Framework reference for fixed and mobile convergence

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. COMBO will target on an optimal and seamless quality of experience for the end user together with an optimized network infrastructure ensuring increased performance, reduced cost and reduced energy consumption.

COMBO WP2 provides the preliminary work for fixed, mobile, wireless and converged networks in order to put the basis for the remaining work packages.

This deliverable (D2.1) of Task 2.1 defines the reference framework for fixed and mobile networks and identifies important network use cases (UCs) relevant for convergence aspects between fixed, mobile and wireless (Wi-Fi) networks. The framework is based on the state of the art provided by Task 2.2, and it shows a high level view of the different network segments in today's fixed (including Wi-Fi) and mobile networks: customer premises, access, aggregation, and core. As a result of this assessment all necessary data like number of households, typical distances, number of fixed network sites, number of antenna sites etc. needed as common reference parameters are consolidated and provided for further studies e.g. in the architecture, and techno-economic work of COMBO.

Three basic areas of convergence between fixed and mobile networks (FMC area) are identified: access resource sharing, aggregation resource sharing, and operator cooperation. Across these three areas, eight UCs are focused for addressing structural and/or functional convergence.

Finally, the deliverable includes considerations on market aspects developed in collaboration with WP5 to provide an initial view on current markets and projections towards 2020. The data provided show the actual trends in the separated networks and the need for further convergence mainly driven by the exponential growth of data traffic not sustainable with current networks. This results in the necessity of changes

in the network types, taking care, at the same time, of cost minimization and the need for new revenue models.

The results of the different activities included in this task will feed current and future studies of other work packages, mainly:

- The reference framework is used to define the main common reference areas in which fixed and mobile networks can converge. Thus, D2.1 also provides reference parameters, such as number of households, reach distances, and number of sites, as an input to the techno-economic model that is developed in WP5 (that deals with the techno-economic assessment of current fixed and mobile networks and the proposed FMC architectures). Additionally, these reference parameters are an important WP3 input for the design of the network scenarios as a reference to current networks.
- Network use cases address the needs for functional and/or structural convergence and they are the pre-stage to identify the requirements and Key Performance Indicators (KPIs) for COMBO that will have to be defined in Task 2.4 of WP2. Network use cases are also provided as basis for the FMC architectures and network scenarios that are going to be specified within WP3, for the performance monitoring studies developed in WP4 and for the identification and preparation of future experimental demonstrators inside WP6.
- Both the reference framework and the network use cases will be used to define and model future converged fixed and mobile traffic scenarios in Task 2.3 of WP2.
- The initial analysis on market aspects provides an introduction to the today's market situation of fixed and mobile networks. Global figures on broadband technologies, number of subscriptions, services, the amount of traffic, the future telecommunication drivers and barriers and the first business considerations fed the assessment framework and the economic analysis included in WP5.

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1 Introduction

The work presented within this deliverable is performed within the Work Package 2 (WP2) of the COMBO project. WP2 covers topics such as reference framework and FMC network use case (UC) descriptions, fixed and mobile network evolution, FMC traffic modelling, and identification of FMC requirements and KPIs.

The present deliverable defines the reference framework for fixed and mobile networks with common area descriptions as a basis for the development of future FMC network architecture. Another main part proposes eight FMC network use cases, identifying for each use case today's situation, the goal, the research & innovation relevance and the opportunities for functional and/or structural convergence. Finally, an initial marketing analysis including regulatory aspects is performed.

The document is structured in several chapters. The main chapters are Chapter 2, 3 and 4:

- Chapter 2 describes the basic assumptions of the current fixed (including Wi-Fi) and mobile networks as reference framework in order to have a common reference across the whole project. Target is laying the foundation of the network structure and all necessary data for further definition of the work with respect to network architectures, topologies, and techno-economic assessment. Additionally a common understanding among the different partners about (1) the network segments, (2) the reference location points for potentially hosting equipment and executing network functionalities in the network, (3) the main network elements in both networks, and (4) the typical location of the network elements in today's networks and how they are typically deployed is established. The high-level view of the different network segments in today's fixed and mobile networks is presented and analysed. It starts from the customer premises and continues via the access and aggregation segments to the core network, which is connected to the Internet and other external data networks. The reference framework is then used to define the main common reference areas in which fixed and mobile networks can converge, using different reference parameters to describe them. Reference parameters, such as the number of households, reach distances, and the number of sites, will be needed in other WPs (for example in WP3 as a reference to current networks or in WP5 as input to the techno-economic model).
- Then, Chapter 3 describes a set of use cases that FMC networks shall enable. Three basic areas of convergence between fixed and mobile networks have been identified, spanning from the sharing of technologies in access and aggregation domains up to the end-to-end control and management of the whole network. Across these areas, (1) Access Resource Sharing, (2) Aggregation Resource Sharing, (3) Operator Cooperation, eight FMC use cases are addressed.
- Finally in Chapter 4, an initial overview of the main market drivers for the development of converged networks is given starting from the current market status of the different network types. Furthermore, based on the actual situation of

European regulation on Electronic Communication Markets possible implications on FMC will be presented.

2 Definition of the reference framework

Since COMBO is targeting convergence of fixed (including Wi-Fi) and mobile networks, this chapter describes the basic assumptions of the current fixed (including Wi-Fi) and mobile networks as reference framework in order to have a common reference across the whole project. The focus is on a description of typically available infrastructure like copper or fibre, locations available in the different networks to host equipment and functions and the overall network segments in today's fixed and mobile networks with their typical descriptive values.

The information provided in this chapter will be used for the following purposes:

- To serve as a common reference and data base across the whole project, especially for the technical assessment done in the architecture section and also the techno-economic and business analysis.
- To reach to a common understanding among the different partners about:
    - The network segments in current fixed and mobile networks.
    - The reference location points in the network, such as the Central Office (CO), main CO and core CO.
    - The main network elements (even the names to be used for these elements) in both networks.
    - The typical location of the network elements and how they are typically deployed (i.e. the reference parameters).

The reference framework (represented in

Figure 3 as the reference topology), together with the network use cases defined in Chapter 3, are the main outputs of D2.1. This information is complemented by the details about FMC traffic behaviour and traffic forecast developed in D2.3, the technology state of the art and evolution described in D2.2, the FMC requirements and KPIs specified in D2.4, use case descriptions and market analysis prepared in this document.

A high level view of the relation of these building blocks serving as common reference in the project is depicted in Figure 1. These building blocks are then further used in the architecture and performance analysis to understand where which equipment, functionality and monitoring entity could be hosted. Additionally the info is needed for the techno-economic assessment for network dimensioning e.g. according to traffic volume and service or network requirements. The reference framework contains:

- An initial description of today's network detailing their different segments and reference location points.
- The main network elements in each network segment for both fixed and mobile networks.
- A detailed description of the most relevant parameter (including a typical value) used in the deployment of the network elements.

- A unified network topology diagram with the current status of fixed and mobile networks. This topology contains a high-level view. It will be the starting point of a more detailed network topologies per network type developed in D3.1 of the WP3.

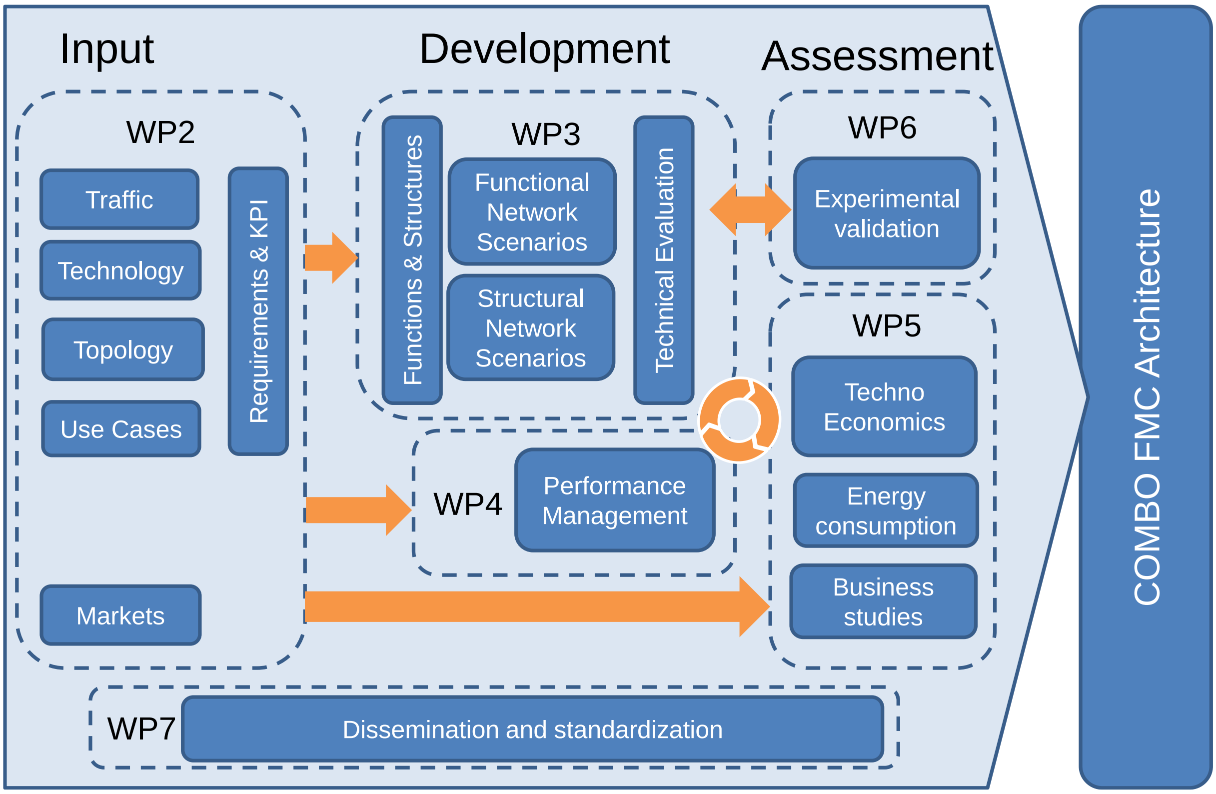


Figure 1: Work structure overview

2.1 Today's network segments

Figure 2 presents a high-level view of the different network segments in today's fixed and mobile networks. It starts from the customer premises and continues via the access and aggregation segments to the core network, which is connected to the Internet and other external data networks.

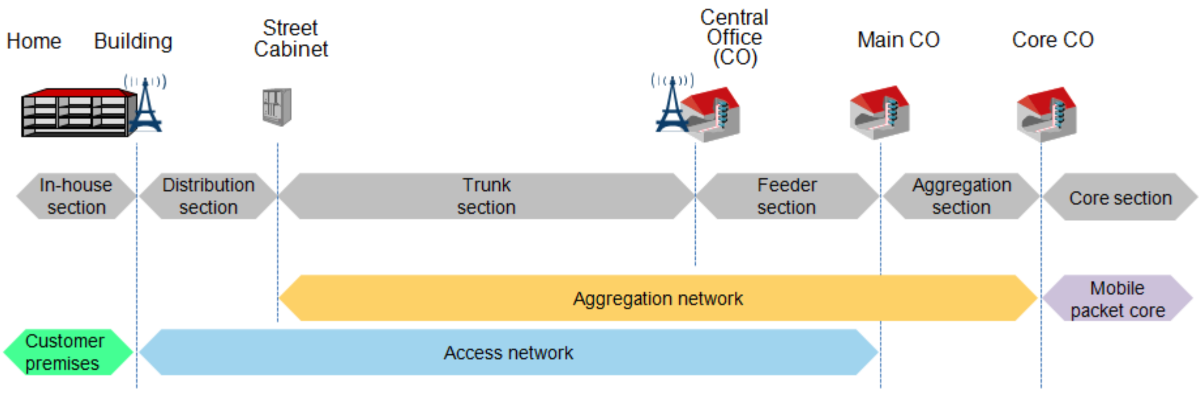


Figure 2: Today's network segments

Figure 2 includes some network reference location points in the upper part:

- The home or buildings represent the location of the customer premises where typically fixed networks provides connectivity. Additionally, antenna sites can be located closer to these buildings or between this point and the CO providing the coverage to mobile users.
- The street cabinet is the network point located in the outside network plan where some network aggregation is typically done. Street cabinet are not always deployed depending on the network topology used.
- The CO is a network operator building where traditional telco copper cables are terminated at the main distribution frame (MDF). It aggregates passive infrastructure routes (e.g. telco copper or fibre cable routes) of multiple street cabinets. The CO is also the building where the first telephone switch of the Public Switched Telephone Network (PSTN) was located in the past. Today, the CO often hosts xDSL or optical access system technologies (e.g. DSLAM, OLT). In addition, a macro cell base station can be installed in a CO in addition to other locations.
- The main CO is a network operator building of the aggregation network section that typically aggregates passive infrastructure routes (e.g. fibre cable routes) of multiple COs (a main CO can be also a CO). The main CO, typically, hosts aggregation network system technologies, e.g. Ethernet switches, ATM switches, WDM de-/multiplexer, etc. In addition, it hosts optical access system technology that is able to support the distance between end user and main CO, e.g. OLT. Typical distances can be found in section 7.1.3.
- The core CO is a network operator building that ends the aggregation network and connects it to the core network (a core CO can be also a main CO). The core network interconnects other aggregation networks and provides connectivity to other networks, such as Internet.

In the following sections are described the different kinds of network segments found in an end to end network architecture. In addition, an overview of the most important network elements including its functions is made in order to understand their current situation.

2.1.1 Customer premises network

Fixed residential network:

Most telecommunication operators are today offering Triple Play services over DSL (copper based) and/or FTTx (fibre) access networks. A typical triple play service bundle is described hereafter:

- Data service: High speed Internet access in the range of 2-200 Mb/s in the downlink and 0.5-50 Mb/s in the uplink. These speeds are supported by different types of access network architectures/technologies that go from ADSL up to FTTH(C).

- Video service: IPTV service that covers live TV (based on Multicast forwarding), video on demand (based on Unicast forwarding) and Digital Video Recorder. Voice service: Telephony provided by Voice over IP (VoIP).

The triple play service bundle requires specific boxes at customer premises, in order to control the access to the network and to guarantee the Quality of Service (QoS). These types of elements are operator managed devices that are installed in the customer's premises and that allow the operator to provide its services. The functional distribution in physical boxes depends on each operator's strategic and marketing choice. A common structural scenario supports 2 or 3 boxes at home:

- Residential Gateway (RGW) is the device that acts as the data gateway within the home or business allowing subscribers to have an Internet connection for all the user devices in the network. It terminates the network for xDSL or CATV networks, provides control to access to the network (e.g., Point-to-Point Protocol (PPP) credentials), supports telephony service, supports high speed Internet service, supports intra-LAN connectivity and supports different kinds of physical interfaces (e.g., Ethernet, Foreign eXchange Subscriber (FXS), Wi-Fi, Universal Serial Bus (USB), etc.).
- Optical Network Termination (ONT) for FTTH: It is a device that terminates the endpoint of an optical access line. The ONT adapts the access system PDUs to subscriber service interfaces.
- Set Top Box (STB) is a device, usually linked to the TV service that allows customers to consume TV contents over the fixed network.

All in all the main functions performed by these devices are related to offer certain services to subscribers. However, they also perform other functions that allow the operator to manage and monitor them. In addition to managed operator boxes, a collection of devices populate the home network; for example, Over-the-Top (OTT) boxes (TV, Wi-Fi, Machine-to-Machine), connected TVs, Network Attached Storage (NAS), Digital Medial Adapters (DMA), Personal Computers (PCs), tablets, etc.

Wireless residential network:

The customer premises network obviously includes the Wi-Fi terminals (laptops, smartphones, and tablets). Because of the relative proximity required for the connection of Wi-Fi terminals, the AP is also located in the customer premises and provides mainly a private access to the Internet and to the customer's local network resources (files server, printer, etc.). Regarding the elements that traditionally have composed Wi-Fi networks, they have been just Stations (Wi-Fi enabled devices) and APs (Access Points). In the beginning APs offered radio connectivity to Wi-Fi enabled devices and a Local Area Network (LAN) was set and configured behind them to obtain Internet access to devices. Over the time, the AP functionality has been integrated into several devices such as RGWs and as a result AP only devices have evolved to include additional functionalities.

The main functions of the AP are the SSID propagation of the networks offered and switching the traffic from the air interface to another interface towards the network gateway.

Moreover, a public Internet access may also be provided as a nomadic service to some users inside or around the customer premises.

That public access is provided by an operator-specific Service Set Identifier (SSID), besides the possible customer private SSID. And that operator-specific SSID may be broadcasted by different types of AP located in the customer premises:

- When the AP is hosted by a residential customer (i.e., in a B2C2C model, also named “community Wi-Fi”), it may be:
    - either a specific AP connected to the hosting customer’s RGW,
    - or the customer’s RGW itself.
- When the AP is hosted by a business customer (i.e., in a B2B2C model), it may also be a (or a set of) standard AP, possibly associated with a CAPWAP-like Access Controller to manage the user traffic.

In a distributed Wi-Fi architecture model for the public Internet access, the Wi-Fi IP edge may also be located in the customer premises. It is generally co-located with the AP for residential customers and may be a specific IP router for business customers.

Fixed Business network:

The SOHO business segment is similar to the residential segment. The operator provides to the customer a business gateway (with for example enhanced telephony features with a private IP phone exchange, an iPBX) and a network termination for FTTH.

Compared to the Residential market, the Enterprise market needs higher data rates and may require a point-to-point optical access. A common structural scenario supports two CPEs (Customer Premises Equipments) in the customer premise:

- A point-to-point line termination CPE
- A business router that provides IP VPN service termination

Mobile network:

Today’s mobile devices are mainly basic mobile phones, smartphones, tablets, laptops, desktop PCs, and routers with a built-in cellular modem or an external USB dongle. Mobile devices are typically connected to macro base stations, however, small base stations located indoor and outdoor also exists; these small base stations are called femtocells and they only provide a limited coverage on the order of 10s meters. Today, most devices support both 2G and 3G but, as the number of commercial LTE networks increases, more and more devices also support LTE.

2.1.2 Access network

Fixed network:

Historically, the copper access network is the network segment between the customer premises and the Central Office (CO) as shown in Figure 2.

The traditional copper access network consists of a distribution segment (between the customer premises and a street cabinet) and a trunk segment (between the street cabinet and the CO). The street cabinet hosts a distribution frame which splits a high capacity copper cable in several smaller cables to address groups of households. This street cabinet is a purely passive location, without any power supply.

Some representative elements located in the access network are the following ones:

- Digital Subscriber Line Access Multiplexer (DSLAM): located within one of the operator's offices, allows providing data access to RGWs using xDSL technologies.
- Optical Line Termination (OLT): it is the device that allows converting from the optical domain on broadband optical access side (customers) to optical (or electrical) domain on operator network side. As for DSLAM devices, a single OLT can aggregate thousands of digital lines.

The main functions performed by these devices are to offer and manage the access of several subscribers and to enable the transport of those communications towards the aggregation network.

With the introduction of FTTC technology, the street cabinet hosts a mini-DSLAM, which links each customer with VDSL or VDSL2 technology and aggregates the traffic towards the legacy CO on an optical fibre. In that case, the copper access network is reduced to the distribution segment.

With FTTH technology, where the fibre is deployed right up to the customer premise, a brand new optical access network is being built. GPON (point-to-multipoint) is the most common FTTH technology for residential customers whereas optical point-to-point access is mainly used for business customers.

