consumption database was created and the values collected for the considered network elements.

The presented cost and energy assessment results for state of the art, separate fixed and mobile networks will be used as the “baseline” solution for the assessment of FMC architectures. The “impact of convergence”, which is the main focus of the techno-economic assessment, will be evaluated by comparing FMC proposals to the solution without convergence, i.e. state-of-the-art, separate fixed and mobile networks.



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1 Introduction

The first year of WP5 was devoted to those preliminary activities needed to perform the techno-economic assessment of the FMC architectures that will be proposed in the next two years of the project by WP3.

As a first step, the **goals of the techno-economic assessment in COMBO were identified**, i.e. we identified the set of results WP5 is expected to provide by the end of the project (see Chapter 1). The next steps to be taken by WP5, in terms of the assessment results and aspects of comparison and evaluation, are the consequence of these long-term goals. As WP5 is strongly related to other work packages, the “scope” and requirements of WP5 were harmonized with WP2, and the assessment aspects reflect the (currently known) plans of WP3 regarding the FMC network architecture proposals.

The first year was devoted to “internal preparatory work” on the **Assessment Framework** (Chapter 3). Our primary goal was to be prepared for assessing FMC candidates and proposals coming from the project in the next two years.

- First, the necessary tools were identified to reach the identified research goals. These tools implement the methodologies defined for assessing “microscopic” and “macroscopic” case studies. Relation between the tools was investigated, in order to combine various aspects of assessment and case study concepts.
- Secondly, the most important initial implementation steps were taken, to make the Assessment Framework ready for future use. Algorithms and assessment methodology were implemented for state-of-the-art fixed and mobile network scenarios. A combination of these methods will support the assessment of FMC architectures, since FMC candidates (2014) and proposals (2015) are expected to be built on existing (“state of the art”) fixed and mobile solutions as building blocks.
- As the third main achievement, the cost and power consumption databases were integrated in the Assessment Framework, in order to combine the component-level cost and power consumption data with the network dimensioning calculations. The Framework was also prepared to pre-process case study data, i.e., the input data and the necessary interfaces are ready for the calculations.
- Finally, capabilities of the Assessment Framework are demonstrated through a set of illustrative results, the preliminary cost and power consumption assessment of state of the art fixed and mobile network architectures. These results are presented in Chapter 6.

Choosing the right **methodology for cost and power consumption assessment** is a fundamental decision for the future work of WP5. Since tasks 5.2 (cost analysis) and 5.4 (energy consumption analysis) were starting only in the second half of the year, there are still some on-going discussions, in particular about OPEX assessment, which is typically the most challenging part of a cost assessment activity. Decisions taken and the open issues of the cost assessment are outlined in

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Chapter 4, while the methodology of power consumption assessment is described in Chapter 5.

Even though, the cost and power consumption evaluations require different methodologies and tools, **defining the structure and scope of the underlying cost and power consumption database** was a common challenge. Such database must contain the relevant network elements for WP5 assessments. It required long discussions and joint work with WP3 on how the different network segments and elements are related to the COMBO scope. Once the database was defined, an initial data set was collected, with all difficulties of harmonizing various data sources, solving confidentiality issues and finding the proper trade-off between abstraction and practical applications. Specific values are not revealed in the public deliverable, but the structure and elements of the cost and power consumption databases are described in Chapters 4 and 5, respectively. In addition, the non-confidential power energy consumption database is included in the Annex of the Deliverable.

The “arena” in which the different FMC candidates will “compete” was defined, i.e. the case study types were also planned. The concept of “macroscopic” and “microscopic” **case studies** were defined, such that the network architectures will be assessed both at a large-scale and in more specific “local” detail (Chapter 6). The two assessment approaches complement each other.

The first, **demonstrative results** of the cost and energy consumption assessment calculations are included in Chapter 7. The role of these numerical results is to demonstrate how the already implemented parts of the Assessment Framework operate, but we are not aiming at a thorough techno-economic assessment of state of the art fixed and mobile networks, as it was done earlier in numerous research projects and publications.

To complete the whole picture concerning the techno-economic assessment of the assessment framework an **analysis of the business ecosystems** of the different networks and related business models was also provided. Analysis of the fixed, mobile and Wi-Fi ecosystem was carried out, and an outlook to FMC state-of-the-art was given in Chapter 8.

2 Scope of the Deliverable

2.1 FMC vision in COMBO architecture

The whole assessment study should focus on the COMBO scope, i.e. the reference framework, and the candidate fixed and mobile access networks should be clarified. Among other initial requirements, we need to define which network segments, structures and functions we need to consider – which should follow guidance of WP3. In this subsection, we first provide an overview of the targeted convergent architecture, we discuss some relevant enablers for this target and we show a possible initial candidate network with limited convergence between the fixed and mobile network segments.

2.1.1 Definition of Convergence in COMBO

As D5.1 concentrates on the assessment framework and evaluation of state-of-the-art networks, it is key to have in mind the ultimate COMBO target architecture, which will help refining the initial scope of the state-of-the-art assessment.

“Convergence” is a trendy word, notably because it is seen as synonym for cost decrease and also because it corresponds to the behaviour of end users, who care for the service, but not for the technology used (3GPP, Wi-Fi, DSL, fibre...). Beyond the trend, convergence of fixed and mobile networks is a desirable, though very complex, target for network operators, because convergence supposes to address complex trade-offs in order to really benefit from moving different functions or pieces of equipment closer to each other. When several network segments are optimised on their own scope that does not imply that the resulting architecture is overall optimized. It is certainly worth accepting only partial improvement of some domains, if this leads to a much better design for the overall scope. This is precisely COMBO target: jointly designing and optimising the fixed and mobile networks as a whole, even if this leads to only partial improvements for the fixed network and the mobile network taken separately.

To achieve this joint design and optimization of fixed and mobile networks, COMBO proposes a new access / aggregation network architecture organized around the concept of Next Generation Point of Presence (NG-POP). NG-POP designates the disruptive evolution of the first aggregation node, also called Central Office (CO), Local Exchange or Local POP by opposition to more centralized POPs. This first aggregation node plays a key role in telco networks because it is the mediation between downstream segments, which are connecting customers (access networks) and upstream segments characterized by converged flows (core networks). Hence this aggregation level has to deal with several constraints: a wide variety of services and technologies, scalability issues, regulation duties, operational constraints, to mention a few.

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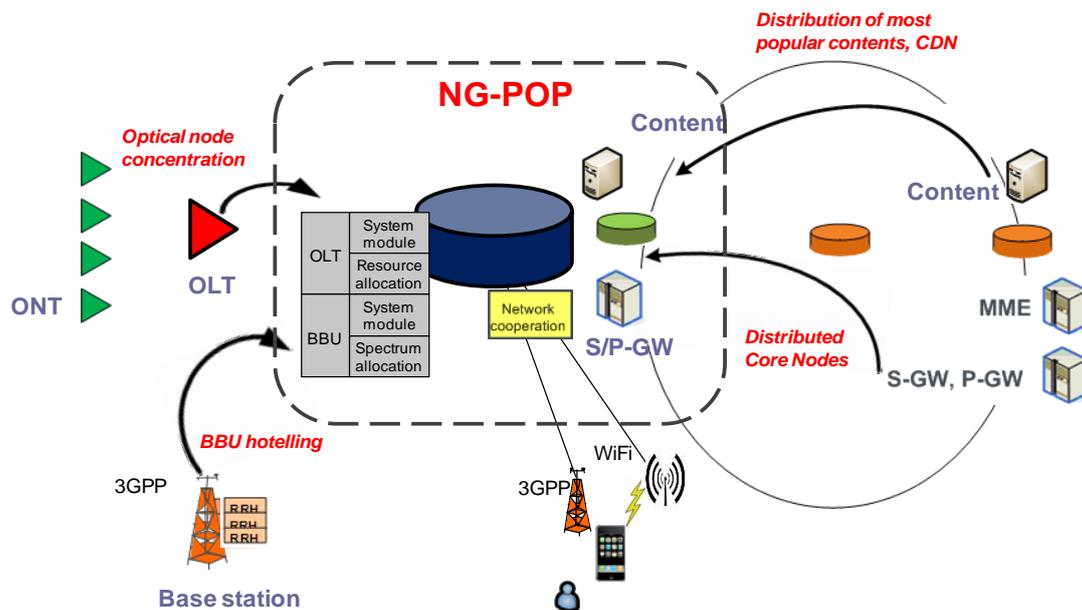


Figure 1: Next Generation Point of Presence (NG-POP) concept

The NG-POPs will be less distributed in the network than the traditional COs, thanks to optical node concentration: Local Exchanges, the local POPs of the copper network, are expected to consolidate to achieve a smaller number of Optical Access Nodes located further up in the network, thanks to the longer reach and higher capacity of FTTx networks compared with xDSL networks. As NG-POPs will be higher in the network than traditional COs, they will be able to host advanced functions of the mobile network such as Serving Gateways (S-GW) or Packet data network Gateways (P-GW). More generally, through this NG-POP concept, COMBO aims at finding a better distribution of all-essential functions, equipment and infrastructures of convergent networks. This will drastically reduce ICT infrastructure costs and energy consumption, whereas guaranteeing an optimal and seamless quality of experience for the end user. The overall NG-POP concept is illustrated in Figure 1. The arrows of the drawing indicate either shifts of some network functions to the NG-POP (e.g. content distribution, S/P-GWs), or even structural changes such as optical node concentration or Base Band Unit (BBU) hostelling. The ultimate NG-POP-based architectures will thus combine basically two important aspects of fixed / mobile network convergence:

- the convergence of fixed and mobile network functions, which we call functional convergence. The goal here is to harmonize and better distribute the various functions of fixed and mobile networks by distinguishing those that should be more "centralised" from those that should be more "distributed";
- the convergence of fixed and mobile infrastructures and equipment, which we call structural convergence. The goal here is to share as much as possible the infrastructures (e.g. cables and civil engineering, cabinets, sites, buildings) and equipment of the fixed and mobile networks by envisaging, where possible and relevant, infrastructures and equipment that are shared between these two types of network.

2.1.2 Some enablers for functional and structural convergence

Functional convergence will benefit the customer by making the service independent of the access technology and the device, not through an additional service control layer but by using natively convergent technologies and protocols in the network domain. Functional convergence should also give the customer the best access to the network for a given service and in a transparent manner. Some of the key enablers of functional convergence are:

- Unified control mechanisms of fixed and mobile networks;
- Streamlining of protocol stack around IP and Ethernet technologies;
- Generalized 3D handover mechanisms combining horizontal handover (between cells), vertical handover (between access technologies, e.g. 3G, LTE, Wi-Fi) and transversal handover (between operators);
- Advanced network-level offloading schemes involving both fixed and mobile networks;
- Openness of network interfaces;
- Harmonization of authentication and subscriber management.

Structural convergence is probably more complex to implement, as it involves sharing the infrastructures and equipment of fixed and mobile networks. In addition to the technical obstacles to overcome, it also requires evolutions in the business relations between mobile and fixed operators, and therefore developments in the regulatory framework. The path towards structural convergence will rely in particular on some technological and architectural enablers such as:

- Optical node concentration allowed by optical access technologies;
- Heterogeneous radio access networks combining small cells and macro cells;
- BBU hostelling with resource pooling, also called Cloud Radio Access Networks (Cloud-RAN);
- Mobile front haul technologies based on Digital Radio over Fibre (D-RoF) for the connection between BBU hotels and RRH at antenna locations;
- Multi-wavelength and multi-service optical access technologies.
- Energy efficiency through involving both fixed and mobile equipment

2.1.3 Current state of the art architecture of fixed and mobile networks

Having described the FMC vision of COMBO, this sub-section now defines the reference overall network architecture, describing the current state of fixed, Wi-Fi and mobile networks, including a small degree of convergence (e.g. by the use of fixed aggregation networks for mobile backhauling purposes). The overall picture of the reference architecture is given here, but details can be found in COMBO deliverable D3.1.[1]

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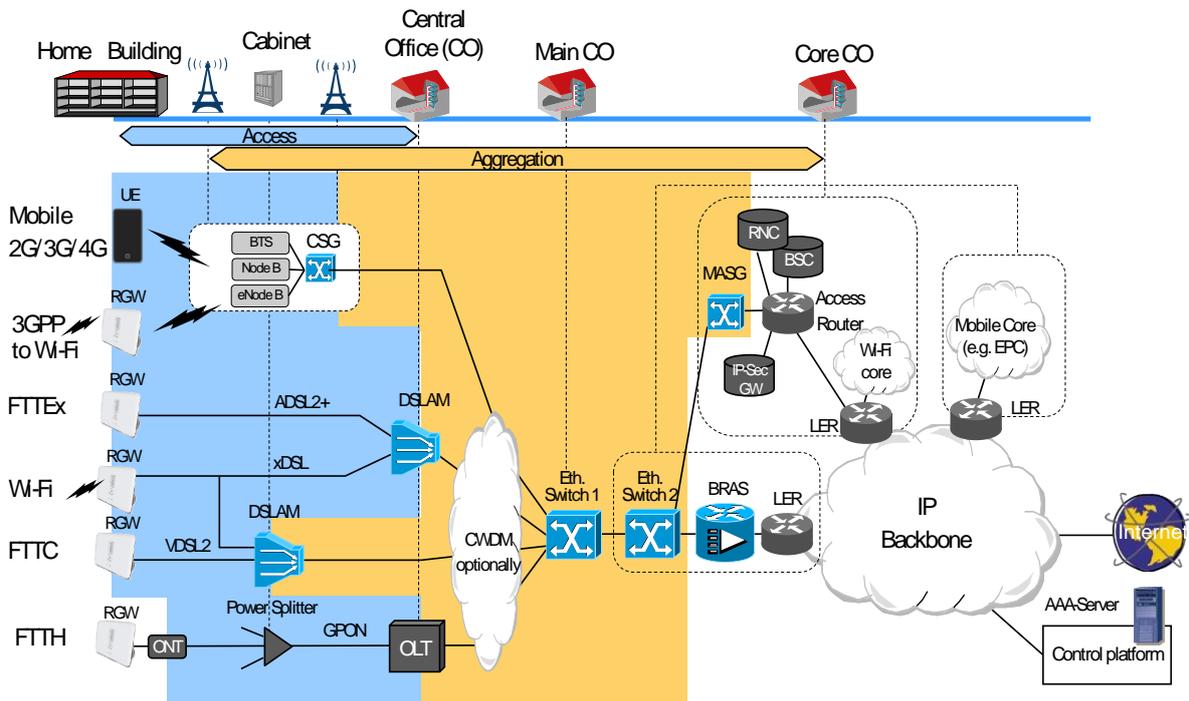


Figure 2: Current state-of-the-art architecture of fixed and mobile networks

It is noted that a certain degree of structural convergence is already realized in today's access and aggregation network deployments as shown in Figure 2. With the evolution towards All-IP, mobile base stations and fixed access nodes (DSLAM, OLT) have been connected to a common Ethernet based aggregation network that is more suitable for IP packet transport than the legacy transmission technologies (SDH/ATM). In addition, backhauling of the different base stations and access nodes is often realized via CWDM technology in order to minimize the amount of fibre in the aggregation network section. Fixed, mobile and Wi-Fi networks are structurally converged in the aggregation network section by sharing the same fibre infrastructure and equipment, at least in some parts of the aggregation network.

A higher level of structural convergence already exists for the Wi-Fi deployment, since Wi-Fi access points are typically connected to the fixed DSL access network via ADSL/ADSL2+ and VDSL2. In contrast to that, backhaul of mobile base stations and fixed access nodes (DSLAM) in the access part is provided by individual dedicated fibres, but the same technology (CWDM) is used. FTTH residential users are served by a dedicated technology (GPON) and fibres in access. So, in the access there is limited structural convergence today.

All access and aggregation networks (fixed, mobile, Wi-Fi) are usually connected to a common IP backbone network that is based on MPLS technology. The control and user plane of the different access platforms are mostly separated, especially between the fixed and the mobile network. In the Wi-Fi case, some central components of the fixed and/or mobile network might be used, e.g., AAA information.

2.2 Objectives of the techno-economics studies

The techno-economic studies in the frame of COMBO primarily focus on the economic rationale behind any changes in the network towards convergence. The optimal trade-off should be identified between pure “technical” performance (e.g., higher bandwidth, extended coverage, reduced latency, improved QoS, etc.) and their cost implications. Obviously such optimality may depend on the service area, service requirements, and numerous other conditions, which have to be considered throughout the techno-economic assessment.

Scope of the techno-economic assessment should be aligned with the COMBO project scope, and follow the guidance of the previous work packages, mainly WP2 and WP3. As the COMBO project primarily deals with the access and aggregation network, these will be the networks segments mainly considered during the techno-economic studies. Only those core network elements will be taken into account, on which the implications of changes in the access and aggregation may be observed.

The “*impact of convergence*” should be the main focus of the techno-economic studies of WP5. In some cases, the architectural/technical difference can be easily highlighted between a state-of-the-art network architecture (i.e., separate fixed and mobile networks), and a proposed converged FMC network architecture. In these cases, a differential cost evaluation will be carried out, in order to point out the impact of convergence on cost.

When a FMC network architecture proposal means a complex re-allocation of a wide set of network functions, and implies extensive structural changes in the network, the differential approach cannot be applied. In these cases, a total cost assessment of the state of the art and the converged network architecture will be necessary, evaluating them against a set of pre-defined *case studies*, in order to point out the difference between them, i.e. the *impact of convergence*.

Main elements of the techno-economic assessment are the following:

Deployment cost (CAPEX)

Methodology followed for CAPEX estimation of network architectures will be outlined later, in Section 4. The network dimensioning results will be matched with the cost database collected for the COMBO project, in order to calculate the deployment costs for all the network elements within the scope of the assessment.

FMC network scenarios proposed by WP3 will be evaluated against a set of case studies, applying differential or total cost calculations, in order to identify economically most attractive solutions. The case studies cover large-scale generic geotypes (such as dense urban, urban and rural areas), and small scale real example networks, in order to highlight both “macroscopic” and “microscopic” aspects (see Section 6 about case studies for more a detailed explanation).

Cost of operating the network (OPEX)

With respect to convergence of fixed and mobile networks, assessment of OPEX, i.e., the cost operating the network has also high importance. In our expectations it might even be the cost factor on which convergence has a decisive impact. However, calculating OPEX is complicated even for already existing networks, hence

estimation of OPEX for new network architecture proposals is a tough research challenge. Within the frame of COMBO, a “mixed” approach will be followed for OPEX calculations. The strictly network related (OAM: Operation, Administration & Maintenance) cost will be a function of the network technology and the capacity of the network (and the given network elements). Simpler models will be used for less network dependent cost components, e.g. floor space. And a specific focus will be dedicated to power consumption.

Power consumption

Energy efficiency in itself is an OPEX cost element of growing importance, but due to its social and environmental impact, it may be even more important than its cost implications. Therefore, a specific task is dedicated to energy efficiency: task 5.4 will deliver the power consumption assessment of the FMC network architecture proposals. These results will also serve as part of the OPEX assessment.

Topology and geography specific effects

The “geographic” methodology of techno-economic assessment in COMBO has an important advantage over the classical geometric approach: it gives some insights about what are the consequences of various network requirements on the underlying physical infrastructure. Increasing bandwidth or capacity, reducing latency, improving reliability or extending coverage translates to different requirements on the cable plant, location of network equipment, etc. These effects typically depend on the geographic conditions, e.g., population density or the structure of the street system.

As a well-known example, lower population density (i.e. longer distribution links) negatively affects the performance of DSL networks, due to the high attenuation on copper links. From a future-proof perspective, it has another important implication: increasing the bandwidth of a PON network does not need significant changes in the cable plant structure. On the other hand it has decisive impact on a DSL network, as DSLAMs should be moved closer to subscribers due to the attenuation of the copper, which necessitates a thorough, and sometimes cost-prohibitive restructuring of the outside plant. The street system, and the size of buildings also has implications on the topology of the cable plant, e.g. the about the number of splitting levels, or optimal decision about the deployment type (i.e. FTTB or FTTH).

This kind of “insights” may be provided using the “microscopic” case studies.

2.3 State of the art fixed and mobile access networks

Fixed and mobile access networks can use different technologies and architectures. This section summarizes them in the scope of access and aggregation networks. Additional information can be found in D2.2 [2] which describes with more details the most important technologies and architectures for current fixed and mobile networks and their future evolution. Aggregation networks have been included in a different subsection as there is less diversity than in access networks.

2.3.1 State of the art of fixed access networks

State-of-the-art fixed networks can be classified based on the physical transmission medium: copper, optical fibre or wireless (Wi-Fi and microwaves mainly).

2.3.2 Copper-based access networks

Digital Subscriber Loop (DSL) is the main technology used to deliver broadband services over the traditional twisted pair copper lines in the telephony loop. The denomination xDSL covers the copper based standards reusing the existing infrastructure connecting the customer to the telephony grid, such as SDSL, HDSL, SHDSL, ADSL and VDSL. The overall idea is to utilize the old, already existing, telephony infrastructure to provide the customers with a high-speed Internet access. The term “high-speed”, however, has had different meaning during the development of the DSL standards, spanning from providing slightly higher rates than in the voice-band modem, to rates comparable with those of Passive Optical Networks (PON).

Inside today DSL deployments, different generations of technologies can coexist, such as Integrated Services Data Digital Network (ISDN), Asymmetric Digital Subscriber Line (ADSL), ADSL2plus and Very high bit rate DSL (VDSL2). Additionally some techniques can be used in VDSL2 to provide higher bitrates, like bonding or vectoring. Currently ITU-T is working on the fourth generation of DSL under the G.fast project that will be able to provide transmission rates up to 0.5 Gbps for low distances (lower than 250 m).

DSL technologies are typically deployed using Fibre to the Exchange (FTTEx) – see Figure 3 – or Fibre to the Cabinet (FTTC) architectures (see Figure 4); with FTTEx, DSL services are provided from the CO (i.e., the local exchange), whereas with FTTC, DSL services (typically VDSL2) are provided from an intermediate element (i.e., the cabinet) that is connected to the CO using fibre technologies. The following pictures show the reference network for FTTEx and FTTC architectures where the Digital Subscriber Line Access Multiplexer (DSLAM) is the central node located at the CO and in the remote cabinet respectively.

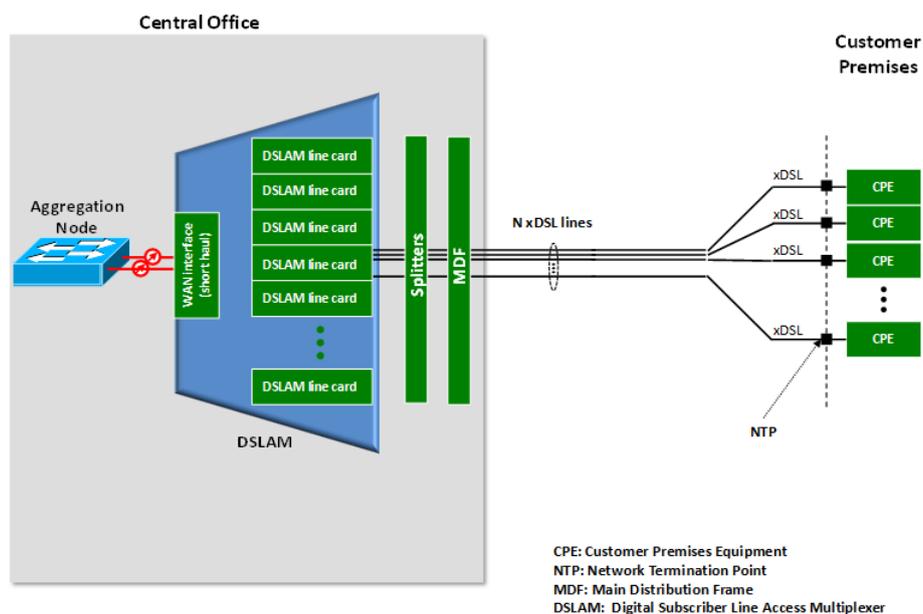


Figure 3: DSL using FTTEx architecture

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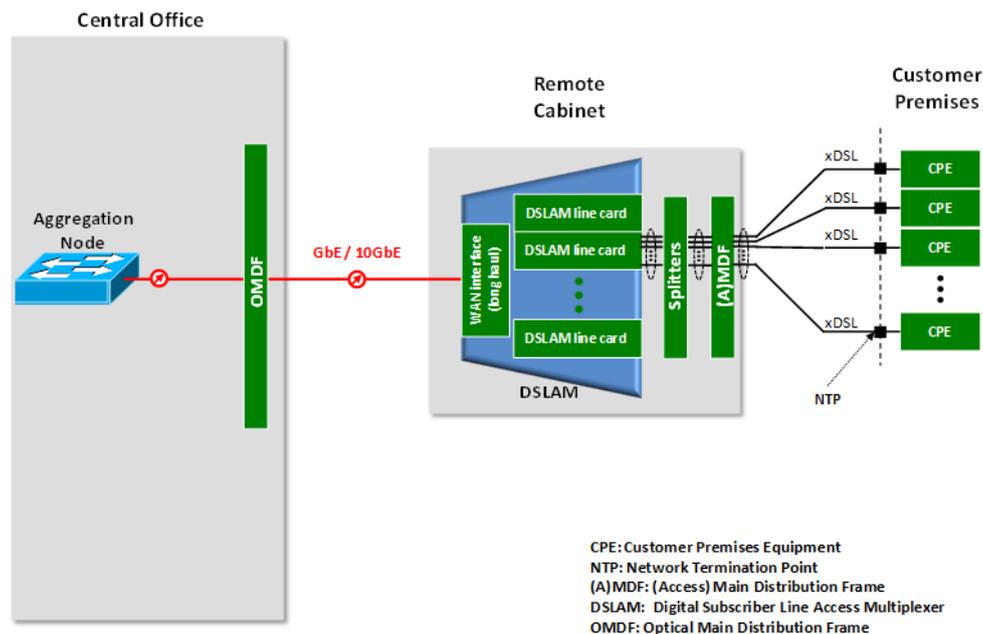


Figure 4: DSL using FTTC architecture

2.3.2.1 Fibre-based access networks

Optical fibre can be used in the access network following two main approaches: point-to-point and point-to-multipoint. *Point-to-point* technologies can be based on different standards, such as ITU-T G.989 1Gbps point-to-point Ethernet-based optical access system or IEEE 802.3ah standards and can provide a capacity up to 1Gbps per user with a reach up to 80 km. *Point-to-multipoint* solutions consist of an Optical Line Terminal (OLT) located at the CO and multiple Optical Network Terminals (ONT) that are connected to it through an Optical Distribution Network (ODN). Active and passive ODNs exist, however a passive ODN (also known as Passive Optical Network or PON) is preferred due to its lower cost. Typically the number of subscribers connected to a PON is limited to 32 or 64 with a maximum reach from 10 to 20 km providing a similar aggregated capacity than point-to-point networks (but in this case, the capacity is shared among multiple users using Time Division Multiplexing (TDM)).

PON can transmit data using different Layer 2 technologies following different standards, where the most common are GPON (ITU-T G.984: Gigabit-capable Passive) and EPON (IEEE 802.3ah: Ethernet Passive Optical Network), however the new standards for 10G-GPON (ITU-T G.987: 10-Gigabit-capable passive optical network) and 10G-EPON (IEEE 802.3av: 10 Gbps EPON) have been released and are currently available both providing an aggregated capacity of 10 Gbps in the downlink with a similar splitting ratio and reach than GPON and EPON. PON is typically used in Fibre to the Home architectures but can also be used in other FTTx architectures such as FTTC or FTTB (Fibre to the Building).

The following picture (Figure 5) shows the reference network for FTTH-PON:

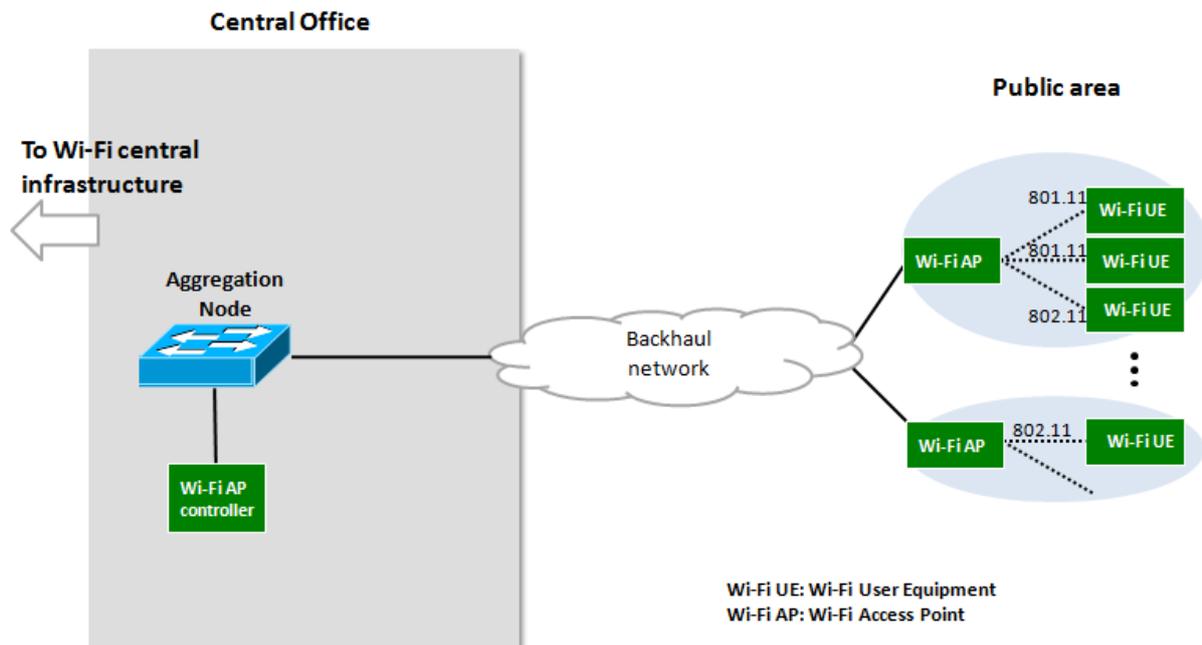


Figure 6: Operator Wi-Fi hotspot

Microwave is another wireless technology that employs the Ultra High Frequency (UHF), Super High Frequency (SHF), and Extremely High Frequency (EHF) bands. Some typical application areas for microwave are corporate service and fixed wireless broadband networks, especially mobile backhauling.

Microwave technology has undergone a tremendous evolution over the last decade with new frequency bands, architectures, and antennas made available. In the beginning of 2000, a legacy microwave link on a 28 MHz channel encoding 2 bits per symbol typically supported up to 37 Mbps, corresponding to a spectral efficiency of 1.3 bps/Hz. New signal spectral shaping at the transmitter, modulations and spatial multiplexing have increased the spectral efficiency to approximately 36 bps/Hz. In modern microwave systems hundreds of Mbps on a single carrier are usual.

2.3.3 State of the art of mobile networks

Over the last 20 years, different technologies have been standardized and used in commercial deployments to provide mobile services. The most representative technologies are 2G, 3G and LTE, which are described in the following sections.

2.3.3.1 2G

2G, the second generation of mobile systems, is not a standard protocol itself but it represents all the families of standards and systems for digital mobile communication such as Global System for Mobile Communications (GSM), Cellular PCS/IS-136, cdmaONE, Personal Handyphone System (PHS), etc. 2G systems support voice services and low speed data communications from 9.6 up to 14.4 Kbps.

GSM networks are composed of different elements, where the most important are: the Base Transceiver Station (BTS), which contains the equipment for transmitting and receiving radio signals, the Base Station Controller (BSC), which provides the

intelligence behind the BTSs, and the MSC (Mobile Services Switching Center), which takes care of switching tasks within the network and provides connection to other networks.

General Packet Radio Services (GPRS) is an evolution of 2G systems for packet exchange services where a certain QoS is guaranteed during the connection. GPRS provides data rates from 56 kbps to 114 kbps and it can be used for access services such as Wireless Application Protocol (WAP), SMS, Multimedia Messaging System (MMS), and Internet services such as email and web access. GPRS introduces new network elements such as the Gateway GPRS Support Node (GGSN), which is a node that connects the GPRS network to external IP networks such as internet; and the Serving GPRS Support Node (SGSN), responsible of interacting with the radio interface and storing the location information in the radio interface of GPRS subscribers

2.3.3.2 3G

3G is the third generation of mobile systems. 3G systems can provide data rates up to 28 Mbps (for users in very good signal conditions), although in practice average data rates in commercial networks are around 3 Mbps.

Today, there are multiple different 3G systems worldwide, e.g., Universal Mobile Telecommunication System (UMTS) is the 3G standard adopted in Europe. UMTS extends existing GSM and GPRS networks introducing new interfaces and network elements, for example the Radio Network Controller (RNC), which is the responsible for the resource allocation and the transmission/reception in a set of cells and the NodeB, which are the elements of the network that correspond to the base stations.

3GPP is the organization that has continued developing the mobile systems defining the UMTS evolution through different releases and introducing new features in each of them. UMTS specification was defined in release 99, however other releases were published later providing additional functionalities and increasing the data rate.

2.3.3.3 LTE

Long Term Evolution is the new standard developed by 3GPP and is specified in Release 8 with additional enhancements in Release 9.

LTE, also called E-UTRAN (Evolved Universal Terrestrial Access Network), is the access part of the Evolved Packet System (EPS). The EPS is an all-IP architecture with relevant interworking with circuit-switched systems and provides 100 Mbps DL/ 50 Mbps UL within 20 MHz bandwidth peak data rate, up to 200 active users in a cell (5 MHz), less than 5 ms user-plane latency, optimized mobility, enhanced multimedia broadcast multicast service (E-MBMS), spectrum flexibility from 1.25 to 20 MHz, enhanced support for end-to-end QoS.

The EPS architecture is composed by the LTE/E-UTRAN and the EPC (Evolved Packet Core), where the most important network elements are the Evolved NodeB (eNB), which handles all radio interface-related functions, the Mobility Management Entity (MME), which handles the control plane, mobility, UE identity, and security parameters, the Serving Gateway (S-GW), which handles the data plane and

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terminates the interface towards E-UTRAN and the Packet Data Network Gateway (PDN-GW), which provides IP connectivity to the UE and gives access to the PDN.

The RNC is removed and its functionalities are therefore distributed between the eNB and other network elements inside the EPC. The following figure represents the reference architecture for a LTE cell site connected to the EPC using a backhaul link.

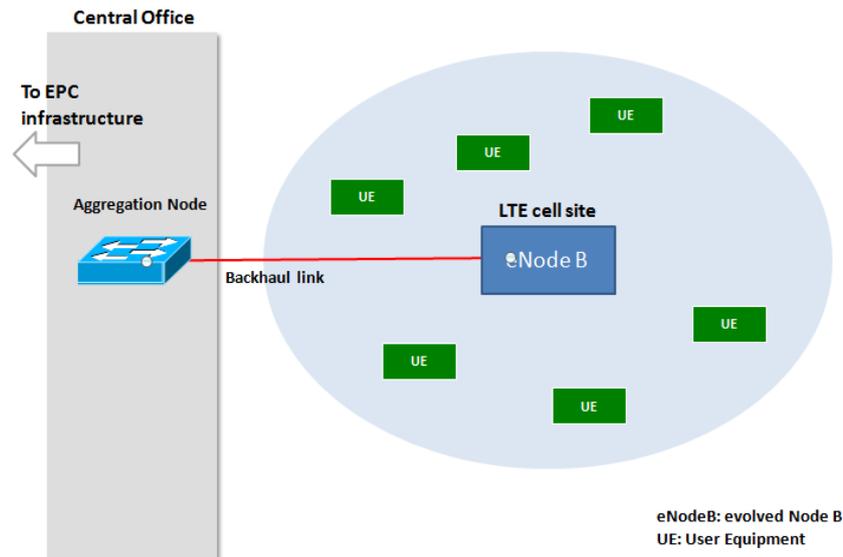


Figure 7: LTE cell site reference architecture

The backhaul link in the previous figure (Figure 7) provides the connectivity between the base stations and their relevant controller and it is always needed whichever technology is used (BSC for 2G, RNC for 3G and MME and S/P-GW for LTE). It usually connects the access and the aggregation segments. Access and aggregation infrastructure can be composed of different technologies mainly based on optical (GPON, fibre point-to-point, DWDM, etc.), copper (mainly DSL technologies) or microwave (point-to-point or point-to-multipoint).

Legacy backhaul networks supporting 2G/3G services are mostly based on legacy technologies such as TDM and ATM using PDH and/or SDH. With LTE, legacy backhaul networks are being replaced with new backhaul networks with more capacity, flexibility and scalability. Some alternatives are the conventional packet backhauling using IP/Ethernet networks and CPRI backhauling from the cell site with a remote base band processing.

2.3.4 State of the art of aggregation networks

Legacy technologies in the aggregation networks, such as SONET/SDH or ATM are being replaced by other technologies, which are now also able to provide -but at a lower cost - high-level of protection and availability, QoS and OAM capabilities. The most accepted strategy is migrating aggregation networks towards the consolidation of Optical, Carrier Ethernet, WDM, IP/MPLS technologies, packet transport (MPLS-TP), without compromising the carrier-graded virtues of legacy technologies such as control, resilience, OAM, scalability, etc.

3 Assessment Framework

The Assessment Framework is a set of tools used for techno-economic assessment of state of the art fixed and mobile network architectures in the beginning, FMC network architectures in the next steps. In line with the research goals outlined in the introduction of the deliverable, the framework must be able to handle the “macroscopic” and “microscopic” case studies, and implement the respective assessment methodology described for them in the following chapters.

Two different dimensioning approaches are presented in the deliverable, and used in the COMBO project to estimate the infrastructural needs of the networks. We will use the terms “microscopic” and “macroscopic” to differentiate between these two approaches. In nationwide or continental scale, only the macroscopic approach applies due to complexity reasons, but in citywide or smaller scenarios the microscopic approach has some clear accuracy gain [4].

3.1 Assessment Framework: tools and components

The Assessment Framework has three primary “building blocks”, concluded here and described in details in the following sections:

- Technology and configuration optimization (Section 3.2)

The techno-economic assessment aims at finding the “optimal” choice of network architectures/technologies for given case studies. Therefore, an in-depth comparison of these network technologies will be necessary, including not only the comparison of completely different technologies (e.g. VDSL or PON) and their possible combinations in the same architecture, but also the comparison of various configurations (e.g. different splitting ratios or splitting levels, or diverse capacity options for any device within each technology). The main constraints of this optimization process are related to signal reach and traffic demand.

Hence, a technology-optimization tool was developed by POLIMI, which highlights the impact of network configurations changes, analyzing different network scenarios them over the same physical layout (which, as the communication interface will be implemented, will come from the physical infrastructure optimization tool from BME).

- Optimization and dimensioning of the physical infrastructure (Section 3.3)

The so-called “AccessPlan Framework” originally developed by BME for optical access networks focuses on the optimization of the physical infrastructure, minimizing the costs of deploying a pre-defined network architecture on a given case study [10]. Scope and capabilities of the tool are further extended to meet the COMBO requirements: not only new fixed network scenarios are added, but the development of a mobile network module has been started, including the integration of fixed access and mobile backhaul.

The optimization methodology takes into account the geographical and topological characteristics of the selected area, and also the physical and technical constraints of the chosen network architecture, and carries out a strategic network design. As a result, a physical network layout is proposed including the system design and the location of the network elements, which fulfils these requirements.

The resulting network design supports accurate dimensioning and bill of material calculations for the selected case studies, which is the basis of the cost assessment.

- Geotype-dependent, high-level network dimensioning tool (3.4)

The first and widely accepted approach of network dimensioning is the use of a set of reference parameters and theoretical network models, which altogether define the so-called “reference areas” or “geotypes”, i.e. dense urban, urban and rural environments.

During the initial cost estimation, the selected network scenarios will be evaluated against these geotypes. The resulting dimensioning data (i.e. the necessary amount of different network elements for covering such an area) will then be coupled with the cost database (chapter 4), and the deployment cost calculated for these network scenarios in a dense urban, urban or rural environment will be compared.

Besides the optimization and dimensioning estimation tools, an important additional component of the Assessment Framework was also developed: a map processing module presented in section 3.5. This will be responsible for reading and processing the geographic characteristics of the case studies.

3.2 Technology and configuration optimization

The techno-economic assessment can be performed by a software tool based on technological feasibility analysis and cost-effective comparison of diverse candidate options. For diverse access technologies and backhauling options this tool is able to find the best trade-off between cost, capacity, and signal reach. The tool aims at selecting the technological options that fulfil the constraints at lowest cost. This tool focuses on the access and aggregation sections of the network and in microscopic scenarios.

In order to achieve the aforementioned objective of this tool, a layered access network model was designed and employed. With this model, different aspects can be evaluated and obtained, such as path finding and connectivity of the end-nodes that exchange data and signal reach verification. From the input data, it is possible to generate a structure of the network and all of its connections. This structure is a layered graph where every layer represents a different channel or wavelength (depending on the technology and transmission medium at every section) and the nodes that are connected to every layer. The layered graph may change later according to the transmission technology options and the restrictions imposed by the intermediate nodes and media.

According to the reference framework proposed in WP2, the nodes can be classified in 4 types, namely: main CO, CO or local exchange, cabinet, and user premises. Nodes are containers of elements. Elements to be used can be parts of the physical node, such as transceivers, optical amplifiers, etc. Each element has attributes such as cost, bit rate, power consumption, etc. In this tool, it is also possible to add functionality to any network node by adding a function element. The attributes of function elements can be the typical or allowed locations in the reference framework and its cost.. The chosen physical and/or functional elements are those that we consider reasonably important for the objective of our evaluation. For every different

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architecture candidate composed by a certain transmission technology in the end-nodes of every link segment, the elements inside the node are going to be replaced, and re-evaluated. This will be very helpful later on when we try to evaluate new nodes that may be proposed later in this project in order to achieve fixed-mobile convergence. A database provides the specific relevant data for nodes and element options for every access technology. Details of this database are presented in Chapter 4. Each element has a number of attributes taken from the input data. The combination of elements inside every node is not filled freely, but by taking into consideration restrictions on the technology and based on typical real scenarios, as well as matching physical properties.

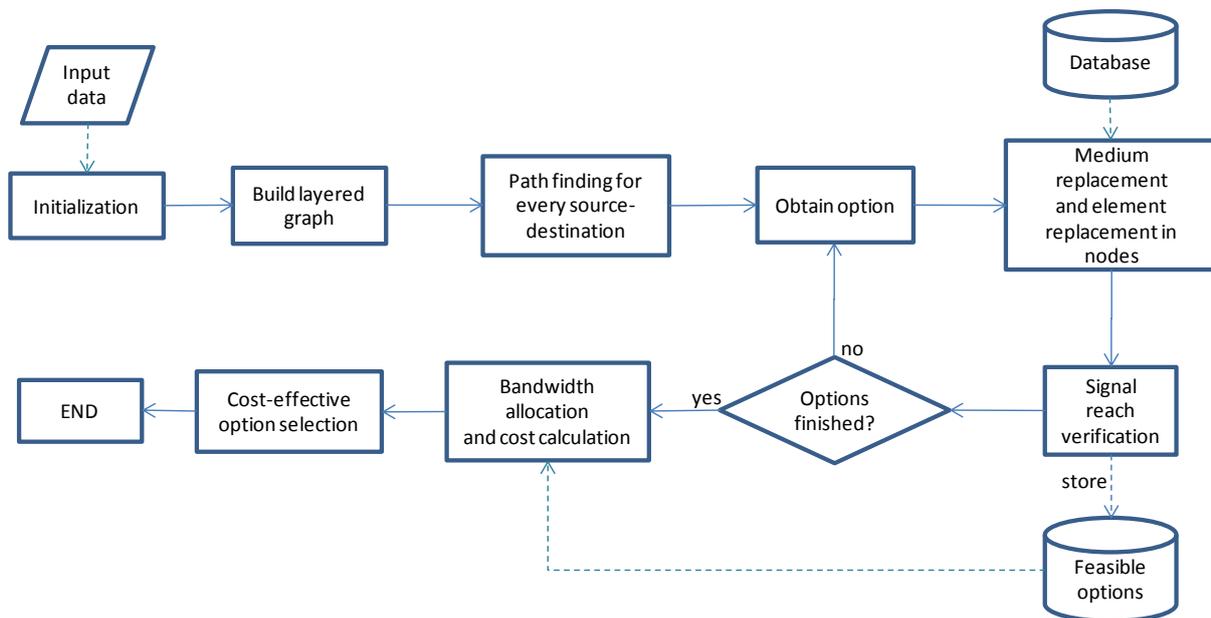


Figure 8: Optimization tool general flowchart.

In Figure 8, we present a general and simplified flowchart of our proposed optimization scheme. After we get the input data related to the topology (coming from the physical infrastructure optimization tool described in the next section), we proceed to build a layered graph. For each specific channel/wavelength, a layered graph is generated that contains all the nodes and links connecting the nodes. Once the layered graph is built, we proceed with finding a path for every source-destination pair. This path physically involves a number of link segments and intermediate nodes. The path is found by checking every possible collection of links from the source node to the destination node on every graph layer. If multiple paths are available, the path with minimal total distance is chosen.

Next step is the core of the optimization scheme, where we start the analysis of feasible options. First, we find the initial option and we perform element replacement in every node and medium replacement. According to the most common scenarios taken from real implementations of fixed and mobile access networks, we define the possible candidate options and technology combinations. Different segments of the reference framework (aggregation, feeder, distribution) can make use of different access technologies. Every access technology is linked to certain node equipment

and transmission media at the links. The information on the available elements and their attributes is extracted from the database.

Every set of node and link type combinations will be treated as an option for further optimization. If a link is set as existing, in the cases of brown-field scenarios, then the link will not be replaced by another type of media. Conditions or restrictions on installation of any link media can be set. For example, if no more copper twisted pair is expected to be installed in the future, copper will not be considered as option for green-field scenarios. For every option, we proceed to validate the signal reach. For instance, in optical segments the optical losses are required not to surpass a pre-defined power budget limit. If the option under consideration does not satisfy signal reach requirement, then it is discarded. Otherwise, this option is stored for further calculations.

If there are more options to be evaluated we repeat the validation process. If there are no more options to be evaluated, then we proceed to allocate bandwidth to every source-destination pair according to the traffic demand specified as input. The allocation is performed in a way that minimal resources are needed. Only the options that satisfy all the traffic demands are counted for the final round on the choice of optimal solution. If any traffic demand is not fulfilled, the candidate option is discarded.

The final optimization step is based on pondering the total cost of every candidate option and choosing the best one. The cost can be composed of CAPEX and OPEX. For example, the OPEX figure can be based on energy consumption, among other possible parameters. After calculating the total cost for the feasible options, we choose the option with the lowest total cost, i.e. the most cost-effective configuration.

3.3 Optimization and dimensioning of the physical infrastructure

When investigating the deployment costs, the underlying physical infrastructure plays an important role. Therefore, one building block of the cost assessment will focus on the cable plant, locations of various network elements, e.g. cabinets, antenna sites or central offices. The cost of a given network element or a “unit” of the cable plant is known (collected in the cost database); therefore, the cost of the network translates to the dimensions and the layout of the network.