In the case of an optical local loop, the street cabinet hosts an optical distribution frame and optical splitters. The distribution network delivers one fibre per customer between the customer premises and the street cabinet. The trunk network delivers shared fibres among several customers between the street cabinet and the CO. The split ratio depends on each operator's engineering rules (e.g., 1:8, 1:16, 1:32, 1:64, etc.)

Optical technologies allow extending the reach of access links, meaning that it is possible to bypass some historic copper COs. The main CO is a CO that is elected to terminate the optical access network; it hosts the Optical Line Termination (OLT) for GPON technology. The feeder segment of the access network transports transparently the traffic from the historic CO up to the main CO. It can be done, for example, with high capacity fibre cables thanks to WDM systems.

The optical access network is extended compared to the copper access network. It comprises a distribution segment, a trunk segment and a feeder segment.

Wi-Fi network:

The Wi-Fi access network consists of several APs that may be located in the customer premises (see Section 2.2.1) and also in some public areas to cover public places for providing a public Internet access (i.e., in a B2B2C or direct B2C model).

In that latter case, the Wi-Fi access network can be deployed and considered as a small cell access network.

Mobile network:

In order to allow the User Equipment (UE) to connect, the different generations of mobile networks provide different radio access stations. They take care of the following functions: indicate the network's presence to UEs, UE association, and transport of the UE's communications.

The mobile network elements in the access segment of the network are radio base stations supporting 2G, 3G, and LTE networks. A 2G base station is called Base Transceiver Station (BTS), a 3G base station is called NodeB, and an LTE base station is called evolved NodeB (eNodeB). In commercial networks, it is common that one base station site can handle multiple standards, e.g., 2G, 3G and LTE simultaneously. This is often referred as single Radio Access Network (RAN) access. The corresponding antennas and radio units of these base stations can often be seen on building rooftops in urban environments or on cell phone towers in rural areas.

2.1.3 Aggregation network

Fixed network:

By definition, the aggregation network is independent of the underlying access network technologies. The aggregation network transports traffic to the core CO

- from the CO for historic copper access network.
- from the street cabinet for copper access network with FTTC deployment.
- from the main CO for optical access network.

It should be noted that the feeder segment is the part of the aggregation network for copper access networks. For FTTH access network, the feeder segment belongs to the access network and may also belong to the aggregation network: the overlap happens when a transport technology aggregates GPON trunks in the feeder segment. The feeder segment also belongs to both access and aggregation networks if we consider a new FTTH deployment that coexists with the previous ADSL deployment.

Several different technologies may be considered for building the aggregation network: e.g. Ethernet transport, MPLS, and Optical Transport Network. The aggregation network can be flat or hierarchical; typically, it is a hub-and-spoke network that is built on a point-to-point and/or a ring physical topology.

Different access networks and different fixed services (residential, business) ideally use the same aggregation network. In practice, the operator may support different aggregation network technologies (e.g., ATM for first broadband deployments) corresponding to different generations of equipment. The operator may also support a dedicated aggregation network for business customers.

Some of the main elements located in the fixed aggregation network are:

- Aggregation Switch: this network element aggregates the traffic of multiple access network domains and forwards it typically on layer-2 using ATM or Ethernet. Depending on the needs the operator has, there may be more than one level of this type of device.
- Broadband Remote Access Server (BRAS): it is the element that behaves as the gateway for fixed access services. Additionally, it enforces the QoS and management policies in the network.

The aggregation network is typically the first network segment allowing for route diverse protection.

Wi-Fi network:

The only possible aggregation node being specific to the Wi-Fi architecture is the AP controller (i.e., a CAPWAP-like Access Controller), and only when it forwards the user traffic (beyond the AP management and the user Wi-Fi connection control).

It may be located in the business customer's premises (see Section 2.1.5), or in the operator's premises (cabinet or CO) for a public Internet access.

The Wi-Fi IP edge is co-located with that controller in a distributed Wi-Fi architecture model for a public Internet access.

The AP controller allows managing the different APs of a network or sub-network to improve the network performance and maintenance. These devices can be deployed on site for medium sized deployments or they can be centralised in the Wi-Fi core. The main functions of this device are to provide a configuration and management interface for the available networks, to remotely and automatically configure APs and to monitor the status of the networks, the APs and the users.

Mobile network:

In the aggregation network, one of the main functions to perform is the transport and aggregation of the mobile traffic of a great number of subscribers. The mobile traffic is typically tunnelled through the aggregation network that was built up for the fixed broadband access.

The mobile network elements in the aggregation segment are base station controllers supporting 2G and 3G. In 2G networks, the network element is called Base Station Controller (BSC) and in 3G it is called Radio Network Controller (RNC). In LTE, this functionality lies in the eNodeB, which belongs to the access network, as mentioned earlier. For LTE, this means one less logical node, resulting in a more flat network architecture (fewer nodes of different types) and simpler network operation.

The mobile network architecture has, in fact, two segments: a Radio Access Network (RAN) and a mobile core network. However, the RAN can be divided in two sub-segments:

a) an access segment from the UE to the base station and

b) an aggregation segment (including the backhaul network) from the base station via the BSC/RNC to the Serving GPRS Support Node (SGSN), or directly to the Serving Gateway (S-GW).

Here we choose to do this division in order to simplify the comparison with the fixed network architecture.

2.1.4 Core network

Fixed network:

The core network interconnects all core nodes together. It also connects:

- The core nodes to the operator's data centres, which host the service platforms (e.g., portal, IPTV service logic, and IMS), the management platforms (e.g., network managers, billing, and customer care), and some control platforms (e.g. DNS and AAA).
- The core nodes and the operator's data centres to other Application Service Providers (ASPs) and other Network Service Providers (NSPs) through peering points.

The core network is commonly a meshed network based on IP/MPLS and OTN technologies.

One of the main elements located in the core network of a fixed network is the Label Edge Router (LER). This network element is located at the border of a labelled network that allows marking certain traffic types in order to treat them with different priority levels (such as e.g. MPLS).

The network elements located in the core of a fixed network take care of the following functions managing user voice calls, routing user data traffic to the Internet, TV content distribution, user management, policy and charging, lawful interception and network monitoring and management.

Wi-Fi network:

The Wi-Fi core network is not defined in any standardization body, but in the case of a Wi-Fi architecture for a public Internet access, it shall at least include an AAA server (typically, a RADIUS server) to perform users authentication.

It should also include:

- a web portal server where the users are redirected to provide their credentials,
- and in the case of a centralized Wi-Fi architecture model, the Wi-Fi IP edge.

The current trend in the Wi-Fi sector is to offer carrier grade Wi-Fi solutions. For that purpose, a new element group has been introduced in the core network segment of operators. This element group, named the Wi-Fi core is the one that allows offering a centralised management of large scale Wi-Fi networks.

The functions covered by this element group are Authentication, Authorisation and Accounting (AAA), mobility enabler, policy and charging, network management and monitoring, lawful interception and roaming enabler.

Mobile network:

The mobile core is the platform that allows operating and managing the whole mobile network and its users. That way it manages the communications and the signalling of all the UEs.

The core of each of the mobile network generation is composed of several elements. Because of the network evolution new elements have appeared over the generations. All in all, the functions performed by the mobile core are voice call switching, data access gateway, user management, policy and charging and network monitoring and management. Typically in a national European country only a very few mobile core locations are established, which due to historical reasons are also not identical with fixed network core PoPs.

The mobile network elements in the core segment of the network are Mobile Switching Center (MSC), SGSN, Gateway GPRS Support Node (GGSN), Mobile Management Entity (MME), S-GW, and PDN Gateway (P-GW). The 2G/3G core segment can be divided into a circuit-switched and a packet-switched part. MSC is used in circuit-switched part, whereas the other network elements belong to the packet-switched part.

Looking further into the packet-switched part, SGSN and GGSN form the 2G/3G packet core network. MME for control plane, S-GW and P-GW for data plane, on the other hand, form the packet core network for LTE, which is called Evolved Packet Core (EPC). The GGSN and P-GW provide gateway functionality for Internet access to 2G/3G and LTE-enabled devices, respectively.

2.1.5 Overview of network elements

The following table gives an overview of the different network elements of the fixed, wireless and mobile network per network section.

Customer Premises Network	Access Network	Aggregation Network	Core Network
Fixed			
RGW STB CPE	DSLAM OLT Remote DSLAM	Ethernet switch Lv1 Ethernet switch Lv2 BRAS	LER
Wireless			
Private Wi-Fi STA AP			
Community Wi-Fi STA AP			Wi-Fi core element
Public Wi-Fi STA	AP	AP controller	Wi-Fi core element
Mobile			
HNB UE	2G BTS 3G Node B LTE eNodeB	BSC RNC HNB GW MBH aggregator Lv1 MBH aggregator Lv2	2G/3G MSC SGSN GGSN EPC MME S-GW P-GW

Table 1: Network elements related to network functions (today commonly deployed in European networks)

2.2 Network data

In the previous section, today's network segments have been analysed taking into consideration the current access and aggregation areas of fixed and mobile networks. This section uses the previous information to define the main common reference areas in which fixed and mobile networks can converge, using different reference parameters to describe them.

Reference parameters, such as the number of households, the range of operation of different technologies, the length of network segments, the number of sites, etc. will be needed in other work packages (for example in WP3 as a reference to current networks or WP5 as an input to the techno-economic model). Reference parameters will be used to assess how the current fixed and mobile networks are used and deployed by network operators, which are the main network elements and which values are typically considered for network dimensioning.

Some parameters, such as broadband penetration, customer distribution, and homes connected, are not considered as reference parameters as they are more related to a specific case study under a techno-economic analysis and reference parameters are common references to any future case study. Additionally, all values for the reference parameters included in the following sections have been proposed for European countries and they are not proposed as the unique values that could be possible, and represent typical or common values that can be found in European operators' networks. It is needed to mention that the final values used for the future studies, inside the range presented, could vary depending on the specific scenario to evaluate.

2.2.1 Common reference areas

The previous section identifies different network areas where network operators deploy their infrastructure to provide broadband services. Up to now, fixed and mobile networks have been deployed independently of each other with a parallel evolution. Additionally, mobile networks have used their own fixed network to transport mobile data and to interconnect mobile users with other mobile or fixed phone lines.

Recently, network operators have started to use fixed networks to transport fixed and mobile data, such as the fixed IP backbone. However the target of FMC networks is to transport and manage both mobile and fixed data using a single network.

For this study it has been considered as common reference areas the network segments identified previously:

- Customer premises
- Access network
- Aggregation network
- Mobile packet core

For each of them, the main elements inside these areas have been identified, defining the main reference parameters used to characterize them.

It is important to remark that the values selected for the reference parameters that appear in the next sections are considered typical or 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.

2.2.2 Geotypes

Reference parameters typically depend on the geotype (e.g. rural, urban or dense urban area). For example the same reference parameter, such as the number of households, is different in urban areas compared to rural areas. Typically this kind of reference parameters is more related to the access network. However, it is also possible that reference parameters are geotype independent. These are mainly related to the aggregation or core networks, for example the number of aggregation levels in the aggregation network.

Three geotypes are proposed to differentiate three possible environments where reference parameters can have different values depending on the residential density measured by the number of dwelling units in a given area. The following definition is given just to provide a general classification of the different areas:

- Dense urban areas are characterised by a high customer density since many customers are connected to one building termination point within typical multi-dwelling buildings or even tower blocks. It is typical to find in these areas a high development in telecommunication's infrastructure with a high duct availability for the trunk and distribution cable segments and a high density of mobile macro sites. Dense urban areas can be found in the urban core of a big city.
- Urban areas have a lower population density than dense urban areas and are usually regions surrounding a city or the entire area of small cities or towns (suburban areas are also considered in this classification as urban areas). In urban areas the CO can often be found in a town centre. The duct availability is high but mainly around the CO. Additionally a high customer density around CO and some multi dwelling buildings are in place. Typically, a few "satellites" are also connected via buried cable and a medium business customer density characterizes this area type.
- In contrast, rural areas have a much lower customer density and the CO is often located in a dense village centre. Almost no ducts are available and some "satellites" are kilometres away from the CO with only few buildings, connected via buried cable. The buildings have one or two living units (a dwelling intended for use by one household) and are mainly residential customers. The business customer density is usually very small.

2.2.3 Customer premises

Customer premises are the residential homes or business buildings where final users access to fixed and mobile broadband services.

The reference parameters inside the customer premises considering fixed and mobile networks are related to the home/business network (i.e. the internal wireline/wireless local access network that belongs to the subscriber and where users connect to broadband services).

Table 2 contains a summary of the reference parameters related to this section. For a complete description of each parameter, please see Appendix 7.1.1:

Name	Geotype independent	Dense urban	Urban	Rural
Number of households per area unit	-	100 000s	10 000s	100s – 10 000s
Wireline network capacity in the customer premises	100 Mb/s or 1 Gb/s	-	-	-
-Number of connected devices in a home	< 10	-	-	-
Number of connected devices	10s - 100s	-	-	-

in a business building				
Number of residential Wi-Fi APs	1, but several possible	-	-	-
Number of business Wi-Fi APs	10s	-	-	-
Number of public Wi-Fi APs	10s	-	-	-
Number of community Wi-Fi APs	-	800 – 1 200	150 - 500	No deployment

Table 2: Reference parameters: customer premises

2.2.4 Access network

The access network area can be classified in two main areas: the fixed access network and the mobile access network.

2.2.4.1 Fixed access network

The fixed access network is composed mainly of the outside plant, and the access nodes located in the access network operator premises. Additionally, street cabinets with active elements could also be deployed in some types of fixed access networks.

Table 3 contains a summary of the reference parameters related to this section. For a complete description of each parameter, please see Appendix 7.1.2.1:

Name	Geotype independent	Dense urban	Urban	Rural
Outside plant				
Distribution segment length	-	200 m	300 m	400 m
Trunk segment length	-	1-2 km	1-3 km	2-4 km
Feeder segment length	-	1-2 km	up to 5 km	up to 10 km
Splitting level per fibre access node (OLT) port FTTH	-	mainly 2 levels 64 users: 1:4 & 1:16 or 32 users: 1:8 & 1:4	mainly 2 levels 64 users: 1:4 & 1:16 or 32 users: 1:8 & 1:4	different alternatives: -No deployment or - 1-3 levels
Total copper line length for the PSTN	-	< 5 km typ.: 1.5 km	< 7 km typ.: 2 km	< 10 km typ.: 3 km

Total copper line length for FTTex ADSL2+	-	< 2 km typ.: 1.5 km	< 3 km typ.: 2 km	< 4 km typ.: 3 km
Total copper line length for FTTex VDSL2	-	< 1.5 km typ.: 300 m	< 1.5 km typ.: 400 m	< 1.5 km typ.: 600 m
Total fibre line length for FTTH	-	< 5 km typ.: 2 km	< 10 km typ.: 5 km	< 10 km if deployed typ.: 5 km
Cabinets				
Number of subscribers per copper access node (DSLAM) chassis FTTC	48-300 typ. 100	-	-	-
Number of subscribers per cabinet FTTC	-	< 1000 typ.: 200	< 500 typ.: 150	< 300 typ.: 100
Backhaul capacity required for a cabinet FTTC	100s Mb/s – 1 Gb/s	-	-	-
Number of street cabinets per CO area	-	< 100	< 64	< 30
Access nodes				
Number of subscribers per copper CO FTTEx	-	10 000s typ.: 15 000	3 000 - 10 000 typ.: 8 000	< 3 000 typ.: 1 500
Maximum number of subscribers per copper AN (DSLAM) chassis FTTEx	700	-	-	-
Number of subscribers per fibre CO FTTH	-	10 000 - 100 000 typ.: 20 000	5 000 - 20 000 typ.: 8 000	< 5 000 if deployed typ.: 2 000
Maximum number of subscribers per fibre AN (OLT) chassis FTTH	4 096-8 192	-	-	-
Maximum number of subscriber per fibre AN (OLT) port FTTH	32 or 64	-	-	-
Number of connection to the aggregation node per access node chassis	1 or 2	-	-	-
Backhaul capacity required for	1 - 2 Gb/s	-	-	-

a copper AN (DSLAM)				
Backhaul capacity required for a fibre AN (OLT)	10 Gb/s	-	-	-

Table 3: Reference parameters: Fixed access network

2.2.4.2 Mobile access network

The mobile access network is composed mainly of the radio base stations. The numbers in this section depend very much on planning guidelines of mobile operators and also on the specific country. Each operator has different requirements in each country, especially concerning indoor coverage and LTE frequency bands. For example, a premium operator could try to achieve nearly 100% indoor coverage while a low-cost operator will usually accept lower coverage ratios. Additionally, a single mobile operator could use different frequency bands simultaneously to provide LTE coverage in the same areas, so multiple scenarios with specific values are possible.

Table 4 contains a summary of the reference parameters related to this section. The given figures are meant as “typical” without claiming exact mathematical correctness (e.g., macro cell sites per km^2 and macro site inter-site distance relationship). For a complete description of each parameter, please see Appendix 7.1.2.2.

Name	Geotype independent	Dense urban	Urban	Rural
Base stations				
Number of 3G macro cell sites per km^2	-	<20	<10	1-2
Number of active users per 3G macro cell site	<100	-	-	-
Configuration of a 3G macro cell	3 sect / 2 carriers / 5 MHz	-	-	-
3G macro inter-site distance	-	< 240 m	< 340 m	Several km
Area coverage percentage for indoor penetration for 3G macro cells	-	< 70%	< 60%	< 50%
Number of LTE macro 800 MHz cell sites per km^2	-	< 5	< 3	< 3
Number of active users per	< 100	-	-	-

LTE macro 800 MHz cell site				
Configuration of a LTE macro 800 MHz cell	3 sect / 1 carrier / 10 MHz	-	-	-
LTE macro 800 MHz inter-site distance	-	< 600 m	500 – 1 000 m	Several km
Area coverage percentage for indoor penetration for LTE macro 800 MHz cells	-	< 75%	< 70%	< 60%
Number of LTE macro 1800 MHz cell sites per km^2	-	< 20	< 10	< 3
Number of active users per LTE macro 1800 MHz cell site	< 100	-	-	-
Configuration of a LTE macro 1800 MHz cell	3 sect / 1 carrier / 20 MHz	-	-	-
LTE macro 1800 MHz inter-site distance	-	< 300 m	250 - 500 m	Several km
Area coverage percentage for indoor penetration for LTE macro 1800 MHz cells	-	< 70%	< 60%	< 50%
Number of LTE macro 2600 MHz cell sites per km^2	-	< 20	< 10	< 3
Number of active users per LTE macro 2600 MHz cell site	< 100	-	-	-
Configuration of a LTE macro 2600 MHz cell	3 sect / 1 carrier / 20 MHz	-	-	-
LTE macro 2600 MHz inter-site distance	-	< 300 m	250 - 500 m	Several km
Area coverage percentage for indoor penetration for LTE macro 2600 MHz cells	-	< 70%	< 60%	< 50%
Number of active users per LTE small cell	< 64	-	-	-
Configuration of a LTE small	1 sect / 1 carrier / 20 MHz	-	-	-

cell				
Small cell LTE cell site radius (outdoor)	100 – 150 m	-	-	-

Table 4: Reference parameters: Mobile access network

2.2.5 Aggregation network

The aggregation network is mainly composed of the aggregation nodes for the fixed broadband services, the aggregation nodes and specific elements for the mobile backhaul and other specific elements for the fixed and mobile networks such as the BRAS or the RNC.

Table 5 contains a summary of the reference parameters related to this section. For a complete description of each parameter, please see Appendix 7.1.3:

Name	Geotype independent	Dense urban	Urban	Rural
Aggregation nodes				
Aggregation network extent	-	< 20 km	< 60 km	< 100 km
Number of aggregation network nodes per Metro Area Network	10s	-	-	-
Link length between access node and aggregation node	collocated - 10s km	-	-	-
Number of aggregation levels	2	-	-	-
Aggregation level 1 to level 2 link length	collocated - 10s km	< 10 km	< 30 km	< 50 km
Aggregation level 2 to backbone edge link length	collocated - 10s km	< 10 km	< 30 km	< 50 km
Capacity of an access node port in the aggregation level 1 node	1 Gb/s or 10 Gb/s	-	-	-
Capacity of a trunk port in the aggregation level 1 node	10 Gb/s	-	-	-
Capacity of an access port in the aggregation level 2 node	1 Gb/s or 10 Gb/s	-	-	-

Capacity of a trunk port in the aggregation level 2 node	10 Gb/s	-	-	-
Number of redundancy links in the aggregation level 1 node	1	-	-	-
Number of redundancy links in the aggregation level 2 node	1	-	-	-
Mobile backhaul				
Backhaul capacity peak required for a 3G base station (NodeB) per sector	10s Mb/s	-	-	-
Backhaul capacity peak required for a LTE base station (eNodeB) per sector	< 150 Mb/s	-	-	-
Mobile backhaul link length	-	< 1 km	< 3 km	1-10 km
Other network elements				
RNC: maximum throughput	Up to 13 Gb/s	-	-	-
BRAS: Number of subscribers per IP edge	50 000 - 100 000	-	-	-

Table 5: Reference Parameters: Aggregation network

2.2.6 Mobile packet core

The mobile packet core is composed of different network equipment specific for packet-switched mobile communications, such as gateways and other servers for centralized functions. In this section we are going to focus on the most important elements inside the mobile packet core for 3G and LTE. Table 6 contains a summary of the reference parameters related to this section. For a complete description of each parameter, please see Appendix 7.1.4:

Name	Geotype independent	Dense urban	Urban	Rural
SGSN: maximum throughput	up to 36 Gb/s	-	-	-
GGSN: maximum number of PDP contexts	up to 30 Million	-	-	-

GGSN: maximum throughput	up to 500 Gb/s	-	-	-
MME: maximum number of Simultaneously Attached Users (SAU)	up to 18.6 Million SAU	-	-	-
S-GW: maximum throughput	up to 500 Gb/s	-	-	-
P-GW: maximum number of PDN connections	up to 30 Million	-	-	-
P-GW: maximum throughput	up to 500 Gb/s	-	-	-

Table 6: Reference parameters: Mobile packet core

2.3 Reference topology for FMC studies

The previous sections contain the analysis regarding the main segments in the current fixed and mobile networks, the reference locations, the network elements, and the reference parameters.

Figure 3 depicts the reference topology as a schematic view of the FMC analysis field, to be used as the common starting situation for the remaining activities in the project. It represents a single general view of the topology of today's deployed fixed and mobile networks.

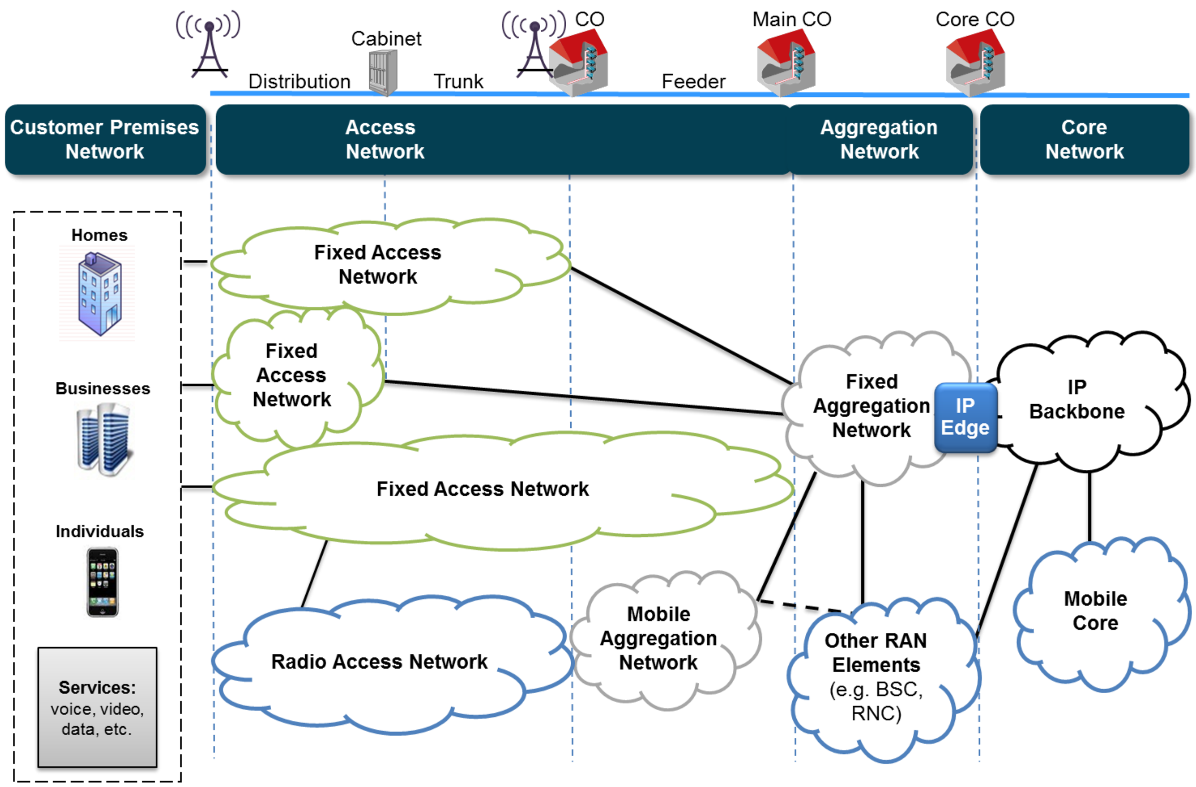


Figure 3: Reference topology of the FMC analysis field

The reference locations, such as the different COs, are included in the upper part of the previous figure, whereas the different customer types and their typical location appear in the left side. The access and aggregation network segments extend their coverage from the customer premises to the core network; these networks could span several reference locations, and the picture shows the most typical situations with an access network reaching up to the cabinet, up to the CO and up to the main CO.

Figure 3 also includes the main areas of the current mobile networks, identifying some points in which the mobile network is connected to the fixed one, such as base stations connected to the fixed access network, the mobile aggregation network using the fixed aggregation network in order to connect to mobile network elements, and the distributed mobile network elements (e.g. BSC, RNC, etc.) connected to the fixed IP backbone to reach the mobile core.

Figure 3 provides a high-level view of the current fixed and mobile network topology. More detailed and specific topologies for the different network types have been developed, taking the above figure as the reference, in deliverable D3.1; this deliverable that deals with the initial studies of FMC architectures.

Figure 3 is also the reference figure used to represent the following FMC network scenarios in Chapter 3.

The previous information in this chapter, including the reference topology, defines the reference framework that will be used in the future work on fixed and mobile convergence in access and aggregation networks. Therefore this framework will be used as a common reference and data base across the whole project.

3 Definition of FMC network use cases

Chapter 3 includes a set of use cases describing the needs of future FMC networks.

The selection of the use cases have been started taking into account today's network status, the network evolution and the main motivations of COMBO, i.e. to save cost, dealt with increasing traffic and changing applications, adapt the network structure, distribution of network functions, multi-operator networks, seamless performance monitoring and management and reduce energy.

The selection of the use cases has also considered that they will be a reference used to assist other activities in COMBO to achieve their targets, such as the definition of the network scenarios or the demonstrator activities. In that sense, use cases must be in line with the project general and specific targets.

Three basic areas of convergence between fixed and mobile networks (FMC area) have been identified, spanning from the sharing of technologies in access and aggregation domains up to the end-to-end control and management of the whole network. Across these areas, eight use cases are addressed.

Each use case is described taking into account the following four topics and their respective guidelines:

(1) Today’s situation: The today's situation and the problems with today’s solutions should be explained.

(2) Goal of the use case: The achievements and benefits of the use case should be presented.

(3) Research and innovation: The gaps between today’s situation and the goal of the use cases should be clearly described.

(4) FMC aspects: FMC aspect should be clear by reading the use case.

The use cases are very focused to network topics (they are network use cases) and during their development process it has been included the points of view of the different partners of the project, including industrial partners, academia and operators. The user point of view has been also considered and in that regard, almost all of them bring benefits in terms of improved QoE, simplicity, throughput and lower cost. Additionally, improving other only network specific aspects, such as QoS, will have a positive effect on the users' QoE.

Use cases define detailed expectations from the network. These expectations will in particular help to define detailed requirements (see Task 2.4 of WP2) in order to quantify the expectations. So, in other words, use cases answer the question “What do users and operators need?”

3.1 Functional versus structural convergence

Functional and structural convergence is defined as follows within COMBO:

- Functional convergence means the implementation of a generic function to realize similar goals in different network types (fixed, mobile, Wi-Fi). This includes the moving of functions in order to merge specific fixed, mobile and Wi-Fi functions into some generic functions.
- Structural convergence is defined as sharing/mutualisation of network equipment and infrastructure resources for several network types. The moving of existing functions of different network types to a unified network entity for a better distribution of functions belongs to structural convergence.

3.2 Convergence classification of the UCs – Overview

As already considered, three basic areas of convergence between fixed and mobile networks (FMC area) have been identified, And across these three areas, eight UCs have been addressed. The following table (

Table 7) shows the association between each FMC area and the related UC:

FMC Area	Use Case
Access Resource Sharing	UC1 - Unified FMC access for mobile devices
	UC2 - Converged content caching for unified service delivery
	UC3 - Reuse of infrastructure for small cell deployments
	UC4 - Universal access bundling for residential gateway
Aggregation Resource Sharing	UC5 - Support for large traffic variations between public, residential, and business areas
	UC6 - Convergence of fixed, mobile and Wi-Fi gateway functionalities
	UC7 - Converged access and aggregation technology supporting fixed and mobile broadband services
Operator Cooperation	UC8 - Network sharing

Table 7: FMC areas and network use cases

The network use cases above address specific needs, case by case, and consequently opportunities for structural and/or functional convergence.

Table 8 resumes for each use case the addressed needs and the targeted convergence: in some cases, both structural and functional types apply, so, the first type mentioned is the targeted one with the higher severity.

More detailed considerations may be found in sections 3.3 - 3.5.

Use Case	Addressed Needs	Targeted Convergence
UC1 - Unified FMC access for mobile devices	This UC allows mobile devices to use Wi-Fi access in combination with mobile access in an FMC network with an advanced cooperation between those access technologies.	Functional
UC2 - Converged content caching for unified service delivery	Considering of the maturity, achieved by the CDN market in fixed networks, and the emerging interests in mobile CDNs, this UC starts now to investigate possible methods for converged content delivery solutions in FMC networks.	Functional
UC3 - Reuse of infrastructure for small cell deployments	The focus of this UC is, thus, the reuse of existing infrastructure in order to reduce costs and deployment time for cost-sensitive small cells.	Structural
UC4 - Universal access bundling for residential gateway	This UC provides integrated functionalities into a converged network in order to provide the user with optimum bandwidth resource dynamically assigned via available fixed, mobile, and wireless technologies.	Functional Structural
UC5 - Support for large traffic variations between public, residential, and business areas	This UC addresses a common infrastructure that supports the dynamic allocation of connectivity resources at the proper granularity and layer.	Structural
UC6 - Convergence of fixed, mobile and Wi-Fi gateway functionalities	This UC aims at the integration of fixed, mobile and Wi-Fi functionality in the same network entity, called Universal Access Gateway (UAG), in order to realize a more efficient operation of transport/control functionalities and optimize costs by reducing the number of network elements.	Functional Structural
UC7 - Converged access and aggregation technology supporting fixed and mobile broadband services	This UC aims at a universal access and aggregation technology that supports all kind of communications services for residential, business and mobile backhauling and fronthauling.	Structural
UC8 - Network sharing	The goal of this UC is to provide multi-operator network capabilities in future FMC networks in order to reduce deployment and operation costs and support more flexible business models by	Structural Functional

	utilizing existing infrastructure for both fixed and mobile communication as much as possible.	

Table 8: Network use cases – Needs and targeted convergence

3.3 FMC UCs – Access Resource Sharing

The following sections describe four FMC use cases with focus on an efficient utilization of access resources:

- The first use case allows mobile devices to use Wi-Fi access in combination with mobile access in an FMC network with an advanced cooperation between those access technologies.
- The second use case investigates possible methods for converged content delivery solutions in FMC networks.
- The third use case aims at a structural convergence with a reuse of the existing access infrastructure for small cell rollouts which are important from an operator's point of view since a deployment of a dedicated small cell feeder network is economically challenging and time consuming.
- The fourth use case addresses a functional/structural convergence of fixed, mobile, and wireless access with the target to provide a dynamic optimum bandwidth via all available access technologies.

3.3.1 UC1 – Unified FMC access for mobile devices

UC1 - Today's situation

Today mobile users generally prefer to use Wi-Fi access for mobile data traffic rather than the mobile connections provided by mobile operators because Wi-Fi is seen as a faster technology and cheaper as it is independent of the data plan subscribed by the customers. Thus, the Wi-Fi access is well known to users and they commonly use public hotspots and Wi-Fi AP at home or in offices.

However, a mobile device usually selects the Wi-Fi access according to a set of static criteria (e.g., a preferred SSID with the highest signal level), but without considering some dynamic conditions (such as the backhaul capacity).

Moreover, when a mobile device is simultaneously attached to Wi-Fi and mobile networks, its traffic is usually forwarded only through a single interface that is selected according to access network static attributes (e.g., the operator identifier provided by the Passpoint-certified Wi-Fi access point). The most advanced devices that can simultaneously use both Wi-Fi and mobile networks, usually balance data traffic over both interfaces in a static manner without considering the network conditions (e.g., Android applications can set some routing rules to forward a part of the traffic over the mobile network).

Finally, mobility with a seamless handover (no data loss during mobility execution) is usually provided for intra-system only (e.g., between mobile base stations) and may be restricted to a specific area for Wi-Fi (e.g., between APs in the same L2 domain).

UC1 - Goal of the use case

This UC allows mobile devices to use Wi-Fi access in combination with mobile access in an FMC network with an advanced cooperation between those access technologies.

That cooperation enables providing mobile devices with:

- a simultaneous attachment to both Wi-Fi and the mobile network,
- some enhanced mobility features (inter-Wi-Fi and inter-system seamless handover),
- and a smart network assistance for the selection and utilization of the different accesses driven by the status of the network and the available connections.

As a result, the mobile devices are able to simultaneously use both Wi-Fi and mobile accesses and seamlessly move all or part of their traffic from one access to another, with possible network assistance for selecting and using the most suitable access(es) according to their needs. Thus, Wi-Fi and mobile access networks should complement each other so that end users can benefit from higher global data rates and also seamless mobility. Hence, the main benefits are the following ones:

- The user benefits of a better QoE when using Wi-Fi thanks to the better throughput, the reduction of the service interruptions whereas the user is under the coverage of mobile or Wi-Fi networks and a transparent network configuration.
- The network utilisation is optimised, by balancing the user traffic on different accesses (in the time and/or in the space).
- Network costs are reduced, by using Wi-Fi (as a cheaper technology or when it is not possible to use more licensed spectrum for mobile communications) to complement the mobile network coverage.

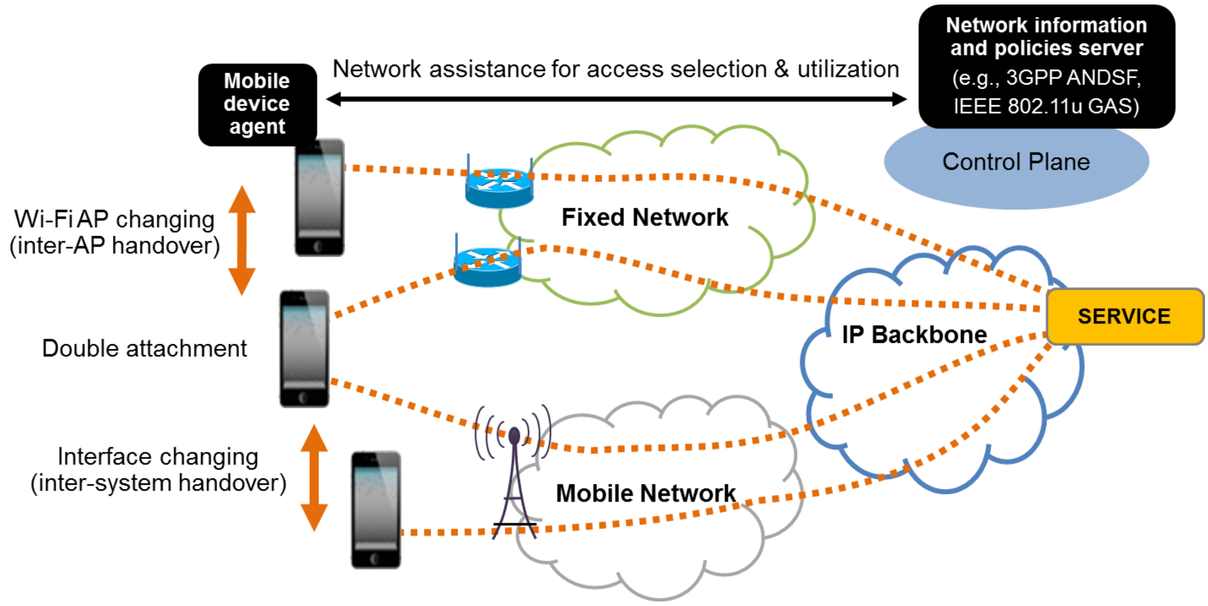


Figure 4: UC1 – Unified FMC access for mobile devices

UC1 - Research and innovation

Regarding the technical solution to cover this use-case, some aspects of it can be satisfied without any functional or structural convergence. In such a case, the interworking between Wi-Fi and mobile networks would be sufficient only at the data user plane level (e.g., the Wi-Fi network being used as an underlying access network of the mobile network). Standardization bodies, mainly at 3GPP, have already introduced a certain level of interworking in their latest specifications ([34] to [36]). However, these specifications consider both networks as independent networks. Innovative solutions can be considered to meet greater convergence. A first flavor consists of gathering mobile and Wi-Fi IP edges in a same physical node in order to provide better efficiency at different levels (e.g., lower latency, faster handover…) and would allow the FMC network to be operated as a single network. An even more advanced solution is to consider a single IP edge for mobile (as S/P-GW) and for fixed and Wi-Fi access as well (as a BNG). In both cases, due to obvious scalability limitations, implementations of such a multi-purpose IP Edge would benefit from software-defined networking (SDN) flexibility and virtualization of network functions (NFV) high efficiency.

UC1 - FMC aspects

The convergence of the use case itself regards the services connectivity that should be agnostic to the access network technology, and thus it can be related to the functional convergence.

3.3.2 UC2 - Converged content caching for unified service delivery

UC2 - Today's situation

In order to reduce network traffic and improve QoS/QoE for end users, caching schemes have been proposed in Content Delivery Networks (CDN). In a CDN infrastructure, a set of CDN servers are distributed in the network to replicate content and facilitate its delivery to end users. Commercial CDNs like Akamai and Limelight have been successfully deployed in current Internet. Recent reports [6] show that about one third of Internet traffic is carried by CDNs in 2012, and by 2017 the traffic crossing CDNs will grow by 51%.