Dimensioning and optimization of the necessary physical network infrastructure begins with a strategic network design phase, hence there is no need for empirical parameters, based on existing deployments (e.g. for average inter-site distances or trunk lengths). Instead, the technology specific (physical) constraints will be defined (e.g. for network reach or capacity of network elements). The minimal cost network layout fulfilling these requirements will be the results of an optimization process, the so-called “strategic network design”.

Independence from empirical parameters coming from existing deployment becomes important when we consider expected FMC network architecture proposals of the COMBO project. For the assessment of not yet deployed FMC network scenarios, the network dimensioning methodology cannot use input parameters based on existing deployments (as those not exist yet). Instead, the optimization process shows how a given network architecture adapts to the specific

geographic conditions (and not only an estimation for generic geotypes, such as the artificial dense urban, urban and rural scenarios).

Each respective case study is characterized by the necessary geospatial information describing the service area: the digital map of the street system, location of the demand points, central office(s), potential cabinets and antenna sites. Existing infrastructure may also be taken into account in a brownfield deployment scenario. This input information is then combined with the cost database and the technology specific parameters, as Figure 9 summarizes.

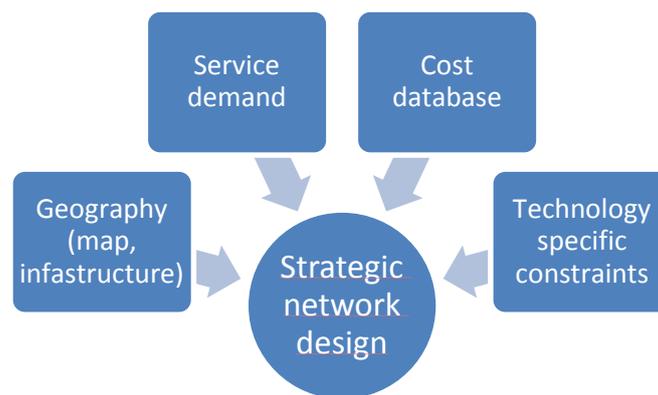


Figure 9: Inputs of the strategic network design process

Solving the optimization problem is a complex algorithmic challenge, but in the past few years a set of scalable heuristics were published which deliver results not only for small example networks, but for real-life scenarios as well. The solutions applied in the COMBO project for strategic network design of fixed and mobile access networks will be briefly described in the following sections.

This approach will be referred to as the “microscopic” approach, which focuses on the details of the physical network infrastructure: location of elements, interconnections, system design, etc.

3.3.1 Fixed access networks

The optimal design of fixed access networks may be translated to a graph theoretical problem, in which the graph (Figure 10) contains the necessary geographic information described above: the demand points, the street system, infrastructure, etc. The fixed access network is a special structure upon this graph: elements of the network architecture are located at suitable nodes of the graph, and the network connections between them follow the edges of the graph.

On an abstract level, a minimum cost, point-to-point or point-to-multipoint architecture is the objective of the optimization problem, connecting demand points (buildings or households) to the central office through cabinets or distribution units, if applicable. During the design of such topology, three basic questions should be answered:

- In the point-to-multipoint structure, which demand points have to be connected to the same distribution unit? Or: which demand points should be in the same group (cluster), assigned to a common DU?
- Where should the distribution units be located?

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- Which path should the connections follow between the demand points and their assigned DUs, and also between the DUs and the CO?



Figure 10: Graph model of a fixed access network

The specific heuristics applied for different network architectures follow different approaches for these clustering, flow and assignment problems. As the deliverable is not a mathematical or algorithmic document, the details are not outlined here – the reader is referred to [3] [5] [6] for details.

The optimization process gives a network layout (Figure 11), with focus on the physical infrastructure (but also the logical interconnections and system design is given). The network dimensioning results, i.e. the bill of material calculations are then carried out by counting up all network elements, optical fibre and the necessary cabling work, and the network deployment costs are derived through combining the Bill of Material with the cost database.

3.3.2 Mobile access networks

During the strategic design of mobile access networks, the specific focus will be on the location of antenna sites. The mobile backhaul will be designed using the above-described methodology for fixed access networks.

In order to determine the number and location of necessary antenna sites over a chosen service area, the case study description has to identify not only the map, but also the service demand, which the network has to serve. The chosen mobile access technology then determines the parameters for coverage planning.

The generally accepted Okumura-Hata ([7]-[8]) and COST 231 propagation models [9] were applied to find a suitable distribution of antenna sites, such that it delivers the required coverage of the service area. Capacity requirements may also be added, which will have an impact on the density of antenna sites. The result of the process is the distribution of antennas over the service area (Figure 12), and for the network dimensioning and cost assessment process, the list of necessary network elements; while dimensions of the backhaul network will be determined using the methodology for fixed access, but taking the antenna sites as demand points.

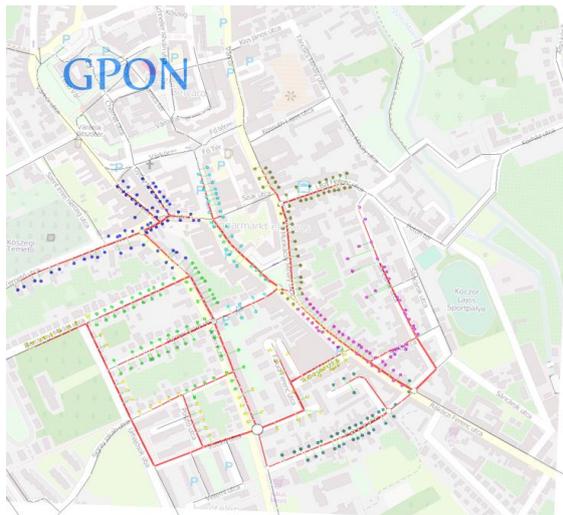


Figure 11:
Example fixed access network



Figure 12:
Example mobile access network

3.4 Dimensioning methodology for state-of-the-art fixed and mobile

As it was described in the previous section, network dimensioning is the first step of cost estimation. Once a list of necessary network elements, the so-called *Bill of Material* results are available, it will be coupled with the cost database to complete the network architecture cost assessment.

This section describes the “macroscopic” approach for dimensioning, which is built on wide-area average descriptors, such as density of network elements and average distances between them for estimating network dimensions, but does not consider local geographic characteristics or variations of the network layout. In nationwide or continental scale, only the macroscopic approach applies due to complexity reasons.

Network dimensioning, is based on a set of reference parameters that can be used to calculate the amount of network equipment, cabling, links, sites, etc. needed to cover the selected service area under study. These reference parameters are defined in section 2.4 “Common reference areas” of D2.1 “Framework reference for fixed and mobile convergence”. Some examples of reference parameters are the number of households, the range of operation of different technologies, the length of network segments, number of sites in an area, etc.

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Reference parameters are classified according to common reference areas. Each common reference area is characterized using their specific reference parameters. Common reference areas considered in this study are the network areas where network operators deploy their infrastructure to provide broadband services, such as the customer premises, the access network, the aggregation network, and several core network elements.

Before analysing the reference parameters in each common reference area, an important factor to consider is the geotype. Three geotypes, which depend on the population density, have been defined: dense urban areas, urban areas and rural areas (see D2.1 [68], section 2.4.2). Reference parameters typically depend on the geotype, however, others can be independent of it. Geotype information has been also provided for those reference parameters that can vary according to the geotype.

Customer premises are the residential homes or business buildings where final users access to fixed and mobile broadband services. Here, the reference parameters taken into account are related to the number of households, network devices and network capacity inside the customer premises.

The reference parameters included in fixed access network are classified according to three different locations: the outside plant, the cabinets and the access nodes. The main reference parameters for the outside plant are those related to the length of the different network segments, the range of operation of different technologies, and the network topology. Reference parameters for cabinets are related to the number of subscriber per cabinet and the number of cabinets per area. Finally, reference parameters for access nodes include the number of subscribers per each different node and the capacity required (considering mainly DSLAMs and OLTs as the main types of access nodes).

The reference parameters defined in the mobile access network are mainly related to the mobile base station. They provide information on how to calculate the number of base stations and active users in a typical area considering different configurations, technologies (3G and LTE) and cell sizes (macro and small cell areas).

The reference parameters for the aggregation network have been divided in three parts: the aggregation nodes for the fixed broadband services (typically network switches), the mobile backhaul and other fixed and mobile network elements inside the aggregation network (e.g. BRAS and RNC). Reference parameters provide information regarding typical distances, topologies, capacity, redundancy, throughput, and number of subscribers in relation to those network elements.

Finally, the main reference parameters for the mobile packet core network are related to the maximum throughput of the main network elements, such as the SGSN and GGSN for 3G networks and S-GW, P-GW and MME for LTE networks.

It is important to clarify that the values selected for the reference parameters are considered typical, common or valid in European countries. However, specific values for a real deployment could vary depending on many factors, such as the services to be provided, service level and coverage, expected penetration, investment, regulation, competition, etc. The network dimensioning methodology will use the reference parameters specified by WP2 as the initial value, however, other values

more appropriate for the service area under study could be used if it is needed to make the scenario more realistic.

The dimensioning methodology, using the reference parameters, and applying geometric models for cable plant estimation, was implemented in an Excel file with. The calculations are included as Excel macros, specifically designed for the dense urban, urban and rural models (geotypes). The applied geometric model is an improved version of the Simplified Street Length (SSL) model [4].

3.5 Map processing module

In order to assess the chosen reference areas, and to carry out the network planning/dimensioning process, we need detailed geographic information of these areas. In this section, we shortly review the specific information requirements, data sources, and the way the Assessment Framework may process this information.

The need for map processing primarily applies for the microscopic case studies, as described in section 3.3, which have much stronger input data requirements. Beyond the cost database and technology specific parameters, geographic (geospatial) information is necessary (accuracy of the input data limits the accuracy of the achieved results).

Therefore, data sources for the street system, the network demand/traffic location and distribution over the reference area have to be identified and integrated. In order to fulfil the requirements, development of the suitable data interfaces for the Assessment Framework has been started:

Digital map of the street system

For research purposes, OpenStreetMap (OSM [11]) data is a strong candidate, as it is freely available for a large part of Europe. Besides OSM, other widespread digital map formats exist, e.g. ESRI shape or AutoCAD formats. Digital maps coming from cartography companies may arrive in these formats, and the Assessment Framework is capable to process the major digital map formats.

Location of fixed demand points

If the freely available OSM data is not used, but a professional map supplier provides the data, the buildings may be part of the OSM format map and processed jointly with the street system layout.

As a second option, an interface was added to the Assessment Framework, which reads an independent data file with an {address, coordinates, households} database, based on e.g. census data. Finally, in the absence of such data, the demand points may be artificially generated along the streets by proper distribution models.

Potential location of antenna sites

An input data file format was specified to record the potential antenna locations. Such data may be defined by network operators located at the area (most probably slightly randomized data of their network). Another option is to indicate in the list of buildings whether antennas may be located on the rooftop. In brownfield deployments, with the objective to upgrade existing antenna sites, location of these sites may be used. Finally, in the absence of data, a random selection of buildings is also a possibility.

Street cabinets

Similar to antenna sites, another input data file may record the locations where street cabinets may be placed. In brownfield deployments, location of the existing cabinets gives the potential location of network elements in the outside plant. In greenfield deployments, or in the absence of such data, potential cabinet locations may be generated (e.g. allowing to deploy cabinets at the street crossings), but in this case the cost of introducing new cabinets needs to be considered.

Mobile network demand

For the optimization of the mobile networks' physical infrastructure, the expected spatial distribution and amount of mobile network terminals and their demand has to be known or modeled. For brownfield deployments or network upgrades, the location of the antenna sites is known and will be re-used.

Brownfield deployments

During the optimization of fixed, mobile or backhaul network layout, the already existing infrastructure can be taken into consideration, which is a natural way of cost effective network deployment (e.g. re-use of existing ducts). The presented tools are capable to take into account this information when assessing brownfield scenarios, if such data is available (or should be generated as a given percentage of the street system).

Workflow

As shown in Figure 13, the workflow of the Assessment Framework begins with the processing of the following information: reading the digital map and infrastructure information, adding network demand to it, and then let the optimization process deliver the layout of the physical infrastructure.



Figure 13: Assessment Framework - workflow

4 Cost analysis methodology

This chapter is devoted to define and describe the rationale behind the cost analysis process. We need to define the basic components required for a proper cost assessment. A first important step was to understand the impact of handling diverse technologies for both fixed and mobile networks in this project. Every technology has its own dimensioning specifications and constraints. The network dimensioning affects the type and number of elements to install and operate, and hence cost. For this reason, we needed to develop a model that considers the dimensioning rules of every technology in different network scenarios, as well as the capital and operational expenses involved. As per the scope of this document, the cost model has been elaborated to support state-of-the-art fixed and mobile networks as separate entities. However, in this chapter we introduce a discussion on the expected impact of FMC networks on the cost model and analysis.

Our proposed cost model consists of three parts: (i) specific network configurations or scenarios, (ii) Capital Expenditures (CAPEX), and (iii) Operational Expenditures (OPEX). We discuss them in the following sections.

4.1 Network Scenarios for Cost Analysis

For a cost assessment, it is not enough to collect and sum up the cost of every component of a network. Indeed, it is needed a prior technical dimensioning of the network that takes into account the capacity and particular design constraints such that the network to study is a valid case. Moreover, each network scenario has its own specifications regarding typical use and capacity of certain devices; therefore the cost must be captured separately for every network scenario. Therefore, as a first step in our model, we define network scenarios that involve typical configurations found in the field. These scenarios are applied for current and independent fixed and mobile networks. Mobile networks yet involve the use of fixed networks for mobile traffic backhauling, which already combines fixed and mobile technologies. However, not a proper fixed-mobile convergence optimization is present in the proposed scenarios of mobile backhauling. On the other hand, scenarios for FMC networks are not within the scope of this document given that FMC solutions have not been proposed yet in the framework of COMBO.

In the following sections we present the network scenarios for fixed networks, Wi-Fi networks, and mobile networks. Although Wi-Fi networks are considered as part of the fixed networks, we have added a specific section for clarity reasons.

4.1.1 Fixed Networks

A set of fixed network scenarios were identified which are in the scope of the current cost assessment activity. These cover mainly state of the art fixed access networks or their short term successors or upgrades, and are intended to cover the most important conceptual technical solutions to fulfil fixed access network requirements (the work of WP2 and WP3 gives the in-depth explanation of these requirements and technologies).

As a first step of the project, the Assessment Framework was prepared to handle these fixed network scenarios. According to our expectations, these network

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technologies will serve as the “building blocks” of future FMC candidates and proposals. Therefore, implementing them in the COMBO Assessment Framework is a natural preliminary step before the assessment of FMC architectures in the coming years.

The following Table 1 summarizes these fixed network scenarios, while a short explanation of them follows the table. In some cases not only the current “state of the art” network scenarios will be presented, but also the next architectural or technological step, which may be the subject of the next years’ work and deliverables. The description and illustration of every typical fixed network scenario can be found in the Annex 11.1.

| Scenario | | | Dense urban | Urban | Rural | Configuration |
|----------|------|---------------|--|--|-------------------------------------|---|
| 1 | FTTH | GPON (10GPON) | 1:4 @cabinet 1:16 @building 10-15km reach* | 1:16 @cabinet 1:4 @building 10-15km reach* | 1:64 @cabinet 10-15km reach* | 100 Mb/s GPON - 1:64 (10G - 1:64) |
| 2 | FTTC | VDSL2 + PtP | ETH switch @CO Copper<300m** | ETH switch @CO Copper<300m** | ETH switch @MainCO Copper<300m** | 100 Mbps @home |
| 3 | FTTB | WDM PON | 1:48 @cabinet 60 km reach | 1:48 @cabinet 60 km reach | 1:48 @cabinet 60 km reach | 1 λ @building |
| 4 | FTTH | NGPON2 | 1:64 @cabinet 20 km reach | 1:64 @cabinet 20 km reach | 1:64 @cabinet 20 km reach | 1Gbps @home 1:64 |

Table 1: Fixed network scenarios

4.1.2 Wi-Fi Networks

Also for Wi-Fi networks, a group of scenarios have been considered in order to analyse the technical solution and fulfil network requirements. Wi-Fi networks are included as general cases in this chapter; however, they are not included in the demonstrative assessment results presented in Chapter 7.

These scenarios have been defined taking into account that Wi-Fi is a wireless access technology that is independent of the backhaul connection technology used. Therefore the same backhaul network is presented for all cases in order to reduce the number of network scenarios presented. However, it is understood that other backhaul options could apply. In this sense, the four scenarios summarized in Table 2 have been defined. The description and illustration of every typical Wi-Fi network scenario can be found in the Annex 11.1.

| Scenario & FTTx type | | Network technology | Wi-Fi integration |
|----------------------|------|--------------------|--------------------------|
| 1 | FTTH | GPON / 10G GPON | Residential |
| 2 | FTTH | GPON / 10G GPON | Community |
| 3 | FTTH | GPON / 10G GPON | Indoor public / Business |
| 4 | FTTH | VDSL2 + PtP | Outdoor public |

Table 2: Wi-Fi network scenarios.

4.1.3 Mobile Networks

A set of Mobile network scenarios were identified which are in the scope of the current cost assessment activity. These scenarios cover the state of the art of mobile access networks and their short future upgrades.

As already explained in section 4.1, these scenarios are intended to cover the most important conceptual technical solutions to fulfil access network requirements (the work of WP2 and WP3 gives the in-depth explanation of these requirements and technologies).

The following Table 3 summarizes these mobile network scenarios. Most of the cases consist of diverse ways to backhaul the main mobile networks, i.e., 2G, 3G, and LTE. The description and illustration of every typical mobile network scenario can be found in the Annex 11.1. Although a single Radio Access Network (RAN) solution is envisioned using a unique backhaul, in this section we present the mobile network technologies separately for simplicity reasons to show the typical configurations.

| Scenario (Radio network + Backhaul network) | | Dense urban | Urban | Rural |
|---|-------------------------------------|-------------|-------|---------------------|
| 1a | 2G + PtP (FTTC) | X | X | X |
| 1b | 2G + Microwave + PtP | X | X | X |
| 2a | 3G + PtP (FTTC) | X | X | X |
| 2b | 3G + Microwave + PtP | X | X | X |
| 3 | 3G (pico/femto cell) +DSL + FTTC | X | X | optional |
| 4a | LTE + PtP (FTTC) | X | X | X |
| 4b | LTE + Microwave + PtP | X | X | X |
| 5a | LTE (small cell) + DSL + PtP (FTTC) | X | X | Maybe in the future |
| 5b | LTE (small cell) + Microwave + PtP | X | X | Maybe in the future |
| 5c | LTE (small cell) + PON (FTTH) | X | X | Maybe in the future |

Table 3: Mobile network scenarios.

4.2 Capital Expenditures, CAPEX

Real or good estimations of the typical CAPEX costs are needed in order to obtain valid and useful results during the techno-economic analysis. Many different costs are needed to have an end-to-end view of fixed and mobile networks, such as, civil works, equipment, and cabling. Additionally, these costs could vary depending on the purchase volume, country, technology, manufacturer, equipment configuration, etc. On top of that, real costs are sensitive information that companies typically do not share.

For this study, a cost database has been implemented to feed the techno-economical tools. The database contains the prices of the main elements that are going to be considered during the network dimensioning process for all the network scenarios under study in both fixed and mobile networks.

This database has been completed with the inputs provided by telecom operators and manufacturers working in COMBO. Partners have tried to provide real cost data

when possible or use the typical cost of the elements under consideration. For other few elements partners have agreed to use the cost of other elements with the same functionality. Most of the partners have provided direct cost values, while others have provided a relative cost with respect to a common reference. In this case, the reference was the cost of a GPON ONU. The assessment tools can perform calculations using either absolute or relative numbers. In this document, we obtain absolute cost results using an artificial currency unit. In this way, it is possible to appreciate the proportional differences among the evaluated technological options.

In order to reduce the barriers to provide this sensible information, only academic partners responsible of the data handling have had access to such information. These partners had to ensure the integrity and consistency of the multiple inputs received.

4.2.1 CAPEX in Fixed Networks

The CAPEX estimation is based on two “pillars”: (1) network dimensioning and optimization, in order to determine the amount of necessary network equipment and cabling to cover the selected service area, and (2) a cost database which records the unitary price of the network equipment, optical fibre and cabling.

Methodology for network dimensioning was outlined in Section 3.3, while the list of elements of the cost database is listed in Table 4. Note that some elements may use diverse typical capacity specifications.

| Reference Location | Network Element |
|--------------------|----------------------------------|
| Customer Premises | RGW |
| | STB |
| | ONT (PtP WDM up to 4 Gb/s) |
| | ONT (PtP WDM up to 10 Gb/s) |
| | ONT (shared WDM, e.g., TWDM) |
| | Customer premises VDSL2 splitter |
| | GPON ONU |
| | XGPON ONU |
| Access Network | GPON OLT |
| | XGPON OLT |
| | OLT (PtP WDM up to 4 Gb/s) |
| | OLT (PtP WDM up to 10 Gb/s) |
| | OLT (shared WDM, e.g., TWDM) |
| | DSLAM (@CO) |
| | VDSL2 remote DSLAM (@ cab) |
| | Fibre Distributor (ODF) |

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| Reference Location | Network Element |
|---------------------|--------------------------------|
| Aggregation Network | Ethernet Switch Lv1 |
| | Ethernet Switch Lv2 |
| Core Network | BRAS / BNG |
| | LER |
| | Radius Server |
| Outside plant | Optical splitter |
| | AWG |
| | Cabinet with power supply |
| | Cable installation cost per km |
| | Channelling cost |
| | Splicing box |

Table 4: Fixed network elements for the CAPEX database.

Wi-Fi networks are also assumed as part of the fixed network in COMBO. The elements of the Wi-Fi database are indicated in Table 5.

| Reference Location | Wi-Fi Network Element |
|--------------------------------------|--|
| Customer Premises | AP |
| | CPE: RGW |
| Access, Aggregation, or Core Network | Wi-Fi AP Controller |
| | Wi-Fi Access Gateway |
| Core Network | Wi-Fi Core platform (AAA systems, security, AP controller, lawful interception system, logging facilities) |

Table 5: Wi-Fi network elements for the CAPEX database

It is important to note that the final architecture of a Wi-Fi core depends on the needs of the operator. Additionally, there is a strong dependency of the platform with the number of hotspots that are to be managed by such a platform.

These costs have been calculated using actual costs in Wi-Fi networks deployments in several countries all around the world with different GIP, population density, etc.

4.2.2 CAPEX in Mobile Networks

Given that that mobile network uses the fixed network for traffic backhauling and transportation of signalling data to the mobile network core, many of the devices found in the fixed database, could also be found in the cost analysis of the mobile networks. In Table 6, we only include mobile network devices in order to avoid repetition of devices.

| Reference Location | Network Element |
|---------------------|---------------------|
| Customer Premises | HNB |
| | HeNB |
| Access Networks | 2G BTS |
| | 3G NodeB |
| | LTE eNodeB |
| | CSG |
| Aggregation Network | MBH aggregator Lv 1 |
| | MBH aggregator Lv 2 |
| | HNB GW |
| | HeNB GW |
| | MASG |
| Core Network | 2G/3G - MSC |
| | 2G/3G - SGSN |
| | 2G/3G - GGSN |
| | 2G / HLR |
| | EPC - MMF |
| | EPC - P-GW |
| | EPC - S-GW |
| | HSS |
| | PCRF |

Table 6: Mobile network elements for the CAPEX database.

4.3 Operational Expenditures, OPEX

The OPEX assessment is one of the most challenging tasks in the cost analysis process, given its many complex components, which are difficult to estimate. Some simplifications could be expected during the project lifecycle with regard to OPEX calculations. For example, if changes can be easily identified, only those network elements would require an in-deep cost study. However, the OPEX analysis model to be followed depends on the new proposed FMC architectures. FMC network architecture proposals are not yet defined in the COMBO project.

For this deliverable, the objective is to show that the assessment framework is capable of performing OPEX calculations. However, OPEX values collection take considerably longer time than the CAPEX database collection. At the current time, a complete database of energy consumption cost is available for every network

element. Therefore, we will focus on providing some values related to OPEX using this very important parameter (energy cost) and in this way, we can also extract some initial demonstrative results from the assessment tools. Floor space is also available, and will be an additional result of OPEX calculations provided in this deliverable.

In the following sections, we discuss the main components to be considered in the OPEX assessment per type of network.

4.3.1 OPEX in Fixed Networks

The well-proven operational models, which have been developed in the former EU-project OASE, are addressed in this chapter, taking into account FMC network operation specific issues. These models can be reused as basis for the FMC OPEX evaluation in COMBO.

Since the aggregation and IP backbone (excl. EPC) are usually shared (from structural viewpoint) today, the main OPEX differences are expected in the access and EPC. The focus of the FMC delta OPEX study lies on small cell deployment scenarios and hybrid concepts, which drive the need for common Fixed/Mobile access solutions. OPEX differences in the access are mainly expected on system level. Today's macro sites have typically a dedicated access connection.

Exemplarily OPEX research questions:

- Differences of dedicated vs. common access backhaul
- Differences of fixed end-user broadband service enhancement by fixed only (reference) vs. small cells only (substitution) vs. hybrid vs. pure OTT
- Differences of mobile broadband service enhancement by macro site upgrades only vs. small cell deployments vs. both
- Impact on OPEX by reallocation of EPC functions, taking into account e.g. the NG-PoP concept

The focus of the OPEX assessment lies on the main cost driving processes such as service provisioning, fault management, maintenance and power consumption, as shown in Figure 14. Beside the impact of different FMC architecture designs on operational expenditures, also the impact of node consolidation, business co-operation and deployment strategies will be investigated.

Today's operational trends show an increasing complexity of the network architecture resulting in high cost for IT support and network maintenance (e.g. caused by heterogeneous access solutions like A/VDSL, GPON, Mobile backhaul, P2P fibre access for business lines etc.). This is intensified by higher frequency of changes and higher requirements on new service offers regarding quality, time-to-market and value for money. The challenge is to get knowledge of how OPEX will change with evolving FMC architectures and new service offers in order to find funded strategic guidelines for cost efficient system and architecture designs.

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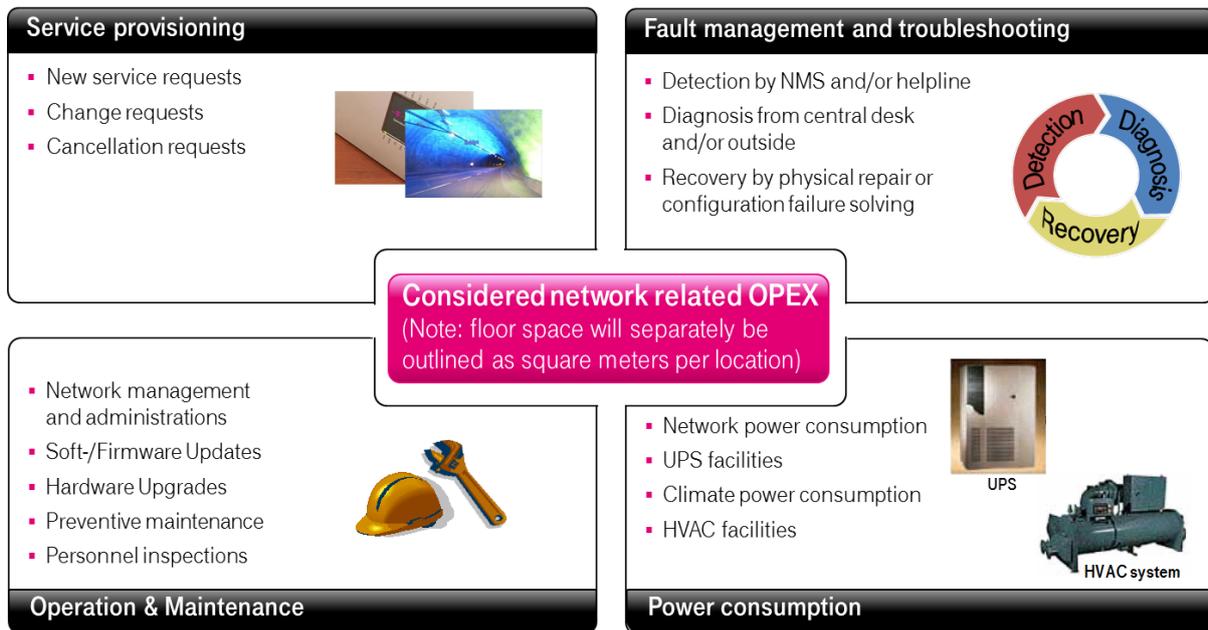


Figure 14 Main operational aspects of a NGOA network (OASE)

4.3.1.1 Failure Management and Troubleshooting

The major targets of fault management are the minimisation of the service related Down-Time per year and the minimisation of the “Mean-Down-Time” (MDT) in the failure case. The service Down-Time per year is mainly determined by the network components quality (robustness and life-cycle behaviour) as well as the network redundancy degree. The components and network quality is usually expressed by the “Mean-Time-Between-Failure” (MTBF) as key-parameter for the determination of the E2E service availability. The “Mean-Down-Time” (MDT) per individual failure can be minimised for instance by operational process improvements aiming fast failure recovery. The fault management and troubleshooting process comprises the three major sub-routines prevention, detection/diagnosis and recovery/troubleshooting.

For architecture differentiation of the fault management cost, different failure types must be distinguished. These are for instance hardware failures (e.g., I/F, fabric, WSS, RE), configuration and software failures (e.g. DCN, EMS, NMS) and failures of the passive infrastructure (e.g. splitter, AWG, fibre cable, patch connectivity failures).

4.3.1.2 Service Provisioning

The service provisioning process deals with the overall order handling procedure of adding, changing or cancelling of customer services.

Service provisioning is expected to differentiate operational costs of different FMC solutions. The required network equipment to connect a new customer, the possibility of remote configuration, the type of required CPE/UE, etc. will impact the total cost.

4.3.1.3 Operation and Maintenance

The operation and maintenance process comprises all tasks, which are required to keep the network up and running (in failure-free situations). This includes also

software release updates and hardware upgrades (e.g. new controller line cards). However, the hardware upgrades do not comprise any migration towards new technical architecture generations.

FMC networks should be highly automated and manageable for simplified and less time consuming work in the field (without sophisticated tools). This includes for instance remote manageability of active network elements (base stations and backhaul path), remote auto-configuration and management of customer equipment where technically viable. Also seamless software (SW) updates without service interruptions has to be supported (e.g. firmware updates on network elements or CPE/UE).

For the TCO assessment, a simplified maintenance calculation approach will be considered. For fixed network infrastructure components like cables, splitters, ducts etc., a maintenance-free operation is required and will be assumed in failure-free situations. The cost impact of infrastructure failures is considered in the fault management process.

4.3.1.4 Power Consumption

Fixed mobile convergence allows higher network integration in the access, aggregation and core with the potential for higher system compactness and better utilisation of active network components. Additional node consolidation in the fixed network may further increase the system compactness and reduce the number of powered locations with the expected positive effect on the total power consumption. Beside FMC and node consolidation, also future innovations regarding the reduction of system power consumption and the support of power-saving modes such as power down and sleep modes offer the potential for the reduction of the total power consumption. The power consumption will be calculated for active network components as well as for required climate facilities. The power consumption of base stations and other mobile network components is considered in the mobile OPEX model. A detailed list with fixed network power consumption values can be obtained from the OASE project.

4.3.1.5 Floor Space

Floor space is mainly related to fixed network deployments of active systems and means the space demand that is needed to install, operate and manage the system technologies (switches, OLTs, WDM coupler ...), which are typically installed in system racks. A 19" system rack can accommodate up to 4 system shelves (typically only 2 shelves installed), depending on the varying power consumptions and heat conditions of the different backhaul systems. The required space demand for new antenna sites is considered in the mobile OPEX model. In addition to the active system racks, some architecture variants require pure passive shelf racks e.g. for WDM couplers. Also the space demand for the termination of the fibre cable infrastructure at the Optical Distribution Frame (ODF) and the through-connection to the systems racks via in-house cabling have to be considered. A detailed floor space model can be obtained from the OASE project.

4.3.1.6 OPEX in Wi-Fi networks

For Wi-Fi networks, OPEX also depends on the specific hardware needed to operate a Wi-Fi network:

- AAA systems
- Network management systems
- Logging facilities.
- Security related systems (e.g. Firewalls and load balancers).
- Lawful interception systems (e.g. LNS server).

The main OPEX costs are those related with Service provisioning, Fault management and troubleshooting, Maintenance, Power Consumption, Real Estate and monitoring.

This assessment has been calculated using actual operative costs in Wi-Fi networks in several countries all around the world with different GIP, population density, etc.

4.3.2 OPEX in Mobile Networks

In Figure 15 [12] a typical OPEX breakdown for a European mobile operator is shown. OPEX for network infrastructure is one of the dominating portions in the total OPEX. It is estimated with about 24% but it can be expected that this portion will decrease with the introduction of LTE and single RAN due to elimination of base station controllers in 4G networks, concentration of more functions in fewer hardware nodes or enhanced computational power offered by improved and cheaper microelectronics (Moore’s Law).

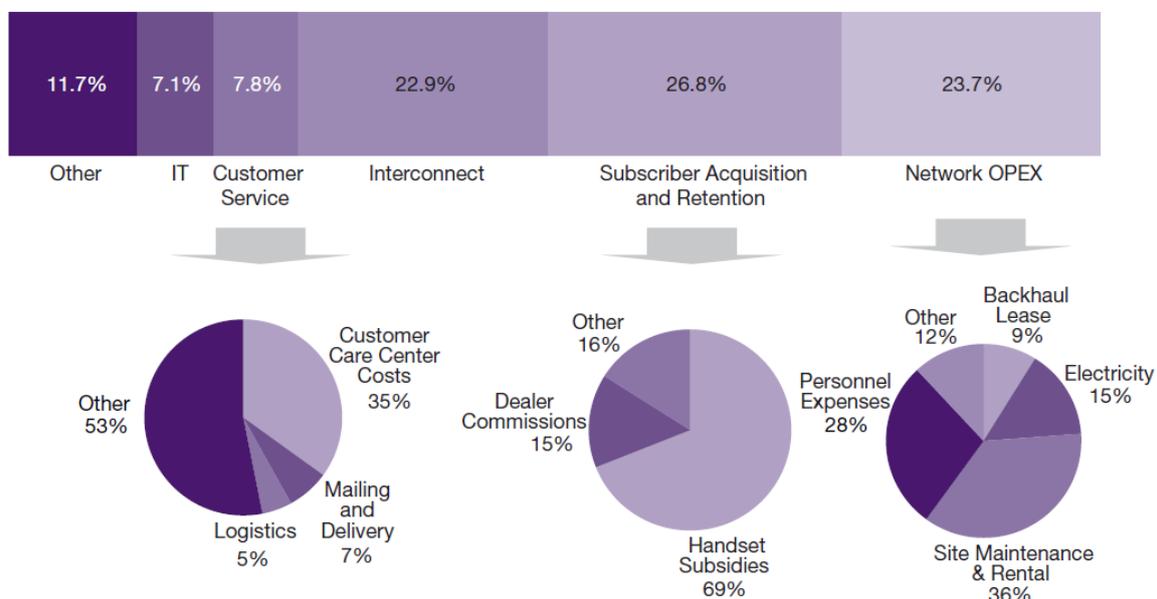


Figure 15: Typical OPEX Breakdown for a European Mobile Operator (% of Total OPEX)

Comparing the values for CAPEX and OPEX of network infrastructure for several years the OPEX is generally assessed with the higher share (CAPEX 30%-40%, OPEX 60-70%). This evaluation is also confirmed for current LTE rollout by a new

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study for the US market: “...Based on the anticipated rapid growth of LTE subscribers and data traffic on the networks, total U.S. LTE infrastructure OPEX projected to be \$57.4 billion, while CAPEX is expected to be only \$37.7 billion between 2012 and 2017”. [13]

Furthermore it can be estimated that RAN near operating expenses sum up to about 70% of total network operating expenses, but core near expenses consume 30% of total network operating expenses.[14]

For the network infrastructure OPEX part of classical business cases, mainly a model closed the technical perception is used. A generic illustration is sketched in Figure 16. It consists of different node and link types. The OPEX at the nodes is thereby split in costs related to the location, maintenance or upgrade of hardware and software and power supply. Second category costs are e.g. manpower, spare parts and travelling expenses. The links between the nodes e.g. for backhaul or IP backbone are often leased from fixed network operators by purchasing a complete service corresponding to wholesale business. In this case there may be nodes e.g. in the aggregation network which are covered by the service costs and therefore invisible for the OPEX calculation. In principle this model supports the operation of software on shared or leased hardware or similar constructs (issue of network virtualization). Furthermore, overarching operation and maintenance in an Operation and Maintenance Center has to be addressed. Costs for basic prerequisites, qualification (e.g. annual spectrum costs) and maintenance of operating processes have not to be neglected.

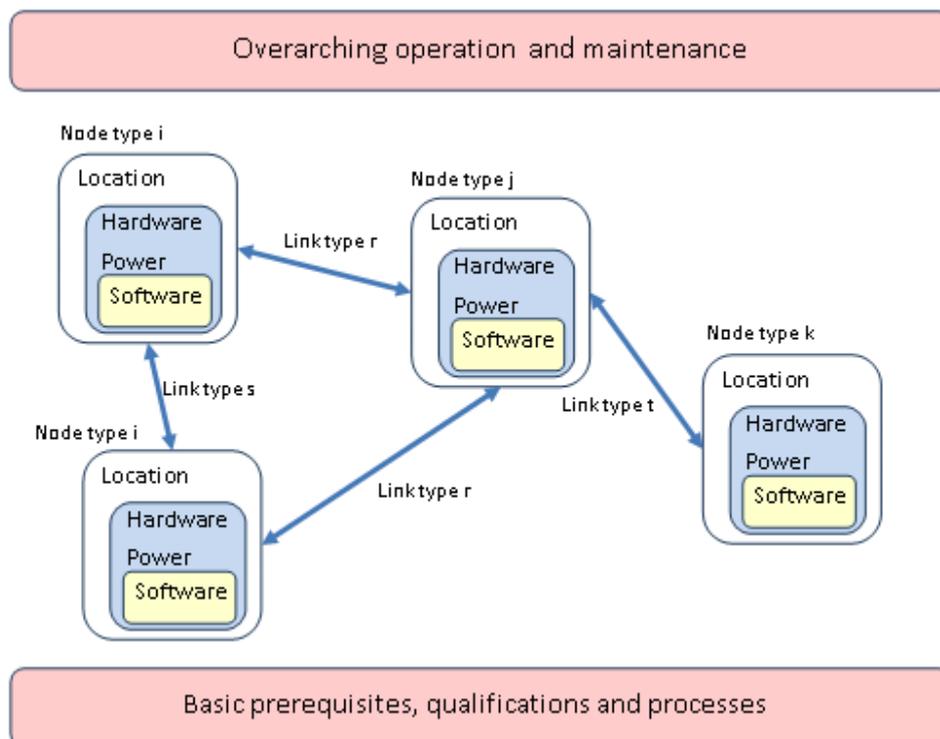


Figure 16: Model for OPEX calculations of mobile network infrastructure

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Based on this generic model, some typical network elements (node types, functions and link types) are listed in Table 7 for a mobile network operator that operates 2G, 3G, and 4G networks. The typical quantities of the different elements are mentioned for a ten million customers' network with mixed geo types. The different potential OPEX items are addressed for the major network segments of the mobile network (radio access network, aggregation and transport network, mobile core).

| Network node, function or link types | Typical number in a 10 million customer network with mixed geo types | Potential OPEX items (state-of-the-art) |
|--|--|--|
| Mobile Radio Access Network | | Maintenance (man power, spare parts ...) |
| BTS (2G) | 6000 | Software upgrade |
| Node B (3G) | 6000 | Operation and network optimization |
| eNodeB | 6000 | Site rental |
| Cell Site Gateway | 6000 | Power supply (Site acquisition belongs to CAPEX) |
| Aggregation and transport network | | Link lease cost, transport fee |
| Backhaul (wired or wireless links) | 6000 | Maintenance (man power, spare parts ...) |
| BSC (2G) | 6 | Software upgrade |
| RNC (3G) | 5 | Operation |
| Aggregation switches and router (if not shared with fixed network) | 30 | Location rental or maintenance |
| Access Router | 1 | Power supply |
| IP sec gateway | 1-2 | |
| IP (Mobile) Backbone | 1 | |
| Mobile Core | | Maintenance (man power, spare parts ...) |
| MSC (2G/3G) | 14 | Operation |
| SGSN (2G/3G) | 2 | Software upgrade |
| GGSN (2G/3G) | 2 | Location rental or maintenance |
| EPC | 2-4 | Power supply |
| PCRF (Policy and charging rule function) | 1 | |
| HLR (2G/3G) | 1 | |
| HSS | 1 | |
| Spectrum | 2-10 channels /bands | Spectrum license (annual fees) |
| Operation and Maintenance Center (OMC) | 1 | Operation of OMC (man power) |
| Operation and Support System (OSS) | 1 | Location rental or maintenance Maintenance of OSS Software upgrade |

Table 7: Elements of mobile networks with corresponding OPEX items.

The network infrastructure of mobile networks is subject to permanent modifications by software updates, new or improved hardware parts or extensive hardware swaps e.g. to Single RAN. These permanent modifications must be accompanied by evaluations of their impact on CAPEX and OPEX. Thereby different trade-off cost relations can appear. Some examples are:

- Software and processes for automation (self-optimization, SON) <> labour
- Centralization <> Travel expenses
- Concentration <> Complexity: bug detection, training of technicians
- Concentration <> outage impact / resilience demand
- Variety of technologies or components <> operation/maintenance processes
- Dedicated hardware or software <> General purpose hardware or software
- Flexible hardware (FPGA, general purpose DSPs): fast update, higher power consumption <> Customized hardware (ASICs, System-on-chip): low power, small components

In principle to assess the impact of modifications or corresponding proposals different procedures can be approached. Examples are:

- Modification of the complete OPEX in the entire business case. Derivation of the impact by comparison of the overall results and key performance indicators. Investigation of the impact of detailed cost parameters by sensitivity analysis.
- Extraction of the relevant OPEX parts. Perform OPEX calculations only on affected parts and derivate the impact. This approach doesn't show the overall impact of the modification, but is sometimes easier to realize, because it does not need access to the complete cost data, which are commonly kept strictly confidential by purchase and controlling departments also company-internal.

4.4 Impact of convergence

In this section we present the expected impact of FMC networks on the cost model and methodology. In particular, we discuss the FMC impact on the three main parts of the cost model: network scenarios, CAPEX, and OPEX. New candidate and proposed solutions for FMC are not available at the moment from the COMBO framework. As a starting point, we have found in literature some experimental proposals for particular cases of FMC. We also develop a discussion around expectations on the possible FMC solutions to be proposed in COMBO.

Increasing number of recent works propose the use of PONs as support and backhauling of mobile traffic, with added changes to optimize this mobile and fixed traffic coexistence in such a way that delay, capacity, and connectivity constraints are guaranteed. In particular, LTE mobile technology requires interconnection of the base stations or eNodeBs. The main idea resides on collocating eNodeBs at the PON user device or ONU. This fact may introduce changes in the topology such that the eNodeBs can communicate between them without passing through the PON head-

end or OLT located at the CO. The reason is that making the signal pass by the OLT, introduces significant delays.

For example in [15], a convergence between LTE and 10G-EPON is proposed. eNodeBs collocated at the ONUs are interconnected by means of a hybrid tree-ring topology. There is a new distribution node composed of a number of devices such as splitters, CWDM couplers and combiners. The usual centralized functions migrate to the access nodes by means of a new distributed mechanism to allocate bandwidth in the network. In [16], authors solve the problem differently, by replacing the typical splitter at the remote node by an $(N+1) \times (N+1)$ optical star coupler. In [18], the star coupler at the remote node, or loopback solution, is compared with the proposal of an active remote node, using a switch. The loopback solution turns to be more cost-effective than the active remote node. Similar solutions are proposed using multiple-wavelength PON. For instance in [19], a WDM-PON is adapted to support LTE by using an unidirectional ring, where ONUs are composed by an OADM, a combiner, and a 1x2 switch.

With these examples present in literature we can observe that not only changes on devices may happen, but also important changes in the topology shape. Also we could note that some functionalities that were usually present at a centralized node, may become distributed and hence, moved to the access nodes. We expect similar changes in the FMC architectures to be proposed by COMBO, but covering more access, metro, and core technologies. All these changes are expected to generate new network scenarios with different new constraints that will determine its dimensioning. As some nodes become more complicated (with more components) and as some functions are moved to other level of nodes, the CAPEX is significantly affected. New costs must be estimated for these changing nodes (with new components and/or functions) according to their complexity or the summation of the items in a node. A new pricing function may be required for certain nodes, especially in cases where the functionalities migrate through the network.

Finally, as the cost of equipment in the new FMC network may change, the estimation of OPEX remains a challenging task.

We foresee that the new FMC architectures to be proposed by COMBO may take any of the following to forms:

- Evolutionary FMC architecture: In this case, the FMC architecture is a result of the evolution of current state-of-the-art fixed and mobile architectures. For such a case, CAPEX and especially OPEX may be calculated using a Delta assessment approach (as mentioned in section 4.3.1). The Delta assessment approach takes into account only the parts/elements of the network that are subject to change. Therefore, since the rest of the network elements remain the same, it is reasonable to compare diverse options using the Delta approach.
- Disruptive FMC architecture: This FMC architecture changes radically most of its elements, their location in the network, and even the topology. In this case, an absolute CAPEX and OPEX calculation is required for the whole network. All CAPEX and OPEX values must be available and/or estimated to be able to perform the cost assessment.

4.4.1 Network Functionalities

Network Function Virtualization (NFV) and Software Defined Networks (SDN) are being considered in this project as key enablers to re-structure or potentially simplify the network structures. This may have a significant impact on the CAPEX and OPEX models. In SDN for example, a simple general purpose machine such as a router can obtain the routing information from the cloud and looking at the IP header structure, instead of a sophisticated switch as used today. We plan to have a cost model that analyses NFV or SDN concepts in the context of fixed and mobile convergence.

As mentioned in section 3.2, the assessment framework is ready to add any functionality with its own attributes (or specifications) to any candidate node in the network. Therefore, the first steps to consider functional convergence in the integration of mobile and fixed networks are already observed in the tool. However, a cost model to define how to locate functions in the network hierarchy and how to price them is necessary.

Because the decisions on the new FMC candidate architectures are still under discussion/study in WP3, the methodology to propose a consistent cost model that takes into consideration network functionalities and software-based changes is still unclear. However, we foresee the following two strategies to propose a cost model: (i) assessment of the network as a whole, where functions are part of the network elements, or (ii) assessment of the network based on the resource requirement of specific functions. The first strategy assumes that existing and new functions will be located in a centralized and/or distributed manner, and all those elements that “functionally” change will have a certain new cost model. The second strategy is more complex due to extra dimensioning calculations/estimations, and the cost will be assigned to the necessary resource.