Due to the increasing popularity of smart phones and emerging mobile applications, mobile Internet is dramatically expanding. Cisco VNI [2] shows that Internet traffic from wireless and mobile devices will exceed traffic from wired devices by 2016 and nearly half of Internet traffic will originate from non-PC devices by then. This does not mean that wired traffic is expected to be a small percentage, on the contrary, it will be the preferred access of mobile devices through technologies such as Wi-Fi. Global mobile traffic will increase nearly 11-fold in 2018. From the same study [2], the major traffic driver is expected to be in video related services, and this is one of the best candidates for content caching.

To meet the growing bandwidth demands of mobile users, studies on content caching in mobile backhaul networks and new infrastructures of mobile CDNs [7] are gaining a lot of attraction recently. That is the case for example, where caching is enabled in 3G RNCs and LTE eNodeBs [9]. Caching solutions for 3G or LTE networks have been also developed by companies like Allot Communications, PeerApp, Altobridge, etc.

However, in the case of a FMC network, further developments can be achieved thanks to the network architecture and functions to be provided by the network. On the one side, this can be achieved thanks to the structural convergence proposed in COMBO, which brings a new network topology. And on the other side, thanks to functional convergence, since both fixed and mobile users, whenever they are served for a requested content by a cache in the convergent network, can experience a lower latency and improve their QoE.

UC2 - Goal of the use case

Considering the maturity achieved by the CDN market in fixed networks and the emerging interests in mobile CDNs, it is worth to start now looking at possible methods for converged content delivery and caching solutions in FMC networks.

The main goal of the use case is to reduce traffic exchanges and operational costs while improving QoE for end users. For that purpose, a collaborative caching system is expected to provide such benefits to a FMC network operator.

Figure 5 depicts a concept scenario where storage and caching functions are enabled in different network elements placed in both the access (DSLAM, eNodeB) and in the aggregation network (NG-POP). By the collaborative caching among the equipment of fixed access network, mobile access network and NG-POP, the content is intelligently duplicated closer to mobile users. The content caching systems can take inputs from other FMC functions as well in order to take full advantage of the converged network.

The main benefits of this UC are (i) reduced network traffic, improved network utilisation and reduced core network traffic; (ii) improved QoE for end-users by achieving a lower service latency and higher combined content delivery throughput; (iii) OpEx reduction and (iv) increased network energy efficiency by designing energy-aware content delivery algorithms, and optimising the number of caches and the cache locations in FMC.

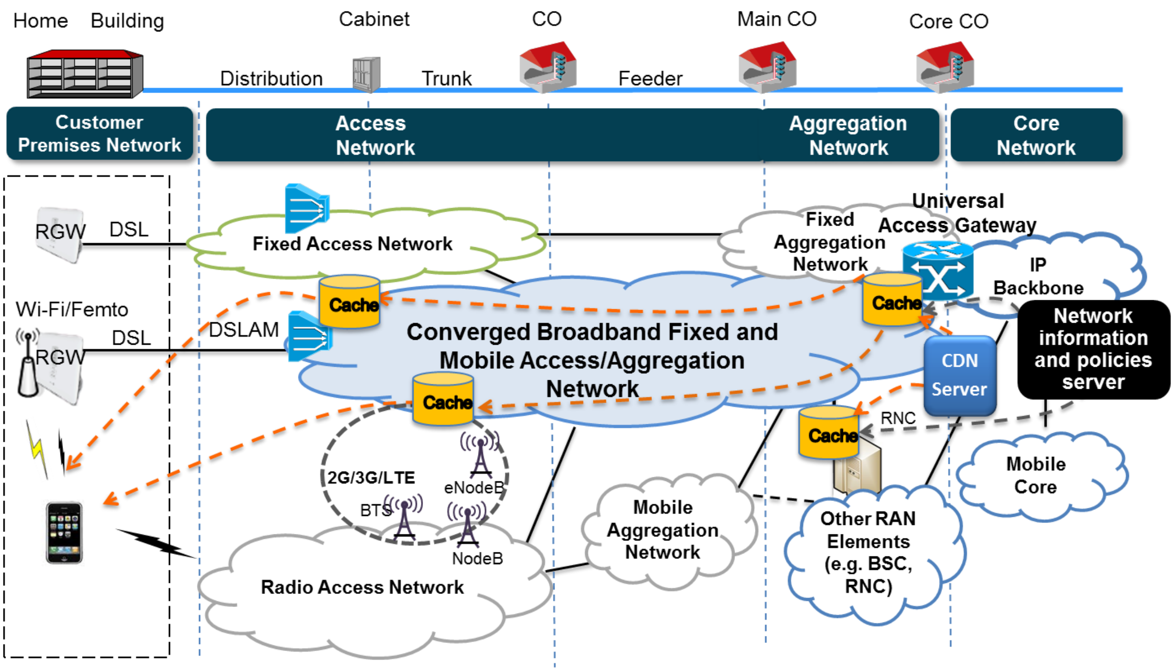


Figure 5: UC2 – Converged Fixed / Mobile CDN Solutions

UC2 - Research and innovation

To realise this use case, it is necessary to evaluate the best approach for content caching within a FMC network. The FMC network, by having a different architecture in comparison to current networks where content caching solutions are developed separately for fixed networks and mobile networks will be able to provide additional functions that content caching can take advantage of. For that purpose, the overall architecture needs to be designed first and the key elements enabling the caching functionality identified; as well any other function the solution relies upon.

Additionally, it may be possible that in a smaller set of cases, where large events are expected or within large infrastructures are involved, the caching systems (in access network and even on public APs deployed by network operators) are brought closer to the user because of the special features of such environments.

Moreover, enabling content caching at the edge with the ability to 'switch and route' content and distributing content by collaborative caching solutions provided by our FMC network, significantly changes the dynamic and creates the possibility for new business models based on quality of experience, network-optimised content, and charging schemes.

Finally, caching algorithms also need to be investigated to achieve the converged content delivery by considering network efficiency, overall energy consumption and user experience. A SDN based caching controller can further ameliorate the caching efficiency by optimising the data flow and the content caching. This would be achieved for example by evaluating the access selection information made by the network as described in UC1 and that can be seen in the diagram under the name "network information and policies server".

UC2 - FMC aspects

UC2 is mainly a functional use case where FMC could be achieved by enabling caching functionality on network devices containing network interfaces to fixed, mobile and Wi-Fi networks. A location that could be common for all those access technologies is for example in a Universal Access Gateway. Furthermore, a hierarchical in-network caching system would make use of the advantages provided by the FMC network and could allow network operators to reduce network traffic, improve network efficiency and ameliorate user experiences.

3.3.3 UC3 - Reuse of infrastructure for small cell deployments

UC3 - Today's situation

While the majority of the broadband traffic is generated indoors, the indoor capacity and coverage from the macro cells are today not good enough to meet the end-users' service requirements. Therefore, operators are looking to deploy indoor small cells to improve the indoor capacity and coverage as well as outdoor small cells as a complement to existing macro cells.

One of the key challenges for small cell deployments is backhaul connectivity. Wired fibre or copper connections should be reused whenever available but a wireless connection is sometimes the only option.

UC3 - Goal of the use case

For the backhaul connectivity of small cells, operators can reuse existing fixed/mobile infrastructure; e.g., the fixed copper and/or fibre infrastructure that already exist in many residential and commercial buildings, the fixed distribution nodes, or the existing macro cell sites and their backhaul links. The focus of this UC is, thus, the reuse of existing infrastructure in order to reduce costs and deployment time for cost-sensitive small cells. This may for example lead to a scenario where residential infrastructure is reused for both mobile and fixed residential services, or a scenario where mobile networks exploiting residential infrastructure is used to provide residential services.

The main benefits of this UC are (i) reduced deployment time and cost; (ii) more efficient utilization of existing infrastructure (both for fixed and backhaul lines); (iii) lower cost for end-users; and (iv) increased capacity and improved coverage for end-users.

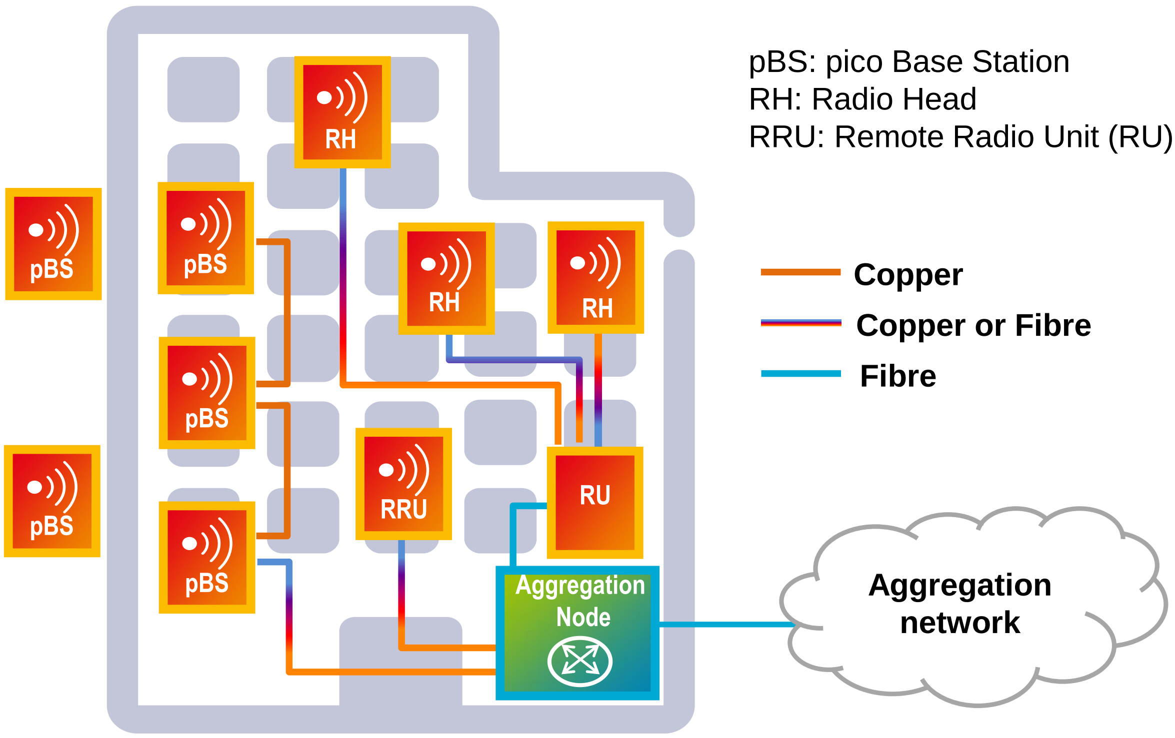


Figure 6: UC3 – Illustration of reusing existing infrastructure for small cell deployments

UC3 - Research and innovation

New technologies are required in order to meet future performance requirements whilst optimally reusing existing infrastructure. The challenge is to identify deployment architectures (structure and distribution of functions, i.e. BB-processing, AD-conversion, amplification, etc.) that enable lowest cost deployment. This in turn may require new technologies for transport depending on type of infrastructure and interfaces exposed in the deployment architecture.

It is worth to mention that the conditions for residential and commercial buildings are different. While small cell deployments in commercial buildings can often make use of existing category 5, 6, 7 copper cables (or sometimes even optical cables), the infrastructure in residential buildings often consists of category 3 telephony cables, where cross talk is the main source of disturbance.

As illustrated in Figure 6, the small cells can be of different types: pico Base Stations (pBSs) with integrated BBUs that are deployed indoors and outdoors, Remote Radio Units (RRUs) with BBUs centralized in the network, or Radio Heads (RHs) connected to a Radio Unit (RU). An indoor small cell gateway provides baseband functionality for the RRUs and aggregates the traffic from all small cells in the building. In residential buildings, the pBS is located in the RGW to provide mobile coverage in the home network.

UC3 - FMC aspects

The use case is related to structural convergence. The key question which has to be answered with respect to this use case is: How can the fixed network be utilized or extended to provide high performance and cost efficient backhaul / fronthaul for small cell deployment? The solutions for this use case will therefore inherently be FMC approaches. This can also be seen from the fact that the deployment of heterogeneous networks / small cells is identified as an enabler and trigger of FMC (see Section 5.2 in COMBO deliverable D3.1 [37]).

3.3.4 UC4 - Universal access bundling for residential gateway

UC4 - Today's situation

Currently, the so-called Hybrid Access (HA) technique is developed to provide end-users (primarily residential customers in rural areas) with the dynamic bandwidth assigned via available fixed and mobile technologies. The focus is on areas where the deployment of optical broadband access cannot be economically justified, such as in rural areas. HA enables the boosting of fixed access bandwidth with capacity from the mobile network.

HA focuses on the bundling of the two access technologies DSL and LTE to one internet connection. In today's implementation it is designed as an "over the top" solution, meaning that a Hybrid Connection Gateway (HCG) is located outside the fixed or mobile network in the IP backbone. The HCG is in charge of redirecting/collecting IP flows to and from multiple paths for a given end-user. The authentication works through the normal fixed and mobile processes. Thus a customer has two identities (e.g. a SIM card for the mobile part and username and password for the fixed network part).

But, there are two major drawbacks for this solution:

- Usage of two authentication procedures is inefficient for the customer as well as the operator.
- The data path between the Residential Gateway (RGW) at the customer premises and the HCG can vary widely which results in high differences in the delays of the paths. This has to be compensated which is inefficient (large buffers required, additional delay) and can also limit the performance of HA.

UC4 - Goal of the use case

The main objective is to provide integrated functionalities into a converged network which solves these problems in order to provide a more efficient solution.

A second target is to provide the user with dynamic optimum bandwidth via all available access technologies. Such access bundling is achieved by using more than two transmission channels simultaneously (e.g. fixed xDSL, Wi-Fi hotspot and cellular radio) (see Figure 7).

The main benefits of this use case are:

- only one authentication for the customer,
- a more efficient network operation for the operator,
- and a higher performance for both.

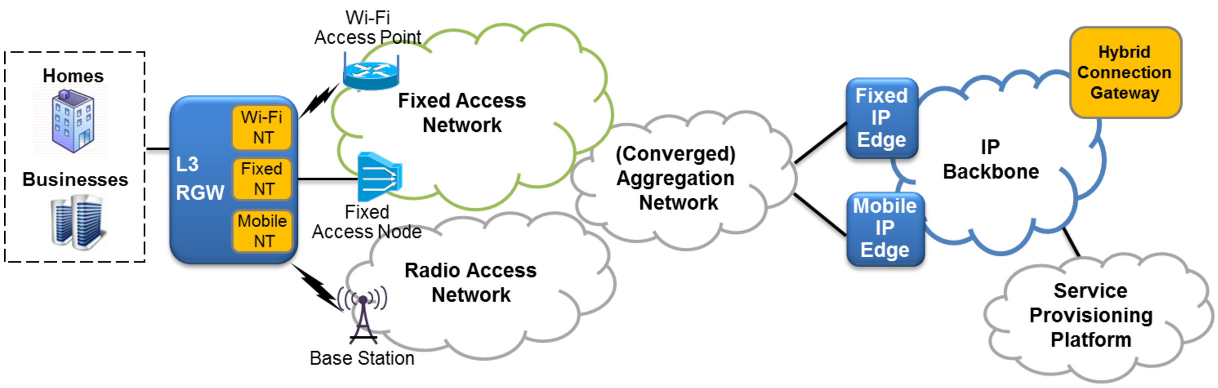


Figure 7: UC4 – Universal access bundling for residential gateway

UC4 - Research and innovation

The use case is achievable mainly by optimizing or introducing the three following functional entities:

- A forwarding decision entity or some kind of Load balancer in the Residential Gateway (RGW). The RGW must forward the upstream traffic toward fixed, mobile and wireless interfaces. Forwarding decision is made upon policies which are driven by the operator or by customer preferences.

- A Hybrid Connection Gateway (HCG) in order to forward the downstream traffic toward several access technologies and to take benefit of the increased overall bandwidth.
- Common authentication and subscriber management (charging, etc.) entity.

The research on that use case may provide several scenarios for implementing the Hybrid Connection Gateway functional blocks in the network. Pro and cons of Flow based versus Packet based forwarding decision has to be balanced regarding business use cases and constraints (e.g. 4K TV transport, difference of access network latency, etc.).

UC4 - FMC aspects

From a first point of view, this use case is functional and thus independent of potential structural network convergence in between. But with regard to a new FMC architecture the HCG functionality will be placed nearer to the customer, i.e., the use case deals with structural convergence as well.

3.4 FMC UCs – Aggregation Resource Sharing

The following sections consider the fixed / mobile convergence for the aspects related to the aggregation network. This portion of the network plays, already, a role in convergence since backhauling different types of services; three use cases described hereafter, aim, then, to stress the need for a further integration between fixed and mobile backhauling networks. This represents the basic requirements for optimizing the costs of infrastructure and functionalities supported, taking into account current and future service applications.

The following aspects are addressed:

- The fifth use case addresses the integration of fixed and mobile access/aggregation networks devoted to backhauling/fronthauling, into a common infrastructure, able to support dynamic handling of connectivity resources over time.
- The sixth use case aims at the integration of fixed, mobile and Wi-Fi functionality in the same network entity, called Universal Access Gateway (UAG), in order to realize a more efficient operation of transport/control functionalities and optimize costs by reducing the number of network elements.
- The seventh use case aims at a universal access and aggregation technology that supports all kind of communications services for residential, business and mobile backhauling and fronthauling.

3.4.1 UC5 - Support for large traffic variations between residential and business areas

UC5 - Today's situation

Fixed/mobile network infrastructures currently deployed are often independent from each other, resulting in un-optimized CapEX and OpeEX (see

Figure 8). Traffic load across the transport network shows meaningful variation over time and location, but network connectivity and network resources (Hw/Sw) are currently statically allocated or updated with a low dynamicity. Current control and management means do not appear suitable to support the sharing of network resources associated to a dynamic "service-driven" network.

E.g. With this constraint applied to the CRAN model, RRUs would have dedicated BBUs and dedicated connections: so, even if the traffic load changes over time, no sharing of resources or network connectivity change would be easily allowed. Moreover, network infrastructure deployed (optical network) could not be shared with fixed network infrastructure (FTTH).