5 Energy consumption analysis methodology

The Information and Communication Technologies (ICT) offers great opportunities for a large reduction of global CO₂ footprint. It is expected that the reduction achieved by 2020 would represent 15% of total emissions in a “business as usual” scenario [20]. But we must also consider that the combined areas of ICT are also directly responsible for a significant amount of the global CO₂ footprint. In 2007, the ICT contribution to global CO₂ production was in the range of 2%, with a total of ~0.83 GtCO₂ produced [20]. This is projected to significantly increase over the next years, as depicted in Figure 17.

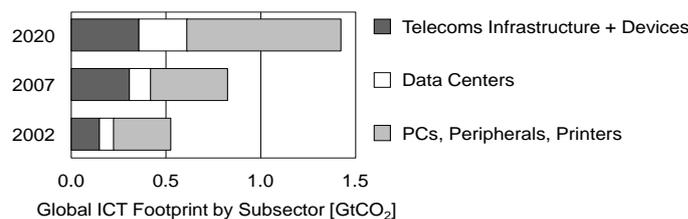


Figure 17: Global ICT carbon footprint

Considering the global ICT CO₂ footprint, telecommunications infrastructure and devices are roughly in the 25% range, a majority going to PCs, printers, and peripherals. Within telecommunications themselves, a significant part of the CO₂ footprint can be assigned to mobile communications. According to Figure 18 [20], this part is to increase towards 2020.

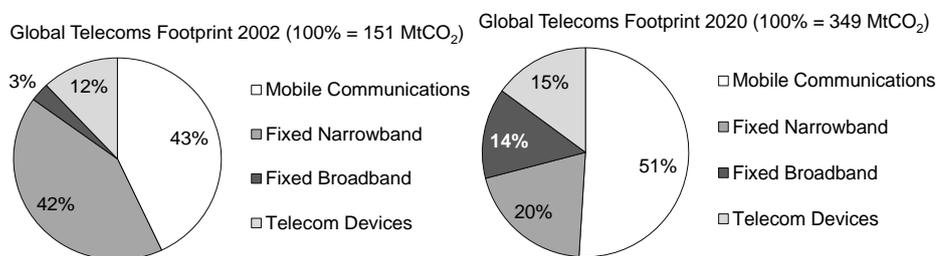


Figure 18: Global telecommunications carbon footprint

A more detailed analysis of the per-sector and per-functionality power consumption shows that wireline telecommunications, and in particular transport (e.g., WDM), is responsible for a minor contribution to total ICT (network) power consumption, see Figure 19 [21].

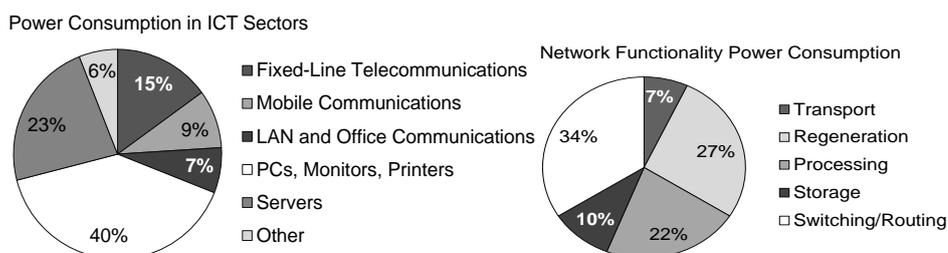


Figure 19: Power consumption in ICT sectors (left), and per network functionality (right)

Nonetheless, due to the exponentially increasing bit rates [22], processing (switching, routing, multiplexing, etc.) and also transport (modulation, framing, skew/deskew, regeneration, etc.) must get significantly more energy-efficient per b/s. This becomes clear when looking at the power consumption as a function of the average residential access bandwidth (Figure 20 [23]).

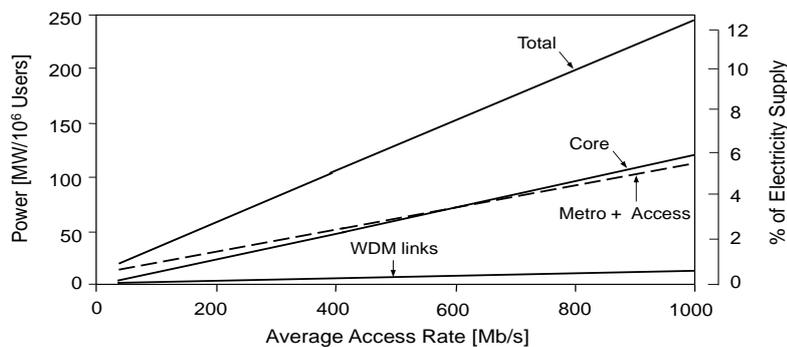


Figure 20: Relative power consumption in telecommunications networks

So, although transport is a minor contributor to power consumption, it also must become more energy-efficient. Reasons include the bandwidth increase – which does not lead to a decrease of the number of transport interfaces – and the increasing amount of digital processing which is required with increasing bit rates. Ideally, energy efficiency increases such that absolute energy consumption decreases. This would lead to exponentially increasing energy-efficiency per b/s processed and transported. Such an increase in efficiency is regarded difficult at best. In any case, strong increase in energy efficiency must be achieved to at least partially compensate the increase in energy consumption, which goes hand in hand with the bandwidth increase.

This chapter is intended to provide an overview of the energy consumption models and values that will be used for the energy-consumption estimations of the state-of-the-art network scenario discussed in Section 4.1. Beside this initial objective, this preliminary activity will be instrumental to the study of the possible energy efficient FMC architecture that will be the object of the Task 5.4 activity for the second year.

Before overviewing the energy consumption models and values in subsection 4.1, we provide in the following a survey of the most relevant EU projects on energy efficiency in telecom networks. Also, an overview of the most relevant standardization initiatives in the field of energy-efficiency is provided in Annex 0.

Overview of existing Energy-Efficiency EU projects

Besides of COMBO, the principle of Energy Efficiency has been the driver of several large-scale collaborative projects during the last few years. A review of the most notable projects, from which we have collected some relevant values reported in the next subsections, is given in the following.

EARTH (Energy Aware Radio and neTwork technologies) was an integrated project founded by the European Commission within the Seventh Framework Programme. The project started in January 2010 and finished in July 2012. EARTH dealt with the important issue of energy saving by enhancing the energy efficiency of mobile

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broadband systems thereby reducing CO₂ emissions, investigating the energy efficiency of mobile systems from component level to network deployment and management. For what concern the components, EARTH provided a detail model for the energy consumption of the LTE base stations, which still nowadays represents one of the most used in the research community (the model will be discussed in the following sections). The target of EARTH was to reduce the energy consumption of mobile systems by a factor of at least 50% compared with the current ones. EARTH overachieved this target by providing Integrated Solutions allowing for savings in the range of 70%. In order to achieve this, many novel solutions have been investigated in different parts of the mobile broadband systems, among them: energy efficient deployment strategies, energy efficient network architectures, load dependent network management mechanisms, innovative component designs with energy efficient adaptive operating points, and new radio and network resource management protocols for multi-cell cooperative networking. The project website is: <https://www.ict-earth.eu>.

TREND (Towards Real Energy-efficient Network Design) was an integrated project funded by the European Commission within the Seventh Framework Programme and a network of excellence under the coordination by Politecnico di Torino. The project started in January 2010 and finished in September 2013. The final goal of TREND was to provide the fundamentals of a new unified approach for implementing energy-efficient communication networks. To do so, TREND performed a quantitative assessment of current and future telecom infrastructures; investigated the ways to reduce energy consumption without sacrificing costs and service requirements; reviewed the engineering criteria to support energy efficiency from design to operation; studied novel management paradigms and communication protocols to achieve a more effective energy control; envisioned the best long-term approaches for both clean state design and progressive migration; incentivized the efforts of network operators, service providers, manufacturers and also end users. The project website is: <http://www.fp7-trend.eu>.

ECONET (low Energy CONsumption NETworks) is a 3-year integrated project (running from October 2010 to September 2013, extended to December 2013) co-funded by the European Commission under the Seventh Framework Programme, addressing the Strategic Objective ICT-2009.1.1 “The Network of the Future”. The ECONET project aims at studying and exploiting dynamic adaptive technologies (based on standby and performance scaling capabilities) for wired network devices that allow saving energy when a device (or part of it) is not used. The project will be devoted at re-thinking and re-designing wired network equipment and infrastructures towards more energy-sustainable and eco-friendly technologies and perspectives. The overall idea is to introduce novel green network-specific paradigms and concepts enabling the reduction of energy requirements of wired network equipment by 50% in the short to mid-term (and by 80% in the long run). To this end, the main challenge will be to design, develop and test novel technologies, integrated control criteria and mechanisms for network equipment enabling energy saving by adapting network capacities and resources to current traffic loads and user requirements, while

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ensuring end-to-end Quality of Service. Therefore, this project aims at exploring a coordinated set of approaches and concepts to deliver novel solutions and technologies for reducing the carbon footprint of next generation infrastructures for telecommunication networks. The project website is: <http://www.econet-project.eu>.

OASE (Optical Access Seamless Evolution) was an integrated project funded by the European Commission within the Seventh Framework Programme. Project runtime was January 2010 to February 2013, including a 2-months extension period. The goal was the analysis of next-generation broadband optical access for the time period of 2020 and beyond. Several principle options for systems and architectures (active vs. passive optical systems, various point-to-point and point-to-multipoint network architectures) were investigated. Further, CAPEX and OPEX were analysed. As part of the OPEX analysis, energy-consumption values of the relevant contender systems and configurations (the survivors of the early investigations of OASE) have been collected. This has been conducted down to the level of relevant sub-systems. This allowed calculating the energy consumption of various different configurations of the respective systems (including G-PON, XG-PON1, AON, and various flavours of WDM-PON). The respective energy-consumption values have been discussed in industry and standardization for a like FSAN, and they have also been published in a number of papers and conferences, including IEEE Communications Magazine and ECOC. The project website is: <http://www.ict-oase.eu>.

Other than the above-mentioned EU projects we mention here also the GreenTouch consortium, as a relevant initiative that can provide useful information for the energy-related aspects of COMBO.

GreenTouch is a consortium of service providers, academic and industrial research institutions and non-governmental organizations, carrying on several collaborative projects on energy efficient networks and technologies. The global mission of GreenTouch is to deliver the architecture, specification and technologies needed to increase network energy efficiency by a factor of 1000, by the year 2015, compared to 2010. GreenTouch projects are divided into three working groups: mobile networks; services, policies & standards; wired core & access networks. Thanks to the heterogeneity of involved members, GreenTouch projects can address several different technological areas, e.g., new cellular network architectures, large-scale antenna systems, bit-interleaved passive optical networks, power-adaptive and service-aware optical networks, green transmission technologies, efficient component-level design, new power consumption models and energy metrics. The reference website is: <http://www.greentouch.org>.

5.1 Energy consumption values and models

In this subsection, we provide energy models and values to be used for the numerical evaluation in Section 6, performed over the network scenarios identified in Section 3. We divide the subsection in 4: fixed access networks, mobile access networks, Wi-Fi networks, consideration on FMC networks.

5.1.1 Fixed access networks

Fixed wired access can be separated into transport and aggregation. Regarding aggregation, the respective Layer-2 switches – including their client and uplink interfaces – must be considered. Components further up towards the core (routers, core transport, BRAS, etc.) need not to be assigned to access. Regarding the access transport part, the relevant technologies and components (network elements) must be considered, including (fibre-based) backhaul. This includes transport equipment for twisted-pair copper (i.e., DSL, since HFC is out of scope) and fibre. Fibre transport can mainly be restricted to PON access and (passive) WDM backhaul.

Implicitly, this also covers PtP single-channel access (either by considering a PON system without power split, or by considering a single-channel pWDM system). In DSL and PON access, headend equipment (DSLAMs, PON OLTs) and customer-premises equipment (DSL modems and/or RGWs or PON ONUs) must be considered. Further, several generations or implementation options need to be considered. Examples include twisted-pair VDSL2 with options for vectoring, bonding and/or phantom modes, and finally G.fast equipment. In PON access, useful options can be restricted to the possibilities, which are covered by ITU Recommendation G.989.x, NG-PON2. NG-PON2 covers WDM as well as TDMA with symmetrical upstream/downstream options for 2.5G/2.5G and 10G/10G. Nonetheless, significant per-channel energy-consumption differences may occur when, e.g., considering a 10-Gbps TDMA ONU as compared to a simpler 2.5-Gbps WDM ONU intended for backhaul. Likewise, a bonded double-twisted-pair with a phantom circuit and vectoring will consume more energy compared to a single VDSL2 connection. These options and differences must be considered for meaningful calculations.

Relevant sources for uncertainty in energy-consumption calculations result from hard-to-predict future developments regarding energy efficiency, and from imprecise energy-consumption data coming from the respective vendors. An example is the data, which is available discussed for NG-PON2. This data was taken from internal FSAN NG-PON2 discussions [39]. However, comparing this data to energy-consumption figures of actual (G-PON, XG-PON1) equipment, it must be considered optimistic. The respective consumption figures may be achievable in the (near) future, but it is not clear at the time of writing, whether they will be achieved in the first NG-PON2 generation or not.

Energy-consumption figures for relevant wireline access components are listed in Table 8. Regarding the ONU, the consumption of the client interface (which can be regarded common to all approaches) must be added. It has not been considered in the FSAN discussions. Also, energy-efficiency modes are not yet included here. Today, no exact numbers are available for energy-efficiency mode savings for NG-

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PON, however, numbers similar to XG-PON1 sleep- and doze-mode savings (in the range of 50%) can be expected.

| Components | Function | EC [W] |
|------------------------------|--|--------|
| RGW | 1 Ethernet port, no modem function | 5.0 |
| STB | Not including DVR function | 10.0 |
| ONT (PtP WDM up to 4 Gb/s) | 1...4 Gb/s, 1 client port, up to 8 wavelengths | 2.2 |
| ONT (PtP WDM up to 4 Gb/s) | 1...4 Gb/s, 1 client port, up to 48 wavelengths | 2.4 |
| ONT (PtP WDM up to 10 Gb/s) | 5...10 Gb/s, 1 client port, up to 8 waves | 2.7 |
| ONT (PtP WDM up to 10 Gb/s) | 5...10 Gb/s, 1 client port, up to 48 waves | 2.9 |
| ONT (shared WDM, e.g., TWDM) | Up to 300 Mb/s sustained, 1 client port, 8 waves | 2.4 |
| ONT (shared WDM, e.g., TWDM) | 1 Gb/s sustained, 1 client port, 8 waves | 2.9 |
| OLT (PtP WDM up to 4 Gb/s) | 1...4 Gb/s, 8 ports | 2.2 |
| OLT (PtP WDM up to 4 Gb/s) | 1...4 Gb/s, 48 ports | 1.6 |
| OLT (PtP WDM up to 10 Gb/s) | 5...10 Gb/s, 8 ports | 2.7 |
| OLT (PtP WDM up to 10 Gb/s) | 5...10 Gb/s, 48 ports | 2.3 |
| OLT (shared WDM, e.g., TWDM) | 100...300 Mb/s, (4...8)x(32 or 64) ports | 0.4 |
| OLT (shared WDM, e.g., TWDM) | 1 Gb/s sustained, (4...8)x(8 or 16) ports | 1.6 |
| ADSL(2) DSLAM | 8 ports | 1.1 |
| ADSL(2) DSLAM | 96 ports | 1.1 |
| VDSL2 DSLAM | 8 ports | 1.7 |

Table 8: Energy-consumption and cost figures for wireline access

All component cost figures assume forward pricing at the beginning of fully ramped-up production. Cost values are provided relative to a G-PON ONU. They are based on a complexity analysis of the respective component, the potential for integration of the main sub-components, and on long-term cost observations of transceivers running at 1, 2.5, and 10 Gbps, respectively. The respective parameters have (partially) been published [40], and have been extensively discussed in standardization (FSAN, [39]), at conferences [41], [42], at workshops [43], in research projects [44], and, on a regular basis, with component vendors.

Generally, aggressive energy-consumption figures have been collected in this project. This means that the respective figures will only be achievable in the near future, or they were taken from industry top-runner equipment. This approach gives at least a certain safety that the calculations will not be overtaken by standardisation or legislation (e.g., the EU Broadband Code of Conduct) by 2020.

Especially with regard to NG-PON energy consumption, the values are also well aligned with the ones from the EU FP7 IP OASE [45], [46], [33], where similar assessments have been conducted.

The energy-consumption figures for set-top boxes (STBs) must also be considered aggressive. Much higher numbers can be found in the literature, where STBs are sometimes considered the second biggest electricity consumer in households, following refrigerators. The numbers presented in Table 8 are based on an actual survey [47], [48], [49].

For the remote gateway (RGW), no new consumption figures have been found so far. The number listed in Table 8 equals 50% of a typical DSL-modem / wireless router / RGW unit as of 2013. This is also in line with [50].

Two further aspects, which lead to uncertainty or different focus with regard to network-wide energy-consumption calculations, need to be considered:

- HVAC energy-consumption overhead in central offices
- Energy consumption at customer premises vs. central office

As mentioned in [38], [32], the HVAC (Heat, Ventilation, Air Conditioning) contribution to the total power consumption can be in the range of 25...50%. This overhead needs to be added to any calculated value, which is based on (access) equipment or components only. This is independent from potential “green” approaches, which offer solar, wind and other renewable energy for power supply or which combine HVAC technology with local climate and environment characteristics.

The question where energy is consumed is relevant because there is a potential mismatch between lowest central-office energy consumption (i.e., operators’ interest) and lowest total-network energy consumption. Optimizing the former in order to reduce OPEX may not necessarily optimize the latter. A simple example consists of these two possible NG-PON2 configurations:

- Single-channel 10G/10G symmetrical TWDM (TDMA) (for ~40 clients)
- WDM PtP configuration in C- plus L-band, with dedicated 1G/1G channels (~40 clients)

These configurations differ in total capacity and possibly also in achievable reach. Apart from this, the first configuration will clearly have less energy consumption in the OLT (CO) due to the shared TDM/TDMA transceiver. However, due to the simpler 1G/1G ONUs, the WDM PtP variant may have lower power consumption per ONU, and thus in total may have similar power consumption despite the fact that it offers higher total capacity.

In general, the contribution of CPE (customers’ premises equipment) to total network consumption must be considered. Since STBs may have to be combined with other functions (e.g., modems or ONUs, RGW, wireless LAN), total customers-premises energy consumption may dominate (future) access networks.

5.1.2 Mobile access networks

Independently of the mobile system generation (2G, 3G or 4G) the biggest part of the electricity consumption (60%-80%) of the network operation is related to the radio access network especially to its major element, the base station. Typically in 2G and 3G radio access network installations, the base stations consume 95%-98% of the power against what base station controllers or radio network controllers need only 1-3%. The mobile switching centres need 1% or less. A 2G or 3G macro base station currently consumes between 550W and 800W (cell site gateway not included). Up to now the base stations of all generations consist of similar components. Therefore, only the newest installed system (LTE) is considered more explicitly in the following.

The European funded project EARTH (Energy Aware Radio and neTwork and tecHnologies) currently provides the most valuable reference in the literature addressing LTE base station power consumption modelling [51]. In this project a

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simple block model of a complete base station was used (see Figure 21). The model can be generalized to all base station types, including macro, micro, pico and femto base stations. In general, a base station is made of multiple transceivers with multiple antennas.

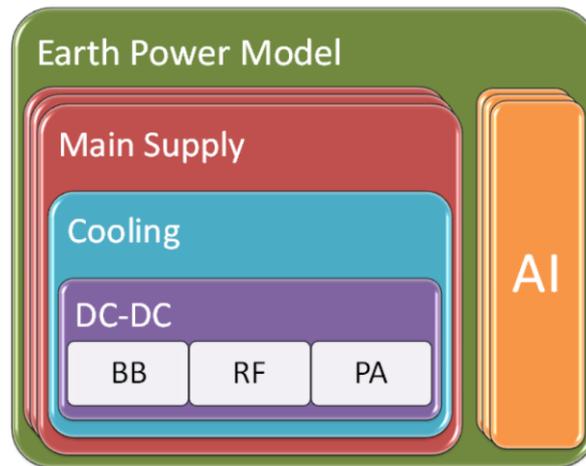


Figure 21: Simple block model of a base station

A transceiver comprises an antenna interface (AI), a power amplifier (PA), a radio frequency (RF) small-signal transceiver section, a baseband (BB) interface including a receiver (uplink) and transmitter (downlink) section, a DC-DC power supply, an active cooling system, and an AC-DC unit (Main Supply) for connection to the electrical power grid. In reality several hardware components for main supply, cooling, DC-DC, or base band are shared between different transceivers. In some implementations these components can be switched off load dependently. Only macro type bases stations need active cooling.

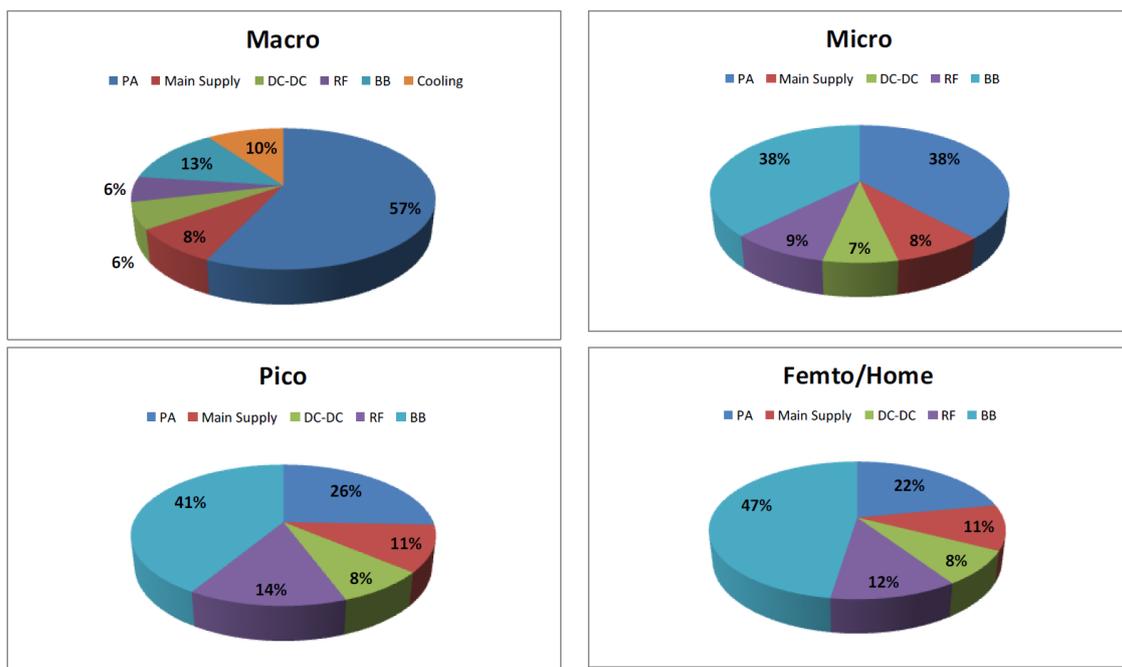


Figure 22: Power consumption for different base station types

The power consumption breakdown for different types of base stations at maximum load is shown in Figure 22. In macro base stations mainly the PA dominates the total power consumption, owing to the high antenna interface losses. The breakdown is more balanced in micro base stations. In pico and femto cells the baseband part dominates the overall power consumption.

Mathematically the equations used in project EARTH for the calculation of the power consumption of a base station W_{BS} can be approximated to a linear function like:

$$W_{BS} = a l + W_0$$

Thereby $l \in [0,1]$ is the traffic load of the BS normalized to its maximum capacity, W_0 is the power consumption without traffic load ($l = 0$), and a is the additional power at maximum traffic load. Regarding macro base stations, the power consumption at maximum load can be up to 80% more than without load. For pico and femto types the load impact is only 10%-20% of the basic power consumption. Much more details and corresponding values are described in [52]. In this document also an estimation of LTE base station power consumption is given for different types of base station. An extract related to the estimation for 2012 is shown in Table 9.

| | Unit | Macro | Remote Radio Head | Micro | Pico | Femto / Home |
|---|----------|------------|-------------------|-----------|----------|--------------|
| Max transmit rms power | dBm | 46.0 | 43.0 | 38.0 | 21.0 | 17.0 |
| Max transmit rms power | W | 39.8 | 20.0 | 6.3 | 0.13 | 0.1 |
| Number of sectors | # | 3.0 | 3.0 | 1.0 | 1.0 | 1.0 |
| Number of PAs/antennas | # | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 |
| Number of carriers | # | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Estimated power consumption for 2012 | W | 964 | 527 | 94 | 9 | 6 |

Table 9: Estimation of LTE base station power consumption related to year 2012

When changes in mobile network systems architecture occur, some of the following factors influencing energy consumption should be considered:

- Air volume where the payload data is made available. This aspect is, e.g., related to cell size, sectorisation or beam forming and addresses generically the transmit power.
- Possibilities to locally switch off radio systems (e.g., 3G), base stations, sectors or channels or to reduce the corresponding transmit power at low traffic load.
- Interference mitigation or coordination like coordinated scheduling or beam forming. This aspect addresses the applicable modulation scheme and therefore the transmit time for a defined amount of data.
- Used microelectronics for digital processing. Although the digital processing must be performed but the used design of microelectronics (general purpose

processor, DSP, FPGA, ASIC, full custom design and corresponding combinations) has to be considered carefully.

- Associated with the microelectronic design aspect are the ways and distances intermediate data has to go. Systems on chip, connections between chips but in same package, connection between packages, connections between network nodes (e.g. data processing centre for base band hosting) have impact on power consumption.
- Appearance of high data volumes in access and aggregation networks, e.g., due to methods with high throughput for intermediate data or high percentage of signalling data.

5.1.3 Wi-Fi access networks

To analyse the energy consumption of Wi-Fi networks, we consider a Wi-Fi core platform similar to the mobile core of a mobile network, and we include also equipment of Customer premises, Access and Aggregation networks.

For customer premises CPEs (also referred as RGW), Indoor APs and Outdoor APs have been considered. For access and aggregation networks, energy-consumption calculations have been performed over various AP Controllers. For the core network, which represent the most significant part of electricity consumption (note that the elements that provide Wi-Fi control functionalities are mostly located in the core network), we have considered core AP controllers, Wi-Fi Access Gateways and the Wi-Fi Core Platform, which includes the necessary AAA systems, Network management systems, Logging facilities, Security related systems and Lawful interception systems.

Table 10 shows the power consumption for Wi-Fi networks.

| Components | Function | EC [W] |
|---|--|------------------------------|
| CPE: RGW | Single Ethernet port up, the WAN port. Device in n mode. To a theoretical limit of the maximum radio bandwidth available. | 2.0 |
| Indoor AP | '802.11b/g/n or b/g/a hotspot | 8.0 |
| Outdoor AP | 802.11n Outdoor Wireless Access Point, 2.4GHz and 5GHz dual band (simultaneously), 2 GbE ports | 8.0 |
| Wi-Fi AP Controller (Access Network) | 5 APs min, 50 APs max, 500 clients max, 500 Mbps max throughput | 80.0 |
| Wi-Fi AP Controller (Aggregation Network) | 12 APs min, 500 APs max, 7K clients max, 8 Gbps max throughput | 125 |
| Wi-Fi AP Controller (Aggregation Network) | 100 APs min, 1K APs max, 15K clients max, 20 Gbps max throughput | 220 |
| Wi-Fi AP Controller (Core Network) | 300 APs min, 6K APs max, 64K clients max, 10 Gbps max throughput | 675 |
| Wi-Fi Access Gateway | | 700 |
| Wi-Fi core platform | <ul style="list-style-type: none"> • AAA systems (e.g. Authentication related servers, which can include a captive portal server for the web based authentication case). • Network management systems (e.g. AP | 5600 for each 5 Million APs) |

| Components | Function | EC [W] |
|------------|--|--------|
| | controller). • Logging facilities. • Security related systems (e.g. Firewalls and load balancers). • Lawful interception systems (e.g. LNS server). | |

Table 10: Energy-consumption figures for Wi-Fi

These values have been obtained from actual measures of existing Wi-Fi networks assuming the following meaningful scenarios based on the scenarios of WP3:

- Residential
- Community Wi-Fi
- Indoor public Wi-Fi
- Outdoor public Wi-Fi

In order to populate this energy consumption database, data and calculations provided by different operators have been used. These figures have been collected considering that they should be valid for the near future and will not be overtaken by standardisation or legislation by 2020. This energy consumption assessment has been calculated using actual measures in Wi-Fi networks deployed in several countries all around the world with different characteristics.

5.1.4 Existing FMC access networks

Existing access network architectures are typically either fixed or mobile access networks, which have traditionally designed in isolation. The description of the main energy consumption values for fixed and mobile network has been just discussed in subsection 5.1.1 and 5.1.2. However, as pointed out in deliverable D3.1 (subsection 2.1.4) [1], some preliminary degree of convergence can be already found in today's state-of-the-art access and aggregation networks. For instance, the evolution of mobile backhauling networks toward a flat All-IP transport allows them to share the same Ethernet aggregation infrastructures (i.e., not only links, but also switches) of co-existing fixed access networks. This can be considered at some extent as a first step towards structural convergence. Another example of embryonic structural convergence comes from the sharing of a single optical fibre link among different base station and fixed access nodes, enabled by the CWDM technology in some deployed scenarios. Also, Wi-Fi access networks imply a degree of structural convergence for their intrinsic nature. In fact, since the Wi-Fi standard does not specify backhauling architecture, typically existing fixed access network are utilized (e.g., DSL).

For these and other similar cases of preliminary attempts towards convergence, the associated energy values can be easily mapped into those of network elements already introduced in subsections 5.1.1 and 5.1.2 (e.g., for previously described cases, the consumption values of Ethernet switches, CWDM optical line terminations and DSL customer premises equipment can be used).

In the following, in order to prepare the activities of T5.4 in the second year, we overview the energy minimization issues that have been covered in scientific

literature regarding some existing proposal for experimental FMC architectures. We remark here that such approaches tend to be highly disruptive for the current metro/access network architecture, while COMBO will explore more practical and retrofitted solutions that are expected to be more relevant for network operators and vendors.

Energy minimization in experimental FMC architectures. There are several examples of experimental FMC access networks in the recent literature. They mostly rely on optical technologies, because they provide a very high capacity, which makes them ideal for transporting mobile backhauling traffic. Specifically, networks based on passive infrastructures are preferred solutions, since they exhibit lower energy consumption.

Many architectures address the requirements of the 4G-LTE radio access network, which needs a meshed topology (X2 interface) among clusters of adjacent eNBs. For instance, in [53] a hybrid tree/ring-based 10G-EPON is proposed, in which a distribution node feeds a ring divided into a number of semi-rings. In every semi-ring, direct communication among adjacent access nodes (ONUs/eNBs) is allowed, which enables implementing peer X2 links among all eNBs, and also a fully distributed control plane. In such architecture, energy efficiency is enabled by the traffic offload from the OLT, even if the direct communication between access nodes gives an extra power consumption contribution due to the optical-electrical-optical conversions at each traversed node.

In [54] and [55], converged PONs are proposed, in which the same concept of intercommunication between ONUs is employed. To do so, an optical bypass infrastructure is adopted, which enables ONUs to exchange traffic without performing optical-electrical-optical conversions, thus saving power. Also, collateral energy efficiency improvements are achieved by consolidating mobile related and PON access functions into converged nodes (e.g., MAP-OLT and AR-ONU in [54]).

Several studies propose the convergence with the concurrent WiMax radio access technology. For instance, in [56] and [57] the focus is on integrating EPON ONU and WiMax BS functionalities into optimized hardware, with performance and QoS benefits coming from the sharing of information between the BS packet scheduler and the ONU packet classifier. As a consequence, the energy efficiency is improved on a per-node basis. The work in [58] investigates the further benefits of the space division multiple access technique in the radio interface.

The TDM-based PON technology will not be able to sustain the bandwidth growth forecasted for next years, so a large part of the research in FMC focuses on WDM-based PONs. In [59], a survey of the key technologies of WDM-PONs, which enable the convergence, is presented. Regarding energy, the most valuable of them is the possibility of adopting transparent wavelength routers, which exchange flows directly in the optical domain, with almost zero power consumption.

In [60] and [61], this feature is combined with the possibility of reserve a specific wavelength for intra-ONU traffic, in a ring network. The shared wavelength is used for direct communication among ONUs, in a TDM fashion whose arbitration is centralized in the OLT. The peculiar ONU architecture allows to optical bypass the transit traffic, thus saving energy.

Some works extend the concept of convergence by incorporating access and metro networks into a uniform domain. For instance, in [62] and [63] an all-optical WDM/TDM access-metro architecture is proposed, which relies on centralized control entities for the resource and mobility management. Thanks to the adoption of transparent optical cross connects and the reduction of the number of central offices large extents of energy savings can be achieved.

Another way to pursue energy efficiency consists in employing low-power and/or sleep-state modes to some nodes or network portions, to properly exploit the periods in which the traffic load is low. Such solutions are suited for a class of FMC access architectures, known as hybrid wireless/optical networks, in which the mobile backhaul is front-ended by a wireless multi-hop relay portion and back-ended by a fixed optical infrastructure.

In [64] the energy efficiency of a converged wireless/optical access network is evaluated, where the wireless part coverage is given by LTE femtocells and the optical backhaul consists in PON technology. The results show that relative higher energy savings (about 10-27%) can be achieved by utilizing low-power modes in urban-suburban scenarios.

In [65] the converged network is composed by a number of WDM-PON segments, in which some designated ONUs are directly connected via self-healing inter-segments rings. When the traffic profile is under a certain threshold, all the ONUs belonging to some segments are put in sleep-state, except for the designated ones, which backlog and forward the traffic through the other segments, via a power saving cluster. This is made possible thanks to the implementation of the wireless front-end as a multi-hop relay mesh. The results of simulations show that about 25-45% of power saving can be achieved with this scheme.

In [66] and [67] some energy efficient design schemes and bandwidth-allocation mechanisms are investigated for long-reach converged fibre/wireless networks. Specifically, an evolved dynamic bandwidth allocation scheme is proposed for an architecture based on low-energy states ONUs, that leads to a decrease of the energy consumption up to about 3Wh per day (relative reduction of 25%), with respect to conventional schemes.

To summarize, by the recent literature about FMC access networks, there are four main ways of improving energy efficiency. The first one is employing passive all-optical transport infrastructures, which drastically reduce the power consumed by electronic switches and o-e-o converters. The second way consists in offloading from the OLT the peer-to-peer intra-ONU traffic, thus reducing the power consumed by transit traffic processing in the OLT. The third solution is integrating different network functionalities into converged nodes, thus achieving a better hardware resource optimization, with a consequent reduction of the per-node consumed power. The fourth way consists in employing low-power states in some network equipment, in order to adapt the network energy consumption to the total traffic load, thus gaining valuable savings during off-peak periods.

As a final note, we remind that the complete list of values that have been collected for Fixed, Wi-Fi and Mobile access networks and that will be used for the energy-consumption evaluation in Section 6 is reported in Annex 11.2.

6 Scenarios and case studies

A set of state of the art network scenarios are the subject of the current deliverable, and various FMC network architectures will be proposed during the COMBO project lifetime. The cost and power consumption assessment of these network architectures requires a “field” in which these proposals will be assessed considering their cost and energy effectiveness. The evaluation and comparison support selection of the best configurations for a given “environment”.

This chapter is devoted to the definition of such “environments” or case studies, i.e. the case study types and concepts will be outlined here. Also the first few case studies will be presented, which will be used for the first demonstrative results included in the deliverable.

As it was already mentioned in the earlier chapters, two different approaches will be applied for the cost and power consumption assessment of the investigated network scenarios, where the “scale” of the investigated area makes the difference. These will be referred to as “microscopic” and “macroscopic” case studies, outlined in the following sections.

These two assessment approaches (and the respective case study types) complement each other. In nationwide or continental scale, only the macroscopic approach applies due to complexity reasons, but in city-wide or smaller scenarios the microscopic approach has some clear accuracy gain. [4]

6.1 Macroscopic Case Studies

Macroscopic case studies are used to give an overview of the cost and power consumption of a given network architecture in a large-scale deployment. Typical areas in which networks are deployed will be used to evaluate how the proposed network architectures perform, and in order to identify the main “trends”. In this way for example, we could get a result conclusion such as: “network scenario X has lower per-user cost in dense urban areas than scenario Y, while the opposing relation applies for sparsely populated rural areas”.

The macroscopic scenarios are not specific areas in Europe, rather artificial models that reflect the most important characteristics of three basic geotypes: dense urban (DU), urban (U) and rural (R) areas. These geotypes were introduced by WP2, in deliverable D2.1, in which a set of reference parameters were also defined for them.

These parameters may be divided in two subsets: some of them are describing the area itself (e.g. number of households), and some of them are more related to the network topology (e.g. typical lengths of distinct network segments). Additionally, some more techno-economic assessment related parameters supplement these reference parameters, just like the extent of existing infrastructure in brownfield deployments.

In the next sections, a brief overview of these geotypes or macroscopic case studies is given, but to avoid repetitions, the reader is referred to D2.1 [68] for further details and complete numerical descriptions. Their geographic descriptors are summarised in Table 11.

6.1.1 Dense Urban (DU) areas

Dense urban areas are the core parts of the largest European cities. These areas are typically well equipped with existing telecommunications infrastructure, e.g. cable ducts. In these areas, high (broadband) customer demand is expected, and usually business customers are dominating.

Network deployment in a dense urban area promises relatively quick return of investment; therefore, new broadband network technologies are typically deployed in these regions first. Among the three addressed geotypes, DU will represent the largest case studies, with the highest traffic demand or number of endpoints.

6.1.2 Urban (U) areas

Somewhat smaller cities and towns, as well as the non-central parts of large European cities are considered as “urban” areas (suburban areas also belong to this geotype). Lower population density, but still typically multi-home buildings are found in these areas, where both business and residential customers are present.

Regarding the telecommunication infrastructure, the CO is typically located in the centre of the town or the district (if the area is part of a larger city). Existing duct availability is usually higher in the vicinity of the CO, and lower at the edge of the area.

6.1.3 Rural (R) areas

Unlike dense urban and urban areas, in rural environment, residential demand is dominant. In these locations, apart from the centre of the area, typically single family houses, or buildings with just a few living units are present, and a significantly lower population density characterizes a rural area.

The typically lower development of telecommunications infrastructure makes new network deployments even more costly, which, coupled with the lower customer demand, sometimes prevents investments for years after the first deployments in urban areas.

| Geotypes and typical parameter ranges | Dense urban | Urban | Rural |
|---|-------------|-----------|-----------|
| Area | 20-50 | 8-25 | 5-20 |
| Number of buildings [N_B] | 5-10.000 | 2-5.000 | 500-2.000 |
| Number of households [N_H] | 100.000s | 10.000s | 1.000s |
| Household density (households / km ²) | 3-5.000 | 600-1.200 | 200-400 |
| Building density (buildings / km ²) | 100-200 | 150-300 | 100-200 |
| Average building size [N_H/N_B] (avg. hh. / building) | 10-50 | 3-10 | 1-2 |

Table 11: Dense urban, urban and rural geotypes and their typical geographic parameters

6.2 Microscopic case studies

Microscopic case studies offers the possibility to investigate how a given network architecture adapts to various geographic conditions and specific service areas. How does the size of the buildings, variations of population density or characteristics of the street system affect the cost or energy effectiveness of a given network scenario? The applied methodology was briefly described in section 3.3. The data requirements will be summarized in this section, along with examples of microscopic case studies, used for the demonstration tool results in chapter 7.

We note that the set of microscopic case studies is not complete yet: collecting data for the case studies used during the COMBO project is still an on-going process. However, the first example case studies were defined, in order to drive the development process of the Assessment Framework.

The whole assessment study should focus on the COMBO scope, i.e. the reference framework (chapter 2.1, Figure 2). According to the decision taken by WP2, the COMBO scope covers the access and aggregation network segments. Since typically different network technologies are used, as well as the distances and scale significantly differ in these two segments, the respective microscopic case studies will be separated. Access network case studies will be introduced in section 6.2.1, followed by an aggregation network case study in section 0.

6.2.1 Access Network example areas

Access network case studies focus on the feeder and distribution network segments for fixed access networks, and on the radio access network and the mobile backhaul for mobile access networks. The access network “terminates” at the local CO, and the upper network hierarchy is addressed as part of the aggregation network (see the next section).

A microscopic case study for assessment of the access network is defined by a map with location of fixed endpoints and distribution of mobile demand (or mobile demand points). These locations will be provided with fixed or mobile connectivity by means of an optimization process over the access network infrastructure. The necessary information is therefore mostly related to the map, the street system, endpoint locations, potential antenna sites and cabinets, up to the CO. Two examples are described in the following sections, which will be used to show that the Assessment Framework can deliver demonstrative results for state of the art network scenarios.

6.2.1.1 Case study #1: Town Centre

The first case study area (map and parameters in Table 12) is mainly used for demonstrating how the methodology work, and how a given network architecture looks like when deployed in a real-world area and then displayed on the map. This case study represents the centre area of a small town in Hungary, called Kőszeg.

| Microscopic case study Access #1 (Town Centre) | |
|--|----------------------|
| Parameters | Map |
| Type of area | Town centre |
| Real location | Kőszeg |
| Map source | OSM |
| Area | 0.50 km ² |
| Street system length | 18.04 km |
| # Buildings | 367 |
| Building density (bd. / km ²) | 730 |
| # Households | 367 |
| Household density (hh. / km ²) | 730 |
| Households / buildings* | 1.0 |



Figure 23: Map of microscopic case study #1 (Town centre)

Table 12: Summary of microscopic case study #1 (Town centre)

*: Since this case study will be used for illustration / demonstration purposes, one fixed demand point per building is assigned in order to have a clearly visible network structure.

6.2.1.2 Case study #2: Urban District

The second case study area (map and parameters in Table 13) is not just a demonstrative example; instead it is a real case study, which will be used for techno-economic assessment of COMBO network architectures.

The selected area is located in Budapest, capital of Hungary, being an urban-suburban district, just outside of the city centre. Broadband optical access network deployments have started in this area in the past few years.

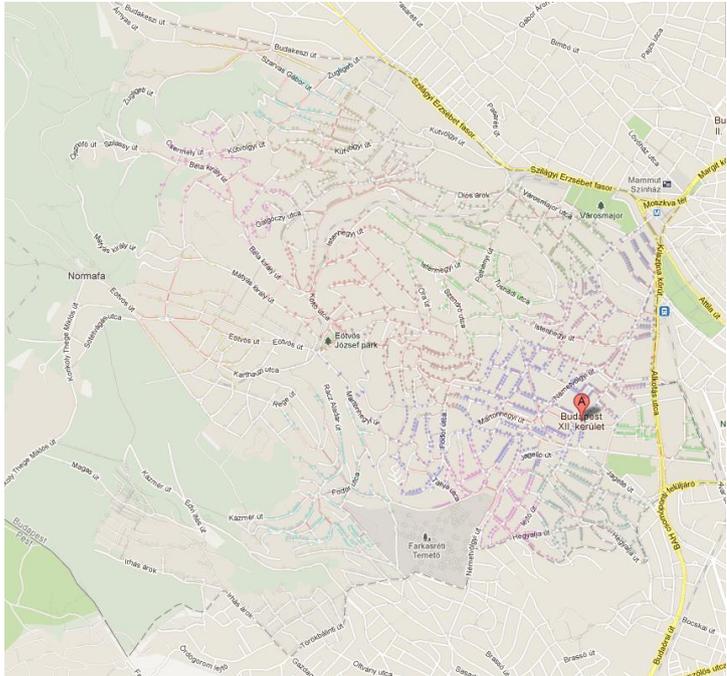
| Microscopic case study Access #2 (Urban district) | | |
|---|----------------|---|
| Parameters | | Map |
| Type of area | Urban district |  |
| Real location | Budapest | |
| Map source | OSM | |
| Area (km ²) | 7.12 km | |
| Street system length | 304 km | |
| # Buildings | 4 132 | |
| Building density (bd. / km ²) | 580 | |
| # Households | 26 489 | |
| Household density (hh. / km ²) | 3 720 | |
| Households/buildings | 6.4 | |

Figure 24: Map of microscopic case study #2 (Urban district)

Table 13 Summary of microscopic case study #2 (Urban district)

6.2.2 Aggregation Network example area

The Aggregation Network requires a different study viewpoint; since its range of magnitude is typically higher than an access network segment (aggregation network connects the access networks to the core).

During the microscopic analysis (and optimization) of aggregation networks, the connected access network are considered as a priori given instances, i.e. the demand that has to be served by the access network. Hence, the local COs, the connected fixed demand points and antenna sites, as well as nodes at higher hierarchy levels (i.e. main and core COs) are the geographic inputs for an aggregation network case study.

6.2.2.1 Case study #1: Brittany

Currently we have one extensively defined example aggregation network area, used as a “microscopic” aggregation network case study. The term “microscopic” may sound contradictory due to the scale of an aggregation network area, but we recall the origin of the terminology. The microscopic approach derives results from real

Assessment Framework and evaluation of state of the art technologies

world reference areas instead of pure statistical models. The selected reference area is a western region of France, namely Brittany (Bretagne) - Table 14 provides an overview of the region.

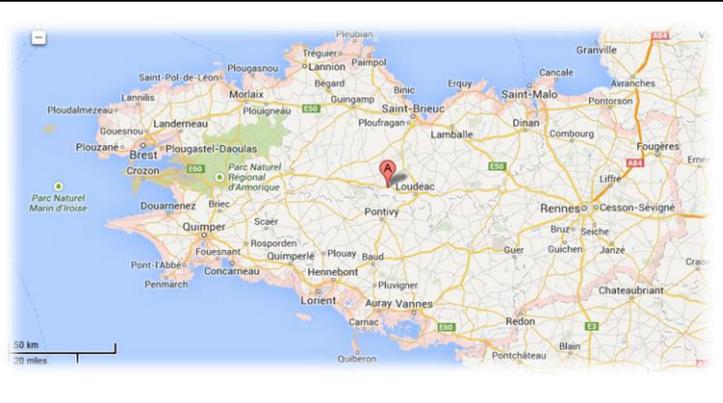
| Aggregation network case study: Brittany | | | |
|---|------------------------|--|-------------|
|  | |  | |
| Area | 34.000 km ² | Fixed Lines | 1.8 Million |
| Inhabitants | 3.2 Million | Central Offices | 879 |
| | | Antenna Sites | 860 |

Table 14: Characteristics of the aggregation network case study (Brittany)

The existing aggregation network infrastructure will be used as a starting point for the technology option optimization. In order to hide confidential data about existing network infrastructure, a randomization was applied: all central offices and antenna sites have coordinates within ± 1 km from its original position. Hence, the global geographic distribution is conserved, but the sensitive information remains hidden.

In addition to location of network nodes, the interconnections and link types (e.g. copper, fibre, microwave) are also defined: a) between adjacent COs, and b) between CO and antenna sites (i.e. backhaul links). For each CO, the amount of managed fixed lines, and the connection length distribution complements the case study description. Figure 25 gives an overview of the area with all the aggregation network nodes and connections.

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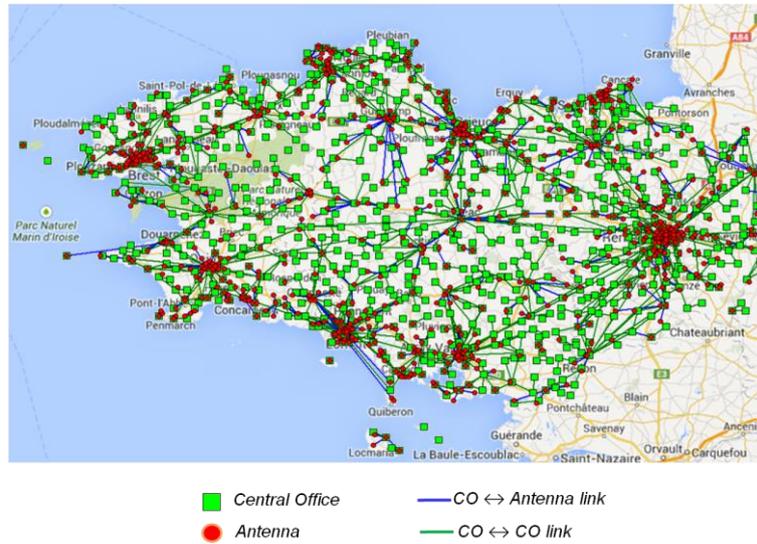


Figure 25: Map of the aggregation network case study (Brittany)

7 Techno-economic assessment of state-of-the-art fixed and mobile network technologies

In this chapter we present and analyse the assessment results through comparison and also discuss the possible implications and impact. The main objective of this chapter is to demonstrate the capabilities of the assessment tools. A partial techno-economic assessment was performed derived from the available collected data and case studies.

Some assumptions and exclusions have been taken for the production of the present results, as follows: (a) The aggregation network was not considered in this study given that the collection of information on how to dimension has not been finalized; (b) Given the difficulties to estimate all OPEX items, the calculations in this document are based on the power consumption as part of the Task 5.4, and the rest of items is still under discussion as collection of data is in progress; (c) Due to the lack of appropriate case studies to assess Wi-Fi, it was not considered in this section; (d) Whenever the copper twisted pair is required (e.g., in xDSL technologies), we assume that it is already installed and no cost is added for its installation.

7.1 Macroscopic case studies

In this section we present the cost and energy consumption assessment results for large scale case studies for three main geotype areas: dense urban, urban, and rural. Their description and reference parameters have been introduced in section 6.1. The actual values used for the numerical calculations are shows in Table 15.

| Geotype | Dense Urban | Urban | Rural |
|--------------------------------|--------------------|--------------------|--------------------|
| Area | 30 km ² | 30 km ² | 30 km ² |
| #Buildings | 10 000 | 6 000 | 5 000 |
| #Households | 150 000 | 24 000 | 9 000 |
| Buildings per km ² | 333 | 200 | 166 |
| Households per km ² | 5 000 | 800 | 300 |
| Households/building ratio | 15.0 | 4.0 | 1.8 |

Table 15: Macroscopic case study settings

7.1.1 Cost assessment

The CAPEX assessment in this section involves the main state-of-the-art fixed and mobile network technologies. For the fixed networks we include in this evaluation: GPON, VDSL2 with PtP feeder, and WDM PON. For the mobile networks we include: GSM (2G), UMTS (3G), and LTE (4G).

For every geotype area in the case study, we have calculated the total cost per user as shown in Figure 26. Here we note in every network technology that the CAPEX increases considerably as the network node density becomes more scarce and covering longer distances, such as the rural case. Hence, in a rural case, the total cost is divided by a lower number of users. Although for WDM-PON the cost becomes higher than GPON, they both follow the same clear tendency. We have to note here that for WDM PON, an FTTB deployment was considered, while FTTH for GPON. It makes WDM PON more cost-efficient for the dense urban case, due to the size of the buildings: the CAPEX is depicted on a per subscriber basis, and in this case a WDM PON connection for the buildings is less expensive, than a GPON connection for all the households. As buildings sizes decrease, the cost of deploying an FTTB WDM PON exceeds FTTH GPON.

In the case of VDSL with PtP feeder, we can see the same behaviour but with no significant grow, compared to the other two counterparts. One of the main reasons is that there is no main requirement for new copper deployment, as stated in the assumptions at the beginning of this chapter. Therefore, there is mainly an increase in the feeder size in the rural area, producing a slight increase in the total CAPEX.

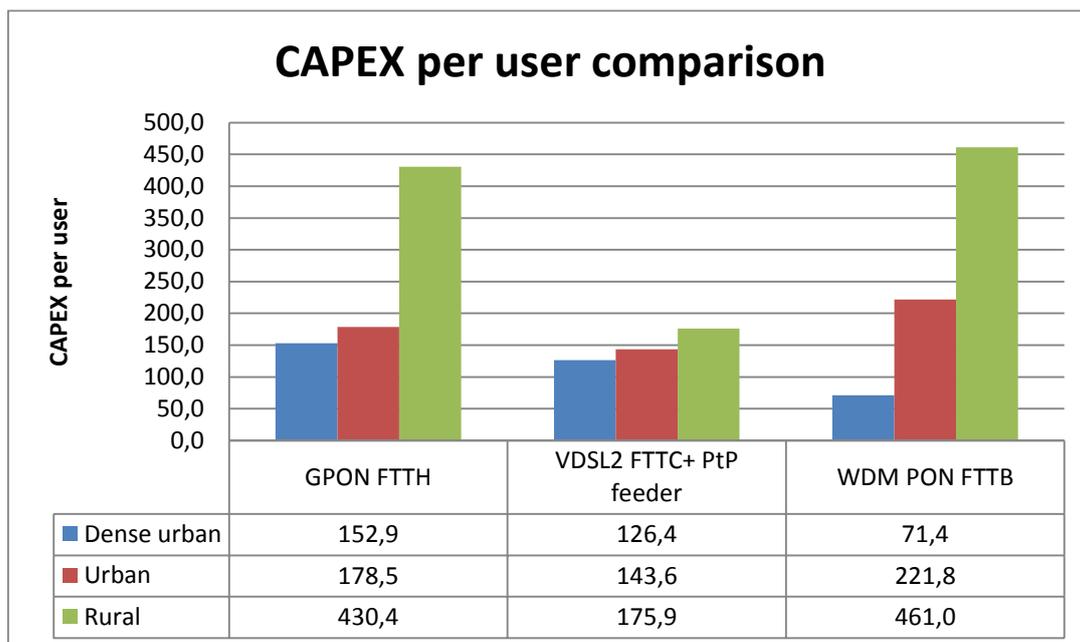


Figure 26: Comparison of CAPEX per user for three main fixed network types (3 geotypes)

In Figure 27, Figure 28, and Figure 29, we observe the proportion of every cost component for the three geotype areas. We can see that the higher is the user density, the higher is the cost component of endpoint equipment, i.e., equipment located at user premises. We note also a high component of outside plant equipment for VDSL with PtP feeder, because in this case there is a need to have active devices (DSLAM) at intermediate nodes, such as a cabinet. We can observe also that there is slight variation in WDM-PON among the different geotype area cases. This is because this type of network tends to be fully equipped providing one wavelength per ONU. However, in this case the fiber reaches the building, and in dense areas the capacity allocated to an ONU is shared among the households of every building.

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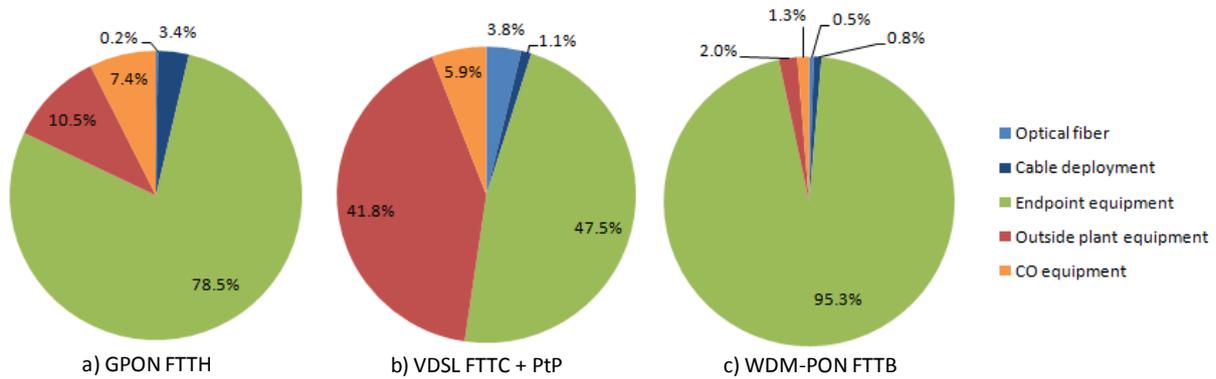


Figure 27: Cost components of every fixed network considered for the dense urban geotype.

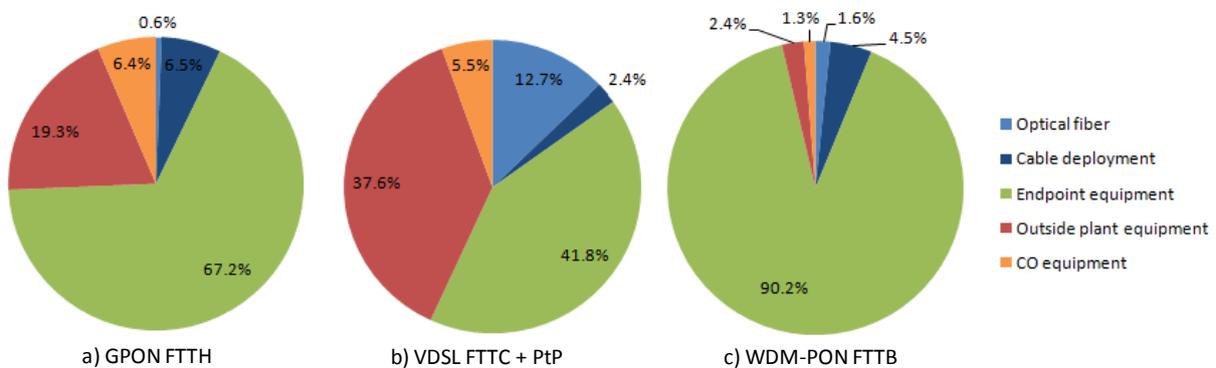


Figure 28: Cost components of every fixed network considered for the urban geotype.

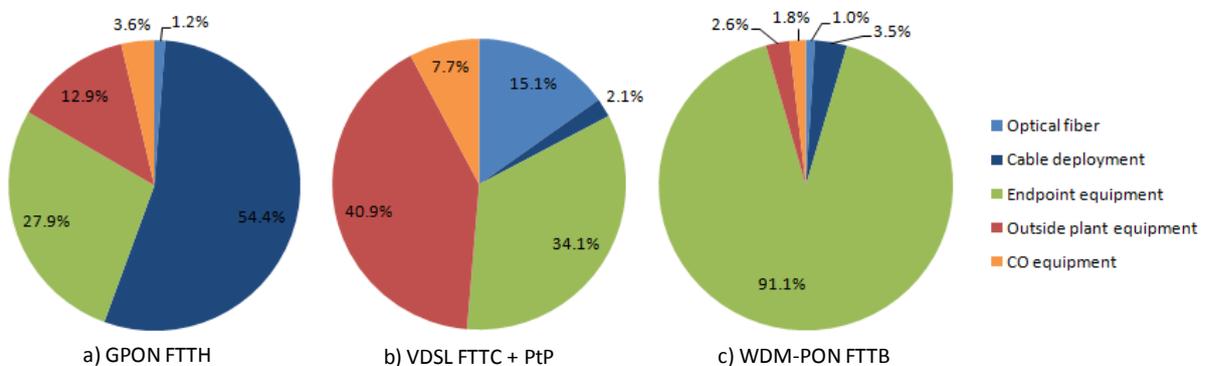


Figure 29: Cost components of every fixed network considered for the rural geotype.

In Figure 30, we show the total CAPEX per antenna site for all the considered mobile network technologies. It is relevant the significant increment in cost when these technologies are deployed in a rural area. The reason is that in a rural case, the antenna site has to cover a larger area, and this impacts the cost. However, the number of antenna sites is lower than for the other two geotype areas. Therefore the overall cost of rural deployment is not higher than the urban cases. This is more evident in Figure 31, where the CAPEX for the rural area is significantly lower than the other two geotypes.

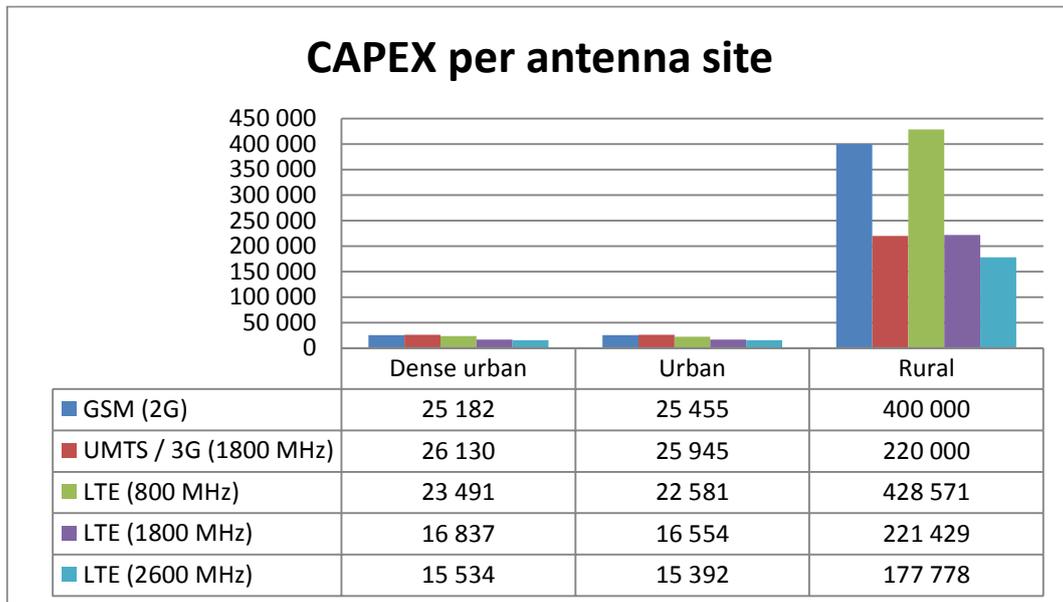


Figure 30: Comparison of CAPEX per antenna site (mobile network types, 3 geotypes)

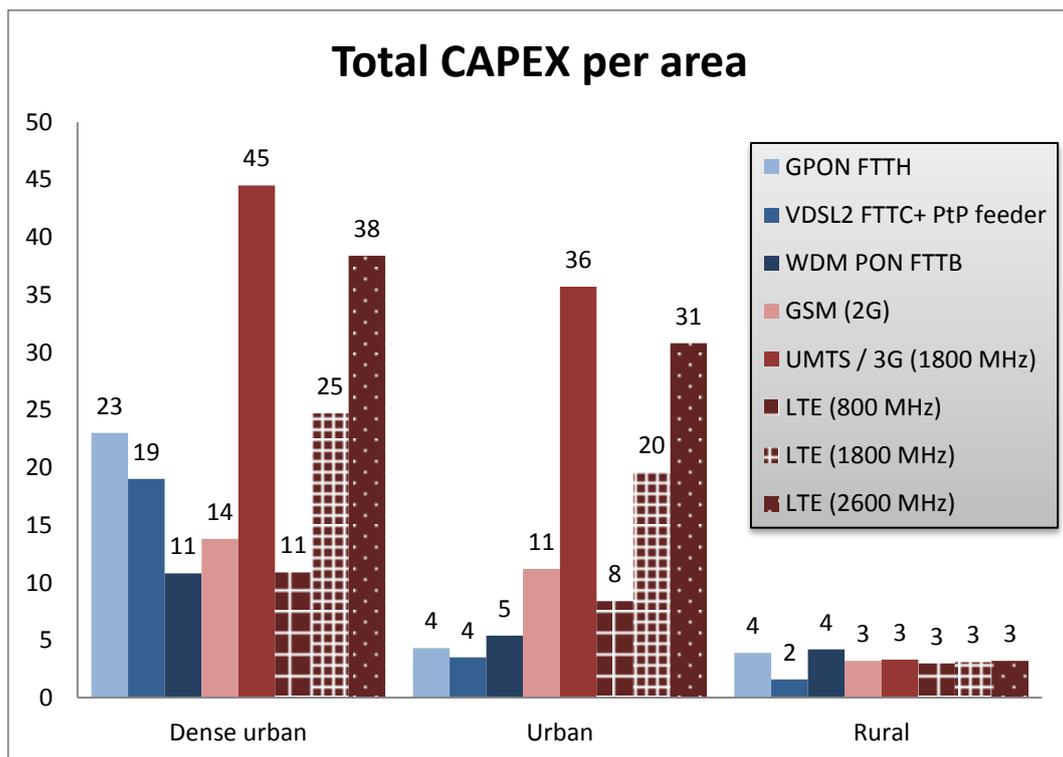


Figure 31: Comparison of CAPEX (fixed and mobile network types, 3 geotypes)

If we calculate the cost per unit of bandwidth (Mb/s), as shown in Figure 32, other interesting aspects of the CAPEX can be observed. While the fixed network, in particular the ones considered, may be able to support high capacity within the same fiber, the radio access networks must provide higher coverage to serve more scarcely located users in the rural case, which impacts the cost. A refinement of these values is expected in the next two years, by collecting more specific cost data, considering different statistical multiplexing gain in fixed and mobile, and avoiding the

simplifications mentioned in the introduction of Chapter 7). However, the trends are clear: a complete replacement of fixed access with mobile is not economically feasible, due to the high difference in cost of bandwidth. This will be the main reason for low range technologies (e.g. Wi-Fi and/or small cells) to be included in the network scenarios: they provide the bandwidth of fixed and ease of access of mobile, with a moderate price increase over the fixed access.

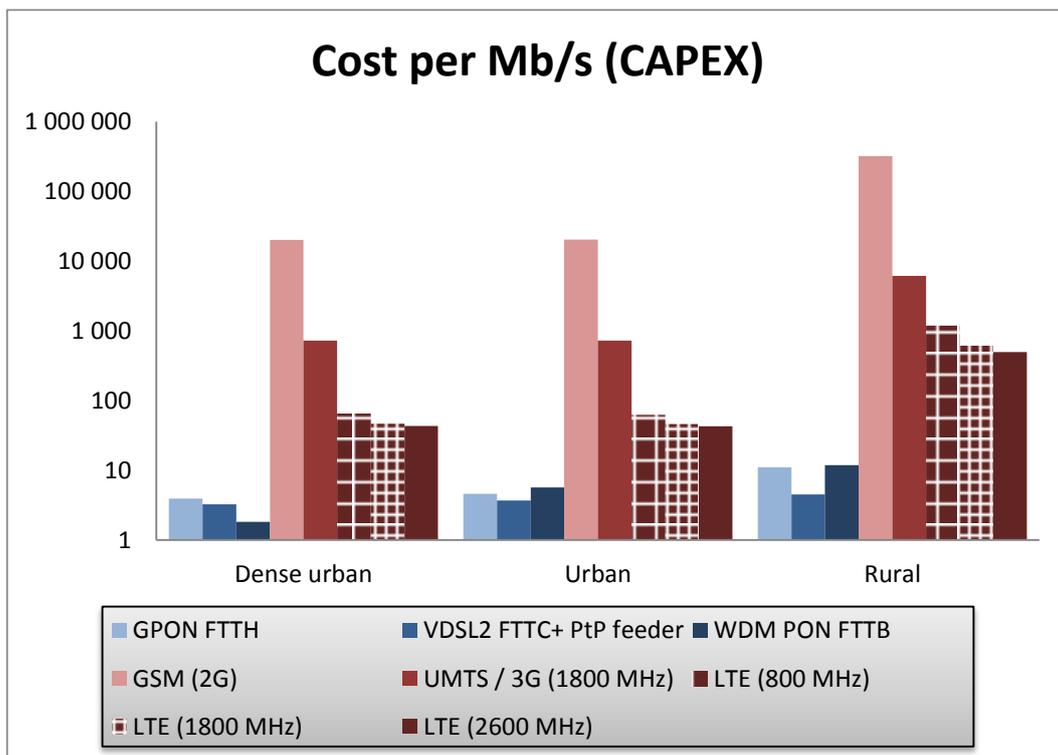


Figure 32: Comparison of CAPEX per Mb/s for the main fixed and mobile network types, and for every geotype area.

7.1.2 Power consumption

The scope of the following preliminary power consumption analysis is trying to identify possible features of state-of-the-art technologies which may have a relevant impact on Energy Efficiency. We remark that such results and relative discussions should not be considered as definitive quantitative evaluations of the energy consumption of each network scenario. Instead, they must be intended as preliminary outcomes of an in-progress work which will lead to a more complete and in-depth analysis during the next years of COMBO project.

7.1.2.1 Fixed Networks

As figure of merit of Energy Efficiency two key performance indicators are used: 1) the Energy per User, and 2) the Energy per Mb/s. They are defined as the ratio between the sum of power consumption values of all access network devices and, the number of served customers, and the total access bitrate (in Mb/s), respectively, for the reference geographic area.

Figure 33 shows a comparison of the Energy per User among the three considered fixed network scenarios and geotypes.

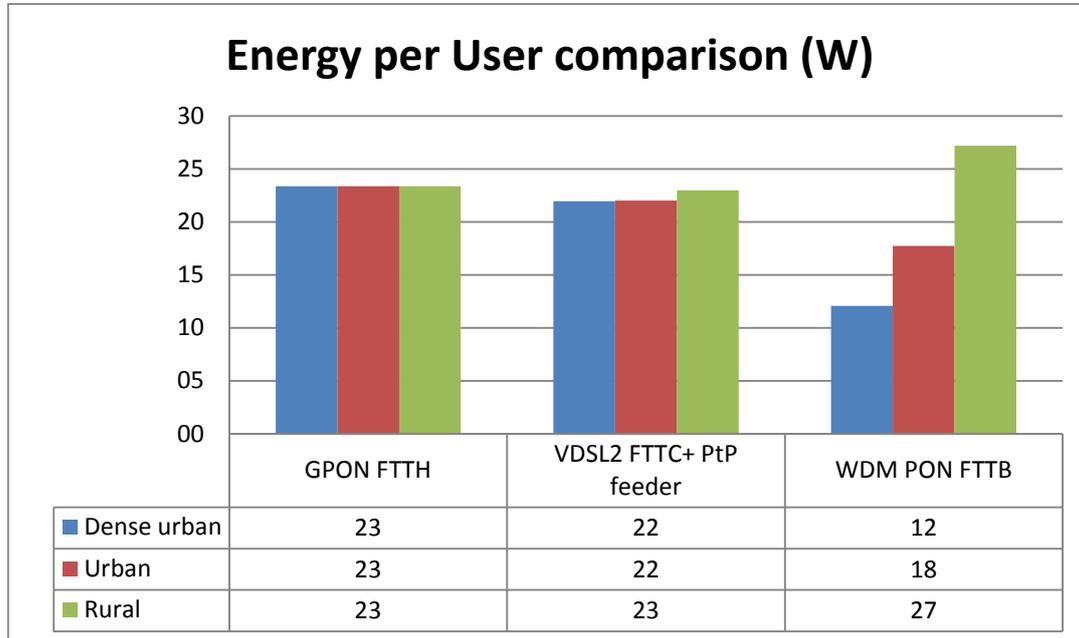


Figure 33: Energy per User for all macroscopic case studies

In all cases, the Energy per User values are in the order of magnitude of tens of Watts, ranging from 10 to about 30 W. Scenarios 1 (GPON FTTH) and 2 (VDSL2 FTTC + PtP feeder) exhibit almost similar values, which are also almost constant over different geotypes. This is due to the fact that the contribution of customer premises devices dominates over the contribution of network and CO devices that are shared among a large number of customers. For example, in Scenario 1, the energy consumption of each GPON OLT is shared by 64 customers, while exactly one STB, RGW and GPON ONT must be installed for each customer. This is an important benefit in terms of Energy Efficiency provided by TDM access technologies. In Scenario 2, in our simplified model, less energy consumption is expected, as the RGW directly interfaces with the DSL line (acting as modem), thus the ONT is not needed. Such energy gain is reduced by the adoption of a Point-to-Point access technology instead of TDM. In fact, there is an additional energy contribution for each customer, coming from the consumption of each VDSL2 interface working in the DSLAMs. A more detailed energy evaluation of the VDSL2 mode might lead to slightly different results.

Different behaviours arise in Scenario 3 (WDM PON FTTB). In this case, the contribution of customer equipment has less impact, since only the STB is needed for each household, while mini-DSLAMs and WDM ONUs are installed on a per-building basis. This leads to a substantial reduction of the Energy per User in the Dense Urban geotype (where Energy per User is almost halved with respect to the other two scenarios) and in the Urban geotype. However, for the Rural geotype, this scenario requires the highest Energy per User. This can be interpreted as an effect of the limited optical reachability constraint which imposes a larger number of COs when

covering larger geographical areas. Therefore, for Rural areas this network scenario appears to be less energy-efficient than others.

Figure 34 shows a comparison of the Energy per Mb/s among the three considered fixed network scenarios and geotypes. The figure confirms the previous trends, as in this preliminary analysis it has been assumed that all customers receive the same bitrate – for GPON and VDSL2. However, WDM PON makes a difference, due to the FTTB deployment: with relatively large buildings, it brings a clear advantage, as the power consumption is shared among a higher number of subscribers. As the amount of subscribers per buildings drops (i.e. the rural case), this gain of WDM PON disappears, and gets close to the other two network scenarios.

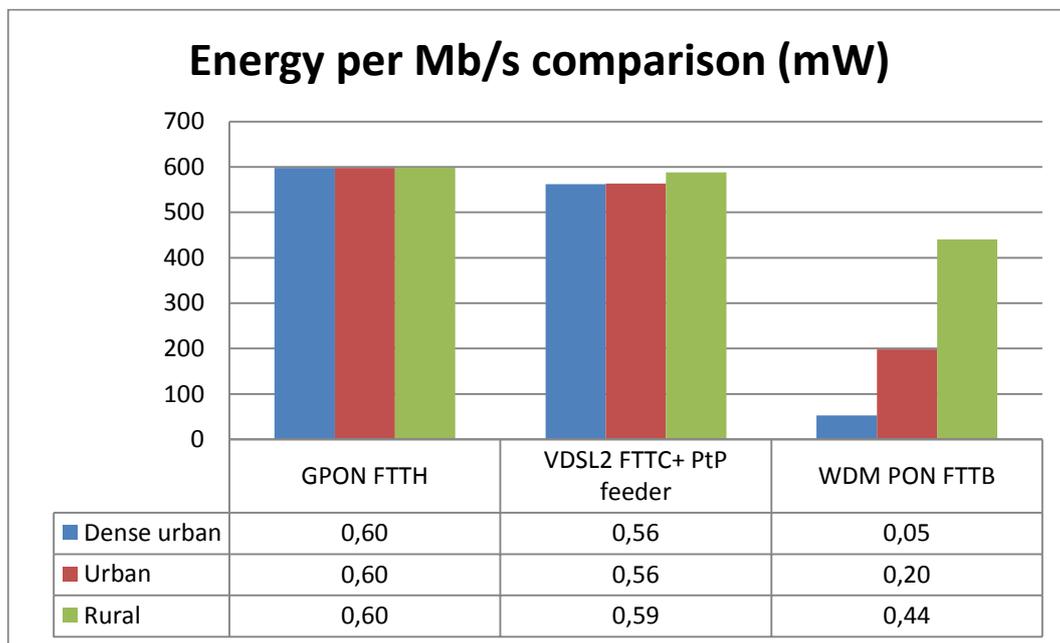


Figure 34: Energy per Mb/s for all macroscopic case studies

7.1.2.2 Mobile Networks

As figure of merit of Energy Efficiency two key performance indicators are used: 1) the Total Power Energy per area, and 2) the Power Energy per user. They are defined as the ratio between the sum of power consumption values of all mobile network devices per unit area and the number of served customers, respectively.

A big variation in power consumption between the three scenarios (Figure 35) can be noticed: dense urban can reach up to 3 MW, urban is up to 2.5MW and rural has figures in the order of 30-50kW. The main reason behind this behaviour is the different user density and coverage of antenna sites in the three scenarios, as described in table 15. In fact, a higher user density leads to a higher antenna density and consequently to a higher power consumption per area. It is worth to highlight also the differences when varying from a technology to another. For example in the dense urban scenario, 2G and LTE (800 MHz) consume much less power than the other technologies. The reason is the cell size which is higher in these two technologies then in the others, due to the lower carrier frequency. Consequently the number of antenna sites to be deployed is lower for 2G and LTE (800 MHz).

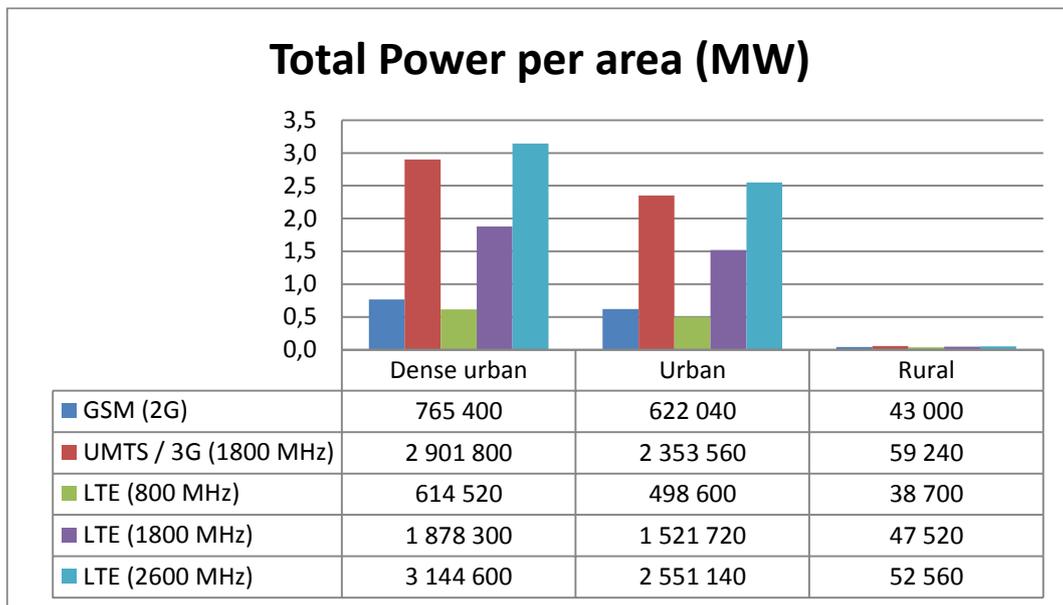


Figure 35: Power consumption of mobile networks

Another interesting result is showed in Figure 36. The power consumption per active user for dense urban and urban is comparable. On the other hand, in rural scenario it is much higher than in the other two. In fact in those zones, the number of active users per base station is quite low, but the base stations have to be maintained active for coverage issues, so the site is generally underutilized.

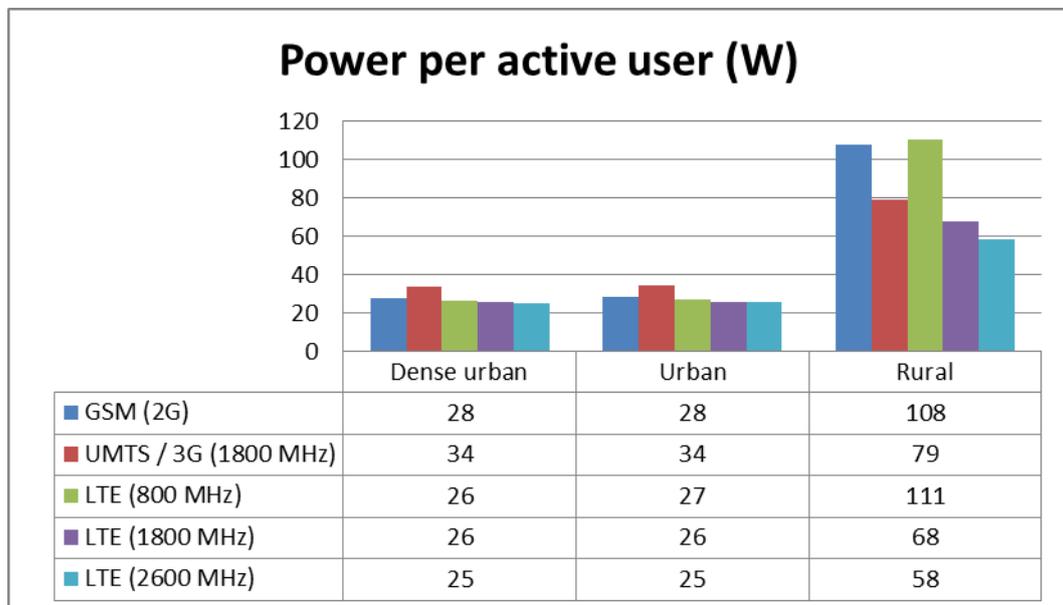


Figure 36: Power consumption of mobile networks per user

The last figure, namely power consumption per Mb/s bandwidth units (Figure 37) justifies the clear evolution of mobile networks (i.e. increased cell capacity): 2G, 3G and LTE require approximately an order of magnitude less energy for the same units of bandwidth.

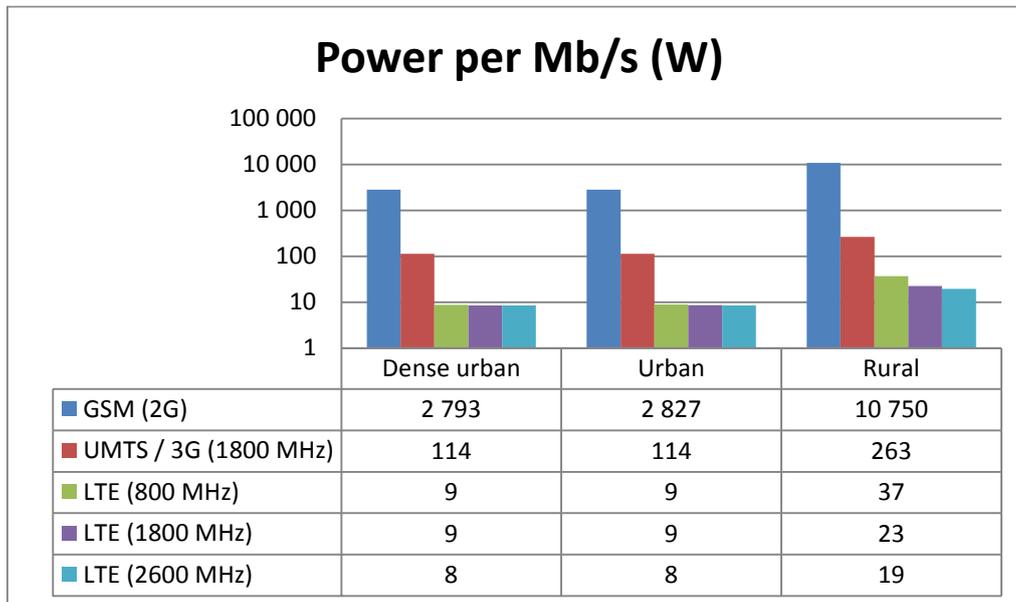


Figure 37: Comparison of power consumption per Mb/s for the main mobile network types, and for every geotype area.

7.2 Microscopic case studies

In this section, we demonstrate abilities of the tools in assessment framework, which were designed to assess microscopic case studies. As it was described earlier, the methodology has three main steps: (1) planning and dimensioning of the network, (2) cost and (3) power consumption assessment.

7.2.1 Dimensioning / topology

The first step, which provides input for the cost and energy calculations, is the network dimensioning. In this case, the network topologies, amount of necessary network equipment and the dimensions of the cable plant are the result of a network planning process.

For demonstration purposes, we have defined three different (fixed) access network topologies, based on the case studies introduced in the Chapter 6.

7.2.1.1 Case study #1 (with up to 64 buildings connected to each cabinet)

This one is a small, exemplary area (see section 6.2.1.1). Hence, whole network topology fits on one page in a readable/visible format (see Figure 38). Such readability was the primary reason to define this case study: the network planning methods were validated on it. The topology depicted below refers to a PON network, with single level splitting hierarchy and 1:64 splitting ratio. The colored nodes represent the buildings; those with the same color are connected to the same cabinet.



Figure 38 Topology of microscopic case study #1

The network dimensioning results are then derived from the network design, which support the Bill of Material calculations for cost and power consumption as well. Overview of the numerical results is given in Table 16.

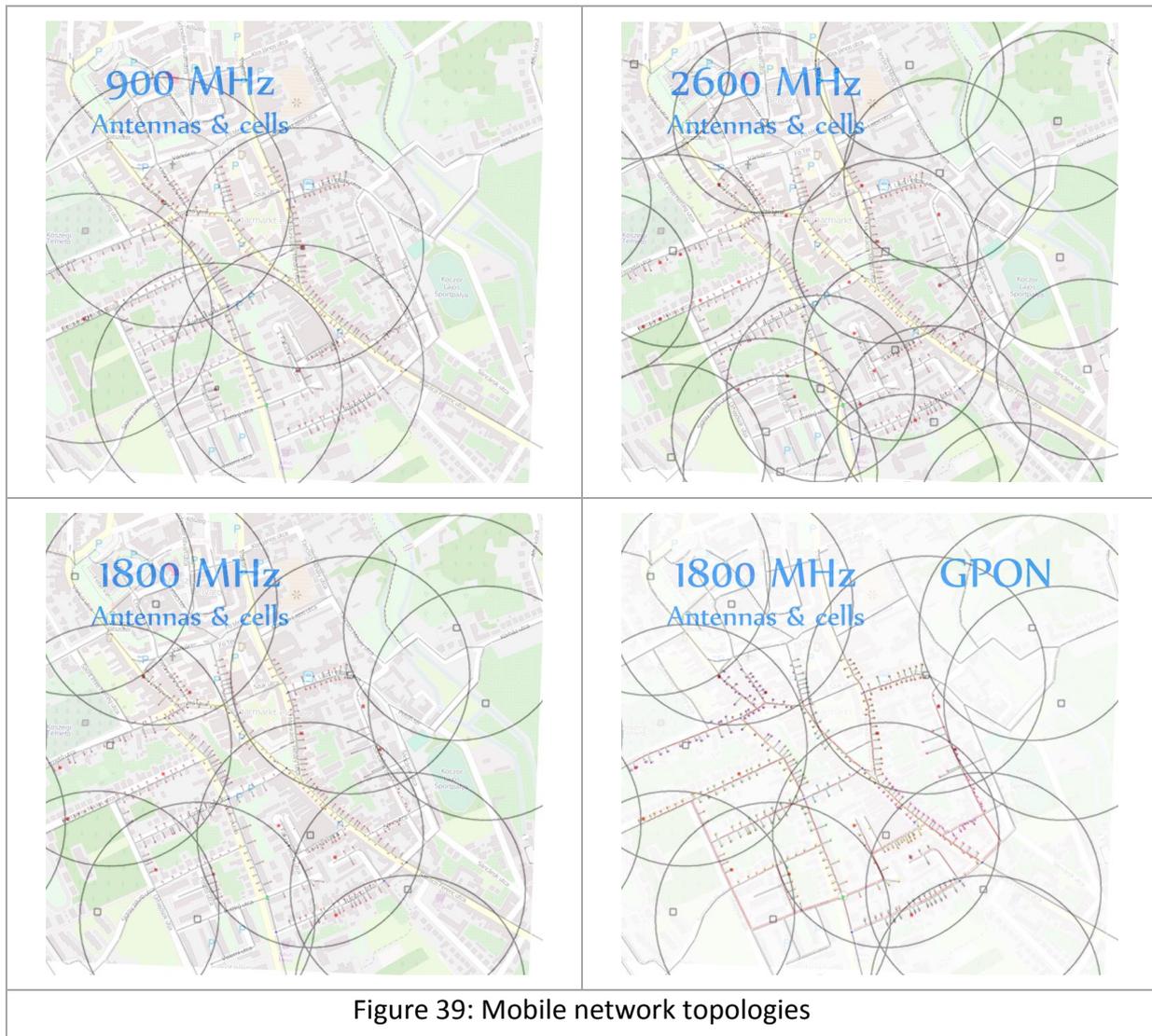
| Dimensioning results | |
|----------------------|-----------------------------------|
| Case study | Access #1 (Town Centre, “Kőszeg”) |
| Buildings | 367 |
| Area | 0.50 km ² |
| Cabinets | 7 |
| Trenching | 5.6 km |
| Optical Fiber | 64.3 km |
| Feeder links | 2.6 km |
| Distribution links | 61.7 km |

Table 16: Summary of network dimensioning for microscopic case study #1

Finally, Figure 39 shows some mobile network topologies for the same case study. The antenna sites are distributed over the service area, according to the Okumura-Hata / COST 231 coverage models, for 900, 1800 or 2600 MHz, respectively. The

last figure (bottom right) depicts a combined planning of the radio access network with an optical backhaul.

Currently, these figures are here to demonstrate the fact that the network dimensioning methodology is working by the time of submitting the deliverable also for mobile networks, however the integration with the cost and energy assessment and technology optimization tools is still an ongoing process. Hence, in the following chapters numerical results will be presented only for fixed access networks.



7.2.1.2 Case study #2 (with up to 64 / 500 buildings connected to each cabinet)

The second case study (Chapter 6.2.1.2) has much more realistic size, it's far not for testing purposes. Calculating (optimizing) the network topology, with respect to all the physical and technological constraints is a tough algorithmic challenge also. However, the implemented high performance heuristics provide optimized network topologies in this scale also.

Figure 40 shows the overview of the network topology, and one PON segment highlighted in the top left corner. Thick red line denotes the feeder link between the Central Office and the splitter, and the blue dots represent the buildings.

Since the network topology is used to feed also the technology optimization tool (Chapter 3.2), two different topology versions were prepared, assigning up to 64 or 500 buildings to a single cabinet. Summary of the respective network dimensioning is given in Table 17.

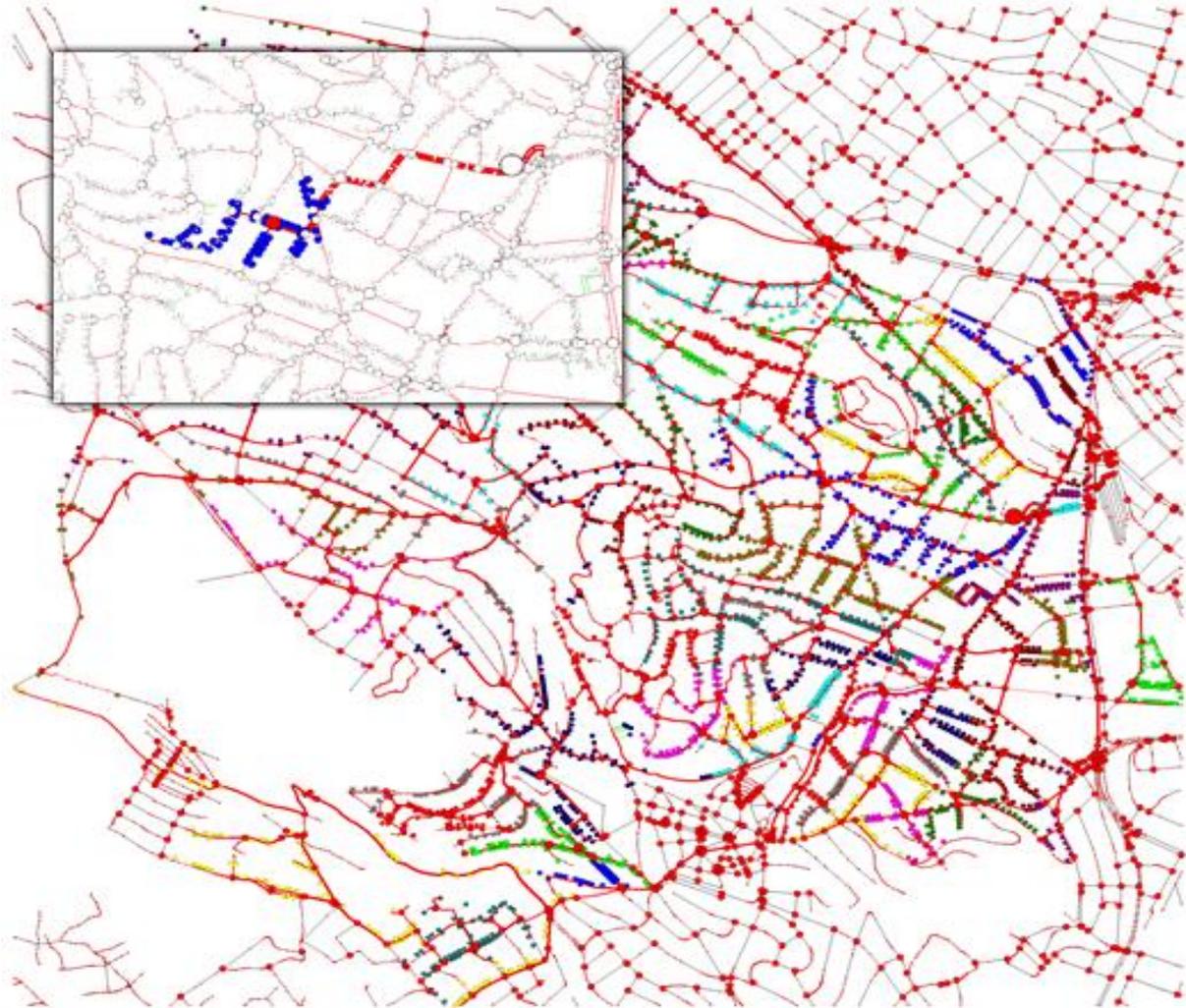


Figure 40: Topology of microscopic case study #2 (up to 64 buildings per cabinet)

| Dimensioning results | | | |
|----------------------|----------------------------------|--------------------|----------------------------------|
| Case study | Access #2 (Urban, “Budapest”) | Case study | Access #2 (Urban, “Budapest”) |
| Version 2/a.) | < 64 buildings per cabinet | Version 2/b.) | < 500 buildings per cabinet |
| Buildings | 4 132 | Buildings | 4 132 |
| Area | 7.12 km ² | Area | 7.12 km ² |
| Cabinets | 76 | Cabinets | 10 |
| Trenching | 141.3 km | Trenching | 143.6 km |
| Optical Fiber | 1 405.9 km | Optical Fiber | 3 142.8 km |
| Feeder links | 173.4 km | Feeder links | 20.5 km |
| Distribution links | 1 232.5 km | Distribution links | 3 122.2 km |

Table 17: Summary of network dimensioning for microscopic case study #2

7.2.2 Cost assessment

For the cost assessment of microscopic cases we have included a number of fixed networks: PtP FTTC with VDSL2, GPON, XGPON, WDM-PON, and TWDM-PON. In this section, the technology optimization tool provides the numerical CAPEX results for the chosen optimal options. In a further section (see section 7.2.3), we discuss the optimization solutions according to a per user bandwidth requirement.