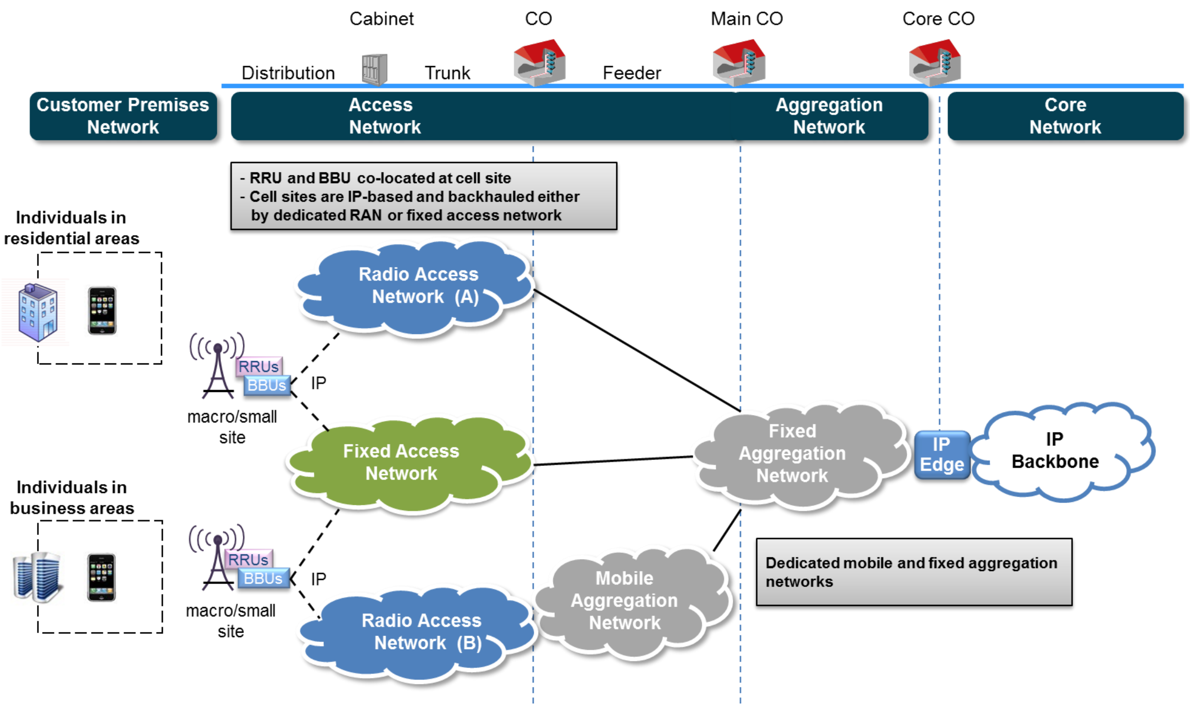


Figure 8: UC5 – Today's situation

UC5 - Goal of the use case

This UC highlights the chance to achieve CapEX and OpEx reduction, respectively, through:

- a convergent common fixed-mobile transport network, able to interoperate with any backhaul and front-haul network element or, in general, with any fixed/mobile access network;

- the dynamic handling of network resources, optimized for the different conditions of traffic demand during the day and for different locations, related to mobile, residential and business services (both IP and CPRI/OBSAI based).

UC5 - Research and innovation

The possible solutions to the needs raised by this UC are expected to support the transport of different services (fixed/mobile) characterized by a wide range of requirements, which may be very strict, depending on the specific service (e.g. delay/jitter in CRAN model); ensuring, at the same time, low cost of transmission per bit. This is basic for realizing an efficient and flexible networking platform able to perform resource sharing. Hence these solutions should:

1. Support appropriate combinations of transport technologies: packets (e.g. MPLS-TP, Ethernet), circuits (e.g. OTN) and wavelengths (CWDM, DWDM), with the granularity of connectivity driven by the amount of bandwidth demand per fixed/mobile service.
2. Support appropriate means of management and control for the dynamic allocation of network resources (e.g. via SDN/NFV model), required to transport any fixed/mobile service.
3. Figure 9 and
4. Figure 10 show an example of application for this dynamicity and sharing by depicting the chance to dynamically allocate network connections to CRAN based cell sites and making flexible use of BBU pooled resources according to the traffic demand over time.
5. Support, as far as possible, a “smooth” evolution to the convergent network starting from passive/active infrastructures currently deployed; leveraging, as well, on low cost/long reach solutions (e.g. G.metro, NG-PON2).

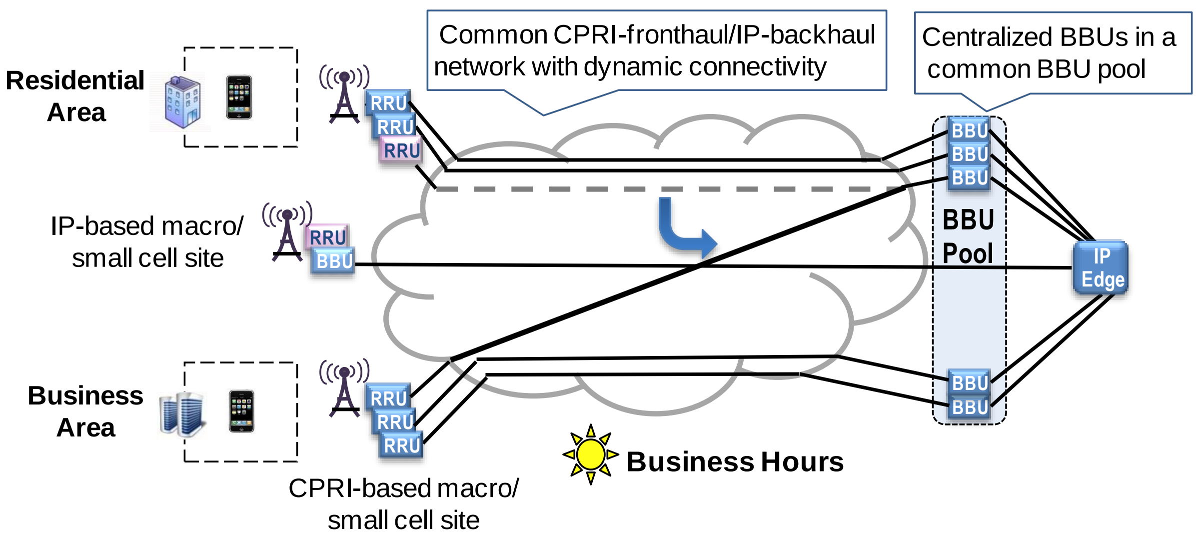


Figure 9: UC5 – Potential impact – "business hours" connectivity

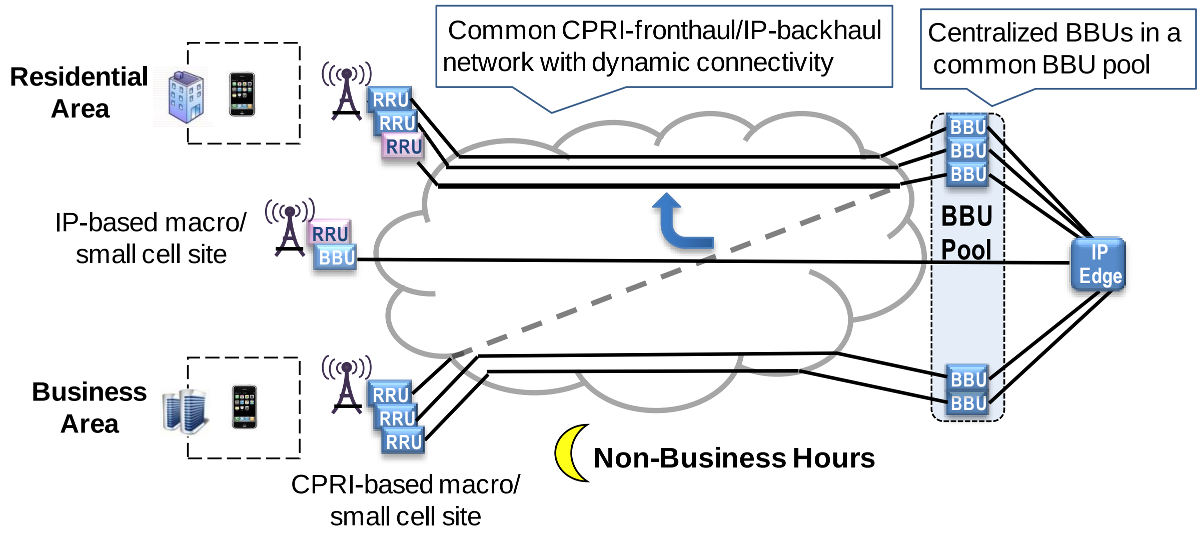


Figure 10: UC5 – Potential impact – "non-business hours" connectivity

UC5 - FMC aspects

This UC addresses a common infrastructure, able to backhaul/fronthaul any kind of service (fixed, mobile, Wi-Fi). This common infrastructure is, also, expected to support the dynamic allocation of connectivity resources at the proper granularity and layer. It represents, consequently, a major need of the FMC research activity, and it points to an opportunity for structural convergence.

3.4.2 UC6 - Convergence of fixed, mobile and Wi-Fi gateway functionalities

UC6 - Today's situation

The current transport and control functions of mobile, fixed and Wi-Fi networks are typically distributed with different degree of centralization and decentralization. For example, the mobile core network is highly centralized whereas the IP edge function of the fixed network (e.g. BNG) is more decentralized. Mobile data traffic is tunnelled on a path from the first active radio equipment towards the mobile core network. All mobile data traffic has to cross various fixed transport IP networks, the Packet Data Network (PDN) Gateway (P-GW) router to eventually reach the public Internet domain. However, for any traffic not related to operator-managed services, it is not necessary to cross the very centralized mobile core, which leads to inefficient utilisation of transport resources and high latency values.

This basically means that a common FMC solution is needed to redirect data traffic originated from fixed, mobile and Wi-Fi access networks to a network location where data processing and routing is performed more efficiently.

UC6 - Goal of the use case

This use case aims at the integration of fixed, mobile and Wi-Fi functionality in the same network entity, called Universal Access Gateway (UAG), in order to realize a more efficient operation of transport/control functionalities and optimize costs by reducing the number of network elements (

Figure 11).

For example, UC6 advocates that mobile gateways (S-GW/P-GW) are distributed and located in a central office closer to end-users, so that LTE mobile traffic can access the national IP network and reach the final destination over the Internet sooner, thus, enhancing latency time and saving transport resources. By distributing the mobile gateways closer to end-users, all traffic that does not need specific treatment (e.g. Deep Packet Inspection) will be delivered locally to the operator IP core network. This allows saving transport resources within the mobile core network.

Optionally, by implementing storage and processing resources, this use case could be enhanced as an enabler for CDN or offer an access (with open APIs) to OTT service providers for their own resource and traffic management, for mobile and fixed users as well

The UAG may also include Wi-Fi hotspot controller functionality, Wi-Fi IP Edge and mobile radio control functions.

Depending on the capacity of the available last-mile technology (radio, copper, or fibre) the UAG may also include BBU functionality.

This use case provides the following benefits:

- More efficient operation of transport/control functionalities by fully integrated production considering fixed, mobile and Wi-Fi network
- Optimize costs by reducing the number of network elements
- Lower latency and better utilisation of transport network resources
- Overcome performance limitations on access router caused by significant traffic increase
- Content delivery optimization considering fixed, mobile and Wi-Fi network

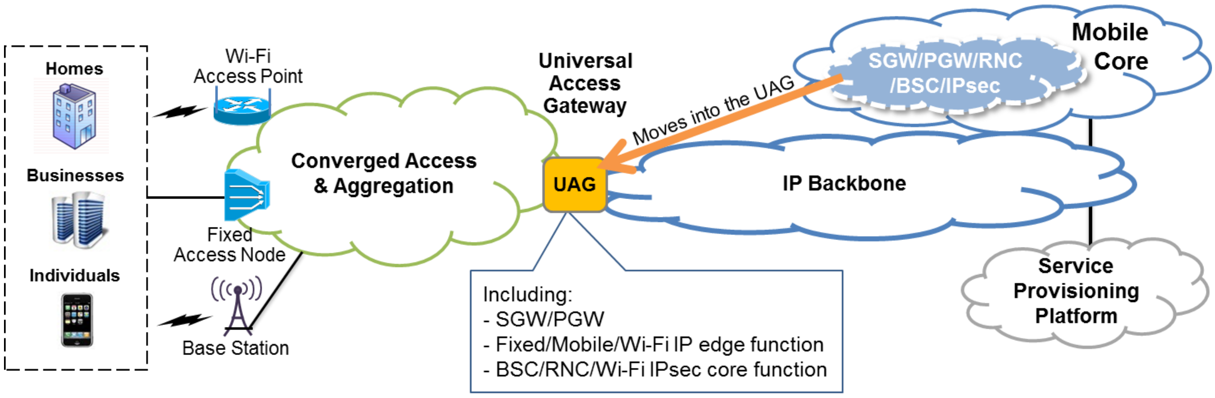


Figure 11: UC6 – Universal Access Gateway concept

UC6 - Research and innovation

The following research questions must be analyzed in order to realize this use case:

- What functions of fixed, mobile and Wi-Fi network make sense to integrate at the same network entity? Especially, what mobile core functions make sense to distribute compared to today's centralized approach?
- What functions of fixed, mobile and Wi-Fi can be converged in the UAG (functional convergence)? Is a common AAA function for authentication, authorization and accounting purposes for fixed, cellular mobile and Wi-Fi access required and would it simplify service provisioning and network operation?
- What is the impact of the functional distribution on scalability, performance and cost?
- How to integrate the fixed, mobile and Wi-Fi functions and a common management based on an open platform (e.g. SDN/NFV)?
- What is the optimal network location in order to place a Universal Access Gateway?
- How to enable content delivery optimization based on access to all end user connectivity's?

UC6 - FMC aspects

This use case addresses both structural and functional convergence. The integration of today's fixed, mobile and Wi-Fi functions in the same network entity (UAG) aims at structural convergence. The UAG may integrate:

- Fixed network functionality, e.g. BNG,
- Mobile network functionality, e.g. S-GW/P-GW, IPSec, BBU hotel,

- Wi-Fi network functionality, e.g.: Wi-Fi IP Edge, Wi-Fi hotspot controller.

In addition, this use case targets functional convergence by integrating common functions that are used by fixed, mobile and Wi-Fi network, e.g. universal AAA function, content delivery optimization, per-session or per-user accounting whatever the access network or device used, etc..

Regarding network sharing concerns, this gateway will provide a single gateway to multiple access networks, simplifying the sharing of these networks by several operators or service providers.

3.4.3 UC7 - Converged access and aggregation technology supporting fixed and mobile broadband services

UC7 - Today's situation

Fixed and mobile broadband networks have been designed and evolved independently using different technologies and protocols as described in chapter 2. From the last years, mobile networks have started to use high capacity tunnels of fixed network aggregation segment to provide enough capacity to the mobile base station and to interconnect the mobile packet core to them. This means that a certain degree of structural convergence is already realized in today's aggregation network segments, for example, by using a common Ethernet based aggregation network that is used for aggregating fixed and mobile network traffic. However, mobile networks use these dedicated aggregation network links transparently and only to carry mobile data traffic, so there is no deep integration yet. It is also expected that such a tunnelling concept is not scaling with respect to the mobile traffic growth and the increasing number of mobile base stations and interconnected devices driven by the evolution towards small cells and 5G in future. This scalability issue gets worse considering the trend towards node consolidation.

In addition, future small cell deployments also require a higher degree of structural convergence in the Last Mile combining FTTH/B and mobile backhauling. The current macro base station backhauling solutions (see D2.2 section 3.4 Current mobile backhaul alternatives" [22] are not optimised for a massive small cell deployment with many base stations (e.g. macro, micro and small cells) per fixed access area. Additionally today's optical FTTH systems (e.g. GPON) are typically only used for residential market and not used for mobile backhauling. However, upcoming high performance optical access systems (e.g. NG-PON2, WDM-PON, etc.) are able to fulfil the requirements beyond the residential FTTH user segment e.g. in terms of bandwidth, which offers the change towards a converged access and aggregation technology supporting fixed, mobile and Wi-Fi broadband services on one transport platform for business and residential customers.

UC7 - Goal of the use case

This use case aims at a universal access and aggregation technology that supports all kind of communications services for residential, business and mobile backhauling and fronthauling. Figure 12 illustrates a scenario in which the fixed access network and the mobile backhaul network can use the same technology to provide fixed and mobile broadband services. Additionally, as new technologies have a longer reach, it is expected that the evolved network could have a reduced fixed aggregation area or even to merge both networks in a single access-aggregation network.

This new access-aggregation network can be used to provide connectivity services to residential and enterprise customers and also to mobile base stations. For fixed customers, it can provide FTTH connectivity directly to end customers or it can be used to provide the backhaul to the technology and infrastructure (e.g. copper) used in the last mile. In the case of mobile backhaul, it can provide a high capacity link to base stations (that could use different radio technologies, such as 2G, 3G and 4G) using conventional packet backhauling, processing the baseband signals at the cell site or using CPRI or similar technologies to enable the baseband signal processing in remote locations (for example in BBU hotels), leaving only the radio parts at the cell site. The latter one clearly has an impact on the potential network consolidation due to the stringent delay requirements in fronthauling (see D2.4 specific requirements for UC7 [23]).

The main benefits of this UC are:

- simplified network operation and management due to reduced technology diversity,
- lower complexity via a simpler network structure,
- more efficient resource usage achieved by the integration of resources and
- enable an open and multi-operator network.

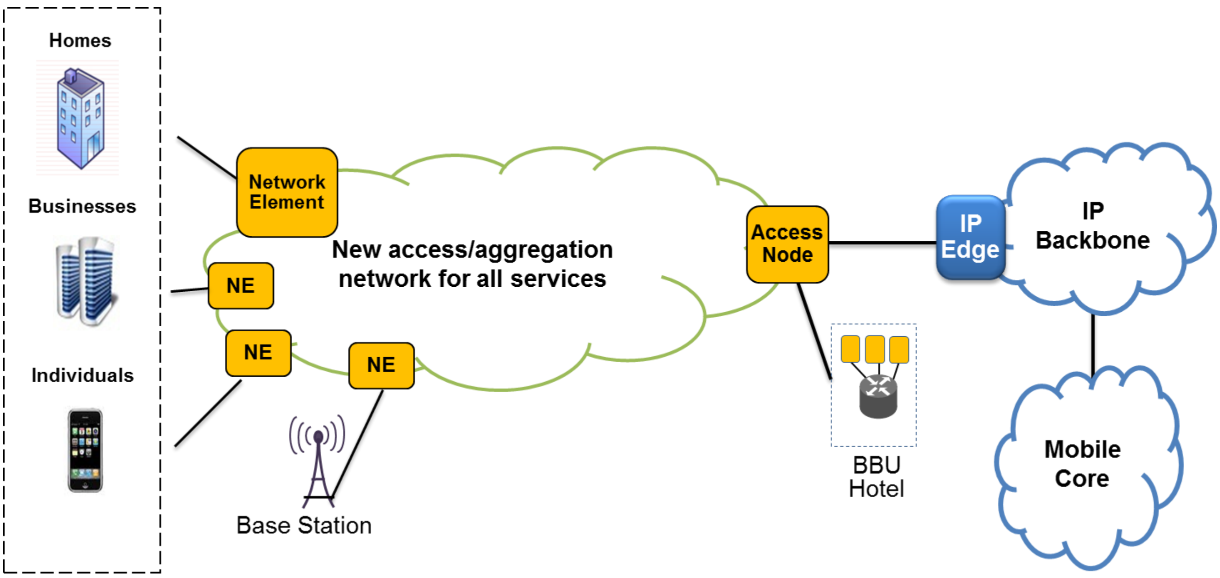


Figure 12: UC7 – Converged access and aggregation technology supporting fixed and mobile broadband services

UC7 - Research and innovation

Today's optical access systems do not support FMC integration in the access and aggregation domain. A unified network technology is needed supporting fixed, mobile and Wi-Fi broadband services with enhanced sharing in both network domains.

A main challenge is a cost optimized implementation of TDM and WDM structures in order to combine a high sharing and large capacity addressing:

- FTTH deployments with many endpoints and data rates up to 1 Gbit/s,
- Backhauling of mobile base-stations, Wi-Fi access points or fixed access nodes (e.g. DSLAM) with data rates up to 10 Gbit/s,
- Mobile fronthaul with data rates of up to 10 Gbit/s and very tight latency requirements,
- Business users with high availability requirements.
- Flexible integration of new endpoints e.g. small cells

Currently there is no cost efficient flexible optical technology that allows automatic WDM link configuration, for example, using cheap tuneable transceivers because the needed silicon photonic integration is still missing.