Initially, we present the proportion of every main cost component in the total CAPEX. In this type of graph, the user component consists of all devices inside the user premises. The cabinet component related to all devices to be installed at the cabinet or distribution location. The Optical Distribution Network (ODN) component corresponds to all the fiber, cable installation, trenching, and civil works for deployment. Finally, the CO component will only include the network headend device to which the user devices are logically or physically connected (example: OLT).

For Case #1, Figure 41 shows a clear difference between VDSL with PtP feeder and all rest types of PONs. The main component for VDSL with PtP feeder is the cabinet devices, which includes DSLAM cards, chassis, racks, and the installation of a powered cabinet. Its ODN is composed by PtP feeders to each of the 7 cabinets in total. On the other hand, the main cost contribution for the diverse types of PONs is the ODN, which accounts for about 75% of the overall cost. Similar proportions are reported for PON in [69]. In all PON cases, the fiber reaches every user house.

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User devices take less than 27% for all the cases. The user devices in VDSL with PtP feeder have less percentage of cost because it installs a STB and RGW, while the PONs adds the ONU to those.

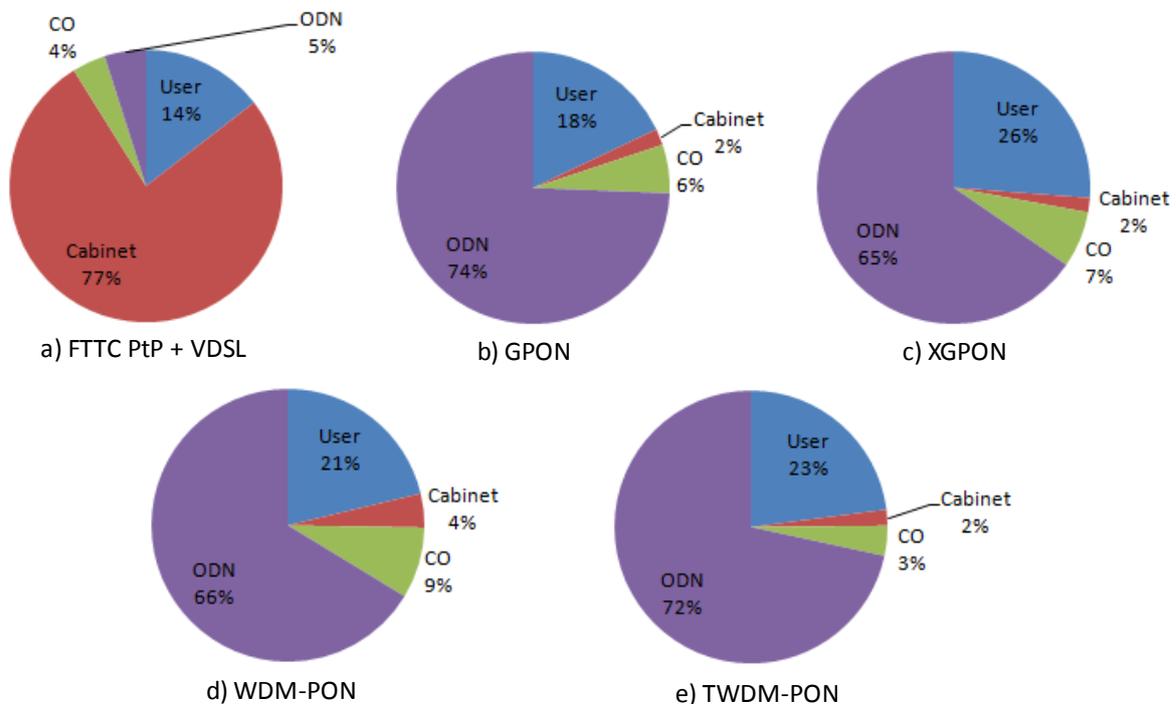


Figure 41: Cost components of every fixed network considered for Case #1.

For Case #2 with up to 64 buildings per cabinet, or Case #2 (a), we have a considerably larger number of users in the network (4132 users), compared to Case #1. The results for every network type are shown in Figure 42. The ODN in PONs will increase since the fiber must reach every house. In the case of VDSL with PtP feeder, the ODN is larger than in Case #1, because feeder fibers must be installed till every of the 76 cabinets present in the network.

Results for Case #2 with up to 500 buildings per cabinet, or case #2 (b), are shown in Figure 43. Similarly like in Case #2 (a), the fiber must be deployed till every building or house. However, now we have only 10 cabinets and up to 500 which multiply the total distribution fiber by a factor of 2.5. This is why the ODN cost component is very high. Also for VDSL with PtP feeder (see Figure 43.a), the component of feeder fiber has increased because the number of DSLAM cards per cabinets have increased and require a fiber for every GbE uplink port.

For both Case #2 (a) and (b), the cost component of the CO for VDSL with PtP feeder is almost 0%. This is because the only device accounted for the CO in this case is an ODF, which cost compared to the large investment in the rest of the network is not significant.

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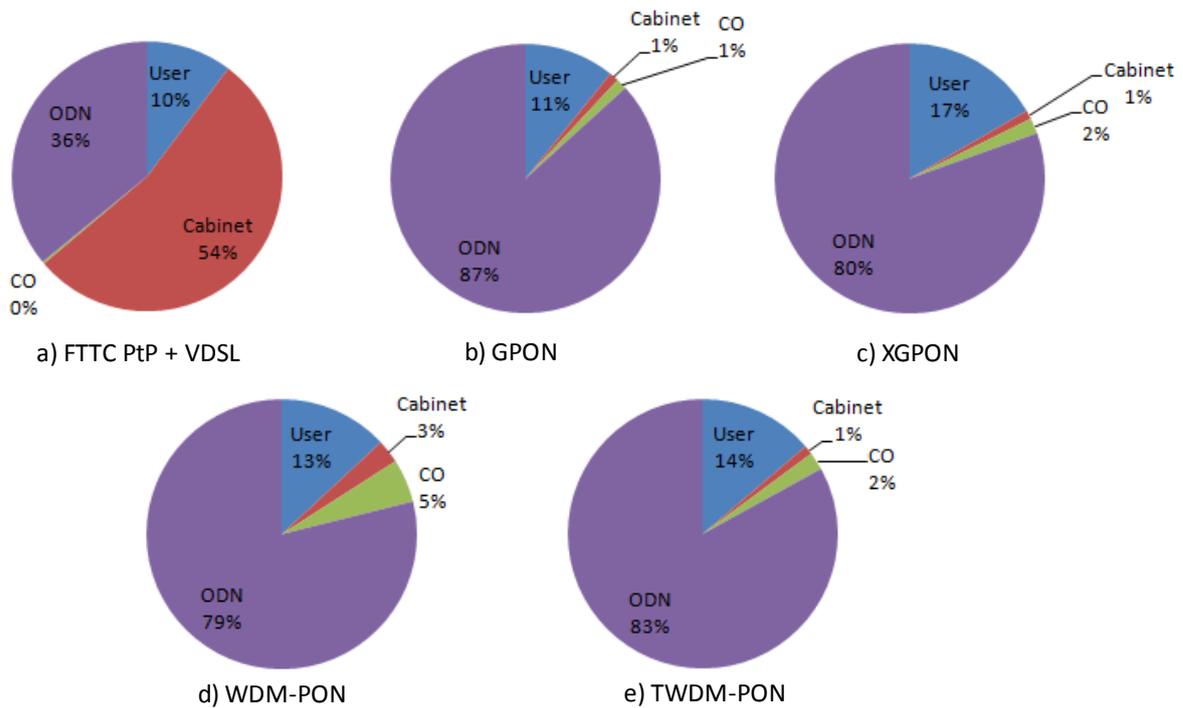


Figure 42: Cost components of every fixed network considered for Case #2 (a).

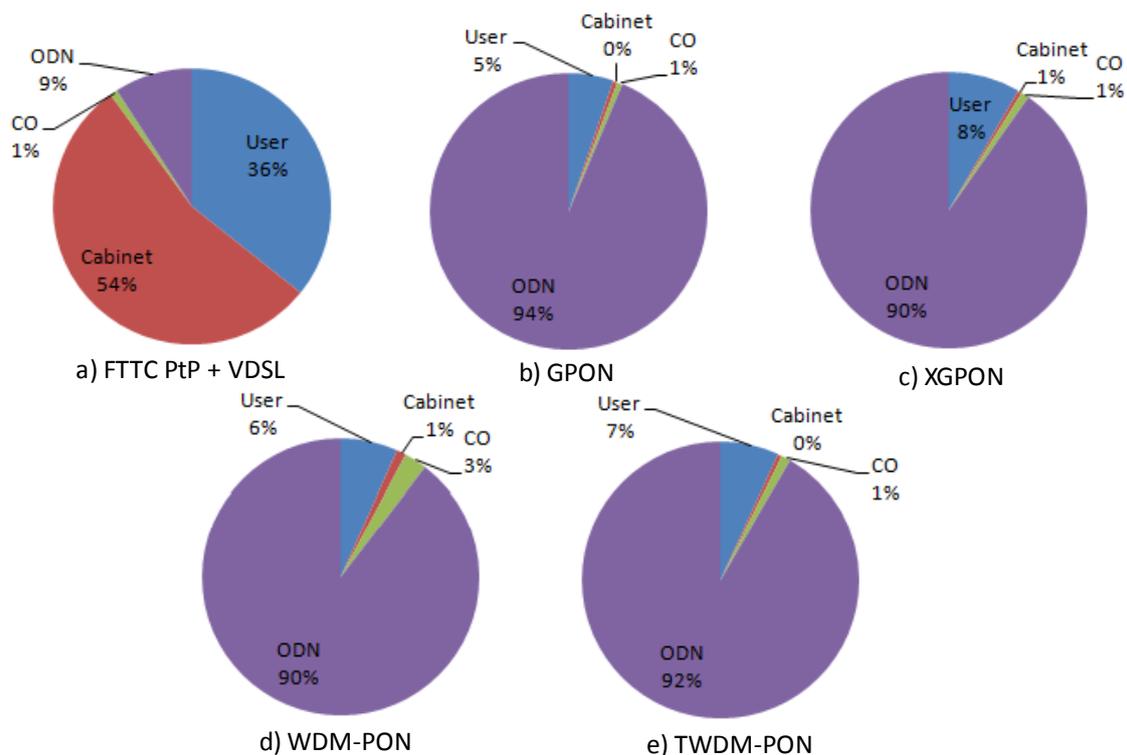


Figure 43: Cost components of every fixed network considered for Case #2 (b).

Finally, in Figure 44 we present the total CAPEX per user for every case and for every network type. It is possible to see that VDSL with PtP feeder is the cheapest solution. This is because the copper plant is considered as installed and available.

The best option to be chosen for every particular network case study will depend on the bandwidth demand of every user, and the contribution of other aspects such as power consumption. Power consumption and optimization solutions will be discussed in the following sections.

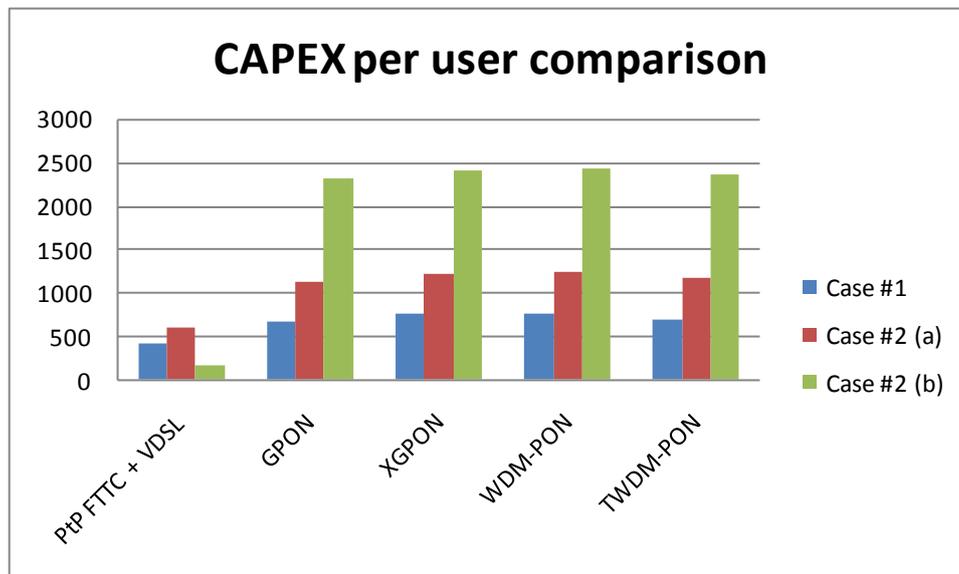


Figure 44: Comparison of CAPEX per user for five fixed network types, and for every case study.

7.2.3 Power consumption assessment

The power consumption assessment of microscopic case studies has been performed considering the same fixed network scenarios analysed in the cost assessment. First, we present the results on the total power consumption for each case study, showing the different power contributions deriving from devices in the User, Cabinet and CO segments of the access network (according to the definition given in the previous section). Note that the contribution of the Optical Distribution Network (ODN) portion is not present, as it has no impact on overall power consumption.

Figure 45, Figure 46 and Figure 47 show the power consumption for the Case #1 (City town with at most 64 buildings per cabinet), Case #2 (a) (Urban district with at most 64 buildings per cabinet), and Case #2 (b) (Urban district with at most 500 buildings per cabinet).

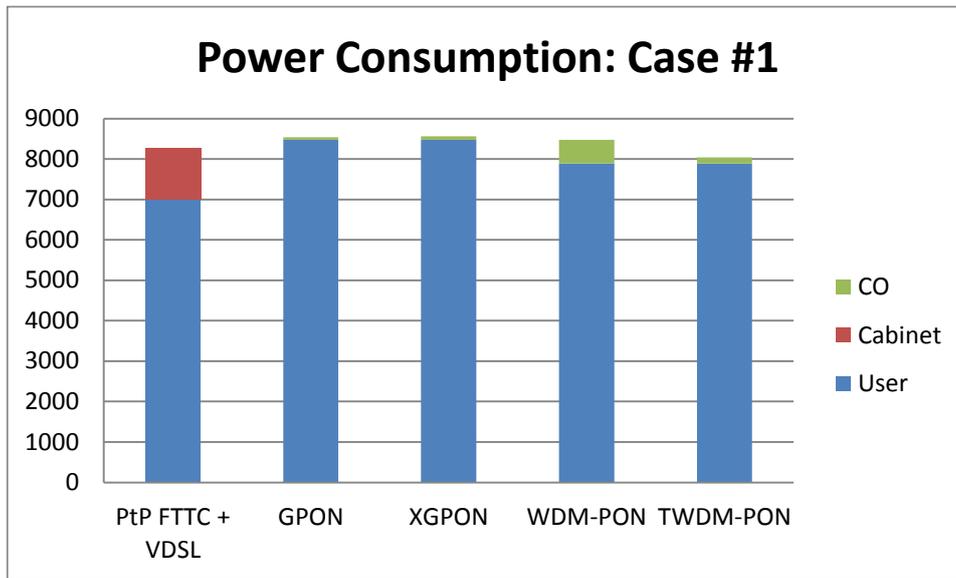


Figure 45: Power Consumption contributions for the microscopic Case Study #1 (City town with at most 64 buildings per cabinet)

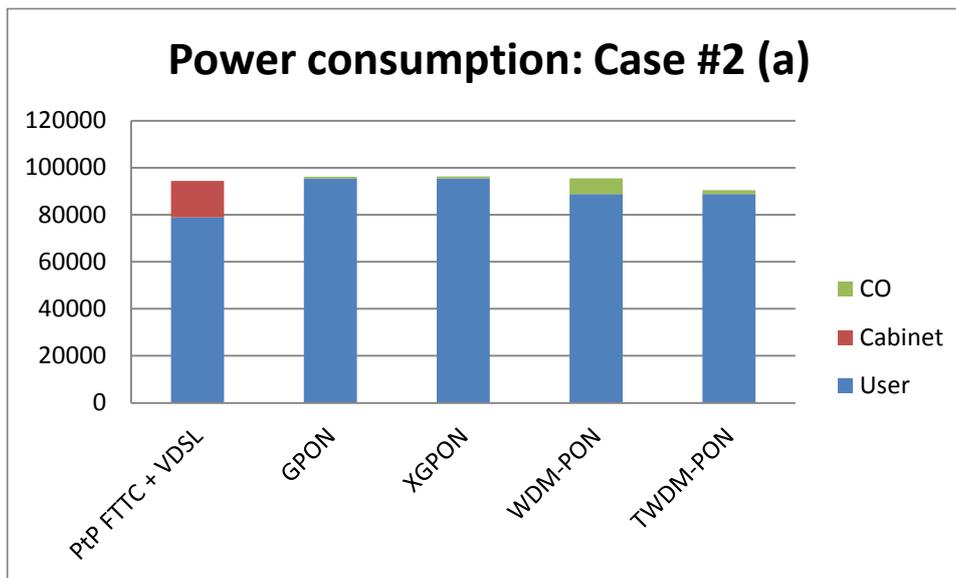


Figure 46: Power Consumption contributions for the microscopic Case Study #2 (a) (Urban district with at most 64 buildings per cabinet)

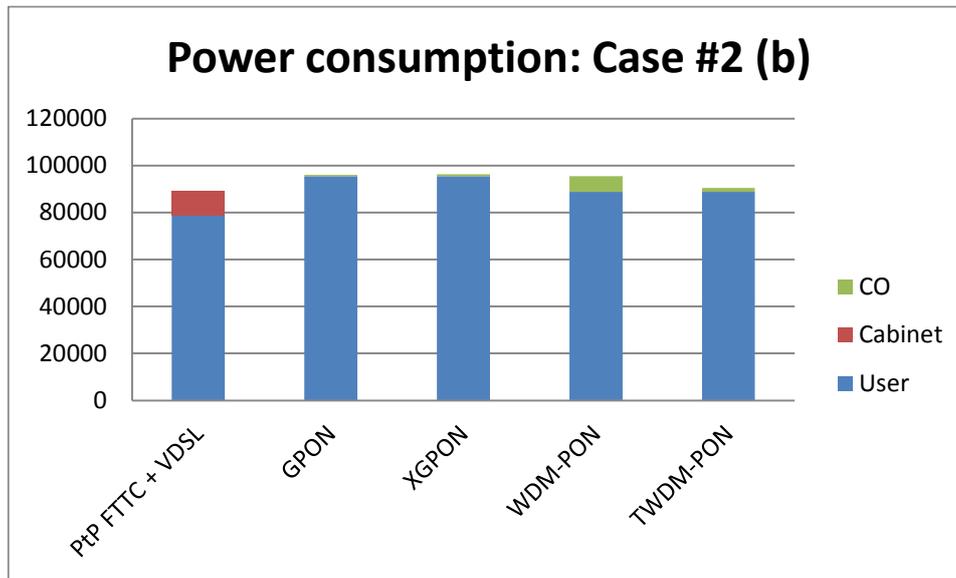


Figure 47: Power Consumption contributions for the microscopic Case Study #2 (b) (Urban district with at most 500 buildings per cabinet)

As a difference with respect to the CAPEX results analysed in the previous section, the relative power contributions of CO, Cabinet and User devices for each network scenario exhibit a very similar trends across the three case studies. Therefore, the considerations drawn below are applicable to all cases.

As already seen for macroscopic fixed access case studies, the User equipment strongly dominates the total consumption for all network scenarios. All-optical access solutions exhibit a slightly higher consumption of User devices, with respect to the VDSL case, because an ONU/ONT must be installed in each household. Also, within all-optical technologies, pure TDM approaches (i.e., GPON and XGPON) show a higher User power, due to the higher consumption of terminal equipment performing dynamic multiple access algorithms. The Cabinet contribution is present only for the VDSL scenario, since both the consumption of the DSLAM and the overhead for powering the cabinet must be taken into account. For all other scenarios, the cabinets are always passive (i.e., equipped with optical splitters or AWGs). Conversely in the VDSL scenario, the power contribution of the COs is zero, because COs are passive (i.e., equipped with an ODF). Instead, for all-optical networks, COs are equipped with OLTs, whose power consumption is shared among a medium (WDM-PON) to large (GPON/XGPON) number of customers. Therefore, the power contribution of CO equipment for the WDM-PON scenario is higher than for the other cases, even if very small with respect to dominant User equipment consumption.

In Figure 48 we show the power consumption per user, for each case study and network scenario.

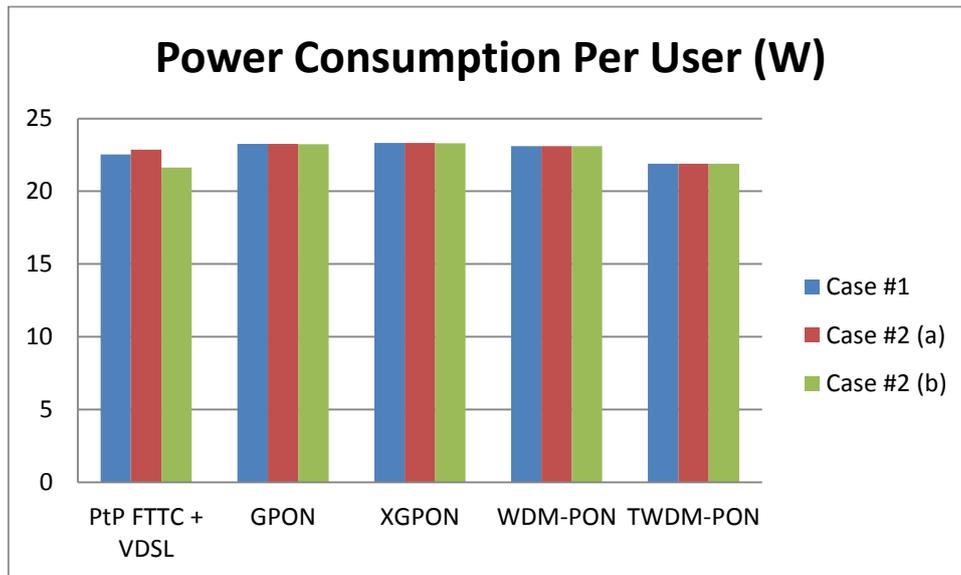


Figure 48: Power Consumption Per User, for all microscopic case studies

Differently from the corresponding comparison in term of CAPEX per user, here no significant power variations are observed, while we can confirm that for all the case studies the total consumption stays constant over different network scenarios. We also observe here that the deployed optimization tool appears to be scalable in response to large variations of the network size.

7.2.4 Optimization aspects

In this section we introduce one of the capabilities of the technology optimization tool. Besides the detailed results for cost and energy, we can obtain the optimal solutions. This section is to discuss the optimization results specific to the microscopic case studies.

Once the specific network topology is uploaded to the tool, it will perform the assessment under the two main constraints: (i) satisfying user bandwidth requests, and (ii) satisfying signal reach under specified distances. The topology, the distance among nodes, and the cable links have been specified as input. However, the per-user bandwidth requests were not part of the input information. Therefore, we run the tool by changing each time the bandwidth request of every user in steps of 50 Mb/s. For presentation simplicity, we have set a equal request for all users, in a range between 1 to 1000 Mb/s. However, it is important to mention that very different bandwidth request can be set for every single user in the network. Among the studied microscopic cases, the optimal technologies obtained for all the user bandwidth request variations, where the same. This is the reason why we present the results here in a unique graph for all microscopic cases in Figure 49.

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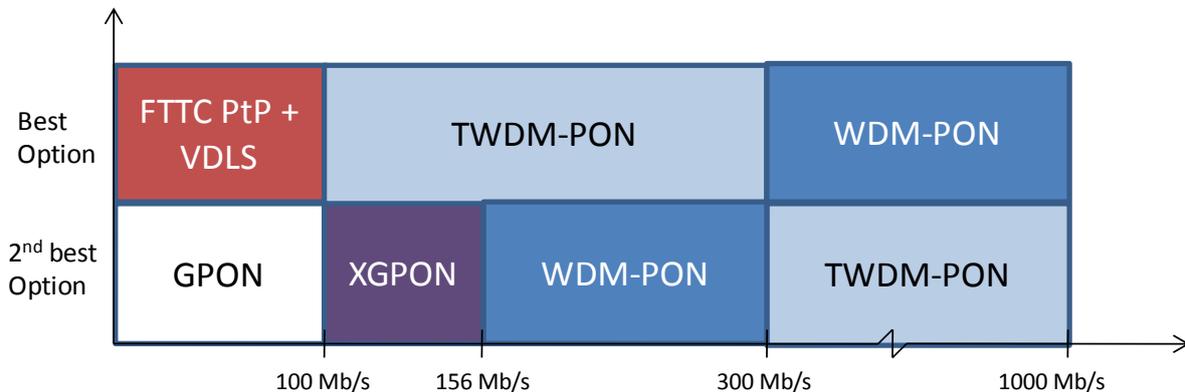


Figure 49: Optimal fixed network technologies for the microscopic case studies.

After evaluation, some technologies prevail as optimal from cost and energy viewpoints. In this way, Figure 49 presents the best options for certain bandwidth ranges. We also present the second best option for each case, for matters of results discussion. For lower bandwidth requests per user, the best option is VDSL with PtP feeder. Once the requests surpass the 100 Mb/s, VDSL is not anymore feasible to satisfy the bandwidth requests, for the given case studies. Over 100 Mb/s, a hybrid TWDM-PON becomes the most suitable solution, which compared to WDM-PON proves to be more energy efficient. This is because of the lower number of interfaces (for every wavelength). Finally, WDM-PON is the best option when the bandwidth requirements arrive around 300 Mb/s. The reason is that for TWDM-PON to respond to higher bandwidth request, it must increase the bitrate or add more wavelengths, and then it becomes slightly more expensive. As can be seen, cost and energy can be used together for the optimization decision. In the same way, other OPEX components besides energy consumption could also be added to the evaluation for the future work in this project.

The second best options are included because they may help in the decision of the best or more convenient migration path in case we want to study how the network evolved. This aspect will be highly valuable for the future FMC network architectures to be evaluated. The decision on the optimal solution should not be based on a unique evaluation, but a whole path in order to foresee best investment strategies. For example in Figure 49, it is not a good strategy to install WDM-PON, and then later TWDM-PON, as shown in the second best line of migration. One can see that XGPON may not be the ultimate solution for future high-bandwidth demanding technologies, since it limits the bandwidth request to 156 Mb/s.

This type of analysis will be important when we evaluate the techno-economic feasibility of the new FMC architectures, and show from CAPEX and OPEX point of view the best options under certain context, such as changing user bandwidth request.

7.3 Macroscopic vs. Microscopic case studies

In this section we intend to emphasize the objectives of having an analysis of two different types of case studies: Macroscopic and Microscopic. Moreover, we discuss the differences found in the results provided for both cases.

Macroscopic case studies are thought to have a generic large-scale scenario for evaluation of techno-economic aspects of different candidate architectures. On the other hand microscopic case studies are specific real examples of a geographical location, which required first a dimensioning to define its topological infrastructure, and then an optimization of the technologies used in order to obtain a well-suited economic assessment. Both case study types use diverse tools and assumptions. They will be helpful to fully analyse the candidate FMC architectures to be proposed during the second year of the project.

If we compare the results for macroscopic and microscopic case studies, we find that the major cost component in macroscopic cases is the endpoint equipment at the user premises, while in the microscopic cases the major component is the outside fiber plant. First of all we have to identify that the microscopic case #1 corresponds to a urban case, and microscopic case #2 corresponds to a dense urban case, given their household density. However, it is not likely to get the same results as in the macroscopic urban and dense urban cases, because of the very large total number of users in such cases. In general, the total fibre plant cost is distributed among the number of users. Moreover, in larger scenarios such as in macroscopic cases, the the fiber ducts, cables and trenching cost are shared and reused by many more users than in microscopic scenarios. On the other hand, the large cost component in user premises devices for macroscopic cases is due to the fact that this cost cannot be distributed among the total number of users. Therefore its component becomes very large compared to a microscopic case where the number of users is much lower.

With fixed and mobile convergence from structural and functional points of view, we expect to identify major cost components that shift from one architecture to another, allowing us to take optimal choices and perhaps decide on the most cost-effective FMC evolution strategy.

8 Business analysis methodology

Following to the general overview of the actual market situation of the different network types as well as the overview of the main market drivers for the development of converged networks provided in the deliverable D2.1 [68], this chapter will give a more detailed information on the business aspects.

In the previous chapters of this deliverable the state-of-the-art networks (1) and the assessment framework (3) had been defined (fixed, mobile, Wi-Fi and current FMC) and a cost analysis (4) was carried out. To complete the whole picture concerning the techno-economic studies of the assessment framework, an analysis of the business ecosystems of the different networks and related business models will be provided.

In subchapter 8.1 the theoretical framework will be introduced providing the basis for the analysis of the fixed ecosystem (8.2), the mobile ecosystem (8.3) and the Wi-Fi ecosystem (8.4). Finally the ecosystem of the state-of-the-art FMC networks will be analysed and the basis will be set for the analysis of the ecosystems of FMC scenarios (2014) and proposals (2015) (8.5).

8.1 Assessment framework

In this deliverable a first approach will be presented, that will be used for further evaluation during the project life time, enabling at the end of the project the answers to the research questions which are basis for the business modelling in COMBO:

- Is there any significant difference between business ecosystems for FMC networks and separate fixed/mobile networks?
- How to improve the existing business model by leveraging the changes in the ecosystem?
- Which could be the different paths in order to implement the changes?

As far as the field of business modelling is very broad and provides a vast number of different approaches and models (both from academic and from commercial side), in the first part of this chapter an initial explanation of the different terms of relevance in this field will be given:

- Business Ecosystem
- Business Model
- Value Creation (Value Chain)

as well as a definition of the actors relevant for the business ecosystem.

In the second part, the method for analysing the business ecosystem used in the COMBO project will be presented.

8.1.1 Terminology

To facilitate the flow of this chapter and at the same time to give essential basic information needed for the understanding of the concept presented, only a short

explanation of each term will be provided and additional background information can be found in the Annex.

8.1.1.1 Business Ecosystem

The term “business ecosystem” was introduced by Moore first in 1993 in an article in the Harvard Business Review [70] and further developed in a follow-up book in 1996, where he described the business ecosystem as “an economic community supported by a foundation of interacting organizations and individuals – the organisms of the business world”. The ecosystem includes customers, suppliers, competitors, and other stakeholders, who “coevolve their capabilities and roles and tend to align themselves with the directions set by one or more central companies” [71] (Figure 50):

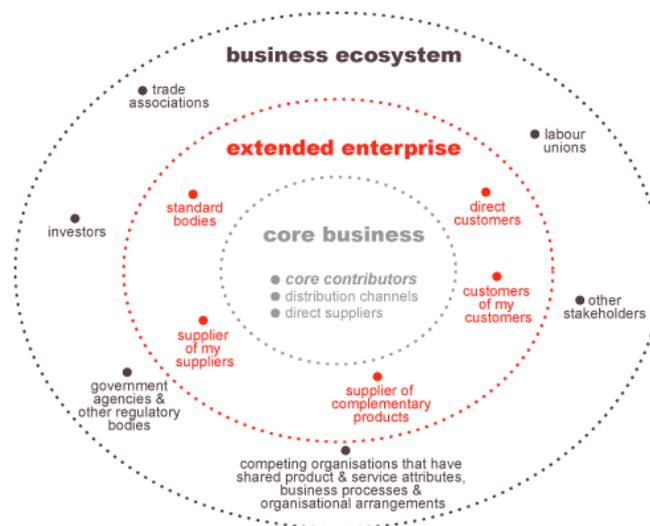


Figure 50: Business ecosystem (Moore 1996)

8.1.1.2 Business Model

A business model addresses the core questions on how the firm will find its competitive advantage and profits by creating and capturing value (see Teece 2010 [81]; Zott et al. [82]); means that, how it will provide benefits to customers that they value (value creation) and in exchange derive profit for the company itself (value capture).

Based on the approach introduced by Chesbrough and Rosenbloom (see 11.4.2) Osterwalder [86] developed a business model ontology, which is a conceptualization and formalization of the elements, relationships, vocabulary and semantics of a business model and which is structured into several levels of decomposition with increasing depth and complexity.

For practical purposes, it is necessary to divide the business model concept into simple elements that are familiar from real business. With this purpose in mind, Osterwalder [87], [88] created the Business Model Canvas that proposes nine elements that make up a business model (the basic idea is that the business model is created by designing and organizing these elements). Together these elements reveal the core logic of business by integrating them in a tool that resembles a

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painter’s canvas, and which allows the user to paint pictures of new or existing business models by defining the following elements and showing their interdependences and interrelations (see Figure 51):

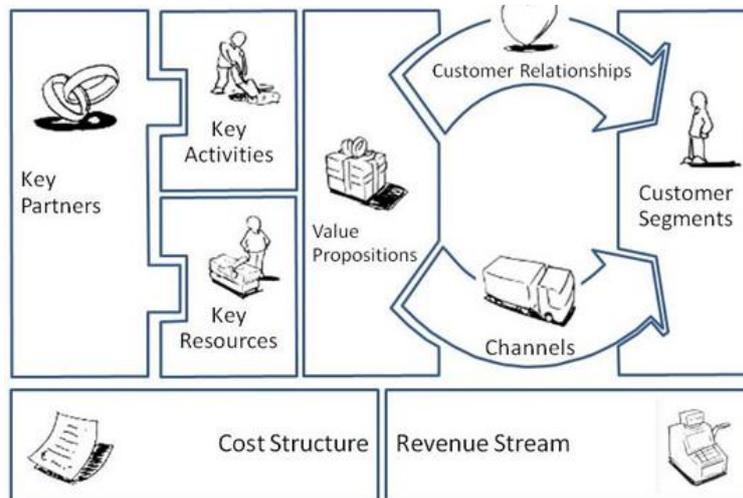


Figure 51: Business Model Canvas

For the evaluation of the business models for the different network areas (fixed, mobile and Wi-Fi) in COMBO an adapted version of the Business Model Canvas related to the telecommunications market will be used. This approach was presented at the International Conference on Mobile Business in 2010 [89] (see Figure 52):

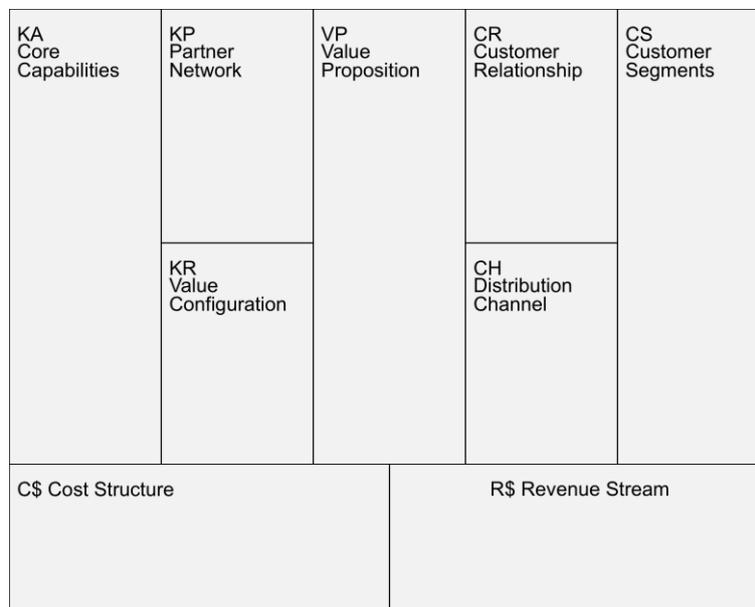


Figure 52: Business Model Canvas used in COMBO

In each network area (fixed, mobile, Wi-Fi) a canvas will be introduced to show the state-of-the-art business model.

8.1.1.3 Actors in the telecommunication market

A key element needed for the analysis of a business model as well as for business ecosystems are the actors involved. Based on market research as well as on meetings with partners following key actors in the telecommunication ecosystem were defined:

- Equipment Provider (End User equipment, Network equipment, IT equipment)
- Component Manufacturers
- IT Infrastructure providers
- Content Providers
- Application Providers
- Network Providers (fixed only, mobile only, Wi-Fi only, integrated)
- Service Providers:
 - Network operators: fixed only, mobile only, Wi-Fi only, integrated;
 - Mobile Virtual Network Operator
 - Internet service provider
- End users
- Public authorities (municipalities)
- Regulators (national, European)
- Roaming intermediary (Wi-Fi specific)

Table 18 shows the actors already assigned to the different ecosystems:

| Actors | Fixed | Mobile | Wi-Fi | FMC |
|--|-------|--------|-------|-----|
| End user equipment manufacturers | X | X | X | X |
| Network equipment manufacturers | X | X | X | X |
| Component manufacturers | X | X | X | X |
| IT equipment manufacturers | X | X | X | X |
| IT infrastructure operator | X | X | X | X |
| Content providers | X | X | X | X |
| Application providers | X | X | X | X |
| End users | X | X | X | X |
| Public authorities | X | X | X | X |
| Fixed only network provider (at access, regional and/or national levels) | X | X | X | X |
| Mobile only network provider | | X | | X |
| Wi-Fi only network provider | | | X | X |
| Integrated network provider | X | X | X | X |

| Actors | Fixed | Mobile | Wi-Fi | FMC |
|--|-------|--------|-------|-----|
| Fixed only network operator (service provider) | X | | | X |
| Mobile only network operator (service provider) | | X | | X |
| Wi-Fi only network operator (service provider) | | | X | X |
| Integrated network operator (service provider) | X | X | X | X |
| Mobile virtual network operator (service provider) | | X | | X |
| Roaming intermediary | | | X | |
| Internet service provider | X | X | X | X |

Table 18: Actors in the telecommunication market

During the further evaluation the focus will be put on the actors that will be directly affected by the architectural changes in the COMBO project.

8.1.1.4 Value chain

The term "value chain" was used by Michael Porter in his book "Competitive Advantage: Creating and sustaining superior Performance" (1985) [91]. The value chain analysis describes the activities the organization performs and links them to the organizations competitive position.

There are four main areas of support activities: procurement, technology development (including R&D), human resource management and infrastructure (systems for planning, finance, quality, information management, etc.) (see Figure 53):

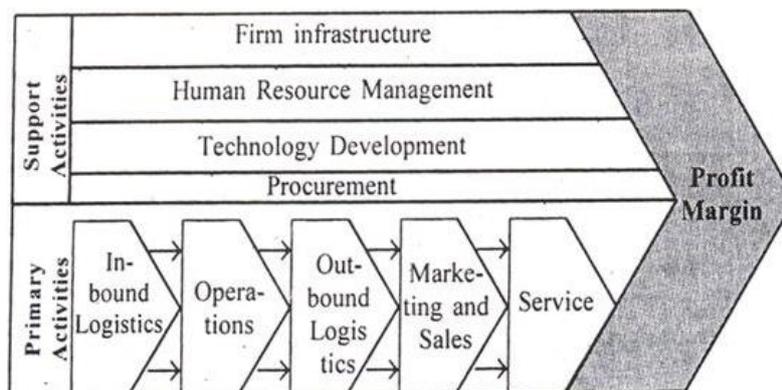


Figure 53: Structure of value chain (Porter)

"The value chain, however, may be too limited. Value creation opportunities in today's markets may result from new combinations of information, physical products and services, innovative configurations of transactions and the reconfiguration and integration of resources, capabilities, roles and relationships among suppliers, partners, and customers" [93].

This model, as mentioned before, contains several limitations (no capture of relationships, ignores environment, etc.) and therefore a need for amplification is evident to analyse value creation in a business ecosystem.

8.1.2 Solution Approach and Method for Business Modelling

As described in the previous chapter, the value chain is linear and the business model is firm centric; approaches that are not sufficient to analyse in depth the interconnected COMBO ecosystem. Value in an ecosystem is created over borders (in networks) and an additional method is needed to see the changes: the value network (see 8.1.2.1).

A specific approach has been selected to set the scene for further evaluation of business models and business ecosystems of the FMC network scenarios and use cases that will be investigated in the following years. It will help to make the comparison between state-of-the-art architectures and the ones developed in the project more transparent and coherent.

The methods were developed and chosen between partners during different meetings and finally agreed upon during a project meeting:

- a value network will be introduced that takes into account the whole ecosystem
- a network structure (matrix) matching the technological part (in vertical) as well as the actors (in horizontal) of an ecosystem was created (the core technical layers are aligned to the state-of-the-art architectures presented in WP2 and WP3) to show the “influence” of each actor about the relative part of the network. The technological part of the layer structure includes also the technical parts of the relative architectures facilitating here the reference to the cost analysis provided in the previous chapters.

8.1.2.1 Value Network

In literature as well as in business over the past 30 years different approaches had been created, trying to explain the interconnected business world in a fast changing competitive environment, focusing on the relationships in the ecosystems, as well as on the value creation within the ecosystem:

- Business ecosystem (was already introduced in 8.1.1.1)
- Value creating ecosystem: Value constellation/Value network

The latter ones were created to show that the linear concept of the value chain did not work anymore in the interconnected world and that Porter’s concept had to be extended (see 8.1.1.4).

Normann and Ramirez already identified the potential of networked value creation in a business ecosystem in 1993. They created the term “Value Constellation”, defining it as follows: “Companies create value when they make not only their offerings more intelligent but their customers (and suppliers) more intelligent as well. To do this, companies must continuously reassess and redesign their competencies and relationships in order to keep their value -- creating systems malleable, fresh, and

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responsive. In the new logic of value, this dialogue between competencies and customers explains the survival and success of some companies and the decline and failure of others” [95].

Based on their work as well as on the concept of the business ecosystem Peppard and Rylander developed in 2006 a further concept of value creation in business ecosystems, the Value Network: “A value network can be seen as any set of roles and interactions that generates a specific kind of business, economic, or social good. Products and services are not the result of linear chains of value adding instances, but the result of cooperation and competition as companies seek to create and capture value within their network” [94].

In order to guarantee fluent reading of this chapter, additional background information about value constellation/value network as well as differences between business ecosystem and value networks had been put into the annex (see 11.4.4).

For the COMBO project, an evolved version of the value network (value constellation), created by Wirtz [92], has been chosen to explain the ecosystem of COMBO, especially due to the fact that his approach includes the relation to the business ecosystem as well as to the business model by showing the relative interconnections.

Based on the previous explained concepts, Wirtz argues that the “idea of connecting value chains in a value system is not sufficient to explain network effects” as far as competitors from other industries are not sufficiently taken into account. Therefore the most important theoretical basis approaches of the value network are added value, network structure and systemic corporate understanding.

Furthermore, value created within the network is distributed according to the importance of the respective connection point. Critical factors for the distribution of value are:

- position in the network
- management of resources
- possession of basic resources (especially important for the operators in COMBO)

There is a strong relationship between the value network and the business model: “Thus, the business model concept is a further logical development of the pragmatic analysis of the value network. Furthermore, in opposition to the value network, the business model concept profits from being able to better focus on companies, business areas and product specification. In contrast, the value network approach has primarily an external view that is interaction-oriented and thus has a better coverage of competition and cooperative relations” [92].

Both approaches, value network and business model, are based on the same structural parameters and can therefore easily be combined, whereas the value network approach can be seen as the overarching approach that influences directly the structure of the relative business model. Value network and Business models are dynamic concepts, subject to interdependent changes. Means that the focus of a

company in a value network and the structure of the related business model are dependent on one another [92].

Therefore changes in the value network can require adaptations of the business model and vice versa. This interdependency is the basis for the analysis in COMBO, being able to make the comparison between state-of-the-art separated networks and the FMC network architecture being developed during the project.

8.1.2.2 Network structure

One of the targets of the COMBO project is to create a Fixed-Mobile converged network architecture, which means that changes in the value network as well as in the different business models will occur due to the technological changes in the network. For this reason, the partners in the project created (in relation to the value network) a network structure (matrix) that refers to the reference framework and network architectures introduced in WP2/3 and will be matched with the key actors of the ecosystem introduced in the previous chapter (8.1.1.3). By this, the actual position of the various actors can be related to the different parts of the architecture they are “encompassing” and so representing their position in the value network.

Figure 54 shows the matrix that will be used for further evaluation in the different networks (fixed, mobile and Wi-Fi); the layers in the vertical direction indicate the actors of the relative ecosystem and the layers in the horizontal direction reflect the main elements in the different network segments.

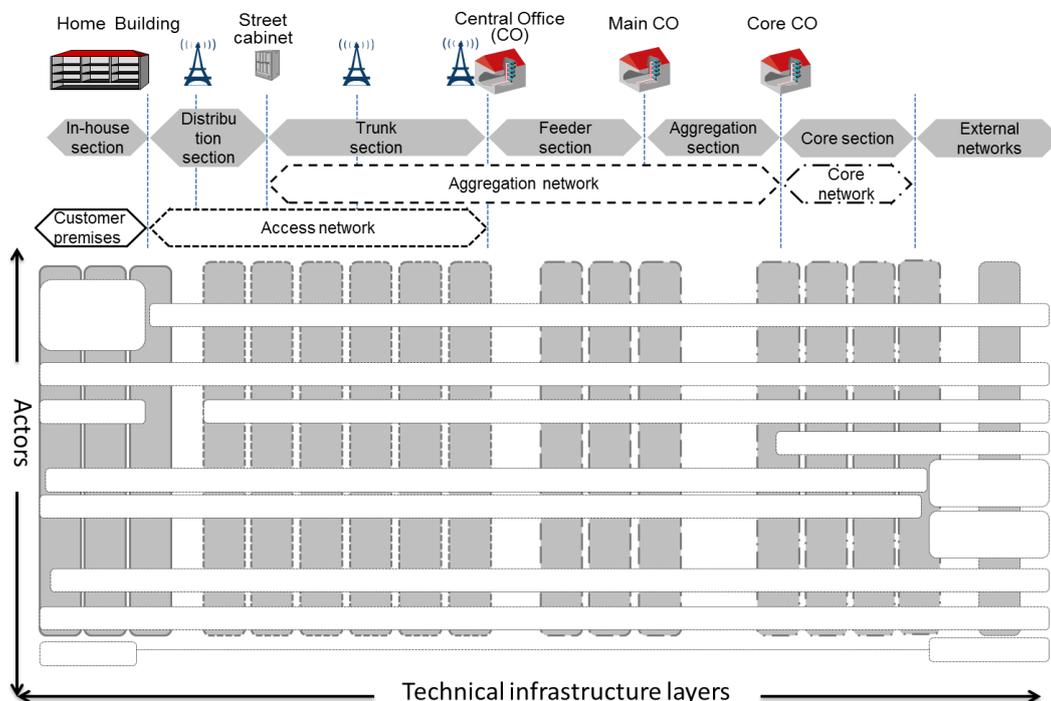


Figure 54: Network structure used in COMBO

This approach had also been chosen to be able to connect the network segments to the cost analysis of the assessment framework provided in chapter 4. Thus, the network segments (e.g. access network, aggregation network) were split into the

various components of the relative networks (fixed, mobile and Wi-Fi) to facilitate the reference to their related costs.

With this approach, the comparison between the state-of-the-art business ecosystems and the ecosystems that will come up with the use cases for FMC developed during the project and assessed later on will be facilitated.

To provide a better overview of the network structure in the following chapters (8.2.2, 8.3.2 and 8.4.2) and thus giving the possibility to capture all details, the network structure for each network (fixed, mobile and Wi-Fi) will be presented in two related figures, one showing the technical components of the different network segments and the other showing the position of the different actors of the system and their position in the various network segments.

8.2 Fixed business ecosystem analysis

8.2.1 Overview of the general environment and actual trends

According to “Broadband Markets” report by European Commission in 2013 [96], there were 144.8 million fixed broadband lines in the EU, which corresponds to 28.8 lines per 100 inhabitants as of January 2013. The report highlights that the fixed broadband market grew by 5.5 million lines in 2012 although the annual growth has been continuously slowing down since 2007. In addition to this, the report sees a potential for further growth in the market, as 24% of EU homes do not have an Internet subscription.

Regarding the broadband technologies used in fixed ecosystem, DSL continues to be the predominant technology in the EU broadband market despite the decrease of its share from 80.9% of all fixed broadband lines in January 2006 to 73.8% in January 2013. In terms of NGA technologies (capable of download more than 30 Mb/s), cable, VDSL, FTTB and FTTH technologies are the most used in the EU countries, with a percentage of 57.4%, 14.9%, 16.2%, 9.5% respectively. 14.8% of European fixed broadband lines provide a headline download speed of at least 30 Mb/s up from 9% a year ago, mainly thanks to the expansion of these NGA technologies.

The progress is more significant when considering lower speed brackets. Five years ago only 9% of fixed broadband lines in the EU region provided at least 10 Mbps, in January 2013 it was 59%. Furthermore, currently only 3.9% of lines are below 2 Mbps as opposed to 35.6% in January 2008.

Globally, the situation is similar, according to data published by Organization for Economic Co-operation and Development (OECD) from December 2012 [97], 53% of global broadband users are using DSL technologies (175 million subscribers of 321 fixed subscribers; 4,4 points less than in 2010). The main reasons for that are two: first, the huge installed base of copper twisted pairs in the telephone loop infrastructure and second, the relative lower cost and complexity against other technologies. The following Figure 55 shows the global fixed broadband subscriptions in December 2012 and in June 2010.

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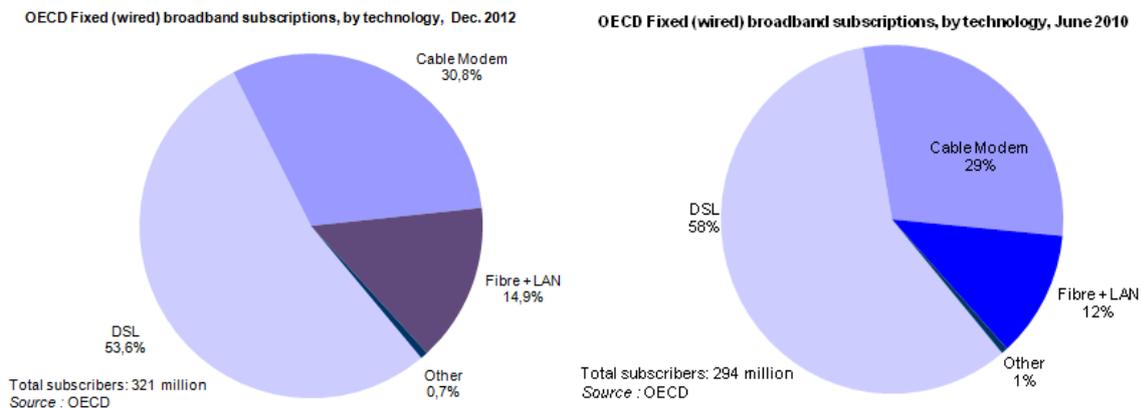


Figure 55 Global fixed (wired) broadband subscriptions

DSL technologies subscriptions continues to decline with a growing number of fibre subscriptions at 16.61% year on year between 2009 and 2011; however there is still a big dependence on DSL technologies that will continue during the next years.

Depending on the country, different alternatives have been chosen in order to boost access speeds offered to clients. These alternatives are chosen with respect to the legacy fixed network and services that are most demanded in each case. In 2011, the average advertised speeds in Mb/s per user were (downlink/ uplink): 15/2, 42/3 and 96/52 for DSL, cable and FTTH technologies [98], with an increasing speed motivated mainly due to the competition.

Five largest fixed broadband markets are United States, Japan, Germany, France and the U.K. (with a share of 32%, 12%, 10%, 8% and 8% respectively) [99].

The global number of broadband subscribers will grow up to 3.6 billion people by the end of 2015 according to OVUM, and OECD estimates that in the next decade billions of devices will connect to internet.

Fixed networks are the backhaul for mobile base stations, where a great percentage of the data used in smartphones is received via Wi-Fi connections using fixed networks. This trend will continue in the future as mobile networks will need to be complemented by fixed connections in order to deal with the expected mobile data traffic evolution (Cisco Systems forecast that overall mobile data traffic will grow at a CAGR of 66% from 2012 to 2017 [100]).

Prices for fixed residential voice services decreased between 5% and 20% from 2010 to 2012, however business prices remained stable according to OECD [101]. Additionally, in the same period, fixed broadband prices increased by 6.76% per year for DSL and 2.48 for cable accompanied by a speed increase. Fixed services are offered typically in a bundle including fixed telephony, Internet access, and television services. From 2011 some new offers have been launched combining fixed and mobile services inside a single offer, and this kind of offers may become more widespread in the future.

In the next years, the number of both fixed and mobile broadband subscriptions will continue to rise, and many people will have access to broadband through both of them (OVUM estimates approximately 1.4 billion people subscribers in 2015). Dual

access subscribers will need specific service bundles with special tariffs in which FMC networks are key to support advanced FMC services and bundles.

Other benefits for the FMC from the fixed network point of view are:

- Currently legacy operators with a fixed broadband network deployed based on copper are upgrading their networks with fibre technologies to offer higher bitrates in order to be competitive. Deploying fibre in the access network is expensive if only fixed customers are considered; however, the business plans could be more cost-effective if the same network can be used to provide connectivity to macro or small cells for mobile services.
- The actual competition in fixed broadband services are pushing operator to reduce prices and offer higher speeds. In that environment, FMC networks can help to reduce the churn rate offering a better level of integration between the fixed and mobile services, improving the quality of experience and keeping the customer loyalty.
- An efficient utilization of access, aggregation and core networks that could carry different types of services using the same communication resources. A single network will bring savings in terms of CAPEX and OPEX savings.
- Re-use of fixed lines reserved for mobile communications that could be re-used for other purposes.

8.2.2 Business analysis

The European telecommunication sector has been challenged on its business structure by many factors, namely the shift in revenue stream sources, the ever-increasing service expectations and the variety of user expectations. Fixed network operators face with this kind of challenges as well. The increasing traffic, mainly driven by video traffic, leads to falling revenues for the fixed network operators as far as they currently cannot monetize this traffic due to regulatory as well as competitive reasons. In addition to this, the ever-increasing traffic volume also adds pressure for fixed operators, which demands network enhancements and more complex service maintenance. The introduction of new dual and even triple-play bundles advertising low cost broadband has started making the market tougher for the fixed operators.

These conditions are also reflected in the following table, which is included in ITU's 2012 Broadband Report [104]. As seen in the table below, the fixed operators are the main entities that are investing the most of the network costs and their payback period is the largest. On the other hand, content aggregators and online service providers that are working in service layer invest less than fixed operators and their payback period is shorter. Hence, the business models need to be re-evaluated in order to make it possible that the "dumb pipe operators" live in the market.

The following Table 19 shows the relations between costs and payback period for the different layers.

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| | Order of Costs | Payback Period | Examples |
|-----------------------------|-------------------------|-------------------------|------------------------------------|
| Passive Layer | 70-80% of network costs | 15 years | Trenches, ducts, dark fibre |
| Active Infrastructure Layer | 20-30% of network costs | 5-7 year rate of return | Electronic equipment, OSS, BSS |
| Service Layer | N/A | Few months - 3 years | Content, services and applications |

Table 19: Investment in different network layers

After this general overview of the actual business situation in the fixed network sector a detailed analysis of the business model of a fixed network operator had been conducted using the business model canvas (8.1.1.2) (see Figure 56).

| | | | | |
|---|--|---|---|--|
| KA Core Capabilities <ul style="list-style-type: none"> •Deploy, operate administrate and maintain (OAM) a network (only fixed) to carry fixed services •Provide end user equipment to use fixed services (modem, router, Wi-Fi APs, ...) •Provide value added services (antivirus, parental control, video broadcast, VoD, etc.) •Bill customers for the usage | KP Partner Network <ul style="list-style-type: none"> •Fixed end user equipment manufacturers •Fixed network equipment manufacturers (DSLAM, OLT, cabinets, core switches & routers...) •ICT equipment manufacturers (to build own services or enhance current services, e.g. Caching, CDN) •Third party fixed content providers (applications, video,...) •Service providers (third party services providers that offer services directly over the top or through the FNO, that is under the FNO brand) •Other FNOs (which use the FNO's network for unbundling or to make roaming agreements) •National/European regulators | VP Value Propositions <ul style="list-style-type: none"> •Fixed network (coverage, capacity) •Fixed services •Bundling of fixed services (with different services, even combined with mobile services) •Customer care | CR Customer Relationships <ul style="list-style-type: none"> • Bundling of different commercial offers (services included, capacity limits, speeds, tariffs, even combined with mobile services) • Business call centre • Technical call centre • Marketing | CS Customer Segment <ul style="list-style-type: none"> •Mass end users segment •Business segment (SME and large companies) •Government segment •Wholesale connectivity (for unbundling) |
| | KR Value Configuration <ul style="list-style-type: none"> •Brand management •Network management •Billing management •Fixed equipment distribution •Service management | | CH Distribution Channels <ul style="list-style-type: none"> •FNO's shops •On-line sites: FNO's telephone, web sites, social sites such as facebook, twitter, ... • External channels (e.g spotify channels) | |
| C\$ Cost Structure <ul style="list-style-type: none"> • Capex: network infrastructure, CO and cabinet building, fixed terminal subsidies, marketing, ... • Opex: site maintenance and renting, electricity, customer care, personnel expenses, logistics, delivery | | R\$ Revenue Streams <ul style="list-style-type: none"> •Voice calls •Internet access •Business services (VPN,point to point links, ...) •Wholesale connectivity •Video / TV services •Value added services (antivirus, parental control, video, etc.) | | |

Figure 56: Business Model Canvas of Fixed Network Operator

To complete the detailed business analysis of the fixed network operator, a network structure (matrix) has been developed showing the positions of the various actors on the different network segments, divided into two figures (see Figure 57 and Figure 58) as already explained before.

Assessment Framework and evaluation of state of the art technologies

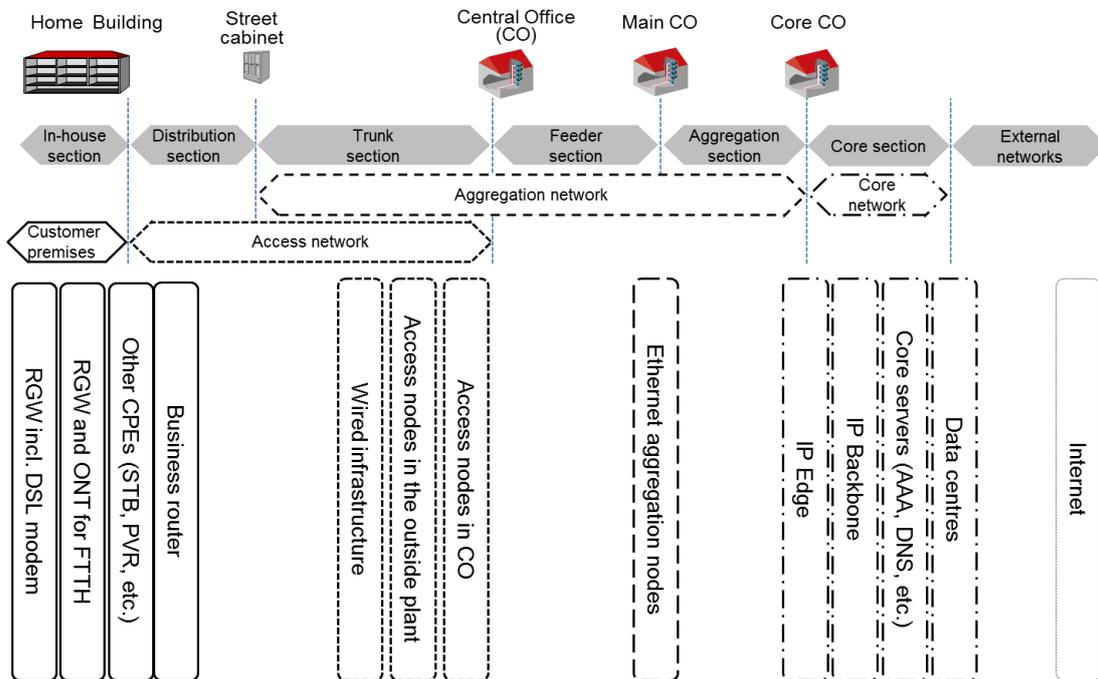


Figure 57: Network segments Fixed architecture

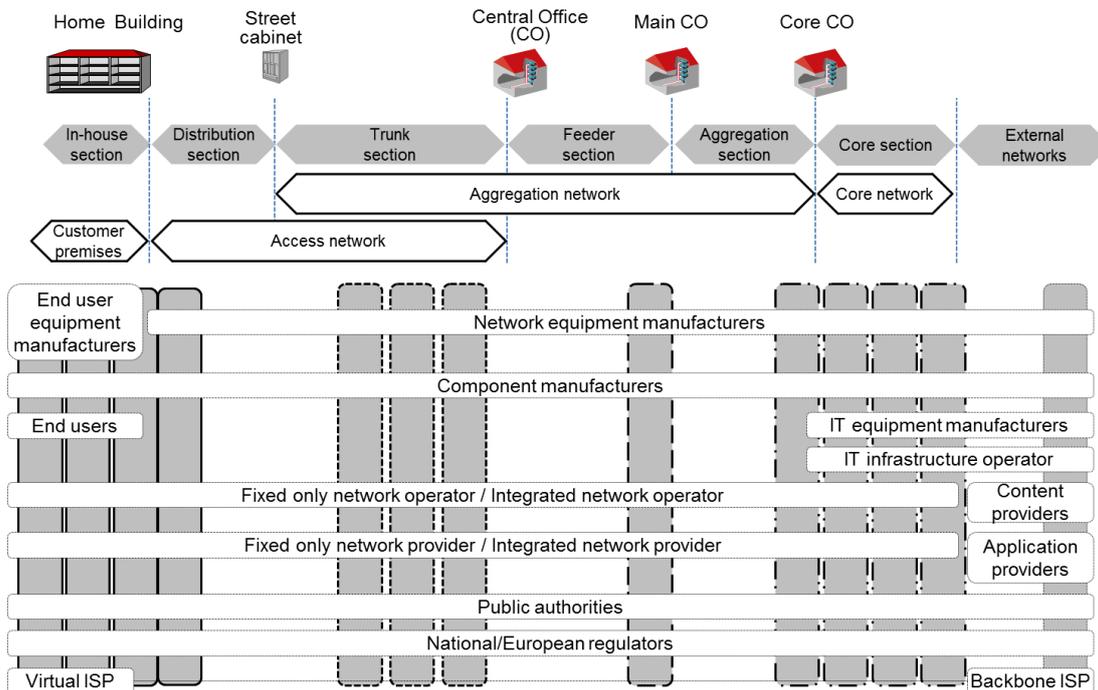


Figure 58: Network structure for Fixed

The figure indicated above captures the influence that each actor has over explicit parts of the network, by this defining his position of value distribution in the value network (“possession of basic resources” – see 8.1.2.1).

8.3 Mobile business ecosystem analysis

8.3.1 Overview of the general environment and actual trends

Latest estimations from the OECD [102] show that the 84.8 percent of wireless broadband users are standard mobile users, which have increased almost a 25 percent in one year (699 million of total subscribers in December 2012 considering only the first 34 countries with more subscriptions). Standard mobile users include those who have data speeds of 256 Kbps or higher and which have been used to make an Internet data connection via IP in the previous three months. In the other hand, almost a 15% corresponds to dedicated data subscriptions which are purchased separately from voice services either as a stand-alone service (modem/dongle) or as an add-on data package to voice services which require an additional subscription. As can be seen in Figure 59, the number of standard mobile subscriptions integrated with data subscriptions is rising whereas the number of dedicated subscriptions used only for data connections is decreasing in the same period (December 2011 to December 2012) [97].

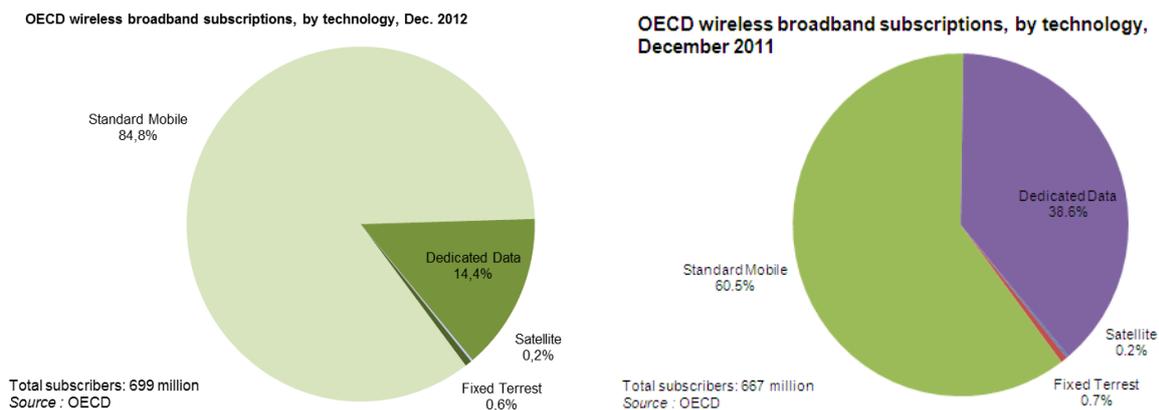


Figure 59: Global wireless broadband subscriptions

Wireless broadband subscriptions increase every year more than a 13% and reached a penetration of 62.75 lines per 100 inhabitants in December 2012 in OECD countries [97]. Compared with fixed networks, wireless subscriptions have grown much more, partly due to the service popularity, the quick deployment of mobile networks and the market competition. Looking the situation in each country, only Finland (106.5%), Sweden (104.8%), Australia (103.4%) and Korea (103.0%) have more mobile broadband subscriptions than inhabitants and there are other 19 countries with more than 50 subscriptions per 100 inhabitants [102]. The five largest wireless broadband markets are United States, Japan, Korea, the U.K. and France (with a share of 38%, 15%, 7%, 6% and 5% respectively) [99].

Considering the current global mobile broadband market in the first period of 2013, there are more than 1.7 billion of subscriptions according to the last Ericsson Mobility Report [107]. The number of global mobile broadband subscriptions is expected to rise up to 9 billion by 2018 (see Figure 60), mainly due to the development of 3G and LTE services, although a significant reduction in the number of 2G subscriptions is also expected.

Assessment Framework and evaluation of state of the art technologies

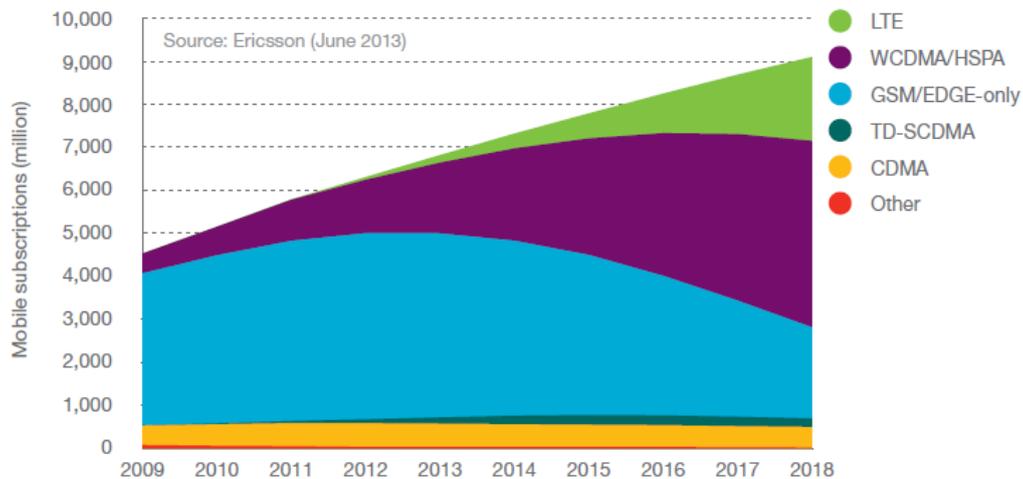


Figure 60: Mobile subscriptions by technology, 2009-2018

Comparing the traffic generated by voice and data services, data traffic growth between Q4 2012 and Q1 2013 was 19 percent, meanwhile voice traffic growth in the last year (2012-2013) was 4 percent. In the Q1 of 2013 the total monthly traffic was around 1,500 petabytes, and it is expected that this traffic grow 12 times by 2018 [107].

Mobile networks will need to make adaptations to tackle these increases in the number of broadband subscriptions and data traffic. An FMC network approach can provide some benefits from the mobile network point of view, for example:

- Currently telecom operators are upgrading their networks to increase the 3G capacities or 4G coverage. Macro base stations will need to use high capacity links in order to provide hundreds or thousands of gigabits per second to their customers and fixed networks can provide that high capacity.
- Many telecom operators are currently deploying or are going to deploy small cells in the coming years (AT&T announced that it will deploy 40,000 units by 2015, while Vodafone UK and Verizon are expected to start deploying in 2013 [108]) and as of February 2013, there are 46 commercial services and a total of 60 deployment commitments [108]. Small cells have lower bitrate requirements than macro base stations; however, the number of small cells deployed will be higher. In that scenario, fixed access networks based on fibre, copper or microwaves can be used to provide the connectivity needed with the mobile core in a more cost-effective way than using dedicated links.
- As it is planned that small cells will incorporate Wi-Fi in the next years [108], a single FMC network could provide a seamless integration of Wi-Fi and mobile services more efficiently than independent mobile and Wi-Fi solutions.
- Mobile data traffic can be offloaded onto the fixed network through Wi-Fi or femtocell devices. An FMC approach can provide enough bandwidth for mobile broadband users with a lower cost for the operators.

8.3.2 Business analysis

Since wireless spectrum resources are limited and more precious than cables or fibre in the ground, mobile operators have to manage the cost of each bit transmitted versus the revenue gained. In the initial period of the mobile communications era, there were only two players: device manufacturers and mobile network operators. Mobile communication was confined only to voice call services. Mobile network operators delivered the text message service. Due to the poor infrastructure of mobile broadband networks and the lack of technology in mobile devices, only these two players remained in the market for a decade.

Traditional mobile network operation strategy is characterized by a high degree of vertical integration where the MNO acquires and develops the sites needed for rolling out the network, plans the network architecture and topology, operates and maintains the network and customer relationships, creates, markets and provides services to its end users. However, technology migration, such as the introduction of third generation (3G) and 3.5G wireless technologies on top of 2G networks, and the introduction of 4G technologies including LTE, is becoming increasingly rapid and complex. Regulatory requirements also mandate coverage of areas that is not attractive from a business perspective. With growing competitive intensity and rapid price declines, mobile operators are facing increased margin pressure and the need to systematically improve their cost position.

Smartphones, such as Blackberry of RIM and iPhone of Apple, spearheaded the expansion of the mobile communication sectors from 2000 onward. Because smartphones allow Wi-Fi use, Internet service providers moved from wire communications to wireless communications. The Mobile Web is a result of Internet service providers entering the mobile communications network. In a major change of business model, the mobile communications sector developed open platforms and markets, such as iOS and App Store of Apple. This new model has led to a rapid increase in the number of application software developers. These applications create content and help media service providers promote their business. Games, utilities, and media services are being developed as application software used in smartphones. Thus, the platform plays a crucial role in interactions between device manufacturers, mobile network operators, and application developers. In addition, the open market provides the place where developers sell their application services. Finally, interactions between traditional and new players increase the size and complexity of the mobile communication sectors transforming them into mobile ecosystems.

The mobile industry has been complex and its structure and value chain are evolving with change of actors. Some actors lost their own dominant position in value network like MNO, while some play a critical role in interacting with other actors like platform and smartphone device manufacturers. In this respect, the concept of mobile ecosystem is emerging to embrace this complex structure and relationship of major actors and their structure exchanged roles over time

To be successful in the telecom markets of the future, operators will have to create new business models that offer customers attractive bundles of integrated services. Indeed, the trend toward the convergence of fixed and mobile telecom assets is

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already well under way in many markets. Virtually every incumbent operator has launched simple fixed and mobile bundles to shore up its market share and to prevent the loss of revenue to challengers.

Many mobile operators have already embarked on FMC strategies. Now they must speed the implementation and broaden the scope of these activities to head off the risk of value destruction as other players make their own aggressive moves in this space. The telecom market will be more integrated in the future than it is today; those mobile operators willing to embrace integration and leverage their strong tradition of innovation and market creation to sculpt new business models can maintain their market-leading positions.

Following the general overview of the actual market situation of the mobile network operator a detailed analysis of the business model had been conducted using the business model canvas (8.1.1.2) (see Figure 61).

| | | | | |
|--|---|--|---|---|
| KA Core Capabilities <ul style="list-style-type: none"> •Deploy, operate administrate and maintain (OAM) a network (both, the mobile and fixed segments) to carry mobile services •Provide end user equipment to use mobile services (handsets, dongles,...) •Provide value added services (antivirus, localization, content distribution, payment, multiSIM, etc.) •Provide roaming services when the user is outside the MNO own network •Bill customers for the usage | KP Partner Network <ul style="list-style-type: none"> •Mobile end user equipment manufacturers •Mobile network equipment manufacturers (base stations, mobile core network equipment,...) •ICT equipment manufacturers (to build own services or enhance current services, e.g. Caching) •Third party mobile content providers (applications, video,...) •Service providers (third party services providers that offer services directly or through the MNO) •MVNOs (which use the MNO's network) •Other MNOs (which share some part of the networks, e.g.: sites or to make roaming agreements) •National/European regulators | VP Value Propositions <ul style="list-style-type: none"> •Mobile network (coverage, capacity) •Mobile services •Bundling of mobile services (prepaid, post-paid alternatives, even combined with fixed services) •Customer care | CR Customer Relationships <ul style="list-style-type: none"> • Bundling of different commercial offers (services included, capacity limits, speeds, tariffs, even combined with fixed services) • Business call centre •Technical call centre •Marketing | CS Customer Segment <ul style="list-style-type: none"> •Mass end users segment •Business segment (SME and large companies) •Government segment •Wholesale connectivity (e.g.: for MVNOs) |
| KR Value Configuration <ul style="list-style-type: none"> •Brand management •Network management •Billing management •Mobile equipment distribution •Service management | | CH Distribution Channels <ul style="list-style-type: none"> •MNO's shops •On-line sites: MNO's telephone, web sites, social sites such as facebook, twitter, ... • External channels (Apple's App store, google play, ...) | | |
| C\$ Cost Structure <ul style="list-style-type: none"> • Capex: network infrastructure, site building, spectrum licenses, handset subsidies, marketing, ... • Opex: site maintenance and renting, electricity, backhaul lease, customer care, personnel expenses, logistics, delivery | | R\$ Revenue Streams <ul style="list-style-type: none"> •Voice calls •Internet access •Business services (VPN, ...) •Wholesale connectivity •Video / TV services •Value added services | | |

Figure 61: Business Model Canvas of Mobile Network Operator

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Completing the detailed business analysis of the mobile network operator, a network structure (matrix) has been developed showing the positions of the various actors on the different network segments, divided into two figures (see Figure 62 and Figure 63) as already explained before.

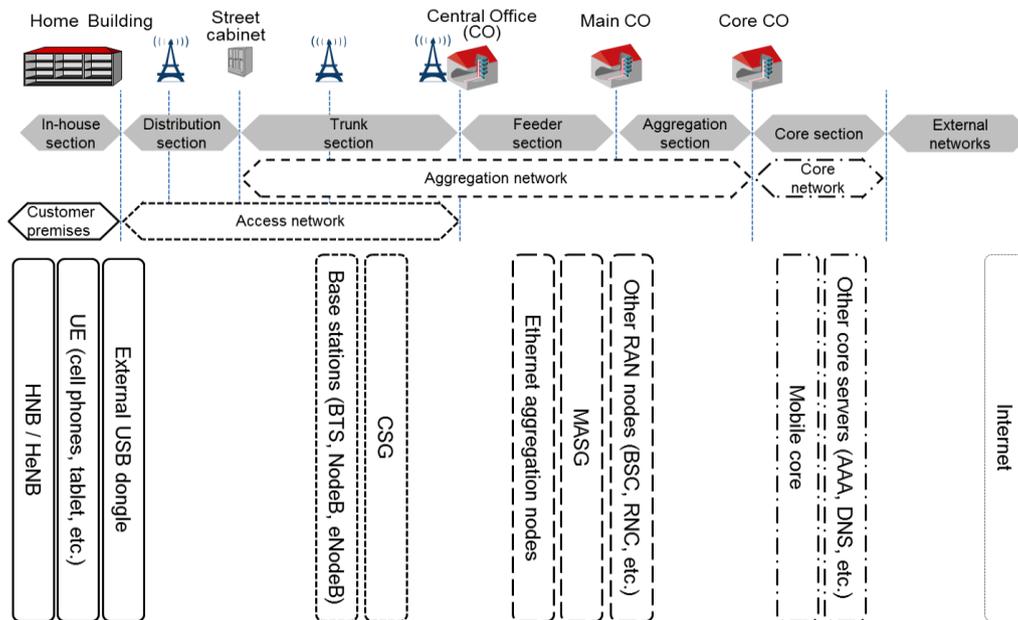


Figure 62: Network segments Mobile architecture

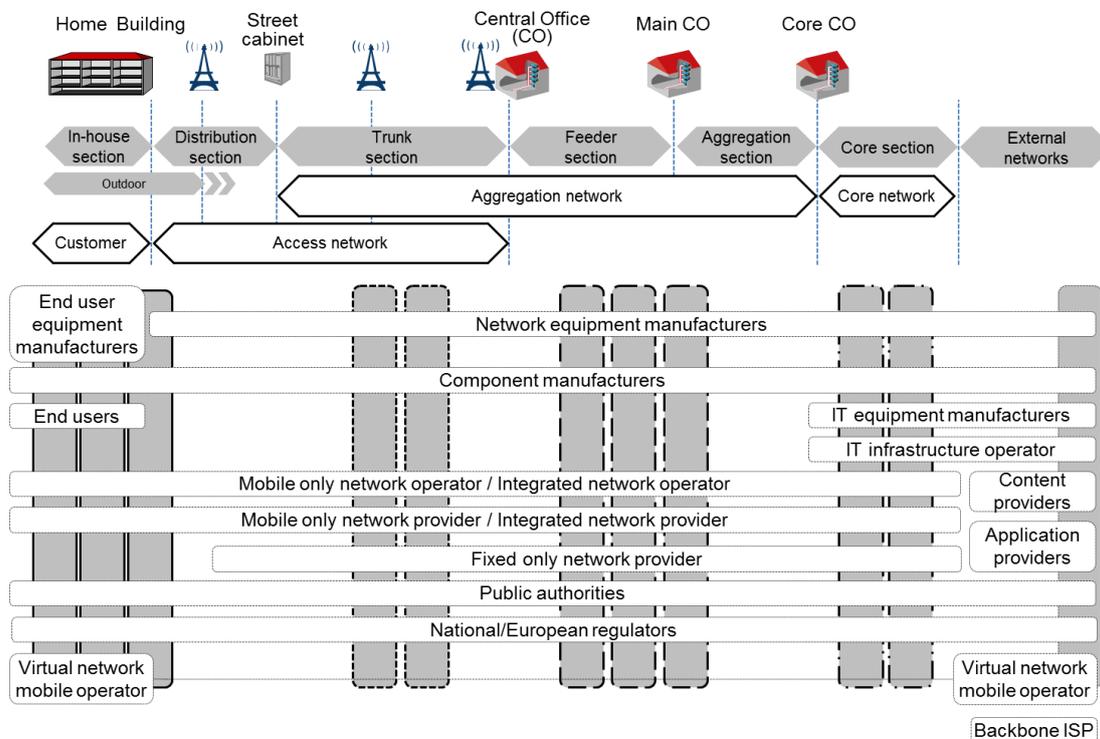


Figure 63: Network structure for Mobile

Figure 63 shows the influence an actor has on a particular part of the network, empowering his position in the distribution of value (see 8.1.2.1).

8.4 Wi-Fi business ecosystem analysis

8.4.1 Overview of the general environment and actual trends

Today, in every continent, one in ten people around the world use Wi-Fi at home or at work in countless ways. Almost half of all households in the world are predicted to have Wi-Fi by 2016, or 83 percent of all broadband households [105]. The Wireless Broadband Alliance predicts that the number of public Wi-Fi hotspots globally will grow more than fourfold, to 5.8 million, by 2015 [106]. This growth is inspired by a plethora of new Wi-Fi enabled devices. Mobile research by Cisco discovered that almost all mobile devices have Wi-Fi as their primary wireless access technology [109].

At the same time, customers have embraced the use of Wi-Fi to connect their mobile devices. A growing move to free access to Wi-Fi hotspots and the bundling of Wi-Fi access with wired broadband and mobile subscriptions have users consciously searching out Wi-Fi connectivity. Today, mobile is increasingly less about walking or driving, and more about the convenience of a “nomadic” lifestyle (moving, sitting or stopping, connecting and then moving on again). Cisco research found that consumers spend 2.5 hours per day using their mobile devices in their homes, compared with just 0.5 hours engaged in real mobile activities [106]. The same research also found that people would happily use Wi-Fi as a substitute, or complement, to mobile access. In fact, smartphone users on average used Wi-Fi more than one-third of the time to connect to the Internet, as opposed to mobile connectivity. Finally, mobile data caps, the cost of data plans, and the variable quality of many third-generation (3G) networks are encouraging users to replace mobile data with Wi-Fi in many cases.

In addition, nowadays Wi-Fi is being incorporated into an ever more diverse set of products, and the more Wi-Fi-enabled devices that users accumulate, the higher their dependency on Wi-Fi to meet their daily connectivity needs. As users have become more dependent on Wi-Fi, their expectations have inflated in parallel too (users now don't just want Wi-Fi to be available, they expect a fast, easy-to-use, secure and, increasingly, free service).

The Wi-Fi market in 2013 is characterized by three key trends: an investment boom that is serving to accelerate the global proliferation of hotspots; a transformation of the Wi-Fi user experience; and a growing user dependence on Wi-Fi as a primary form of connectivity.

Nevertheless, the future evolution of Wi-Fi will be marked by new possibilities, business models and technologies that can be glimpsed on the horizon and are centered in improve the Wi-Fi user experience.

One of the critical challenges facing 3G and 4G Mobile Network Operators (MNOs) is how to deal with the anticipated mobile data tsunami. One technology that is getting the most attention is Wi-Fi Offloading. Network equipment vendors are rushing to develop carrier-grade Wi-Fi infrastructure solutions, while MNOs are analyzing how to integrate Wi-Fi capabilities into their networks in order to offload data traffic from their primary 3G/4G network.



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Recent market research indicates that even though very few dedicated carrier Wi-Fi offload networks exist, a lot of data traffic is already being offloaded to existing private and public Wi-Fi networks in homes, at work and public hotspots. Using Wi-Fi for broadband retention or mobile data offload offers a very compelling return on investment (ROI), largely based on cost reductions, to justify further investment in other layers of monetization.

To cope economically with massive increases in mobile data traffic and spectrum constraints, many mobile operators are looking to Wi-Fi as an alternative access to mobile cellular access. Offloading some of the mobile data traffic to Wi-Fi allows operators to reduce (or at least defer) capital expenditures (CAPEX) from greater 3G and 4G access and helps lower network operating costs.

Therefore, equipment vendors, industry analysts and pundits are all pushing for a move towards Wi-Fi offload, describing universal benefits for all operators as a means to offset the increasing data demands.

Another important trend is Roaming. The Wireless Broadband Alliance states that although there are more than 340 million roaming trips per year, the number of users whose Wi-Fi roaming can be counted in the hundreds of thousands [106]. Many service providers are now forging domestic and international roaming agreements to attack this huge market opportunity. The ultimate goal is to make Wi-Fi roaming as smooth and easy to use as the mobile network. Cisco research found that mobile users are particularly interested in Wi-Fi roaming (52 percent were either somewhat or very interested) because it would significantly reduce their mobile data roaming costs, and they liked the convenience and the flexibility of location [109].

In entering into roaming agreements, service providers not only see the opportunity to enhance the customer experience, they also recognize the new monetization opportunities that it offers. Service providers can charge customers an additional fee for international roaming, or bundle it as part of an enhanced Wi-Fi or broadband service. Equally, service providers can sell wholesale access to other international providers to allow their customers to roam onto their Wi-Fi network without any additional charges at the time of access.

In the other hand, advertising based on Wi-Fi access promises to change the economics of mobile advertising. Wi-Fi can provide much more accurate user location (typically within 3 to 5m or less) than mobile cellular, allowing for much better targeted advertising. Typically, the use of Wi-Fi is opt-in, meaning that customers are much more receptive to advertising than the alternative spam model. Finally, in addition to smartphones, people access Wi-Fi through many larger-screens, more-advertising-friendly devices like tablets. We are observing these differences in the advertising marketplace.

Given the location capabilities of Wi-Fi and its good in-building coverage, many opportunities are now available to monetize Wi-Fi location-based services. Shopping malls and other big venues are now using Wi-Fi location services to provide Google-like maps to help people track their way to stores and services in the mall. In addition, they are beginning to layer on other location services such as targeted advertising and promotions.

8.4.2 Business analysis

Wi-Fi is an unregulated technology, so the barriers to entering the market are quite low. Different types of players, in addition to telecoms operators, can decide to develop a Wi-Fi business by deploying hotspots.

It is important to distinguish between a hotspot service provider and a hotspot owner. A hotspot service provider manages a hotspot, and does not need to be the owner of the venue where the Wi-Fi antennas are located. A hotspot owner is responsible for the venue where the antennas are installed, such as a hotel or café, but is not necessarily the provider of the service. While the hotspot owner can also be the hotspot service provider, the two are usually different.

Hotspot service providers can be divided into two main groups: operators and non-operators. For example, an airport authority can be a hotspot service provider, while the owner of a café or hotel can install a Wi-Fi hotspot and set up a commercial agreement with an external service provider.

Within hotspot service providers that are operators four further subdivisions can be defined:

- Pure Wi-Fi operators that only carry out business related to Wi-Fi services;
- Licensed mobile network operators or virtual network operators (MVNOs) that also provide Wi-Fi services;
- Integrated operators that provide a range of services such as fixed, mobile, internet, broadband and Wi-Fi;
- Fixed and cable operators that often also provide broadband and TV services.

In addition, Wi-Fi operators can be subdivided into the following types:

- Aggregators: Entities that buy access to the hotspots and sell the service.
- Mixed: They have their own access points and also buy access to others.
- Hub providers: Entities that provide interconnection between net operators and provide settlement.

Each has a particular role in the development of the Wi-Fi ecosystem. Nevertheless, the rapid pace of change engulfing the Wi-Fi market is attracting an increasingly diverse set of market participants. At the same time as these new entrants are pushing the boundaries of the types of innovative new services and products that can be enabled by Wi-Fi, Telcos have initiated a global land grab to deploy classic, professionally-managed Wi-Fi to a whole new set of public venues.

In this Wi-Fi market landscape the following business cases can be founded:

- Private Wi-Fi at home (as a feature of the fixed access business model).
- HW / service selling, e.g. Access hardware (APs), Platform selling
- Net exploitation, e.g. Pass based access, Pay as you go, Service subscription, Advertising, Roaming, Offloading.

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As a follow-up of the broad overview of the actual market situation of the W-Fi operator a detailed analysis of the business model had been carried out using the business model canvas (8.1.1.2) (see Figure 64).

| | | | | |
|---|--|---|---|--|
| KA Core Capabilities <ul style="list-style-type: none"> •Deploy, operate administrate and maintain (OAM) a network to provide Wi-Fi access to different end users and operators •Provide value added services (roaming, data offloading, advertisement, etc.) •Bill customers for the usage •Provide CPEs to connect to the network | KP Partner Network <ul style="list-style-type: none"> •ISPs, Fixed Network Operators and Mobile Network Operators* •Wi-Fi platform equipment manufacturers •CPEs manufacturers | VP Value Proposition <ul style="list-style-type: none"> •Wi-Fi network •Roaming services •Cobranded/ Personalized services •Data offloading •Customer care | CR Customer Relationship <ul style="list-style-type: none"> •Services suitable for various end users and operators •Marketing | CS Customer Segments <ul style="list-style-type: none"> •Mass end users •ISPs, Fixed Network Operators and Mobile Network Operators* •Aggregators and resellers |
| | KR Value Configuration <ul style="list-style-type: none"> •Brand management •Network management •Service management •Billing system management •Product and software design | | CH Distribution Channel <ul style="list-style-type: none"> •Wi-Fi operator store •Wi-Fi captive portal | |
| C\$ Cost Structure <ul style="list-style-type: none"> •Platform infrastructure development and maintenance •Hardware and Software design and development •Marketing | | R\$ Revenue Stream <ul style="list-style-type: none"> •Subscription fees •Usage fees •Device revenue •Network sales to Fixed Network Operators and Mobile Network Operators | | |

Figure 64: Business Model Canvas of Wi-Fi Operators

By concluding the detailed business analysis of the Wi-Fi operator, a network structure (matrix) has been developed showing the positions of the various actors on the different network segments, divided into two figures (see Figure 65 and Figure 66) as already explained before.

Assessment Framework and evaluation of state of the art technologies

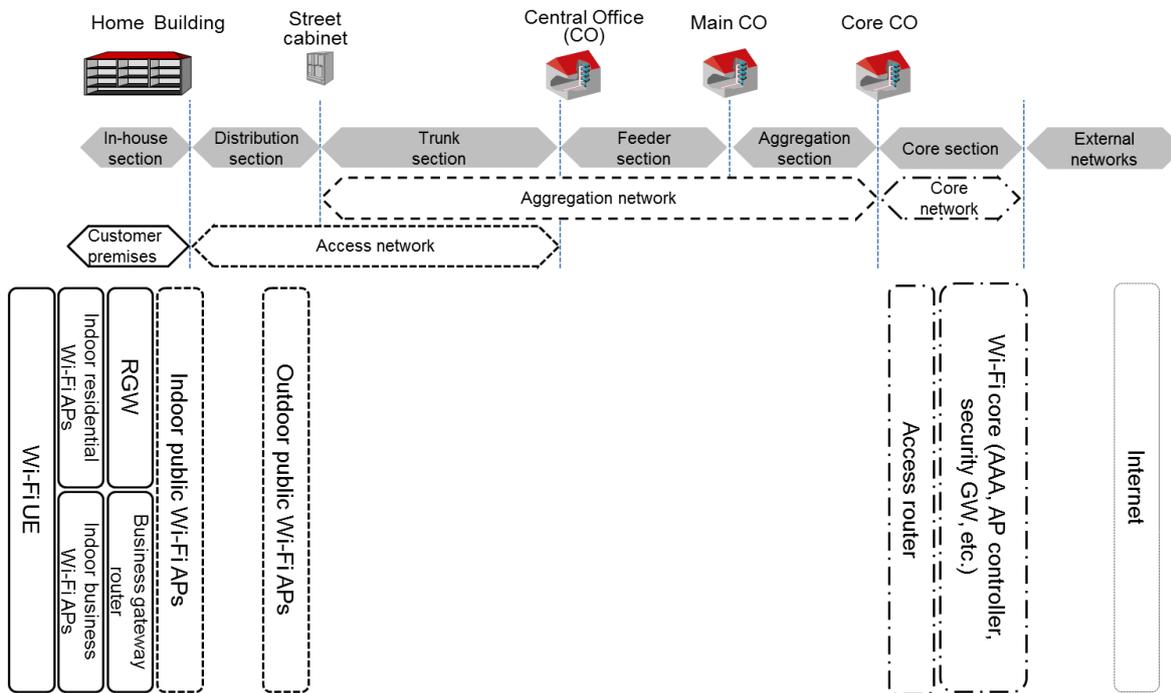


Figure 65: Network segments Wi-Fi architecture

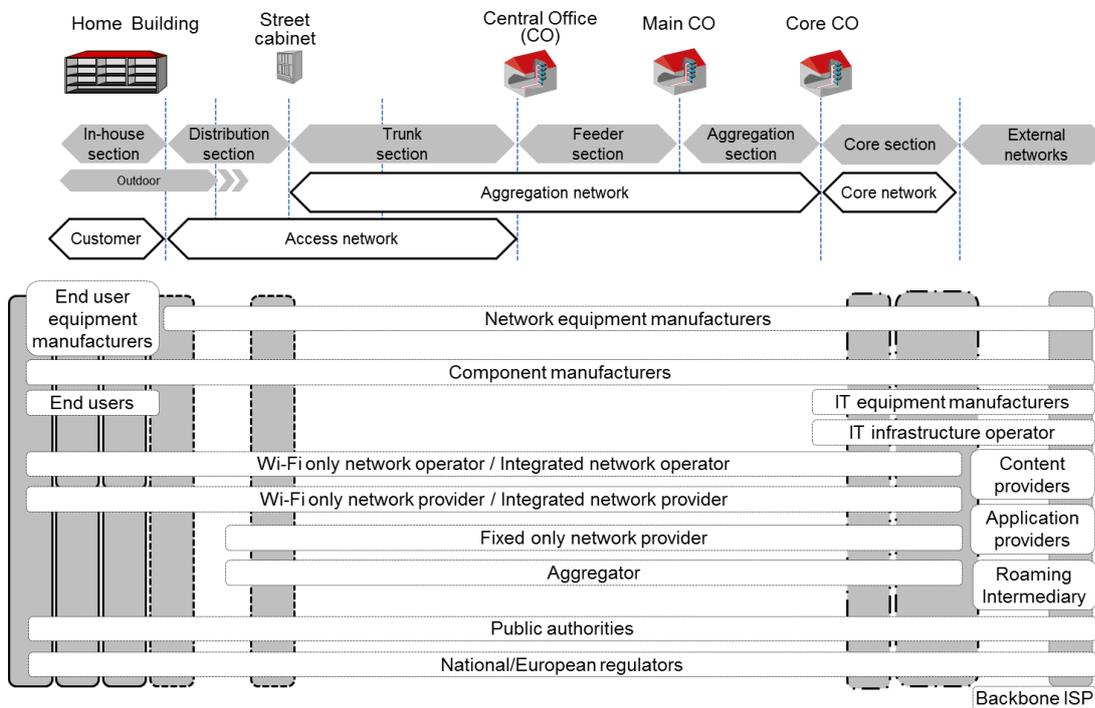


Figure 66: Network structure Wi-Fi

Figure 66 captures the influence the various actors have over explicit parts of the network and by that defining the value of their position in the value network (see 8.1.2.1).