Another challenge is the need for an enhanced redundancy and monitoring mechanisms that prevents a full or partial network outage of fixed and mobile in certain service area with FMC integration.

Moreover a migration concept must be developed considering the legacy network infrastructure.

UC7 - FMC aspects

This use case aims at structural convergence with a unified network technology that allows enhanced sharing of the network infrastructure in the access and aggregation domains for fixed, mobile and Wi-Fi broadband services.

3.5 FMC UCs – Operator Cooperation

The potential benefits of network sharing are obvious. It can result in significant reductions in CapEx and OpEx, speed up network rollouts, improve coverage and help to meet the increasing capacity demands [4]. Network sharing has, therefore, existed for decades in the telecom industry in various forms. It can be a basic cooperation between operators involving roaming and site sharing, or may be more advanced including sharing radio assets and the core network.

The wholesale network sharing model is an evolved form of the models used in the industry so far. It is an alternative to the joint-venture model and simplifies the sharing of operations and assets among multiple operators through a third party [5].

3.5.1 UC8 – Network sharing

UC8 - Today's situation

Network sharing is possible today to some extent e.g. based on bit-stream access and layer 1 sharing in some parts of the fixed access network, but it can be a complex task, particularly if one considers fixed and mobile networks together. In general it requires competing operators to set aside competitive concerns and, instead, cooperate and focus on the cost-saving possibilities. Another challenge is to monitor the usage of the resources and assure the signal performance and provide fair and dynamically adjusted resource sharing between operators and services. For example, when a network failure arises, it should be possible to guarantee a premium service to one or more operators, depending on the subscribed SLA from the wholesale network company. Besides the technical challenges it also requires new business models which allow cost sharing of resources depending on different conditions like pure resource usage, or quality issues etc.

UC8 - Goal of the use case

The goal of this UC is to provide multi-operator network capabilities in future FMC networks in order to reduce deployment and operation costs and support more flexible business models by utilizing existing infrastructure for both fixed and mobile communication as much as possible. Moreover, network sharing is highlighted as a way to address the issues of spectrum availability, shortage of licenses, tougher competition in the telecom sector and global financial pressure.

This use case addresses two important challenges for network operators:

- evolution in terms of network ownership and operator relationships in a multi-operator FMC scenario and
- cost saving, including CapEx and more importantly the long-term OpEx.

In principle, this use case covers both technical and business aspects of a FMC network with multi-operator approach. On the one hand a technical concept needs to be developed enabling a flexible integration of data plane packet processing and control plane functions of multiple operators (fixed, mobile and Wi-Fi network and service providers) into a converged access and aggregation platform (Figure 13). On the other hand, this UC addresses business aspects of a multi-operator environment where competing operators can cooperate via a wholesale network company and share, for example, their infrastructure resources (such as antenna sites, power, RAN, backhaul network, or even network elements in the aggregation and core networks) in order to use them more efficiently and obtain additional cost savings in an FMC network scenario.

The main benefits of this UC are [4] (i) higher utilization of shared resources based on statistical multiplexing gains; (ii) fast network roll-out and quick start of new services; (iii) improved coverage in rural areas; (iv) energy saving by using the same resources for diverse types of access networks; and (v) lower costs for operators and end-users.

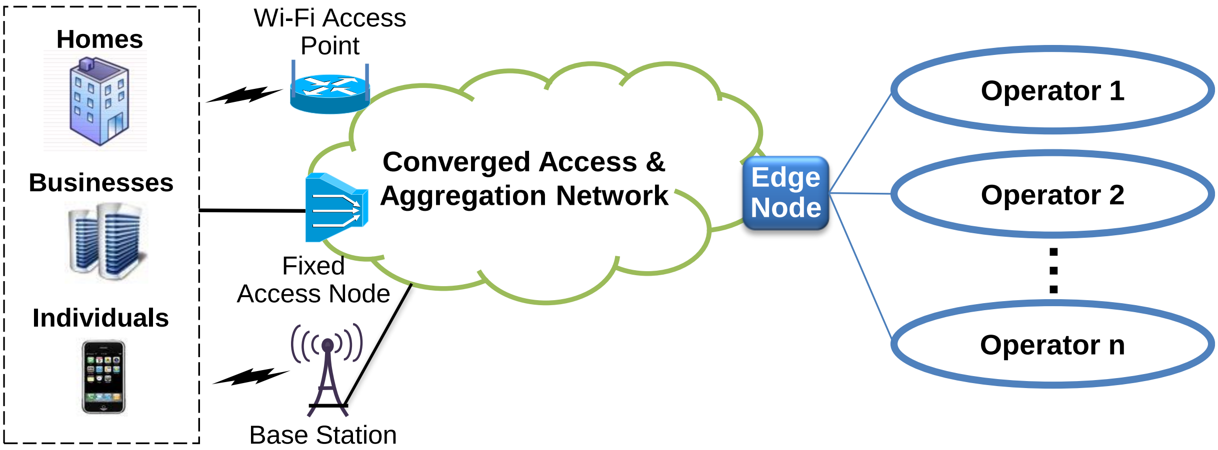


Figure 13: UC8 – Converged access and aggregation network with multi-operator approach

UC8 - Research and innovation

The 5th generation of mobile communications is foreseen as the enabler for the networked society, entailing a large range of new end-user services and use cases. The telecom, datacom and mediacom industries are merging. This will also drive a more complex landscape of actors that will need to share the resources of a converged network because of the benefits listed above. The need for small cell deployment and small cell transport will also likely require increased sharing of network resources/infrastructure among different actors. Today, mobile operators may lease fixed line capacity for their backhaul networks. In an FMC scenario, this type of sharing may become even more common. For new types of services, service providers may need dynamic access to transport capacity, site-connections and processing capacity from access providers. This implies the need for dynamic and programmable network resources as well as increased openness of network interfaces while ensuring fair access to network resources. These network interfaces allow interconnecting the different networks with the converged shared network at layer 2 (mainly Ethernet level) as well as layer 3 (IP level). The FMC network, consisting of resources from various actors, may become an open platform for service innovation, with the ability to quickly and efficiently provide network services on different levels to other actors. Besides a flexible data plane, this will also require a flexible control plane enabling a multi-operator operation of the network. Within this new field, innovative business models based on non-discriminatory infrastructure sharing are required and will be investigated within the techno-economic assessment (WP5).

UC8 - FMC aspects

Network sharing in an FMC scenario may facilitate mobile-only operators to enter the fixed market or vice versa, resulting in new cooperation possibilities. For example, in order to share the investment costs, a mobile-only operator may decide to roll out an LTE-Advanced network together with a fixed-only operator that is interested in entering the mobile market.

With respect to the aforementioned topics for network sharing, in this use case COMBO will focus on structural convergence and flexible control plane for the transport network but functional convergence aspects are also included. The main part of shared networks is shared infrastructure, equipment and maybe even interfaces but there will also be needs for common simplified control and management solutions in order to, for example, enable dynamic traffic management (see UC6). Furthermore, since use cases are a main source of input to WP3, network sharing approaches in line with this use case will be considered when specifying FMC network scenarios in WP3. And in WP5 we expect to investigate the business ecosystem as well as new business models for FMC networks in relation to these network scenarios.

4 Market analysis

In the previous chapters, the reference framework (chapter 2) and the different FMC network use cases defined (Chapter 3) had been described explicitly. Chapter 4 tries to complete the picture of the framework reference for fixed and mobile convergence by providing an initial general overview of the actual market situation of the different network types as well as an overview of the main market drivers for the development of converged networks.

As part of the market analysis, also regulatory aspects - based on the actual situation of European regulation on Electronic Communication Markets - will be presented as well as possible further implications the new recommendations of the European Commission may have on FMC.

4.1 Overview of current market situation

Currently, fixed and mobile networks are separated (completely functional and physical separation of fixed line access/aggregation networks and mobile networks) and both have been optimized independently over the past. Customers can get Internet access services via fixed line networks or mobile networks, often at a flat rate price allowing nearly unlimited access. Recently operators start limiting the data volume in relation to the rate paid by the customer for mobile access (higher price, more data volume) while the fixed line rate still offers unlimited data volume. The data The data provided in the subsequent sections - based on the assumption and market research results of different official organisations, private companies and the project partners - show the actual trends in the separated networks and the need for further convergence. Some contradictory predictions related to numbers (e.g. percentage of increase) can be found in the text, mainly related to the time horizon companies or organisations are referring to as well as to the relative approach that had been chosen by them.

4.1.1 Fixed

According to data published by the Organization for Economic Co-operation and Development (OECD) from December 2012 published in June 2013 [11] 53% of global broadband users are using xDSL technologies (175 million out of 321 million fixed subscribers in total; 4.4 points less than in 2010 – see

Figure 14). This high percentage of xDSL can be attributed mostly to two factors: first, there is a huge installed base of copper twisted pairs in the telephone loop infrastructure and second, in several scenarios copper media is easier to install and it has an advantage of not requiring signal conversions (e.g. electrical to optical, or electrical to radio and vice versa) which makes xDSL devices smaller and cheaper.

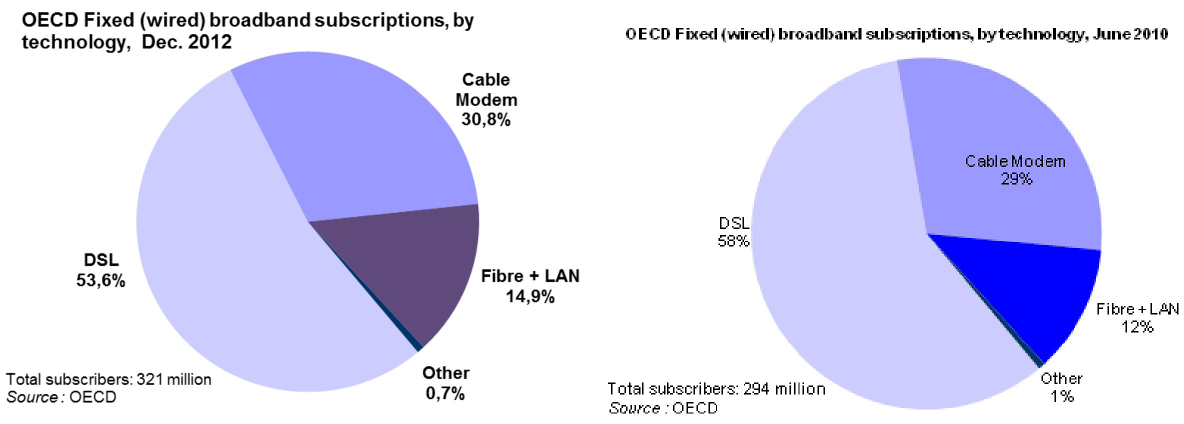


Figure 14: Global fixed(wired) broadband subscription

In order to provide higher bitrates and future services to customers, telecom operators are updating their networks from copper solutions to full fibre or hybrid copper-fibre options. In Fibre-to-the-building (FTTB), fibre reaches the boundary of the building and the final connection to the individual subscriber is made via alternative means, such as twisted pair, coaxial cable, wireless, or power line communication. Although, as previous mentioned, DSL technology subscriptions continue to decline with a growing number of fibre subscriptions at 16.6% year on year between 2009 and 2011, there is still a big dependence on xDSL technologies that will continue during the next years.

Fixed networks are typically used for backhaul of mobile base stations; additionally 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) [2].

4.1.2 Mobile

In a recent report Ericsson [3] exposed the actual situation in the mobile market by arguing “the number of mobile subscriptions worldwide has continued to grow 7 percent year-on-year and 2 percent quarter-on-quarters. Global mobile penetration reached 93 percent in Q1 2014. Total mobile subscriptions in Q1 2014 were around 6.8 billion.” Global mobile broadband subscriptions – due to the continuous uptake of Smartphones – grew by around 35 percent year-on-year and reached 2.3 billion in Q1 2014.

They further stated that these factors combined have led to the point that Mobile data traffic has grown 65% between Q1 2013 and Q1 2014 and has exceeded in Q1 2014 the total mobile data traffic in 2011 (see Figure 15). It is expected to grow at a CAGR of around 45 percent between 2013 and 2019. Voice traffic remains static decreasing in relation to data traffic.

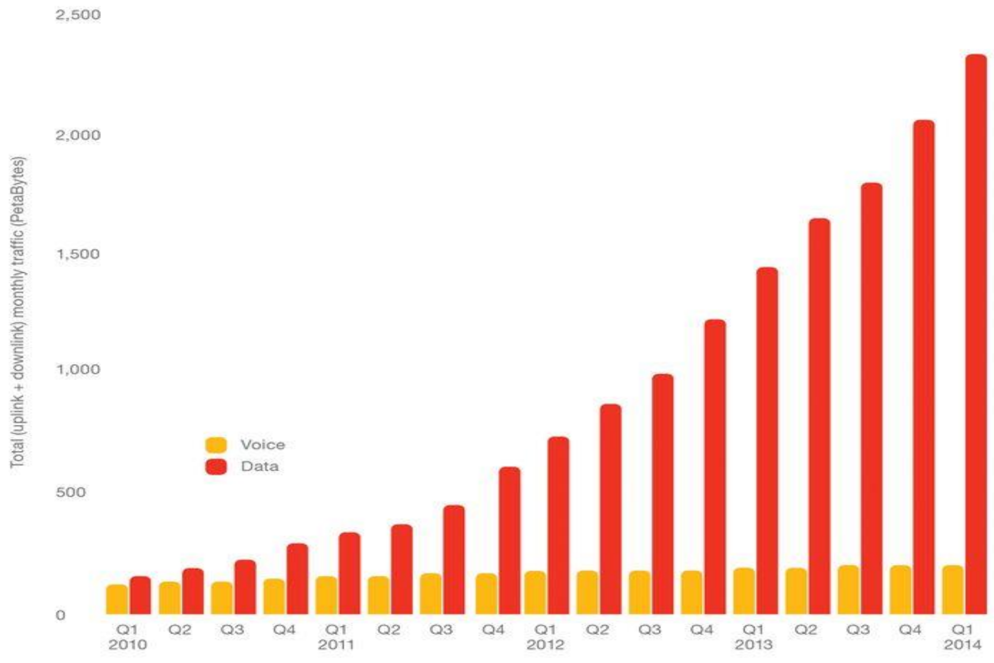


Figure 15: Global total data traffic in mobile networks, 2010-2014

As per Ericsson, the currently used mobile technologies which are GSM/EDGE technology (2.5 G) has by far the widest reach and covers over 85 percent of the world's population. LTE covered around 20 percent of the world's population at the end of 2013. This was a doubling of LTE population coverage compared to 2012. It is predicted that this will increase to over 65 percent by 2019

LTE (4G) networks have been launched in 104 countries and the number is growing. LTE Advanced carrier aggregation continues to increase; necessary for operators to make most efficient use of spectrum assets supporting them in delivering approved app coverage with higher peak data rates. In 2013 aggregation started with 20 MHz LTE carrier which would support download speed of up to 150 Mbps arriving in the latest trials at 60 MHz (3x20 MHz) supporting download speeds of up to 450 Mbps depending on the capacity of the devices.

Another study published by Cisco provides some more interesting data on the mobile market [2]:

Global mobile data traffic grew 70 percent in 2012. Global mobile data traffic reached 885 petabytes per month at the end of 2012, up from 520 petabytes per month at the end of 2011.

Smartphones represented only 18 percent of total global handsets in use in 2012, but represented 92 percent of total global handset traffic. In 2012, the typical smartphone generated 50 times more mobile data traffic (342 MB per month) than the typical basic-feature cell phone (which generated only 6.8 MB per month of mobile data traffic). But, basic handsets still make up the vast majority of handsets on the network (82 percent).

Globally, 33 percent of total mobile data traffic was offloaded onto the fixed network through Wi-Fi or femtocell in 2012. In 2012, 429 petabytes of mobile data traffic were offloaded onto the fixed network each month. Without offload, mobile data traffic would have grown even more than 70 percent in 2012.

4.1.3 Wi-Fi

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 [12]. 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 [13]. This growth is inspired by a plethora of new Wi-Fi-enabled devices. Mobile research by Cisco discovered that almost all new mobile devices have Wi-Fi as their primary wireless access technology [2].

The same research also found that people will 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 3G networks are encouraging users to replace mobile data with Wi-Fi in many cases.

In addition, more and more Wi-Fi communities are developed and marketed, and this technology is seen by many operators as a crucial differentiator among their competitors. Therefore, there is a huge, industry-wide focus on sharpening the Wi-Fi user experience to address issues such as improving Wi-Fi network performance, enhancing and simplifying the discovery and authentication experience of Wi-Fi, and alleviating concerns around security and privacy.

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.

4.2 Future Market Developments

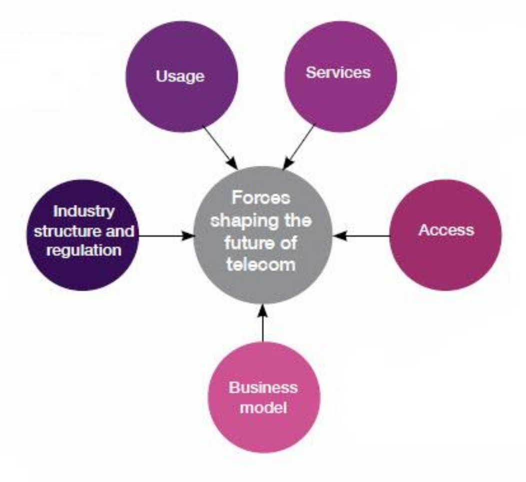
As unisonously stated in various statistics, studies and publications of public authorities like OECD [11], ITU [14], ETNO [15] etc. as well as private companies such as consultant companies like Booz & Co. [16], Arthur D. Little [17], Roland Berger [18] etc. or network manufacturers such as Ericsson [3], Cisco [2], IBM [19] etc., the future of the global telecommunications market will change dramatically in the upcoming years, even more than in the past ten years.

Main drivers will be the increasing data traffic driven by the massive uptake of smartphones and tablets, the mobile Internet, and digitization technologies such as cloud computing. Furthermore, customers are used to interact in the service ecosystems offered by OTT players like Apple, Facebook, Google, etc.; this creates further traffic growth and thus a need for empowered networks.

It is estimated that between now and 2016, mobile data traffic will multiply tenfold, with video acting as the biggest driver. By 2020, the OTTs' video offerings will account for more than half of total data volume [18].

According to a study conducted by IBM [19] the forces driving telecommunications through 2015 and beyond will be (see Figure 16):

1. Usage – changes to user consumption patterns
2. Services – changes in services composition
3. Access – device and network access technology evolution
4. Business model – future revenue structure and sources
5. Industry structure and regulation – future of industry structure and regulation.