8.5 Introduction to fixed-mobile convergence ecosystem

An introduction and an overview of the actual status of the fixed-mobile convergence as well as of the future trends had been provided in chapter 4 “Market Analysis” in Deliverable 2.1.[1] In this context it was already referred to use cases and studies on fixed-mobile convergence that had been done previously in other projects. Just to mention a few challenges and future trends:

- “Established players in the telecommunications ecosystem must seek sustainable new business models, focused on exploiting the core competence of operators, separating access and services and innovative network design” [110].
- “Network deployment needed using a mix of technologies tailored to the specifications of the market” [110].
- Strong rise of both fixed and mobile broadband subscriptions → exponential growth of data traffic.

Different analysis has been done in the previous years by different international organisations as well as consultancy companies showing how the value chain in the telecommunications market is continuously changing. In a recent report produced by AT Kearney [111] for ETNO, the future perspectives of the telecoms market were analysed, showing the future trends and the movement of the involved actors over the value chain (see Figure 67).

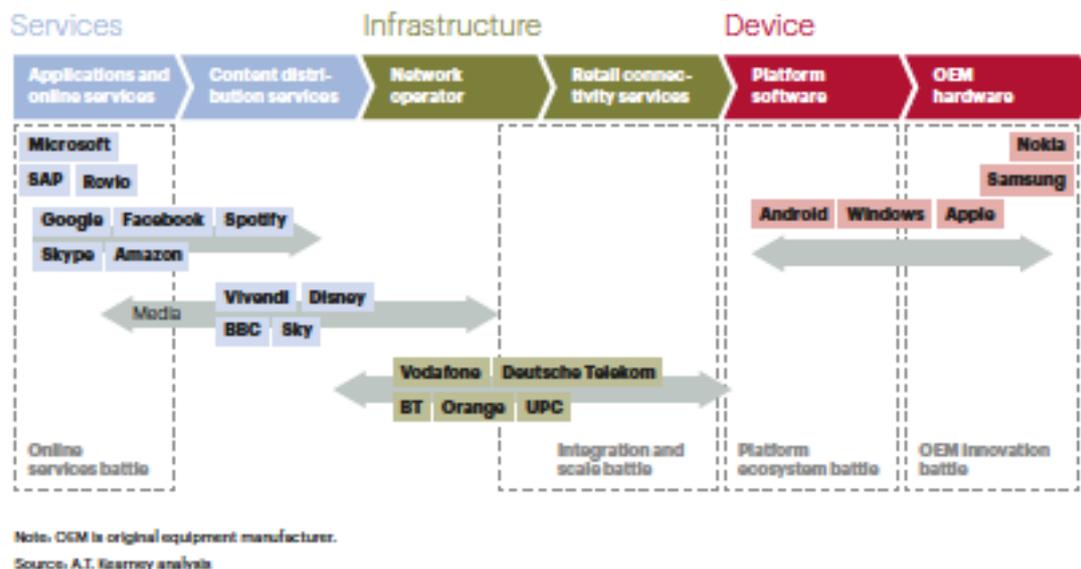


Figure 67: Movement of Value Chain Players

They point out in their report that “operators are exploring a wide range of possible opportunities, and their assessment of these will depend on their own capabilities, service portfolio, customer base and local market specifics.” Future areas in this context to be tackled are content, eHealth, telematics, smart metering, M2M, mobile payment, IPTV, cloud computing, etc. Here a convergence in architecture, as it is the scope of the COMBO project, can be a booster for new opportunities.

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Following to the before-mentioned market analysis, in this deliverable the focus will be put on the business analysis of fixed-mobile convergence based on the approach of the FMC state-of-the-art introduced in WP 2, as well as on the assessment framework developed in WP 5 (3).

Based on work done within the project a Business Model Canvas was created for current state-of-the-art FMC networks (see Figure 68), which can be considered as the model of an integrated operator where the level of convergence is quite limited (normally only at the service layer level):

| | | | | |
|---|---|--|---|--|
| KA Core Capabilities <ul style="list-style-type: none"> •Deploy, operate administrate and maintain (OAM) an integrated network (fixed, mobile and/or Wi-Fi) to carry FMC services •Provide end user equipment to use mobile services •Provide value added services •Bill customers for the usage | KP Partner Network <ul style="list-style-type: none"> •ISPs, Integrated Network Operators, Fixed only, Mobile only and Wi-Fi only Network Operators* (including virtual operators) •Content providers •Service providers •Equipment manufacturers •National/European regulators | VP Value Proposition <ul style="list-style-type: none"> •FMC network •FMC services •Bundling of fixed services •Data offloading •Seamless network connectivity •Single sign-on for fixed and mobile •Customer care | CR Customer Relationship <ul style="list-style-type: none"> •Bundling of different commercial offers •Services suitable for various end users and operators •Business call centre •Technical call centre •Marketing •Online portal | CS Customer Segments <ul style="list-style-type: none"> •Mass-market residential users •Individual-market business users (SME) •ISPs, Integrated Network Operators, Fixed only, Mobile only and Wi-Fi Network Operators •Wholesale connectivity (e.g.: for MVNOs) |
| KR Value Configuration <ul style="list-style-type: none"> •Brand management •Network management •Billing system management •Equipment distribution •Service management | CH Distribution Channel <ul style="list-style-type: none"> •FMC operator's shops •On-line sites •External channels | C\$ Cost Structure <ul style="list-style-type: none"> •Same basic Capex and Opex cost structure than fixed, mobile and Wi-Fi networks, but with more efficiencies and synergies | | R\$ Revenue Stream <ul style="list-style-type: none"> •FMC residential services •FMC business services •FMC wholesale services •FMC Value added services •Device revenue |

Figure 68: Business Model Canvas of state-of-the-art Fixed-Mobile Convergence

Please note that in this constellation ISP's, Integrated Network Operators, Fixed only and Mobile only Network Operators can be both, customers and partners.

Furthermore a network structure (matrix) was developed based on the methodology explained in subchapter 8.1.2.2 and showing the technological state-of-the-art FMC network as well as the actors that are relevant in this system (see Figure 69 and Figure 70).

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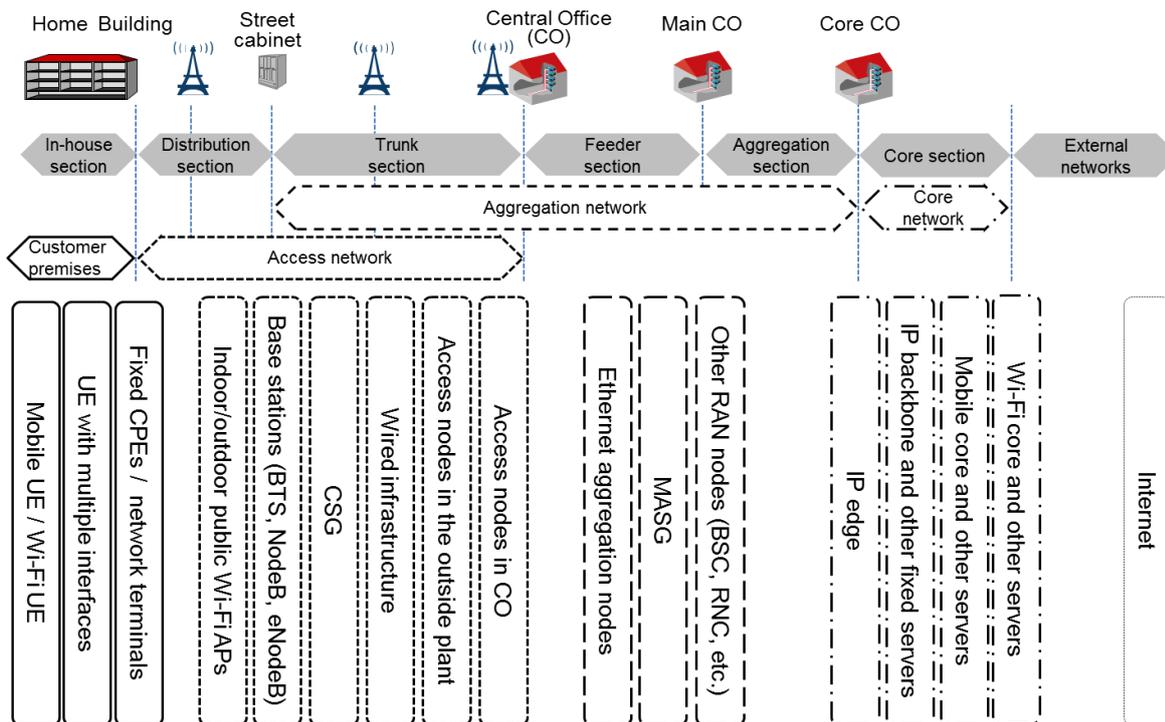


Figure 69: Network segments for SOA Fixed-Mobile Convergence architecture

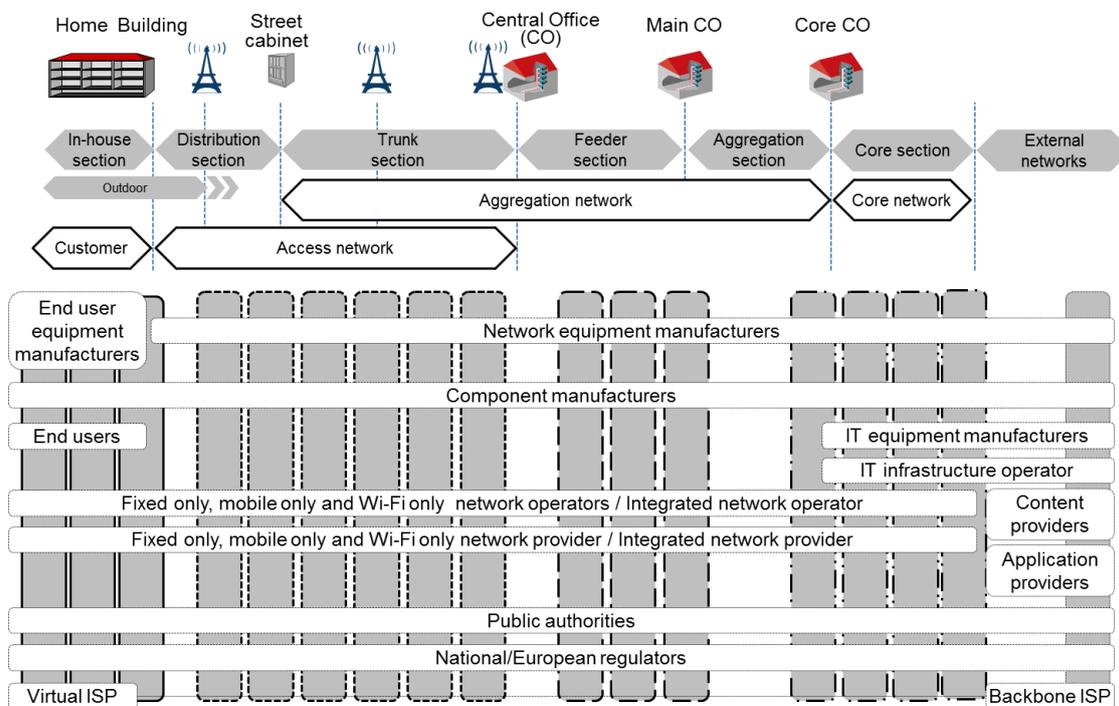


Figure 70: Network structure for SOA FMC

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As already explained in subchapter 8.1.2.1 changes in either the value network or the business model will affect the other one as far as they are correlated.

Two types of processes can induce changes within a value network or business model of a company: one is that there are external influences in the form of value migration (changes between industries, between businesses or between different business models within a company). Another option is that developments within the business influence value creation in the form of business migration.[92]

The whole telecommunications market is affected by value migration, especially when considering the OTT Players (see Figure 67), as well as by business migration, considering e.g. the substitution of fixed through mobile access (internal business migration in case of an integrated operator). The need for new business models and different value creation is evident. A fixed-mobile convergence in the architecture, as it will be developed in COMBO, will have implications on the existing value network as well as on the business models of the different actors in the ecosystem.

In the next phase of the COMBO project FMC use cases and scenarios, based on changes in the architecture – both in the hardware and most probably also in the software –, will be developed in WP3. Based on these use cases an assessment framework will be prepared which will serve as the basis for further analysis of the business ecosystem/value network and the business models of the existing actors as well as possible upcoming new actors (e.g. virtual service providers).

Based on the methodology introduced in this chapter, the FMC scenarios defined by WP 3 will be evaluated in depth during the next phase. A complete analysis of the business ecosystem/value network and the business models of the newly developed FMC scenarios will be prepared to enable a comparison between them and the actual situation of separated networks and state-of-the-art FMC networks. This analysis will enable us to answer the research questions that are the scope of the business analysis within the COMBO project (see 8.1).

9 Conclusion

In this deliverable, the foundations of techno-economic assessment in COMBO were laid. The methodologies and tools were defined, and the state-of-the-art network architectures addressed.

Our goal was not to provide an in-depth techno-economic assessment of the existing network technologies, as the literature already provides numerous high quality studies, and several earlier European research projects provided these studies, such as the OASE project.

However, the techno-economic assessment of FMC network architectures to be proposed by COMBO, which will be the objective of WP5 in the next two years, required significant preliminary work, in order to prepare the Assessment Framework.

Hence, the tools for infrastructure and network technology optimization and assessment were identified and implemented, which will be used to analyse the impact of structural and functional convergence architectures. The cost and power consumption databases were defined, and an initial data set was collected, as well as an initial set of case studies were prepared for calculations.

Similarly, the business ecosystems for fixed, mobile, Wi-Fi and current FMC networks were analysed, which will serve as the basis for analysis of business ecosystems and business models for the proposed convergence architectures of COMBO.

In summary, this deliverable presents the results and work of WP5 for the first year, demonstrating that WP5 is ready for the techno-economic assessment of candidate FMC architectures, which are expected to arrive from WP3 in the next year.

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11 ANNEX

11.1 Annex I: Network Scenarios

In this section, we describe in detail the most typical network configurations for fixed, Wi-Fi, and mobile network scenarios.

11.1.1 Fixed Network Scenarios

11.1.1.1 FTTH GPON

Among state of the art optical access network technologies, GPON is the dominant solution for the time being (at least in Europe). Therefore, FTTH GPON will be the first network scenario (Figure 71) to be assessed, with the typical 1:64 splitting ratio (in one or two levels).

Namely, in dense urban scenarios a two-level splitting hierarchy will be considered, with 1:4 splitters at the cabinets, and 1:16 splitters in the buildings. The split ratios will be swapped for rural scenarios (with smaller buildings), i.e. the 1:16 splitters will be located in the cabinets, and the 1:4 splitters in the buildings. Finally, in a rural environment 1:64 splitters will be deployed in a single level “hierarchy”.

According the objectives of D5.1, not only the state of the art (GPON), but also the short-term successor, namely 10G GPON will be considered as a variant of this scenario, as 10G GPON operates over the same cable plant and physical network infrastructure, but fulfils higher requirements.

Scenario 1: FTTH GPON

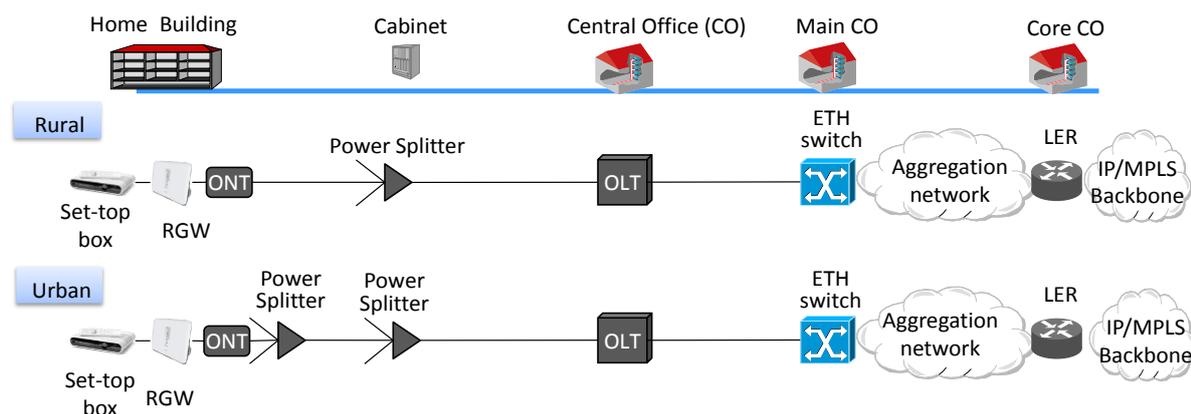


Figure 71: FTTH GPON network scenario

11.1.1.2 FTTC VDSL2 + Point-to-Point optical backhaul

Since a major part of Europe already has copper access deployed, an xDSL network scenario will be considered during the techno-economic assessment. As long as the evolution of xDSL networks will be able to fulfil the requirements, from cost

perspective these will be an attractive solution - at least for the incumbents already having the copper access networks deployed.

During the assessment activity presented in the current deliverable, the xDSL network scenario (Figure 72) considered will be a VDSL2 access network, with point-to-point optical links between the DSLAMs located at cabinets and the central infrastructure. An ODF will be deployed in the local Central Offices to merge the optical feeder of the DSLAMs, and these will be connected to a L2 Switch at a higher hierarchical level, the Main Central Office. In the future, also a WDM feeder network scenario will be considered, which gives a virtual point-to-point connectivity to the DSLAMs (that is the second scenario on the figure).

Scenario 2: FTTC VDSL2 + PtP feeder

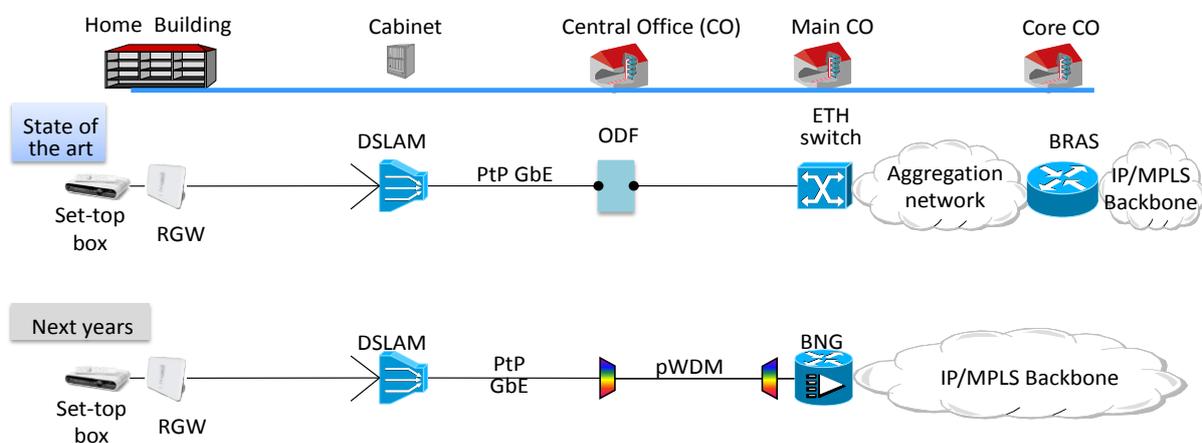


Figure 72: FTTC VDSL2 network scenario

11.1.1.3 FTTB WDM PON

Even though WDM PON is not a dominant or widespread fixed access technology yet, the technology has the level of maturity, which makes it a promising solution even in the short term. Therefore, a WDM PON network scenario was also selected for the current assessment.

Due to the significantly higher bandwidth of a WDM PON system over traditional TDM PON systems, WDM PON will be taken as an FTTB deployment, in which the offered bandwidth per household will be comparable with FTTH GPON systems – otherwise it would be a comparison of apples and oranges.

The selected WDM PON network scenario (Figure 73) will be a wavelength switch WDM PON system, utilizing 1:48 AWGs in the distribution network, and connected each building with a dedicated wavelength, providing 1 Gbps data connectivity.

Scenario 3: FTTB WDM PON

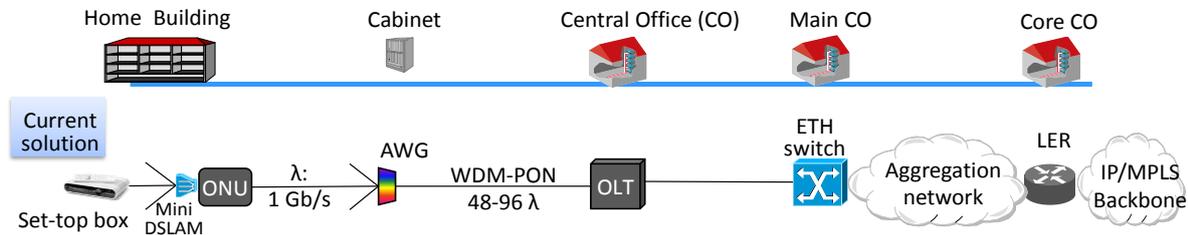


Figure 73: FTTB WDM PON network scenario

11.1.1.4 Hybrid TDM/WDM PON

The last, and probably the most ambitious fixed network scenario to be considered in the deliverable will be a hybrid TDM/WDM PON system (Figure 74). Among the currently known different technical solutions we have selected the one which is in line with the NGPON-2 concept [39]. There will be 4 different wavelengths used in the network, and a 10 Gbps TDM PON on each of these 4 wavelengths, resulting in $4 \times 10 = 40$ Gbps cumulated bandwidth.

The distribution network is not wavelength switched in this case (e.g. the higher cost of AWGs is avoided); passive optical splitters are used instead. As a conclusion all four wavelengths reach all ONUs in the network.

Scenario 4: WDM/TDM Hybrid PON

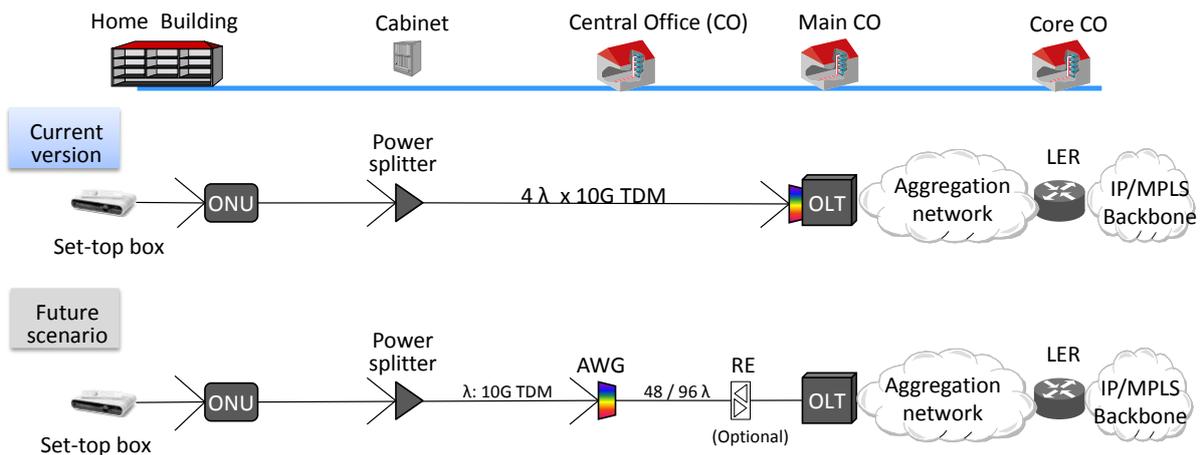


Figure 74: TDM/TDM Hybrid PON (TWDM PON) network scenario

11.1.2 Wi-Fi Network Scenarios

11.1.2.1 Residential Wi-Fi

In this scenario, the operator is offering Wi-Fi as a feature of the broadband service at home. The Wi-Fi network is developed typically from the RGW as shown in Figure 75, and only the broadband subscriber can connect. In this case, there is no requirement for a Wi-Fi core.

Residential Wi-Fi (+ Fixed Access)

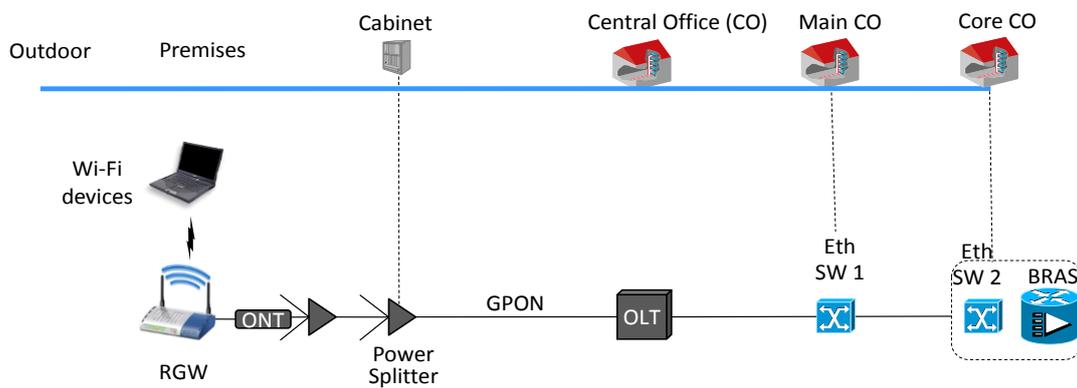


Figure 75: Residential Wi-Fi scenario integrated in the fixed access

11.1.2.2 Community Wi-Fi

The Operator is offering Wi-Fi as a broadband service's feature for users out of the home. The Wi-Fi network is typically deployed from the RGW with additional SSIDs (see Figure 76), which is reachable from outside the home. Any user enabled by the operator can connect to those public SSIDs. Here the residential case is also fulfilled at the same time. A Wi-Fi core is required to offer this service.

Community Wi-Fi (+ Fixed Access)

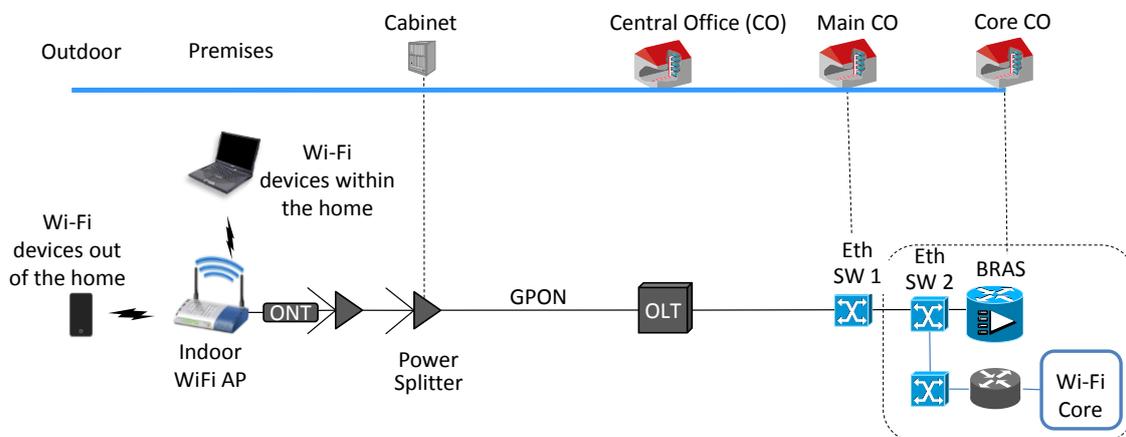


Figure 76: Community Wi-Fi scenario integrated in the fixed access

11.1.2.3 Indoor public / Business Wi-Fi

In this scenario the operator offers Wi-Fi in a public place or business (Hotspots). The Wi-Fi APs are located in the infrastructure of the buildings, such as: shopping malls, office buildings, or airports. Any user authorised by the operator or business can connect to the service, and the operator’s subscribers can connect automatically. The Wi-Fi is typically installed using specific brand equipment, as presented in Figure 77. A Wi-Fi core is required to provide service.

Indoor public / Business Wi-Fi (+ Fixed Access)

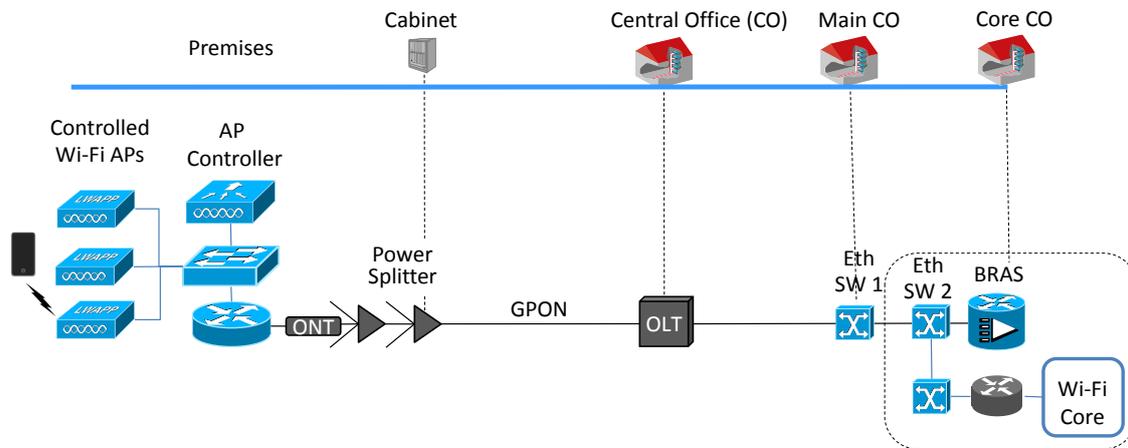


Figure 77: Indoor public / Business Wi-Fi scenario integrated in the fixed access

11.1.2.4 Outdoor Public Wi-Fi

In the outdoor public Wi-Fi, the APs in the street are connected through cabinets. A Wi-Fi core is required to provide this service. Like in the previous case, the Wi-Fi network uses specific brand equipment, which is managed from the core. This network scenario is illustrated in Figure 78.

Outdoor Public Wi-Fi (+ Fixed Access)

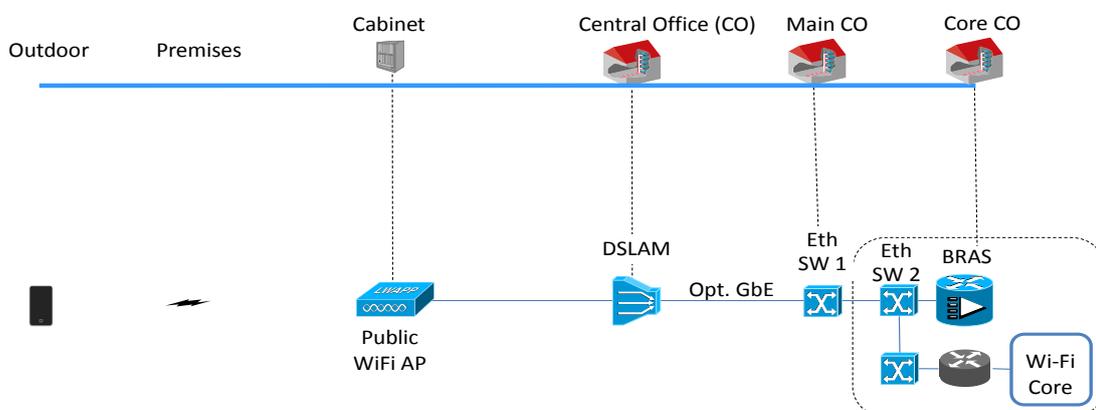


Figure 78: Outdoor Public Wi-Fi scenario integrated in the fixed access

11.1.3 Mobile Network Scenarios

11.1.3.1 2G Mobile Network and Point-to-Point optical backhaul using FTTC

A typical option to backhaul the 2G mobile traffic is through the use of Point-to-Point (PtP) optical GbE links between the main CO and the base station (BS) site. The optical PtP is also known as Fibre to the Curb (FTTC). In 2G networks, the BS is composed by a BTS and a CSG (see Figure 79).

11.1.3.2 2G Mobile Network with a combination of microwave and Point-to-Point optical backhauling

As shown in Figure 80, the 2G mobile traffic can be also backhauled using microwave links until the CO and PtP optical links from the CO till the Main CO.

Scenario 1a: 2G + PtP (FTTC)

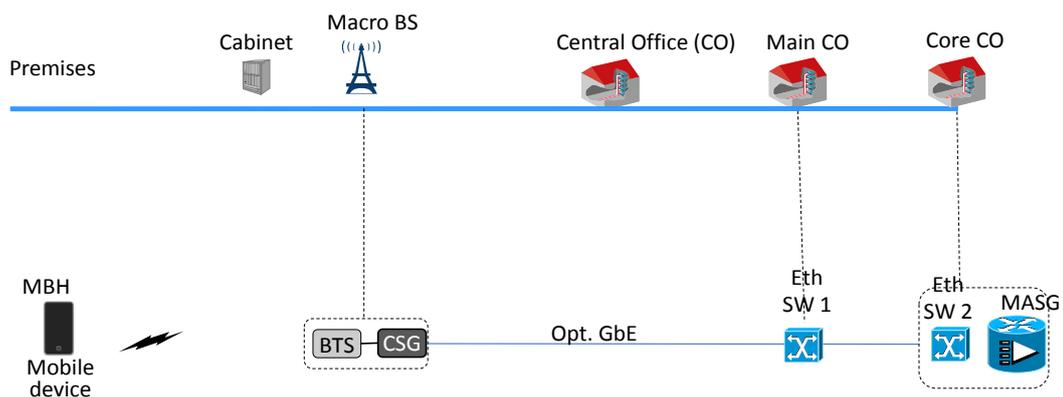


Figure 79: 2G and FTTC network scenario

Scenario 1b: 2G + Microwave + PtP

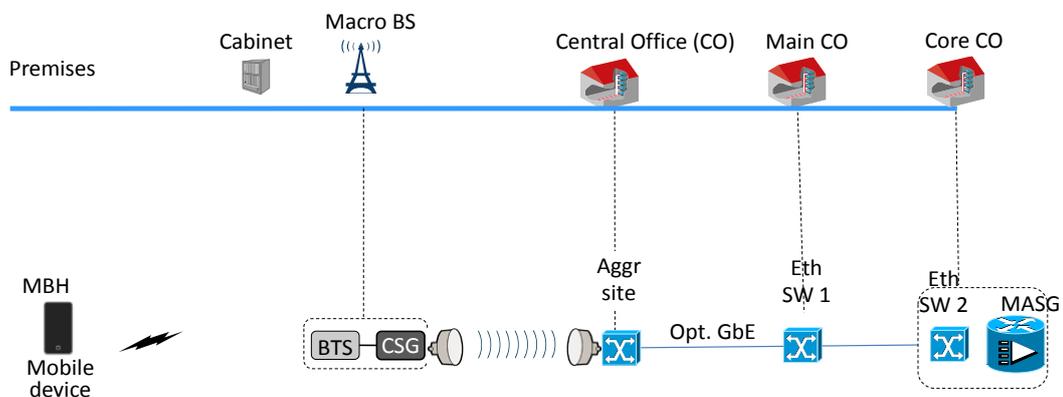


Figure 80: 2G, microwave, and optical PtP network scenario

11.1.3.3 3G Mobile Network and Point-to-Point optical backhaul using FTTC

In Figure 81, the 3G network makes use of PtP optical links for backhauling its traffic from the macro BS to the Main CO. In this case, the macro BS is composed by a Node B and a CSG.

Scenario 2a: 3G + PtP (FTTC)

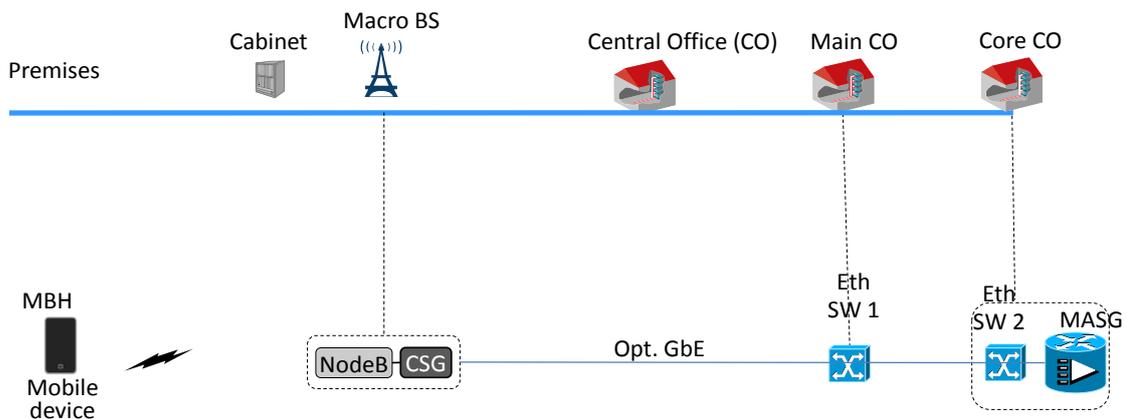


Figure 81: 3G and FTTC network scenario

11.1.3.4 3G Mobile Network with a combination of microwave and Point-to-Point optical backhauling

Similarly to the 2G network, the 3G network can also combine microwave links from the macro BS to the CO, and PtP optical links from the CO to the Main CO (see Figure 82).

Scenario 2b: 3G + Microwave + PtP

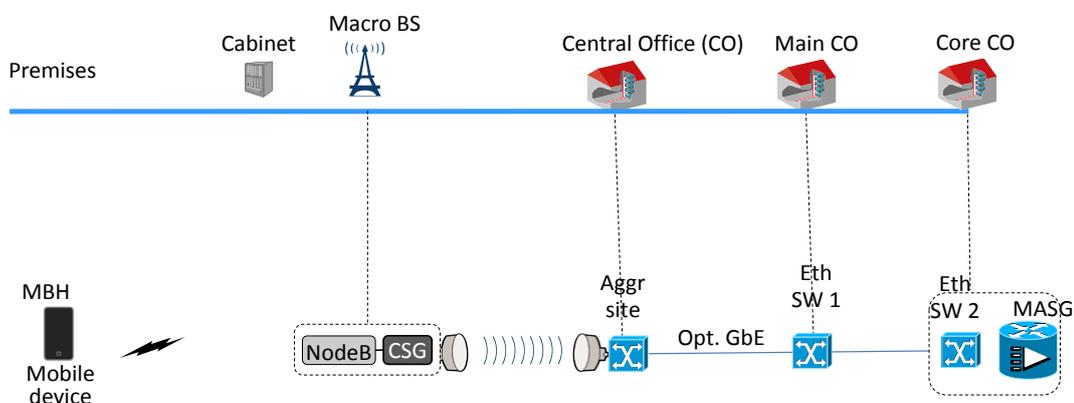


Figure 82: 3G, microwave, and optical PtP network scenario

11.1.3.5 3G pico/femto-cell Mobile Network with a combination of DSL and Point-to-Point optical backhaul using FTTC

In the case on 3G pico or femto cells the most typical network configuration is shown in Figure 83. The mobile traffic backhauling is performed through the use of PtP optical links from the Main CO till the cabinet. At the cabinet, it is installed a VDSL+ DSLAM that links with the pico/femto BS using copper twisted pairs. This network scenario is optional for rural deployments.

Scenario 3: 3G (pico/femto cell) + DSL + FTTC

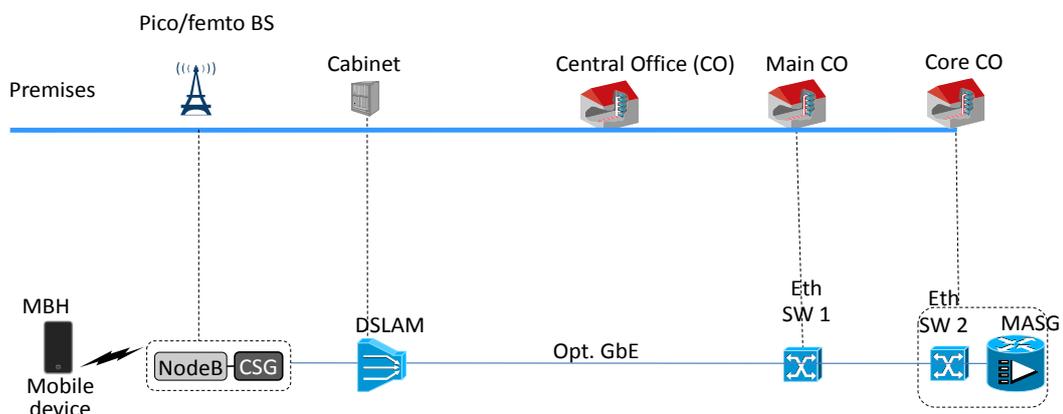


Figure 83: 3G pico/femto-cell, DSL, and FTTC network scenario

11.1.3.6 LTE Mobile Network and Point-to-Point optical backhaul using FTTC

In LTE macrocell deployment, one of the most typical traffic backhauling options is based on PtP optical links from macro BS to the Main CO, as shown in Figure 84. In LTE networks, the BS is composed by an eNode B and a CSG.

Scenario 4a: LTE + PtP (FTTC)

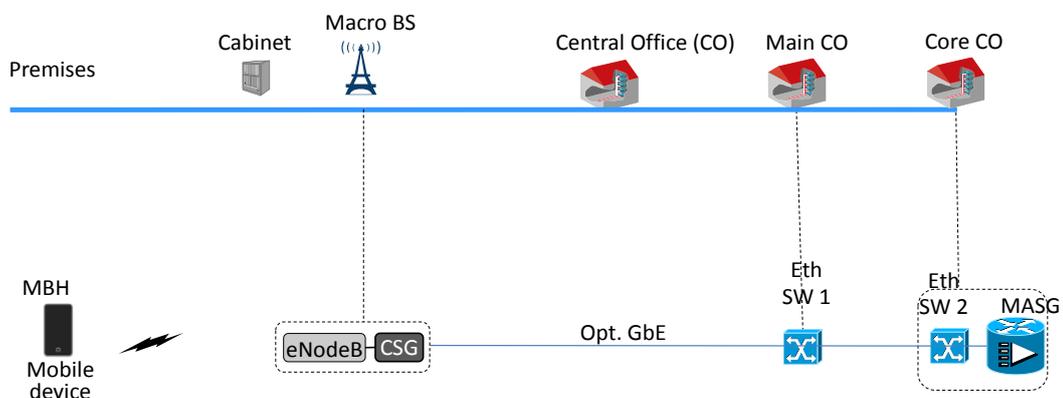


Figure 84: LTE and FTTC network scenario

11.1.3.7 LTE Mobile Network with a combination of microwave and Point-to-Point optical backhauling

LTE mobile network can make use of a combination of microwave links from BS to CO, and PtP optical links from CO to Main CO to backhaul its macro cell traffic (see Figure 85).

Scenario 4b: LTE + Microwave + PtP

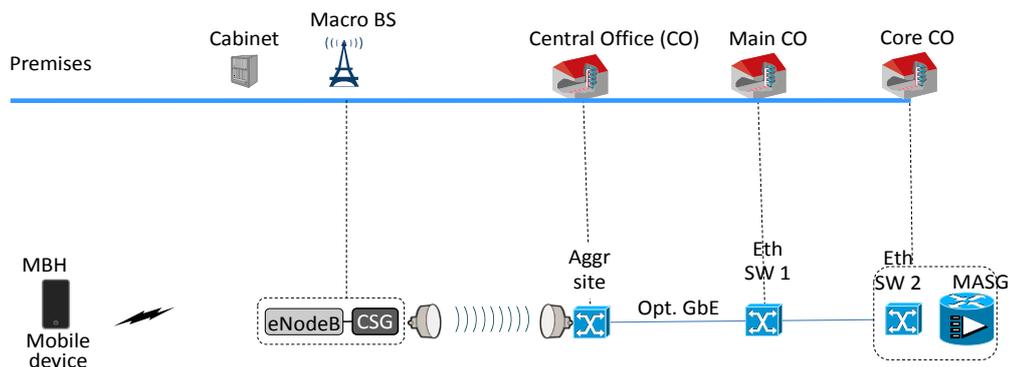


Figure 85: LTE, microwave, and optical PtP network scenario

11.1.3.8 LTE small-cell Mobile Network with a combination of DSL and Point-to-Point optical backhaul using FTTC

In the LTE small cell deployment, it is typical to use a combination of DSL (VDSL+) and optical PtP to backhaul the mobile traffic, as shown in Figure 86. The DSL links are located between the small BS and the cabinet where a VDSL+ DSLAM is installed. Then from the Cabinet to the Main CO, PtP optical links are deployed to carry the traffic to the metro/core network. This network scenario is currently not considered for rural deployments. Maybe in the future it will be an option for rural locations.

Scenario 5a: LTE (small cell) + DSL + PtP (FTTC)

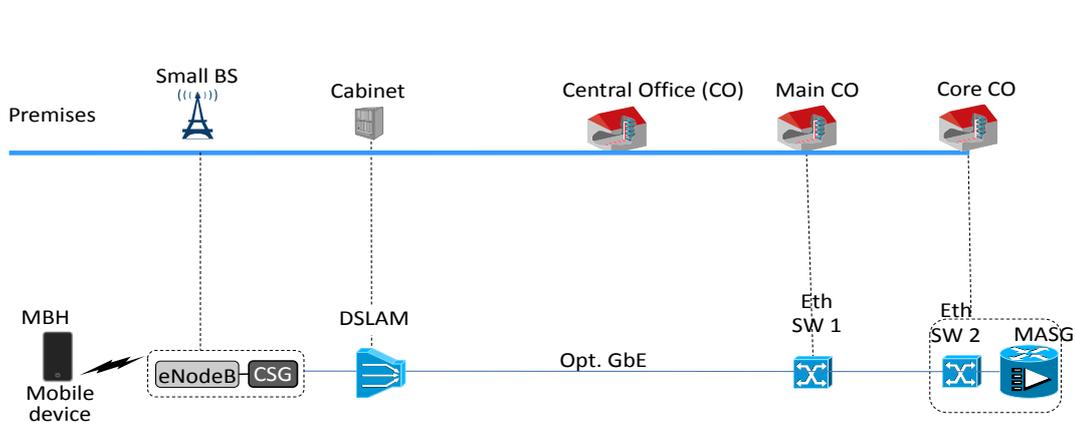


Figure 86: LTE small-cell, DSL, and optical PtP network scenario

11.1.3.9 LTE small-cell Mobile Network with a combination of microwave and Point-to-Point optical backhauling

A mobile traffic backhauling based on a combination of microwave links and PtP optical links is a possible option for LTE small-cell (see Figure 87). The microwave links transport the mobile traffic from the small BS to the CO, and PtP GbE optical links transport the traffic from CO to Main CO. This network scenario is not considered for rural deployments, but in the future it may be a feasible option.