Source: IBM Institute for Business Value and IDATE Analysis

Figure 16: Forces shaping the future of Telecommunications industry

And Delta Partners [20] argue that by 2020 the telecom industry will look radically different from today; there will be a

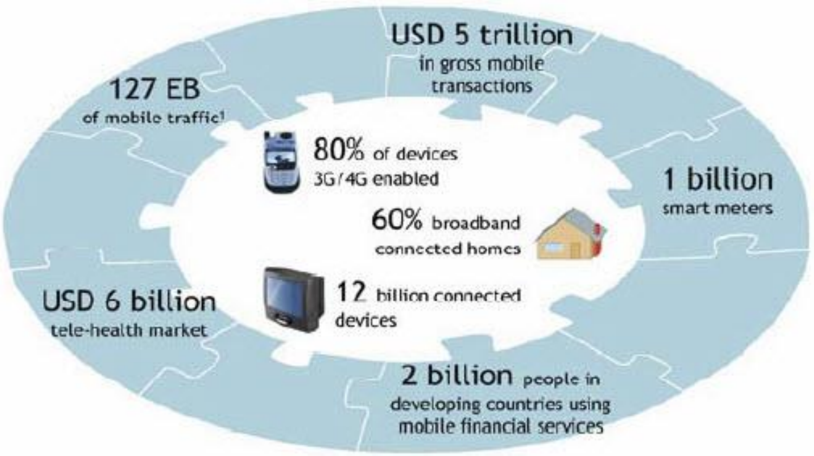
- Fundamental shift in revenue mix: the rise of non-traditional services (i.e. mobile broadband, cloud services, M2M, social media)
- Fundamental shift in margins: Revenue growth at riskier margins (new services like M2M have the risk of tighter margins)

They further emphasize that this radical shift will not imply by any means the disappearance of fixed network. On the contrary, "network topologies will rely more and more on Wi-Fi and FTTH/GPON, FTTB as mobile networks simply will not be able to handle the data traffic volumes and speeds required by customers due to a constraint in spectrum/more spectral efficiency mobile technologies."

4.2.1 Drivers and barriers

Exponential growth of data volume can be considered as one of the main drivers for investments in telecom infrastructure, and in particular in FMC.

According to Delta Partners [20] the data connectivity by 2020 is expected being so advanced that almost everyone and everything will be connected to the Internet (see Figure 17).



Source: Pyramid, GSMA, World Bank, IMS Research, UMTS Forum, Pike Research, Delta Partners analysis

Figure 17: Key Figures in 2020

Additionally, it was reported “Data services will explode, increasing from a share of 52% of the market to 72% by 2020. The bulk of this growth will be driven by mobile data, M2M and cloud computing.”

And IBM [19] stated that, “due to the forecast of mobile data traffic growth at 130 percent year-to-year, the capacity on current 3G networks will likely be exhausted by 2013,, increasing therefore the pressure on providers for additional investment in radio access and backhaul networks.”

Roland Berger argued in his report “Telco 2020” [18], that “pureplay broadband access – the mainstay of traditional telcos' business today – will remain the cornerstone of digital communication in the future for both landlines and mobile communication. While usage and associated data volumes continue to grow exponentially, however, telcos are under the price pressure that inevitably accompanies commoditization while the industry so far has failed to monetize volume growth.”

As already outlined before, the main driver behind the exponential growth of data traffic and therefore for FMC infrastructures is the evolution of consumer demand – to be online everywhere every time with different devices at the same time [18]. The need for more capacity in Internet access, in relation to connectivity speed as well as network dimensioning, will lead to the necessity of changes in the network types due to the limited capacity actual networks can offer in relation to the exponential growth of data traffic and customer demand.

To increase the capacity, investments in infrastructure are needed, in new technologies as well as in the upgrade of the existing networks. As McKinsey pointed out in his report about investments in telecoms infrastructure [38]: “as data traffic is increasing exponentially, telecoms industry everywhere needs to make huge investments to cope with this outlook, both in fixed as well as in mobile infrastructure.” Investments in FMC infrastructures can leverage synergies and by that reduce the costs of the investment.

In general, cost reduction in operators’ networks can be considered another driver for FMC, tackling both CapEx and OpEX – detailed analysis of the cost structure of separated networks as well as future FMC networks will be performed in the techno-economic assessment (WP5). This is especially related to the fact that there is a big gap between revenues and traffic volume.

IBM emphasized in a report about Telco 2015 [19] that due to the “all-you-can-eat” current revenue model (flat rate tariffs) a gap has been generated between traffic and revenue, which is at the heart of the telco revenue model challenge (see Figure 18).

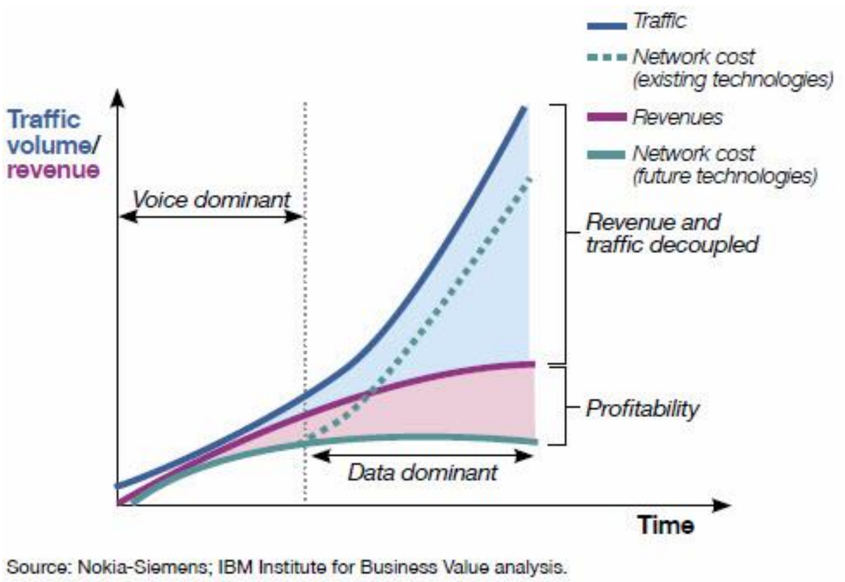


Figure 18: Revenue and traffic are disassociated in an increasingly data-dominant world

Consumers are requiring usability and service experience, which are the keys to customer acceptance. FMC can here support a better QoS through "intelligent" hand-over of traffic between different networks. Detailed performance evaluations will be undertaken in “Traffic and performance management (WP4).

4.2.2 Fixed Mobile Convergence

ITU argued in his report that “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.” [14]

Furthermore, ITU emphasized the importance of delivering the socio-economic benefits of broadband equitably, thus “requiring network deployment using a mix of technologies tailored to the specifications of each market”. Therefore, an integrated, unified approach of mobile, wireless in the home and fibre backhaul could be appropriate for developed urban areas, whereas wireless technologies are often key for people living in rural areas.

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 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 (currently many operators are offering bundles with access to WiFi but they still have separated customer accounts, so no real convergence).

The importance of FMC had already been pointed out in the European Research project ECOSYS in a study in 2009 (see Figure 19) showing that market shares would decrease for separate operators. [21]

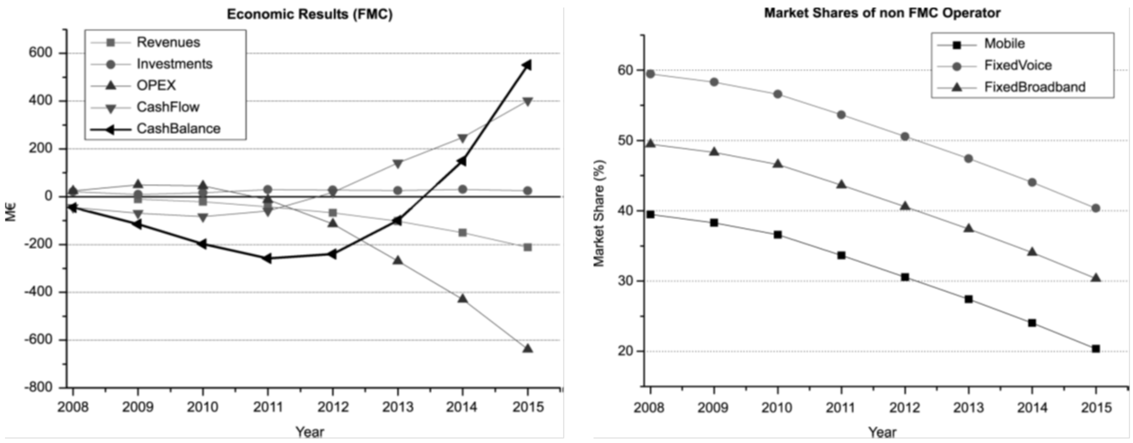


Figure 19: Economic results in FMC and development of market shares of non FMC Operators

To be able to face the challenges mentioned above, the development of an FMC network is essential for the future of the telecommunication industry, both in technical and economic aspects. FMC can support players in the field, in particular operators, to develop new revenue models and enter new areas of business such as eHealth, Smart Energy, payment services (m-payment), smart home services (ambient assisted living), M2M, etc.

While up to now FMC has mainly been implemented at service level,, allowing a converged service control layer, COMBO is proposing a really integrated FMC network architecture.

Based on this general market analysis, which reflects the current business situation, and the related future predictions pointing out cost and revenue constraints, further economic analysis (cost analysis as well as analysis of business ecosystem, business models and value network) of the reference framework (including state-of-the-art FMC networks) will be elaborated in the techno-economic assessment (WP5); (the complete techno-economic analysis of the state-of-the-art frameworks will be finalized in Deliverable 5.1 - *Assessment framework and state of the art architectures*).

4.3 Regulatory aspects

In this chapter an overview about the current regulatory situation as well as further developments in the telecommunications sector will be provided. The regulation of markets has a clear impact on the business models of the different actors when being effected e.g. by wholesale offers and interconnection fees. Regulation will most probably have also an influence on the FMC network scenarios developed in WP3 and analysed in the techno-economic assessment (WP5).

4.3.1 Current regulatory situation in Europe

After the privatisation of many former state-owned operators in the 1990s European regulation on Electronic Communications Markets started in 2002 when the European Commission introduced the EU regulatory framework on electronic communication. Due to continuous rapid technological developments the EC made recommendations for adaptions of the framework in 2003 and 2007, which led to an amendment of the regulatory framework in 2009.

Currently the Fixed and the Mobile market are subjects to regulation, the Wi-Fi is market is not regulated. The first version of the Recommendation, issued in 2003, listed seven retail markets (regulating services and facilities provided to end-users) and 11 wholesale markets (regulating upstream access to facilities and networks which are necessary for operators to provide competitive access services to end-users), which were susceptible to *ex ante* regulation (forward looking analysis of the market addressing the lack of effective competition that is expected to persist over a time horizon). [25] The next version of the Recommendation, issued in 2007, reduced this list to one retail and six wholesale markets [28], where Markets 1-6 are dealing with regulation of the fixed market and Market 7 is regulating the mobile sector.

Markets will be identified by three cumulative criteria and will be regulated only when all three are relevant: [27]

- The presence of high and non-transitory barriers to entry
- A market structure which does not end towards effective competition within the relevant time horizon
- The insufficiency of competition law salon to adequately address the market failure(s) concerned

An overview of the current regulated markets in the telecom sector, retail and wholesale, and their inter-relationship is shown in

Figure 20. [27]

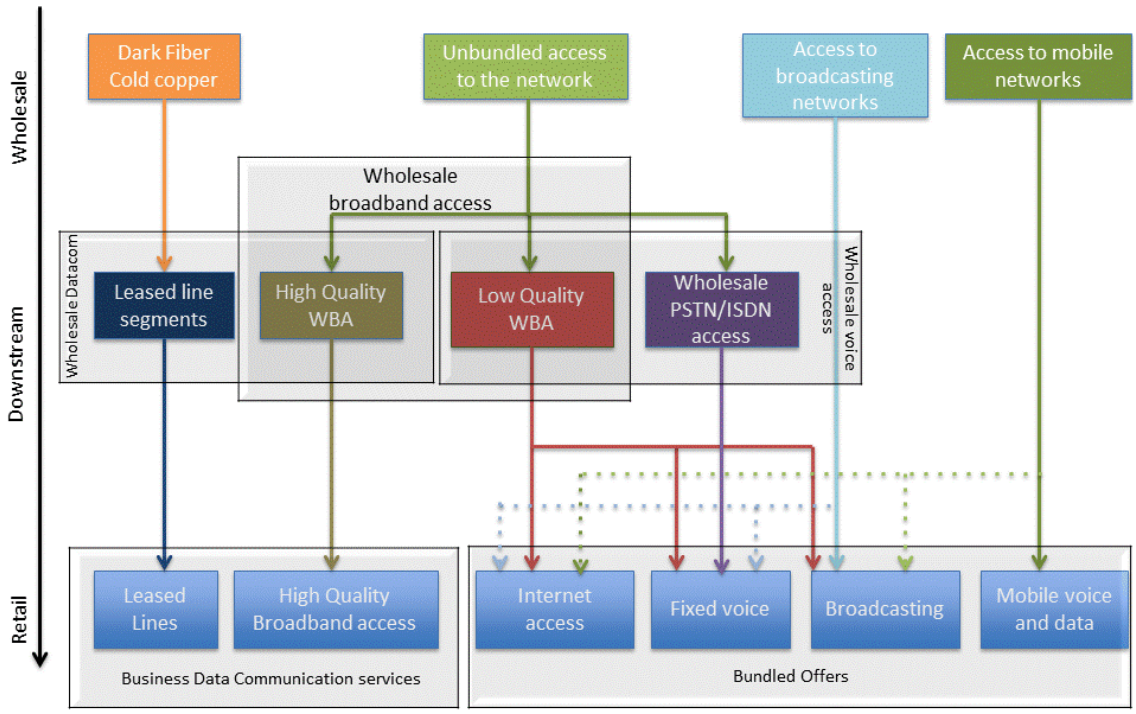


Figure 20: An overview of retail and wholesale markets

To guarantee a fluent reading a more detailed description of the history as well as the actual situation of the European Regulatory Framework can be found in the Appendix.

4.3.2 Future developments

As already mentioned before the European Commission has to take into account new technological developments for the regulatory framework.

Therefore, the EC is currently working on the second review of the Recommendation on Relevant Markets, based on consultations, studies and position papers from stakeholders, which will lead to an amendment of the regulatory framework and published already Draft Recommendations [24] as well as a Draft Explanatory note. [25]

Further details about the preparatory work for the recommendations as well as the Draft Recommendations can be found in the Appendix.

Some of the new recommendations that are taking into account new technological developments will also have an impact on Fixed Mobile Convergence.

The FMC architectures that are developed within the COMBO project will allow various fixed and mobile applications to share the same infrastructure, while at the same time aiming at allowing strict separation (unbundling) and by thus, ensuring that general regulation principles are satisfied.

Despite of this open approach possible implications in relation to the actual regulation and future amendments of the regulation based on the recommendations may arise. Based on the different use cases, some aspects may tackle parts of the Wholesale Markets as well as retail market regulation (the removal of the retail market is still under discussion) [33] when dealing with new or differentiated approaches such as

- Wholesale network sharing
- content caching (in-network)
- small cells/backhaul
- bundling of DSL and LTE
- Universal Access Gateway
- Combination FTTH/B and mobile backhauling

and, at least, how to handle "unbundling" (open approach of the COMBO project).

Current recommendations [24] do not foresee the introduction of new markets into regulation, an approach, which is also supported by BEREC [33]; the definition of actual markets should be refined and adapted to the extent to empower the national regulators to act within existing markets.

And as already recommended by the EC [24], "newly emerging markets should not be subject to inappropriate ex ante regulatory obligations, even if there is a first-mover advantage (the purpose here is to promote innovation)" and "incremental upgrades to existing network infrastructure rarely lead to a new or emerging market."

Based on the network scenarios that will be developed in WP3, which will serve as a basis for fixed-mobile convergence architectures, a more profound analysis in relation to the potential regulatory aspects will be provided as part of the analysis of the "impact of convergence on business ecosystems" (Task 5.3 in WP5), as far as regulation most probably will have an impact on a converged business ecosystem as well as on certain business models later in the project. Eventually, at that time the amendment of the regulatory framework will have already been established.

5 Conclusions

This deliverable contains the initial work for fixed, mobile and converged networks and will serve as the basis for the overall COMBO project since it is the starting reference point for WP2 (Framework definition, Architecture and Evolution) itself, WP3 (Fixed Mobile Convergent architectures) , WP4 (Traffic and Performance Management), WP5 (Techno-economic Assessment) and WP6 (Functional Development & Experimental Research Activities).

The deliverable captures the reference framework which shows a high-level view of the different network segments in today's fixed and mobile networks. It defines the main common reference areas in which fixed and mobile networks can converge, describing the different reference location points in the network, the main network elements and the most important reference parameters, such as the number of households, the reach distances, and the number of sites. The reference framework covers the technologies and architectures deployed nowadays which are considered more in detail in deliverable D2.2. The reference framework will be further developed to address the network evolution without an FMC approach so that it serves as a basis for comparison to the FMC network scenarios developed in WP3. This comparison will be evaluated in the techno-economic studies (WP5) where the network dimensioning information coming from the current network segments and reference parameters studies will be used for the techno-economic assessment.

Eight FMC network use cases are identified and described. These use cases address the needs, for functional and/or structural convergence, which future converged fixed/mobile networks shall fulfil. The use cases are structured in the following three groups: four use cases focus on *access resource sharing*, three use cases relate to *aggregation resource sharing*, and one use case addresses the topic of *operator cooperation*. Some of the use cases (UC4 and UC6) are used to define and model future converged fixed and mobile traffic scenarios (see Task 2.3 of WP2). Furthermore, requirements and key performance indicators related to the use cases here described have been further defined in Task 2.4 of WP2. The use cases also provide input for WP3. Task 3.1 will investigate how these use cases could be realized based on architectural and technological analyses in the form of network scenarios. Within Task 4.1 of WP4 the use cases are analysed from the points of view of performance monitoring, QoS, and QoE aspects. Finally, WP6 also analyses the uses cases to make an initial assessment about how the use cases can be included as part of the tests and demonstrations activities.

The last chapter of this deliverable, which sets the scene for the analysis of "the impact of convergence on business ecosystems" and is part of the techno-economic assessment (WP5), provides an initial general overview of the actual market situation of the different network types as well as an overview of the main market drivers for the development of converged networks:

- Enormously increasing data traffic (due to increasing usage of mobile internet, usage of bandwidth consuming OTT services)
- Increasing number of subscribers

- Change of user consumption behaviour (use of multiple devices simultaneously)
- Evolution of device and network access technologies (shift from functionalities from the network into the device)

as well as revenue decreasing for operators due to the current revenue model (flat rate tariffs) that has generated a gap between traffic and revenue (currently revenues and traffic are decoupled in the data dominated world - Figure 18 shows the gap widening over time), FMC (as developed in the COMBO project) is needed to cope with the current situation in two ways: (1) Cost reduction for operators tackling CapEx and OpEx of existing networks as well as future investments, (2) Generation of new revenues through the development of new business models (creation of new services, entering new areas such as eHealth, smart energy, M2M, m-Payment, etc.).

As far as regulatory aspects have an impact on the market (especially when dealing with operators to whom Significant Market Power (SMP) could be assigned and therefore regulation is applied) as well as on the business ecosystem and the related business models, an overview of the current regulatory aspects of European regulation on Electronic Communication Markets and possible further implications on FMC in relation to the new recommendations of the European Commission highlighted actual and potential fields of intervention.. The potential regulatory impact on FMC as developed in COMBO, namely the networks scenarios in WP3, will be included into the analysis of the “impact of convergence on business ecosystems” which is part of the techno-economic assessment (WP5).

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7 Appendix

7.1 Common Reference Areas

Section 2.3 details the common reference areas and the main reference parameters inside these areas. This appendix provides more details for all these reference parameters.