Scenario 5b: LTE (small cell) + Microwave + PtP

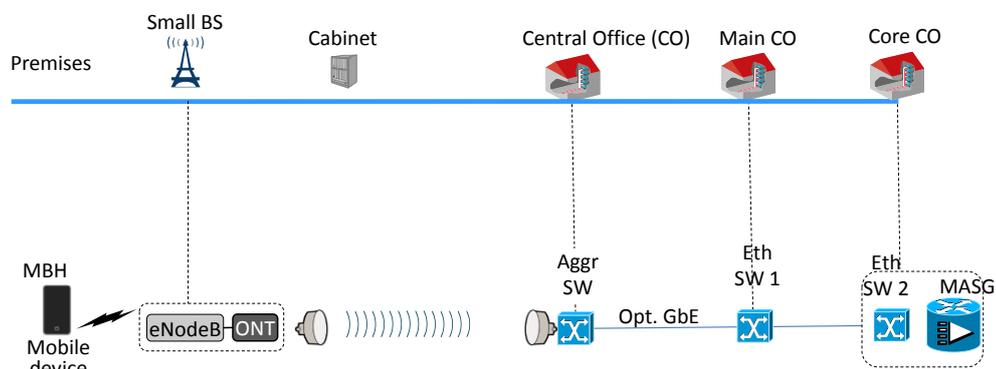


Figure 87: LTE small-cell, microwave, and optical PtP network scenario

11.1.3.10 LTE small-cell Mobile Network with PON (FTTH) backhauling

Finally, in Figure 88, the mobile traffic backhauling of an LTE small-cell is provided by a PON. In this case, the ONT is co-located with the small BS, with a fibre connection to the optical splitter placed in the cabinet. From the cabinet, a feeder fibre link is deployed till the CO, where the OLT is installed. This scenario is a good option for dense-urban and urban areas, and may be considered for rural cases in the future.

Scenario 5c: LTE (small cell) + PON (FTTH)

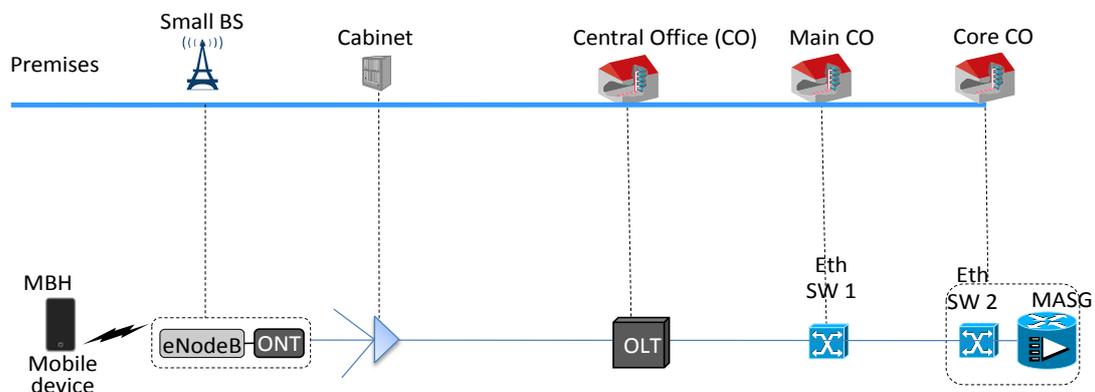


Figure 88: LTE small-cell and FTTH network scenario

11.2 Annex II: Power consumption values of network equipment

In this section, we provide a detailed list the energy consumption of network devices used for the network configurations described in the previous Annex. For each device, the reference value of power consumption is expressed in Watts (W). Such collected values have been used for the energy-consumption evaluation in Section 6.

Where explicitly indicated, values are referred for a specific capacity unit (e.g., per subscriber line, per port, per card slot, per user). When a traffic load dependency is present, such values must be intended as high-to-full load values. For each device, the source for power consumption data is indicated, in terms of reference normative documents (e.g., the Broadband Code of Conduct (BB CoC) v4.1), final documentation of other projects (e.g., the BMWi project Communicate Green), commercial products (extrapolated from data-sheets), or the contributor partner that provided such value.

The list is divided among three tables: Table 20, Table 21 and Table 22, respectively for Fixed, Wi-Fi and Mobile networks.

11.2.1 Fixed Networks

| Device | Details (Optional) | Power Consumption (W) | Source |
|------------------------------|---|-----------------------|-----------------------------------|
| STB | Not including DVR functionality | 10 | ADVA-DE |
| RGW | With VDSL2 (profile 8, 12a, or 17a) WAN interface, 4 Fast Ethernet interfaces, 1 Wi-Fi b/g interface, 1 FXS port, 2 USB ports | 9.1 | BB CoC v4.1, Tier 2013 (p. 22-24) |
| ONT (PtP WDM) | 5...10 Gb/s, 1 client port, up to 8 waves | 2.7 | ADVA-DE |
| ONT (PtP WDM) | 5...10 Gb/s, 1 client port, up to 48 waves | 2.9 | ADVA-DE |
| ONT (PtP WDM) | 1...4 Gb/s, 1 client port, up to 8 wavelengths | 2.2 | ADVA-DE |
| ONT (PtP WDM) | 1...4 Gb/s, 1 client port, up to 48 wavelengths | 2.4 | ADVA-DE |
| ONT (shared WDM, e.g., TWDM) | Sustained 1 Gb/s, 1 client port | 2.9 | ADVA-DE |
| ONT (shared WDM, e.g., TWDM) | Sustained 100...300 Mb/s, 1 client port | 2.4 | ADVA-DE |
| ONT GPON | With 1 GbE LAN port | 4 | BB CoC v4.1, Tier 2013 (p. 24) |
| ONT 10G-PON | - | 6 | BB CoC v4.1, Tier 2013 (p. 24) |
| DSLAM (@CO) | ADSL2plus (including ADSL and ADSL2), | 1.1 per subscriber | BB CoC v4.1, Tier |

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| | | | |
|----------------------------|---|--|-----------------------------------|
| | with more than 100 subscriber lines | line; 4.5 per uplink GbE interface | 2013 (p. 28-29) |
| Remote DSLAM (@ cab) | ADSL2plus (including ADSL and ADSL2), with less than 100 subscriber lines | 1.4 per subscriber line; 4.5 per uplink GbE interface | BB CoC v4.1, Tier 2013 (p. 28-29) |
| VDSL2 remote DSLAM (@ cab) | VDSL2, with less than 100 subscriber lines | 1.9 per subscriber line; 4.5 per uplink GbE interface | BB CoC v4.1, Tier 2013 (p. 28-29) |
| Ethernet Switch Lv1 | - | 648 per card slot | ALU 7750 SR12 |
| Ethernet Switch Lv2 | - | 648 per card slot | ALU 7750 SR12 |
| BRAS / BNG | 96k subscribers | 1100 | Huawei ME60-X3 |
| BRAS / BNG | 256k subscribers | 3300 | Huawei ME60-X8 |
| BRAS / BNG | 512k subscribers | 6500 | Huawei ME60-X16 |
| LER | - | 1275 | Cisco ASR 1006 |
| Radius Server | - | 200 | Typical medium-size rack server |

Table 20: Network equipment list with power consumption values for Fixed networks

11.2.2 Wi-Fi Networks

| Device | Details (Optional) | Power Consumption (W) | Source |
|---------------------------|--|-----------------------|---------------------------------------|
| RGW (@ customer premises) | - | 5 | FON |
| Indoor AP | Wi-Fi 802.11b/g/n or b/g/a hotspot | 8 | BB CoC v4.1, Tier 2013 (p. 34) |
| Outdoor AP | 802.11n Outdoor Wireless Access Point, 2.4GHz and 5GHz dual band (simultaneously), 2 GbE ports | 15 | TID |
| AP Controller | 5 APs min, 50 APs max, 500 clients max, 500 Mbps max throughput | 80 | Cisco Wireless Controller 2500 Series |
| AP Controller | 12 APs min, 500 APs max, 7K clients max, 8 Gbps max throughput | 125 | Cisco Wireless Controller 5500 Series |

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| | | | |
|---------------------|---|-----------------------------|---------------------------------------|
| AP Controller | 100 APs min, 1K APs max, 15K clients max, 20 Gbps max throughput | 220 | Cisco Wireless Controller WiSM2 |
| AP Controller | 300 APs min, 6K APs max, 64K clients max, 10 Gbps max throughput | 675 | Cisco Wireless Controller 8500 Series |
| WiFi Access Gateway | Serves up to 10000 AP, includes controller function | 800 | DT |
| Wifi Core Platform | Includes: AAA systems , Network management systems, Logging facilities, Security related systems, Lawful interception systems | 5.6k for each 5 Million APs | FON |

Table 21: Network equipment list with power consumption values for Wi-Fi networks

11.2.3 Mobile Networks

| Device | Details (Optional) | Power Consumption (W) | Source |
|--------------------|--|-----------------------|--|
| HeNB | Femto cell for home use, RF power <=10mW | 7 | BB CoC v4.1, Tier 2013 (p. 24) |
| HNB | Femto cell for home use, RF power <=10mW | 7 | BB CoC v4.1, Tier 2013 (p. 24) |
| 2G macro BTS | GSM/EDGE, 3 sectors, 4 carriers per sector, 20W output power at antenna interface (per carrier, per sector) | 800 | BB CoC v4.1, Tier 2013 (p. 34) |
| 3G macro NB | WCDMA/HSDPA, 3 sectors, 2 carriers per sector, dual-TX RRUs, 20W output power at antenna interface (per carrier, per sector) | 800 | BB CoC v4.1, Tier 2013 (p. 34) |
| LTE macro eNB | LTE, 3 sectors, 2.6GHz, 20MHz bandwidth, 2x2MIMO, 20W output power at antenna interface (per antenna, per sector) | 900 | BB CoC v4.1, Tier 2013 (p. 34) |
| MBH Aggregator Lv1 | - | 648 per card slot | ALU 7750 SR12 |
| MBH Aggregator Lv2 | - | 648 per card slot | ALU 7750 SR12 |
| 2G/BSC | Capacity > 25k erlangs, up to 4 200 BTS sectors | 4000 | NSN Flexi BSC |
| 3G/RNC | Up to 51k erlangs, 5100 cells (=sectors), 1700 NodeBs, 6.4 Gbit/s throughput | 10k | Motorola Horizon RAN controller |
| HNB GW | - | 800 | Same value of WiFi Access Gateway has been used (hint by CTTC) |

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| | | | |
|--------------|---|------|--|
| HeNB GW | - | 800 | Same value of WiFi Access Gateway has been used (hint by CTTC) |
| MASG | - | 100 | RAD ACE-3400 |
| IP-Sec GW | - | 7500 | Cisco SRX5800 |
| 2G/3G - MSC | - | 4000 | EU Strategic Research Agenda, e-mobility, Dec. 2008 |
| 2G/3G - SGSN | - | 5000 | BMW project ComGreen (results May 2011) |
| 2G/3G - GGSN | - | 2800 | BMW project ComGreen (results May 2011) |
| 2G/HLR | - | 4000 | BMW project ComGreen (results May 2011) |
| EPC – MME | - | 5000 | BMW project ComGreen (results May 2011) |
| EPC - S-GW | - | 3800 | BMW project ComGreen (results May 2011) |
| EPC - P-GW | - | 3800 | BMW project ComGreen (results May 2011) |
| HSS | - | 4000 | BMW project ComGreen (results May 2011) |
| PCRF | - | 3600 | BMW project ComGreen (results May 2011) |

Table 22: Network equipment list with power consumption values for Mobile networks

11.3 Annex III: Overview of standardization initiatives in the field of Energy Efficiency

Several relevant bodies require increased energy efficiency for all ICT sectors, including transport, access and aggregation. These bodies include:

- Large network operators
- Legislation
- International Standardization Bodies (ISBs)

Several large network operators are amongst the leading-edge drivers behind increasing telecommunications energy efficiency. Such operators need improved energy efficiency because, for many of their sites, a massive increase of energy consumption is not tolerable. Several aspects drive the respective work. Some of the energy-consumption limitations, in turn, are determined by site layout, including Heating, Ventilation, Air Conditioning (HVAC), and also by the difficulties that utilities providers have with massively increasing energy supply to certain sites. The second driver for many network operators is their CSR framework (Corporate Social Responsibility). Finally, increased energy efficiency significantly contributes to OPEX savings. Amongst the most advanced network operators in these respects are NTT (Japan), Verizon (US), and BT (UK).

Legislation and standardization also provide guidelines or requirements regarding energy efficiency of telecommunications equipment. An example is the European Broadband Code of Conduct [24], which is to be applied to broadband access. Other examples include ITU-T Recommendations L.1300 on green data centres [25], and L.1310 on energy efficiency metrics and measurement methods for telecommunication equipment [26].

An overview on energy efficiency in telecom optical networks is also given in [27].

IEEE has developed a standard on energy-efficient Ethernet, IEEE 802.3az [28]. Its objectives are to define mechanisms to reduce power consumption during periods of low link utilization for the PHYs, to define a protocol to coordinate transitions to or from a lower level of power consumption which do not change the link status or drop frames, and to define a 10-Mb/s PHY with a reduced transmit amplitude requirement so that power consumption can be decreased. This effort was completed in September 2010.

The ETSI Green Agenda is one of ETSI's major strategic topics [29]. In this context, standards for Measurement Methods for Power Consumption in Transport Telecommunication Networks and Measurement Methods and Limits for Power Consumption in Broadband Telecommunication Networks Equipment (DSL and PON OLTs) have been developed [30], [31].

The ECR (Energy Consumption Rating) Initiative has been initiated in 2008. Current members include Ixia and Juniper. They have defined a document covering Metrics, Test Procedure and Measurement Methodology for Energy and Performance Assessment of Network and Telecom Equipment [32].

Requirements more relevant to transport, access and aggregation networks can be found in the ICT Ecology Guideline Council guidelines [27] and in the energy-

efficiency requirements [34], [28] from Verizon, which in turn are based on the ANSI ATIS-0600015.0x.2009 standards series [35], [29]. These requirements define the so-called Telecommunications Equipment Energy-Efficiency Ratings, or TEEERs. (The ANSI version is called TEER, refer to ATIS-0600015.02.2009 for transport equipment). The respective TEEERs are applied by large network operators like NTT in Japan or Verizon in the US. Besides defining TEER values, the ATIS standards series also defines Methodologies for Measurement and Reporting in the context of energy efficiency for telecommunications equipment.

The ATIS TEER is adopted by Verizon for their TEEER metric quantification. This is part of the Verizon energy-efficiency initiative and is described in their Technical Purchasing Requirements, VZ.TPR.9205 [33]. The purpose of this program is to set Verizon technical purchasing requirements and to foster the development of energy-efficient telecom equipment, thereby reducing GHG (green-house gas) emissions. TEEER is defined as an average rating of the power consumption of equipment at multiple utilization levels. TEEER metric applies to all new equipment purchased by Verizon after January 1, 2009. It is also worth mentioning that ITU-T Recommendation L.1310 [26] and ETSI Standard ES 203 184 [30] both refer to the ANSI ATIS-0600015.0x.2009 standards series.

In TEEER documents, *Normative References* (N.R.) are defined for each configuration. These are the energy-efficiency values, which at least have to be achieved by the system under ranking consideration. Based on the N.R., five energy-efficiency classes (★ to ★★★★★) have been defined. The ★-class just achieves the N.R., the ★★★★★-class most clearly over-achieves the N.R. requirement. The document also defines how the related Figure-of-Merit (FoM) is to be calculated. Here, a higher FoM relates to better results (higher ★-class).

TEEER examples for WDM transport equipment, according to ICT Ecology Guideline Council guidelines [33] and to be applied from the end of 2012 (e.g., by Japan's NTT), are given in Table 23 [33].

| Equipment | FoM | N.R. | Achieve N.R. by | Notes |
|-----------|--|------|-----------------|---|
| DWDM | Max. throughput [Gb/s] / AVG PC [W] | 0.32 | End of 2012 | AVG PC = (PC @ full wavelengths + PC @ 1 wavelength) / 2 |
| CWDM | | 0.48 | | |

Table 23: WDM TEEER (AVG PC: Average Power Consumption)

The ICT guidelines [33] also state specific (WDM) configurations, which have to be rated. For example, specific static point-to-point DWDM and reconfigurable (ROADM-based) DWDM configurations comprising 80-channels, 10-Gb/s systems are specified. Today, [33] only states configurations for 80 × 10-Gb/s DWDM, and CWDM with 40 Gbps total capacity. However, it is very likely that Normative References will be added soon for coherent 100-Gb/s systems. It is also likely that the respective requirements will be applied (in Japan, by NTT, similarly for example by Verizon in the US) during the course of 2013.

Similar numbers for broadband routers, Layer-2 switches, PONs (Passive Optical Networks), broadband wireless equipment (WiMax, LTE), servers, storage equipment, and PSUs (Power-Supply Units) can be found in the same document. The respective TEEER definitions are discussed hereinafter in more detail since they

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pose more stringent requirements as compared to the ANSI ATIS series [35], combined with the Verizon requirements [34].

Table 24 [33] lists the requirements and definitions for PON OLTs and ONUs. The values are applicable to GE-PON. TEEER definitions for other PON types are still missing. Note that in particular for GE-PON ONUs, maximum (average) power consumption is defined.

| Equipment | FoM | N.R. | Achieve N.R. by | Notes |
|--------------|------------------------------------|------|-----------------|---|
| OLT (AC) | AVG PC [W] / total number of lines | 0.46 | End of 2012 | AVG. PC = (P100 + P50 + P0) / 3 Total number of lines = total number of IF ports × no. of PON branches |
| OLT (DC) | | 0.42 | | |
| ONU 100 Mb/s | AVG PC [W] | 3.68 | | |
| ONU 1 Gb/s | | 4.45 | | |

Table 24: GE-PON TEEER (AVG PC: Average Power Consumption)

Table 25 [33] summarizes the TEEER requirements for Layer-2 box-type switches. Here, various management approaches for the switches (SNMP, web-based, w/o) have been differentiated.

| Equipment | FoM | N.R. | Achieve N.R. by | Notes |
|--------------------|---|------------------------|-----------------|--|
| Type B w/ SNMP | PC [W] / maximum effective transmission rate (Gb/s) | $(\alpha n + P_n) / T$ | End of 2011 | αn : sum of PC of port and fixed PC P_n : additional PC of PoE T : maximum effective transmission rate n : Category (B, C, D). FoM and N.R. shall be compliant with top runner assessment standards. |
| Type C w/ webmgmt. | | | | |
| Type D w/o mgmt. | | | | |

Table 25: Layer-2 switch (box type) TEEER (AVG PC: Average Power Consumption)

Regarding Table 25, it has to be noted that only box-type switches, i.e., switches with single or few 100-Mbps and/or 1-Gbps ports are considered. This does not cover large aggregation switches.

Table 26 [33] lists the TEEER requirements with regard to LTE base stations (BS), as currently defined in [33]. Segregated and integrated BSs have been considered.

| Equipment | FoM | N.R. | Achieve N.R. by | Notes |
|-----------------------------|---|-------|-----------------|--|
| BS (segregated 20 W device) | $\Sigma P_n / \{ P_{idle} \times (1-\alpha) + P_{max} \times \alpha \}$ | 20.32 | End of 2013 | P_n : power transmission by antenna terminal n (W) P_{idle} : primary supply-side power when there is no load (W) P_{max} : primary supply-side power at maximum transmission (W) α : average daily down link transmission traffic rate. |
| BS (integrated 20 W device) | | 13.77 | | |
| BS (segregated 10 W device) | | 6.91 | | |

Table 26: LTE base station (BS) TEEER (AVG PC: Average Power Consumption)

Reference [33] currently provides the most comprehensive list of telecommunications-equipment energy-efficiency ratings. As such, it provides valuable insight how such TEEER values can be constructed. However, even in its latest version, the document is not covering all relevant equipment in an end-to-end network. Complements are needed, e.g., with respect to large switches, 100-Gbps WDM transport, or consumer end devices (for example, smart phones).



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According to [37], Green IT should be separated into the aspects of *Green-by-IT* and *Green-of-IT*. *Green-by-IT* relates to saving which are achieved in areas other than IT, and which are enabled by intelligent use of IT. Examples are reductions in truck rolls. *Green-of-IT* relates to the energy efficiency of the ICT gear itself. Obviously, increased TEEER contributes to better *Green-of-IT*. Note, that much higher savings regarding CO₂ production are associated with the area of *Green-by-IT*, i.e., savings in carbon footprint enabled by ICT, and especially telecommunications. The telecommunications-related CO₂ abatement for 2020 is estimated to be five times as high as the direct ICT contribution to CO₂ production.[20]

Regarding total power consumption (or CO₂ footprint), the HVAC contribution in the respective PoP or central office has to be added. In large sites (e.g., data centers), the HVAC contribution to total power consumption can be in the range of 25...50% [38].

11.4 Annex IV: Business Ecosystem terminology

11.4.1 Business ecosystem

The term “business ecosystem” was introduced by Moore (1993) in a McKinsey Award-winning article in Harvard Business Review: “Predators and Prey: A new Ecology of Competition” [70]. In this article, Moore argued for an ecological approach to management, where the modern business is not viewed as a member of single industry, but rather part of a business ecosystem that crosses a variety of industries. Companies within a business ecosystem are said to “co-evolve capabilities around a new innovation: they work cooperatively and competitively to support new products, satisfy customer needs and eventually incorporate the next round of innovation” [70].

In a follow-up book (1996), Moore further developed this idea (see also chapter 8.1.1.1). Moore argued that an ecosystem is a dynamic system in which coexist different members and activities, these members have their characteristics and dynamics, with evolving relationships, conditioning thus the life in the ecosystem. Therefore the life cycle of a business ecosystem can be divided into four stages:

- **Birth stage**: in the birth stage, the business ecosystem needs to do more than just satisfying customers. Strengthening business is also necessary.
- **Expansion**: in this stage, the scale-up potential of the business concept is judged and tested with feedback by the parties concerned.
- **Leadership stage**: in the leadership stage, the business ecosystem reaches stability and high profitability. New business models are tested and implemented.
- **Self-renewal or death**: this stage is caused by the threat of rising new ecosystems.

In 2004 lansiti and Levien refined the idea based on the approach that a business ecosystem can also be understood as a network of specialized and complementary opportunity niches [72]: “A firm that takes an action without understanding the impact on the ecosystem as a whole is ignoring the reality of the networked environment in which it operates”.

As in the biological ecosystem, “each member of a business ecosystem ultimately shares the fate of the network as a whole, regardless of that member’s apparent strength” [73].

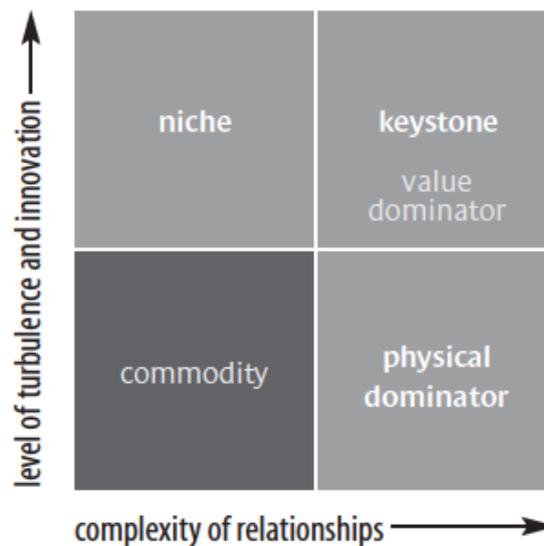
lansiti and Levien introduce four different roles that organizations can take in business ecosystems (see Figure 89):

- **Keystones** exercise leadership to their own benefit, but also to the benefit of other ecosystem members. Keystones create platforms of services, tools or technologies that other members of the ecosystem can use to enhance their own performance. “They share throughout the ecosystem much of the value they have created, balancing their generosity with the need to keep some of that value for themselves”.
- **Dominators** instead are acting in a more traditional way, exploiting a critical position to either take over the network or more insidiously, drain value from it, eventually destroying the whole ecosystem.

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- Niche players are the kind of companies that serve as the enablers and have a great impact on the whole system. According to lansiti and Levien, niche players make up the largest mass of the business ecosystem.
- Commodity: when working in a mature and stable environment and operate relatively independently from other organisations, no ecosystem strategy needed, as long as there are no changes in the market.

Figure 89 shows the positions of the four different roles between the level of turbulence and innovation and the complexity of relationships:



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Figure 89: Match of strategy and environment

Firms occupying influential hub positions (i.e., network nodes that are highly connected to other nodes) can adopt either a keystone role or a dominator role.

Roles in an ecosystem are not static: A company may be a keystone in one domain and a dominator or a niche player in others. And niche players may eventually become the keystone for their own new ecosystems.

According to them there are three critical success factors of a business ecosystem:

- Productivity is a very basic factor, which, at some point, will define the success of any kind of business.
- Any business ecosystem should be robust. Robustness in natural ecosystems means capabilities of surviving when shocks from inside or outside the ecosystem threaten to destroy it. In business life this means drawing competitive advantage from many sources and having the ability to transform when the environment changes.
- Ability to create niches and opportunities for new firms: the success of a business ecosystem is based on competition and cooperation. The ability of the members to be more cooperative presents some opportunities for new firms and contributes to the expansion of the ecosystem.

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Since the first introduction of the term “business ecosystem” in management literature through Moore in 1993 [70], over the past decades extensive research has been done on this topic, highlighting the different aspects [74]: “Some have focused on understanding coordination among partners in exchange networks that are characterized by simultaneous cooperation and competition (Brandenburger and Nalebuff, 1997; Afuah, 2000). Further studies in this vein explore the challenges that arise when incentives across the ecosystem are not aligned (Casadesus- Masanell and Yoffie, 2007), the role of established relationships with ecosystem partners in shaping firms’ motivations to compete for different market segments (Christensen and Rosenbloom, 1995), and the activities that focal firms undertake to induce exchange partners to favour their specific technology platforms (Gawer and Cusumano, 2002).”

Business ecosystems can provide substantial opportunities for participating companies. However, these opportunities come with a catch – the business model of the company must fit together with the business models of the other companies in the ecosystem, so that the business model provides value for both the company and the market ecosystem [75] as represented in Figure 90 (the fields in the triangle represent the nine fields of the BM Canvas):

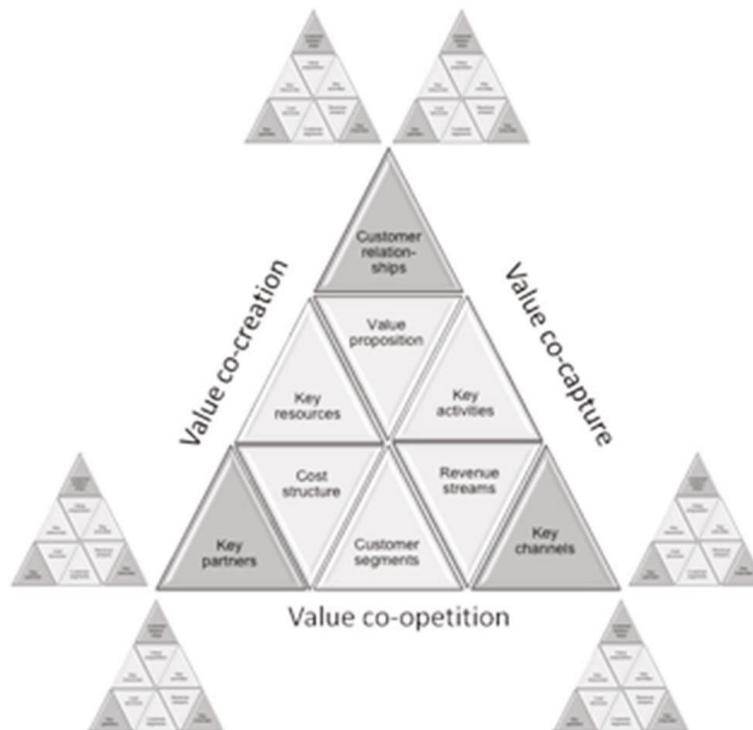


Figure 90: Business Model based Ecosystem

Thus it can be assumed that the ecosystem is held together by the cooperative and competitive interactions between different companies. When trying to determine the connections between different firms within the ecosystem, the business model can be a useful concept, using the approach that companies are connected with each other through their business models. The evolution of the ecosystem occurs when companies synergistically adjust their business models towards an optimal fit (see Figure 90) [76].

In a recently published paper [75], it was argued that business ecosystems could provide substantial opportunities for participating companies. However, there is a catch – the business model of the company must match with the business models of the other companies in the ecosystem, so that the business model provides value for both the company and the market ecosystem.

However, as the University of Cambridge argued in a recent paper, few tools exist for the analysis of firm strategies in ecosystems [77]

And in a recent conference of the Academy of Management in August 2013 [112] it was argued, "...much attention, rightly so in our opinion, has been given to value creation and value capture. Yet, it remains a challenge to systematically measure how value is created, captured, or migrates among firms. The ecosystem construct encompasses multiple domains or levels of analysis, involving firms or other actors operating in one or more industries. This raises the question of how we address these different domains and levels in our research designs."

11.4.2 Business Model

"At a general level, the business model has been referred to as a *statement* (Stewart & Zhao, 2000), a *description* (Applegate, 2000; Weill & Vitale, 2001), a *representation* (Morris, Schindehutte, & Allen, 2005; Shafer, Smith, & Linder, 2005), an *architecture* (Dubosson-Torbay, Osterwalder, & Pigneur, 2002; Timmers, 1998), a *conceptual tool or model* (George & Bock, 2009; Osterwalder, 2004; Osterwalder, Pigneur, & Tucci, 2005), a *structural template* (Amit & Zott, 2001), a *method* (Afuah & Tucci, 2001), a *framework* (Afuah, 2004), a *pattern* (Brousseau & Penard, 2006), and a *set* (Seelos & Mair, 2007)" [78].

Although up to now, no common definition in literature has been reached, we can refer to one of the most widely influential definitions from Zott et al. in 2001 [79]:

"A business model depicts the content, structure, and governance of transactions designed so as to create value through the exploitation of business opportunities".

And Zott added in 2011 [78]: "One important role of the business model could consist of unlocking the value potential embedded in new technologies and converting it into market outcomes".

This value-centric logic is the common thread between the business model elements, as far as the elements should be organized in a way that maximizes value creation and capture; thus means, that the success of the business depends on the firms' ability to maximize customer satisfaction (value creation) and aggregate profits in return (value capture) [76].

In the absence of a commonly accepted definition, - as Zott and Amit [78] argue: "scholars' attempts at conceptual refinement have helped clarify at least what a business model is *not*":

- First, the business model does not involve a linear mechanism for value creation from suppliers to the firm to its customers. Value creation through business models involves a more complex, interconnected set of exchange relationships and activities among multiple players.

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- Second, the business model is not the same as product market strategy (i.e., it does not refer to firm positioning in product markets based on differentiation or cost leadership in certain activities) or corporate strategy (i.e., it does not describe or prescribe the areas of business in which a firm becomes active).
- Third, the business model cannot be reduced to issues that concern the internal organization of firms (e.g., control mechanisms, incentive systems); activity systems, even though centred on a focal firm, typically span firm boundaries. However, the business model can be a source of competitive advantage.

In another approach chosen by Chesbrough and Rosenbloom [80] to define the business model, they suggested the functions a business model fulfils:

- Articulates the value proposition (i.e., the value created for users by an offering based on technology);
- Identifies a market segment and specify the revenue generation mechanism (i.e., users to whom technology is useful and for what purpose);
- Defines the structure of the value chain required to create and distribute the offering and complementary assets needed to support position in the chain;
- Details the revenue mechanism(s) by which the firm will be paid for the offering;
- Estimates the cost structure and profit potential (given value proposition and value chain structure);
- Describes the position of the firm within the value network linking suppliers and customers (incl. identifying potential complementors and competitors); and
- Formulates the competitive strategy by which the innovating firm will gain and hold advantage over rivals.

In 2004, Osterwalder developed the Business Model Canvas (see subchapter 8.1.1.2), using a painter's canvas to rebuild a real business by dividing it into nine areas:

- The key partners: the cooperation with other companies (key partners) in order to efficiently offer and commercialize the value; the key partnerships are connected with the key resources and key activities (can be acquired and utilized both internally and externally);
- The key activities: outlines the activities to produce the value and to operate successfully;
- The key resources: the necessary competencies and resources to execute the activities;
- The value proposition: gives an overall view of products, services and their benefits and the value created through the offering, which can be quantitative (e.g. price, time) or qualitative (e.g. customer experience);
- The customer relationships: shows the different links established with customers;
- The channels: defines the means to get in touch with customers to deliver the value proposition;
- The customers segments: the groups of customers targeted by the offer, based on the distinct channels used to reach them;

- The cost structure: sums up the monetary consequences of the means employed (implications for the business model);
- The revenue streams: shows the way a company makes money through a variety of revenue flows (the earning logic and pricing model).

A comprehensive overview about existing literature as well as analysis of Business models has been provided – among others - by the ETICS [83] project as well as the Aarhus University [84] and ESADE Business School [85] in scientific papers that were presented during the AOM conference in August 2013.

A business model cannot be assessed in the abstract; its suitability can only be ascertained against a particular business environment or context. Neither business strategies nor business models can be properly classified without an assessment of the business environment; and the business environment itself is partially a choice variable; i.e. firms can both select a business environment, and be selected by it and they can also shape their environment. [81]

11.4.3 Value Chain

A first introduction to the value chain and the related figure can be found in subchapter 8.1.1.4.

Value chain analysis describes the activities within and around an organization, and relates them to an analysis of the competitive strength of the organization. Therefore, it evaluates which value each particular activity adds to the organizations products or services.

This idea was built upon the insight that an organization is more than a random compilation of machinery, equipment, people and money. Only if these things are arranged into systems and systematic activates it will become possible to produce something for which customers are willing to pay a price. Porter argues that the ability to perform particular activities and to manage the linkages between these activities is a source of competitive advantage.

Porter distinguishes between primary activities and support activities. Primary activities are directly concerned with the creation or delivery of a product or service. They can be grouped into five main areas: inbound logistics, operations, outbound logistics, marketing and sales, and service. Each of these primary activities is linked to support activities that help to improve their effectiveness or efficiency.

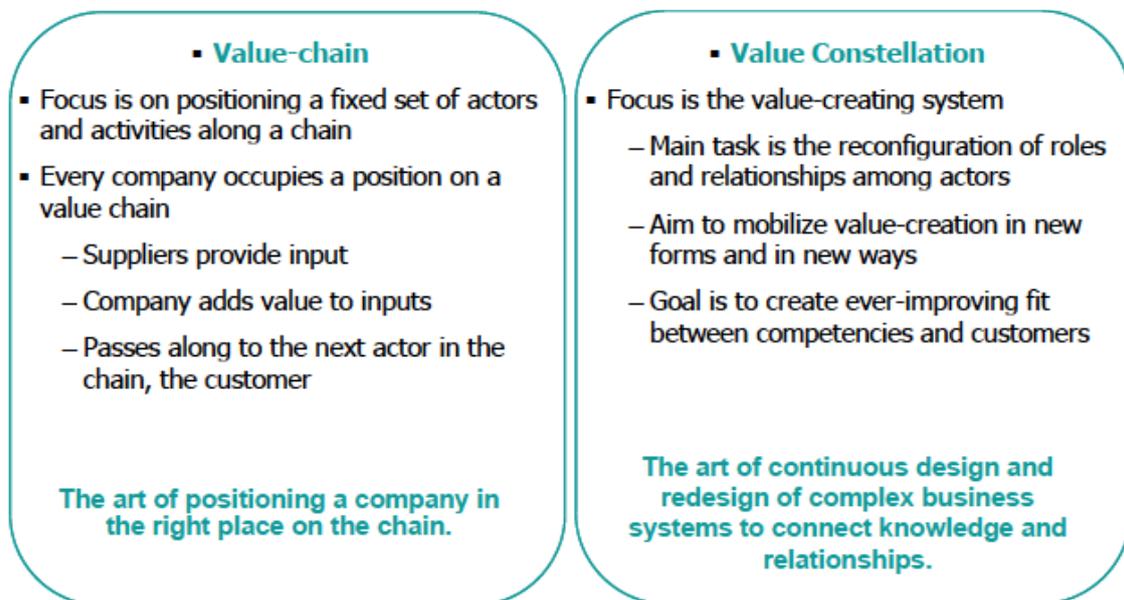
The value chain framework analyses value creation at the firm level, identifying the activities of the firm and their economic implications. Porter defines values as “the amount, buyers are willing to pay for what a firm provides them” [91]. Value can be created by differentiation along every step of the value chain, through activities resulting in products and services that lower buyers’ costs or raise buyers’ performance - add value to the product emphasising cost optimisation and value maximisation.

In a value chain, competitive advantages can be achieved through cost advantages or differentiation potential, the foundation being optimization and coordination of value-adding activities and their links to one another.

In terms of business models, the value chain is a restricted analytic tool for value creation primarily relevant to industrial producing companies [92].

11.4.4 Value Network

An initial explanation has already been given in subchapter 8.1.2.1. Value constellation is a network-based value creation model that identifies relationships between internal and external actors [92]. The concept was introduced by Normann and Ramirez in 1993, who had already identified the potential of networked value creation in their book “From Value Chain to Value Constellation: Designing Interactive Strategy” [95] (see Figure 91).



Normann, R. & Ramirez, R. (1993). From value chain to value constellation: Designing interactive strategy. HBR, 71, 65 – 77.

Figure 91: From value chain to value constellation

The new logic of value presents companies with three strategic implications [95]:

- In a world where value occurs not in sequential chains but in complex constellations, the goal of business is not so much to make or do something of value for customers as it is to mobilise customers to take advantage of proffered density and create value *for themselves*.
- Second, what is true for individual offerings is also true for entire value-creating systems. As potential offerings become more complex and varied, so do the relationships necessary to produce them. A single company rarely provides everything anymore. Instead, the most attractive offerings involve customers and suppliers, allies and business partners, in new combinations. As a result, a company’s principal strategy task is the reconfiguration of its relationships and business systems.
- Third, if the key to creating value is co-produced offerings that mobilise customers, then the only true source of competitive advantage is the ability to conceive the entire value-creating system and make it work. To win, a company must write the script, mobilise and train the players and make the customers the



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final arbiter of success or failure. To go on winning, a company must create a dialogue with its customers in order to repeat this performance over and over again and keep its offerings competitive.

According to Normann and Ramirez, “Companies create value when they make not only their offerings more intelligent but also their customers (and suppliers) more intelligent as well. To do this, companies must continuously reassess and redesign their competencies and relationships in order to keep their value -- creating systems malleable, fresh, and responsive. In the new logic of value, this dialogue between competencies and customers explains the survival and success of some companies and the decline and failure of others”.

The creation of fixed-mobile convergence architecture in COMBO will enable network operators to generate new services by so creating more value for the customers as well as for themselves.

In a recent paper about cloud businesses an overview over the differences between business ecosystems and value networks was provided, especially focusing on how they are defined, function and how they evolve: [90].

- “Business ecosystems are focused on renewal and innovation, or novelty. Through integration of resources, the utilization of complementary capabilities, and contributions, they strive for constant innovation trajectories to gain ‘the only true sustainable (competitive) advantage’.
- Value networks tend to stress the capture of value and are intentionally set-up to increase their efficiency and consequently the profits for their members through meeting customers’ needs better.”

A summary of the business ecosystem and value network concepts from [90] is presented in Table 27:

Assessment Framework and evaluation of state of the art technologies

| | Characteristic | Organic Business Ecosystems | Strategic/Value Networks |
|------------------------|-----------------------|--|---|
| What is it about? | Seminal works | Moore [6],[7],[8] Iansiti & Levien [13] Iansiti [14] | Normann & Ramirez [15] Nalebuff & Brandenburger [9] Parolini [16] Kothandaraman & Wilson [18] Möller & Rajala [10] Helander & Kukko [17] |
| | Theoretical framework | Ecology approach: resemblance to biological ecosystems | Strategic approach: value chain successor, value and strategy-oriented |
| | Core | Coevolution, joint value creation for innovation, interplay of collaborative and competitive strategies | Intentionally built, customer-oriented co-creation of value with competition only between networks |
| How is it constructed? | Structure | Evolving, complex Sometimes highly modular | Customer-centered and distinguishable from other networks in various configurations |
| | Boundaries | Crosses industries Fluid boundaries | Subjective borders by means of defined influence range |
| How does it work? | Governance | Shifts in leadership in and between ecosystems over time Self-organizing, decentralized decision-making | One or few managing and leading actors Hierarchical and self-organizational governance possible |
| | Roles | Different roles in different domains, may change Leaders, niche players, financing bodies | Supporting, realizing, consuming, and external transactions managing roles |
| | Actors | Actor change possible E.g. producers, customers, partners, innovators, financiers, governmental institutions, competitors, a variety of other interested bodies | Suppliers, intermediaries, system integrators, and end-customers; All network actors can be both complementors and/or competitors |
| How does it evolve? | Change | Constant coevolution Evolutionary stages: birth, expansion, leadership, self-renewal/death | According to the degree of stability, value networks can move from emerging to renewing to current networks |

Table 27: Summary of the Business Ecosystem and Value Network concepts

12 Glossary

| Acronym / Abbreviations | Brief description |
|-------------------------|--|
| 3GPP | 3rd Generation Partnership Project |
| AAA | Authentication Authorization and Accounting |
| ADSL | Asymmetric digital subscriber line |
| ANSI | American National Standards Institute |
| AP | Access Point |
| ASIC | Application-Specific Integrated Circuit |
| ATIS | Alliance for Telecommunications Industry Solutions |
| ATM | Asynchronous Transfer Mode |
| AWG | Arrayed Waveguide Grating |
| BBU | Base Band Unit |
| BNG | Broadband Network Gateway |
| BRAS | Broadband Remote Access Server |
| BSC | Base Station Controller |
| BSS | Base Station Subsystem |
| BTS | Base Transceiver Station |
| CAPEX | Capital Expenses |
| CO | Central Office |
| CPE | Customer Premises Equipment |
| CPRI | Common Public Radio Interface |
| CWDM | Coarse Wavelength Division Multiplexing |
| CSG | Cell Site Gateway |
| CSR | Corporate Social Responsibility |
| DCN | Data Communication Network |

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| | |
|---------|---|
| DL | Downlink |
| D-RoF | Digital Radio Over Fiber |
| DSL | Digital Subscriber Line |
| DSLAM | Digital Subscriber Line Access Multiplexer |
| DSP | Digital Sensor Processor |
| DWDM | Dense Wavelength Division Multiplexing |
| EHF | Extremely High Frequency |
| EMS | Electronic Message System |
| eNB | Evolved NodeB |
| EPC | Evolved Packet Core |
| EPON | Ethernet Passive Optical Network |
| EPS | Evolved Packet System |
| ETSI | European Telecommunications Standards Institute |
| E-UTRAN | Evolved Universal Terrestrial Access Network |
| FBB | Fixed Broadband |
| FMC | Fixed Mobile Convergence |
| FPGA | Field Programmable Gate Array |
| FSAN | Full Service Access Network |
| FTTB | Fibre to the Building |
| FTTC | Fibre to the Cabinet |
| FTTEx | Fibre to the Exchange |
| FTTH | Fibre to the Home |
| FTTx | Fibre to the X |
| GbE | Gigabit Ethernet |

Assessment Framework and evaluation of state of the art technologies

| | |
|-------|---|
| Gbps | Gigabit per second |
| GGSN | Gateway GPRS Support Node |
| GHG | Green House Gas |
| GIP | |
| GPON | Gigabit Passive Optical Network |
| GPRS | General Packet Radio Services |
| GSM | Global System for Mobile Communications |
| GW | Gateway |
| HDSL | High Data Rate Digital Subscriber Line |
| HeNB | Home eNode B |
| HLR | Home Location Register |
| HNB | Home Node B |
| HSS | Home Subscriber Server |
| HVAC | Heating, Ventilation, Air Conditioning |
| ICT | Information and Communication Technologies |
| IEEE | Institute of Electrical and Electronics Engineers |
| IP | Internet Protocol |
| ISDN | Integrated Services Digital Network |
| ITU-T | International Telecommunications Union - Telecommunications Standardisation Sector |
| LAN | Local Area Network |
| LER | Label Edge Router |
| LNS | L2TP Network Server |
| LTE | Long Term Evolution |
| MASG | Mobile Aggregation Site Gateway |

Assessment Framework and evaluation of state of the art technologies

| | |
|--------|--|
| MBB | Mobile Broadband |
| MBH | Mobile Backhaul |
| Mbps | Megabits per second |
| MDT | Mean-Down-Time |
| MME | Mobility Management Entity |
| MMS | Multimedia Messaging System |
| MNO | Mobile Network Operator |
| MPLS | Multiprotocol Label Switching |
| MSC | Mobile Switching Center |
| MTBF | Mean-Time-Between-Failure |
| MVNO | Mobile Virtual Network Operator |
| NG-POP | Next Generation Point of Presence |
| NMS | Network Management System |
| OADM | Optical Add-Drop Multiplexer |
| OAM | Operation, Administration & Maintenance |
| ODF | Optical Distribution Frame |
| ODN | Optical Distribution Network |
| OECD | Organisation for Economic Co-operation and Development |
| OLT | Optical Line Termination |
| ONT | Optical Network Terminal |
| ONU | Optical Network Unit |
| OPEX | Operational Expenses |
| OSM | OpenStreetMap |
| OSS | Operations Support System |

| | |
|-------|--|
| OTT | Over-The-Top |
| PCRF | Policy and Charging Rules Function |
| P-GW | Packet Data Network (PDN) Gateway |
| PON | Passive Optical Network |
| PtP | Point-to-Point |
| POP | Point of Presence |
| pWDM | Passive WDM (Wavelength Division Multiplexing) |
| QoS | Quality of Service |
| RAN | Radio Access Network |
| RE | Reach Extender |
| RGW | Residential Gateway |
| RNC | Radio Network Controller |
| ROI | Return on investment |
| RRH | Remote Radio Head |
| SDH | Synchronous Digital Hierarchy |
| SDSL | Symmetric Digital Subscriber Line |
| SGSN | Serving GPRS Support Node |
| SHDSL | Single-Pair Highspeed Digital Subscriber Line |
| SHF | Super High Frequency |
| S-GW | Serving Gateway |
| SME | Small and Medium-sized Enterprises |
| SNMP | Simple Network Management Protocol |
| SONET | Synchronous Optical Networking |
| SSID | Service Set Identifier |

Assessment Framework and evaluation of state of the art technologies

| | |
|-------|---|
| STA | Station |
| STB | Set-Top Box |
| TDM | Time Division Multiplexing |
| TEER | Telecommunications Energy Efficiency Rating |
| UE | User Equipment |
| UHF | Ultra High Frequency |
| UL | Uplink |
| UMTS | Universal Mobile Telecommunication System |
| VDSL | Very high bitrate Digital Subscriber Line |
| WAP | Wireless Application Protocol |
| WDM | Wavelength Division Multiplexing |
| Wi-Fi | Wireless Fidelity (IEEE 802.11 wireless local area network) |
| WiMax | Worldwide Interoperability for Microwave Access |
| WSS | Wavelength Selective Switch |
| xDSL | DSL technologies |
| | |



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