7.1.1 Customer premises

The reference parameters inside the customer premises considering fixed and mobile networks are related to the home/business network (i.e. the internal wireline/wireless local access network that belongs to the subscriber and where users connect to broadband services). The main reference parameters are the following:

- Number of households per area type. The number of households per area unit (where an area is a single representation of a geotype, e.g., the dense urban area of a city, a small urban town, a village, etc.) is geotype dependent. Typically, the number of households is in the order of hundreds of thousands in a dense urban area, tens of thousands in an urban area and hundreds to tens of thousands in a rural area. A household is a person or a group of people living in the same residence.
- Wireline network capacity in the customer premises. Typically, LAN interfaces use 100 Mb/s links in the home and enterprises networks. However, almost all new CPE have currently 1 Gb/s interfaces, so both of them should be considered as typical wireline network capacity in the customer premises. Ethernet is the most common interface used.
- Number of connected devices in a home (wireline and wireless). Typically, the number of CPE in a home is lower than 10 (e.g., laptops, personal computers, TV sets, Wi-Fi devices, video game consoles, tablets, gateways, etc.). However, this number is increasing due to the popularity of mobile phones (using Wi-Fi interfaces) and tablets, so it is possible (but not common today) to find more than 10 connected devices in a single home.
- Number of connected devices in a business building. The number of connected devices in a business environment depends on the size of the business, but it is common to find from dozens to hundreds of devices connected to an enterprise LAN inside a single building.
- Number of residential Wi-Fi APs. Only a single AP is typically needed for each home, but some customers use Wi-Fi repeaters or several APs to extend coverage in case of multi-storey buildings or larger houses.

- Number of business Wi-Fi APs. Several APs are needed to provide Wi-Fi connectivity to a business and the number of APs depends on the area to be covered and the expected number of users. It is usual to have dozens of APs inside a single building.
- Number of public Wi-Fi APs. Wi-Fi services can also be offered in public zones by service operators, municipalities, etc. This case is similar to the previous one, where it is usual to deploy dozens of APs in order to provide coverage to a limited public area.
- Number of community Wi-Fi APs. Community Wi-Fi operators offer Wi-Fi access to Internet using end-user Wi-Fi routers connected to residential fixed broadband lines and AP that they deploy in special areas to enhance the coverage.

It is common that fixed lines provide connectivity to a single house in a fixed location in which a group of people share that fixed line, however, mobile lines are normally assigned to a single person, so the number of mobile phone customers is much higher than fixed customers. Mobile phone subscriptions per 100 inhabitants are currently higher than 100% in most of European countries [1], so mobile terminals in an area is generally equal or higher the number of inhabitants in that area.

7.1.2 Access network

The access network area can be classified in two main areas: the fixed access network and the mobile access network.

7.1.2.1 Fixed access network

The fixed access network is composed mainly of the outside plant and the access nodes located in the access network operator premises. Additionally, street cabinets with active elements could also be deployed in some types of fixed access networks.

The main reference parameters for the outside plant are described below:

- Distribution segment length. The typical length for the distribution segment varies according to the geotype. Typical values are 200 m for dense urban, 300 m for urban and 400 m for rural areas.
- Trunk segment length. The trunk segment length varies according to the geotype. Typical values are 1 or 2 km for dense urban, 1 to 3 for urban and 2 to 4 for rural.
- Feeder segment length. The trunk segment length varies according to the geotype. Typical values are 1 or 2 km for dense urban, up to 5 for urban and up to 10 for rural.
- Splitting level per fibre access node (OLT) port FTTH. This parameter includes the number of levels in which the fibre is divided in the Optical Distribution Network (ODN) and the ratio of each splitting. Typically 2 splitting levels are used by network operators in the ODN (3 splitting levels are also possible but less common) with a total splitting ratio of 1:32 or 1:64 in both dense urban and urban areas. Rural areas are not always considered for fibre deployment, however when

FTTH is deployed in rural areas, the same splitting level approach of urban areas is used.

- Total copper line length for the PSTN (Public Switched Telephone Network). It depends on the geotype. In dense urban, urban and rural areas typical distances is below 5 km (typ. 1.5 km), below 7 km (typ. 2 km) and below 10 km (typ. 3 km) respectively.
- Total copper line length for FTTex ADSL2+. It depends on the geotype. In dense urban, urban and rural areas typical distances are below 2 km (typ. 1.5 km), below 3 km (typ. 2 km) and below 4 km (typ. 3 km) respectively.
- Total copper line length for FTTex VDSL2. It depends on the geotype. Typical distances are below 1.5 km although longer distances can be found in rural areas (typ. 600 m) than in dense urban and urban areas (typ. 300 m and 400 km respectively).
- Total fibre line length for FTTH.). It depends on the geotype. In dense urban, urban and rural areas typical distances are below 5 km (typ. 2 km), below 10 km (typ. 5 km) and below 10 km (typ. 5 km) respectively, however rural areas is not always considered for an FTTH deployment because of its higher cost per customer.

The main reference parameters for street cabinets (in case they are deployed) in the access network are:

- Number of subscribers per copper access node (DSLAM) chassis FTTC. A street cabinet typically has between 48 and 300 ports (one port per xDSL subscriber) in order to accommodate the service demand (a common number is 100 ports).
- Number of subscribers per cabinet FTTC. It depends on the geotype. In dense urban, urban and rural areas the typical number of subscribers per cabinet in an FTTC access network is below 1 000 (typ. 200), below 500 (typ. 150) and below 300 (typ. 100) respectively.
- Backhaul capacity required for a cabinet FTTC. The backhaul capacity required for a single copper cabinet in an FTTC access network is from 100 Mb/s to 1 Gb/s. Currently a single 1 Gb/s interface is provided per cabinet in order to provide enough capacity up to the aggregation point.
- Number of street cabinets per central office area. It depends on the geotype. In dense urban, urban and rural areas the typical number of street cabinet per CO is below 100, below 64 and below 30 respectively.

The main reference parameters for the access nodes (AN) are the following:

- Number of subscribers per copper CO FTTEx (Fibre to the Exchange). It depends on the geotype. In dense urban, urban and rural areas the typical number of subscribers per copper CO FTTEx is in the order of tens of thousands, from 3.000 up to 10 000 and below 3 000 respectively.
- Maximum number of subscribers per copper AN (DSLAM) chassis FTTEx. Typically is 700.

- Number of subscribers per fibre CO FTTH. It depends on the geotype. In dense urban, urban and rural areas the typical number of subscribers per fibre CO to provide FTTH services is in the range of tens of thousands (typ. 20.000), from 5 000 up to 20 000 (typ. 8 000) and below 5 000 (typ. 2 000, but not always it is deployed) respectively.
- Maximum number of subscribers per fibre AN (OLT) chassis FTTH. Typically from 4 096 to 8 192.
- Maximum number of subscriber per fibre AN (OLT) port FTTH. Typically 32 or 64.
- Number of connection to the aggregation node per access node chassis. Typically 1 although 2 connections for redundancy reasons are possible.
- Backhaul capacity required for a copper AN (DSLAM). Typically 1 or 2 Gb/s.
- Backhaul capacity required for a fibre AN (OLT). Typically 10 Gb/s.

7.1.2.2 Mobile access network

The main reference parameters for the mobile access network with the most typical values are described below:

- Number of 3G macro cell sites per km2. It depends on the geotype. In dense urban, urban and rural areas the typical number of 3G macro cell sites per km2 is less than 20, less than 10 and 1-2 respectively.
- Number of active users per 3G macro cell site. Typically less than 100 users.
- Configuration of a 3G macro cell. A common configuration is to have 3 sectors with 2 carriers per sector and 5 MHz bandwidth cannels.
- 3G macro inter-site distance. It depends on the geotype. In dense urban, urban and rural areas typical values are less than 240 m, less than 340 m and several kilometres respectively (although it depends on the indoor service level required).
- Area coverage percentage for indoor penetration for 3G macro cells. It depends on the geotype. In dense urban, urban and rural areas typical values are less than 70%, less than 60% and less than 50% respectively.
- As commented before different requirements per operator and country are possible and different operators could have different indoor service levels (that depends on different parameters such as the considered buildings, the bandwidth or the frequency used). Previous values correspond to a service level of 2 Mb/s downlink using the 800 MHz band.
- Other requirements from different operators could be proposed, for example to provide an indoor penetration for indoor urban, urban and rural areas higher than 70%, higher than 50% and lower than 50% respectively.

- Number of LTE macro 800 MHz cell sites per km2. It depends on the geotype. In dense urban, urban and rural areas the typical number of LTE macro cell sites per km2 using the 800 MHz frequency band is less than 5, 3 and 3 respectively.
- Number of active users per LTE macro 800 MHz cell site. Typically less than 100 users.
- Configuration of a LTE macro 800 MHz cell. A common configuration is to have 3 sectors with 1 carrier per sector and 10 MHz bandwidth cannels.
- LTE macro 800 MHz inter-site distance. It depends on the geotype. In dense urban, urban and rural areas typical values are less than 600 m, between 500 m to 1 km and several kilometres respectively (although it depends on the indoor service level required).
- Area coverage percentage for indoor penetration for LTE macro 800 MHz cells. It depends on the geotype. In dense urban, urban and rural areas typical values are less than 75%, less than 70% and less than 60% respectively. Similar comments than 3G apply for LTE indoor penetration.

- Number of LTE macro 1800 MHz cell sites per km2. It depends on the geotype. In dense urban, urban and rural areas the typical number of LTE macro cell sites per km2 using the 1800 MHz frequency band is less than 20, 10 and 3 respectively.
- Number of active users per LTE macro 1800 MHz cell site. Typically less than 100 users.
- Configuration of a LTE macro 1800 MHz cell. A common configuration is to have 3 sectors with 1 carrier per sector and 20 MHz bandwidth cannels.
- LTE macro 1800 MHz inter-site distance. It depends on the geotype. In dense urban, urban and rural areas typical values are less than 300 m, between 250 to 500 m and several kilometres respectively (although it depends on the indoor service level required).
- Area coverage percentage for indoor penetration for LTE macro 1800 MHz cells. It depends on the geotype. In dense urban, urban and rural areas typical values are less than 70%, less than 60% and less than 50% respectively. Similar comments than 3G apply for LTE indoor penetration.

- Number of LTE macro 2600 MHz cell sites per km2. It depends on the geotype. In dense urban, urban and rural areas the typical number of LTE macro cell sites per km2 using the 2600 MHz frequency band is less than 20, 10 and 3 respectively.
- Number of active users per LTE macro 2600 MHz cell site. Typically less than 100 users.
- Configuration of a LTE macro 2600 MHz cell. A common configuration is to have 3 sectors with 1 carrier per sector and 20 MHz bandwidth cannels.

- LTE macro 2600 MHz inter-site distance. It depends on the geotype. In dense urban, urban and rural areas typical values are less than 300 m, between 250 to 500 m and several kilometres respectively (although it depends on the indoor service level required).
- Area coverage percentage for indoor penetration for LTE macro 2600 MHz cells. It depends on the geotype. In dense urban, urban and rural areas typical values are less than 70%, less than 60% and less than 50% respectively. Similar comments than 3G apply for LTE indoor penetration.

- Number of active users per LTE small cell. Typically less than 64 users.
- Current hotspot small cells support 32 active users. 100 users could be supported using much powerful small cells (5 or 10 W).
- Configuration of a LTE small cell. A common configuration is to have 1 sector with 1 carrier and 20 MHz bandwidth cannels.
- Small cell LTE cell site radius (outdoor). Typically from 100 to 150 m.

7.1.3 Aggregation network

The main reference parameters for the aggregation nodes are described below:

- Aggregation network extent. It depends on the geotype. In dense urban, urban and rural areas the typical reach of the aggregation network is less than 20, 60 and 100 km respectively.

  This wide range in extent is due to the assumption that the aggregation network includes both Metro Aggregation (i.e. the portion of the network adjacent to access nodes up to the Main CO) and Metro Core (i.e. the portion of the network between the Main CO and the Core CO, where the backbone edge is located, see Figure 21). The size of the two areas could be quite variable, depending on the specific geographical region.

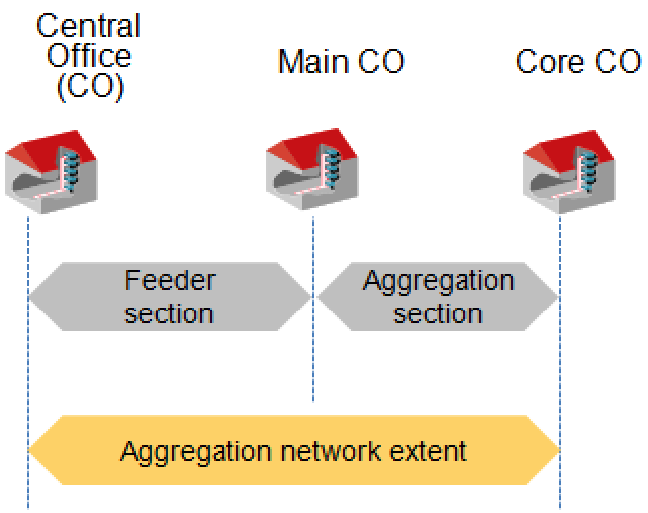

Figure 21: Aggregation network extent

- Number of aggregation network nodes per Metro Area Network. Typically dozens of nodes.
- Link length between access node and aggregation node. This is assumed to be the link between the AN location and the first level of aggregation. Two main possible cases exist:
  - the AN and first level of aggregation are inside the same CO (see Figure 22.A): collocated.
  - the AN and the first level of aggregation are in different CO inside the same metro area (see Figure 22.B): dozens of kilometres.

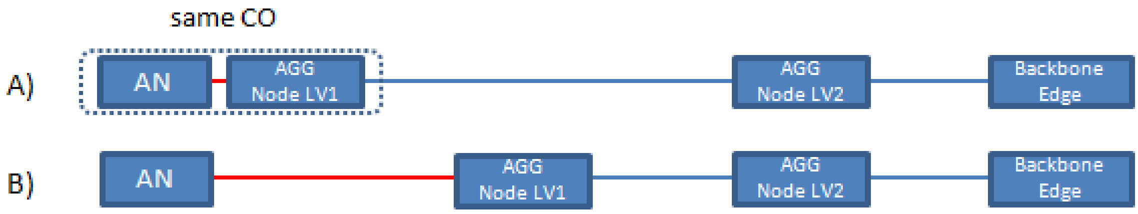

Figure 22: Link length between access node and aggregation node

- Number of aggregation levels. Typically 2.
- Aggregation level 1 to level 2 link length. This is assumed to be the link between the first level of aggregation and the second level of aggregation. Two main possible cases exist:
  - the first and the second levels of aggregation are inside the same CO (see Figure 23.A): collocated.
  - the first and the second levels of aggregation are in different CO inside the same metro area (see Figure 23.B): dozens of kilometres. In dense urban, urban and rural areas the typical reach is less than 10, 30 and 50 km respectively.

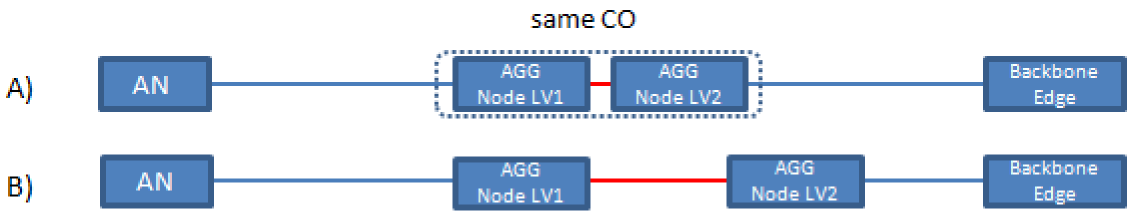

Figure 23: Aggregation level 1 to level 2 link length

- Aggregation level 2 to backbone edge link length. This is assumed to be the link between the second level of aggregation and the backbone edge. Two main possible cases exist:
  - the second level of aggregation and the backbone edge are inside the same CO (see Figure 24.A): collocated.

- the second level of aggregation and the backbone edge are in different CO inside the same metro area (see Figure 24.B): dozens of kilometres. In dense urban, urban and rural areas the typical reach is less than 10, 30 and 50 km respectively.

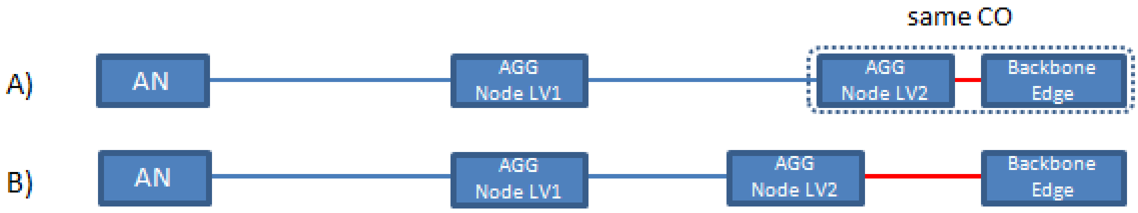

Figure 24: Aggregation level 2 to backbone edge link length

- Capacity of an access node port in the aggregation level 1 node. Typically 1 or 10 Gb/s.
- Capacity of a trunk port in the aggregation level 1 node. Typically 10 Gb/s.
- Capacity of an access port in the aggregation level 2 node. Typically 10 Gb/s but 1 Gb/s is also common.
- Capacity of a trunk port in the aggregation level 2 node. Typically 10 Gb/s although 40 and 100 Gb/s are expected to be used in the short-term.
- Number of redundancy links in the aggregation level 1 node. Typically 1.
- Number of redundancy links in the aggregation level 2 node. Typically 1.

The main reference parameters for the mobile backhaul elements are described below:

- Backhaul capacity peak required for a 3G base station (NodeB) per sector. Typically dozens of Mb/s. 3G technologies in the radio segment are able to provide a maximum capacity of dozens of megabytes and the backhaul capacity needed for a 3G base station is obtained from that value. In case of a base station with three sectors, the backhaul capacity needed for the aggregated traffic is the same because the average traffic is typically low compared to the peak traffic.
- Backhaul capacity peak required for a LTE base station (eNodeB) per sector. Typically less than 150 Mb/s. LTE in the radio segment is able to provide a maximum capacity of 150 Mb/s and the backhaul capacity needed for a LTE base station is obtained from that value. In case of a base station with three sectors, the backhaul capacity needed for the aggregated traffic is the same because the average traffic is typically low compared to the peak traffic.
- Mobile backhaul link length. This is assumed to be the link between the base station and the next aggregation node. It depends on the geotype. In dense urban, urban and rural areas the typical values are less than 1, 3, and from 1 to 10 km respectively.

The main reference parameters for other network elements in the aggregation network are described below:

- RNC: maximum throughput. The maximum throughput of an RNC is measured according to the data traffic that it is able to process. Typically is up to 13 Gb/s (source: Ericsson Evo Controller 8200/RNC).
- BRAS: number of subscribers per IP edge: Typically from 50 000 up to 100 000 users.

7.1.4 Mobile packet core

The mobile packet core is composed of many network nodes. The main reference parameters for the main network elements in 3G and LTE are described below:

- SGSN: maximum throughput. The maximum throughput of an SGSN is measured according to the data traffic that it is able to process. Typically is up to 36 Gb/s (source: Ericsson MkVIII).
- GGSN: maximum number of PDP contexts. Typically up to 30 million (source: Ericsson SSR 8020).
- GGSN: maximum throughput. The maximum throughput of a GGSN is measured according to the data traffic that it is able to process. Typically is up to 500 Gb/s (source: Ericsson SSR 8020).
- MME: maximum number of Simultaneously Attached Users (SAU). Typically up to 18.6 million SAU (source: Ericsson MkVIII).
- S-GW: maximum throughput. The maximum throughput of a S-SW is measured according to the data traffic that it is able to process. Typically is up to 500 Gb/s (source: Ericsson SSR 8020).
- P-GW: maximum number of PDN connections. Typically up to 30 million (source: Ericsson SSR 8020).
- P-GW: maximum throughput. The maximum throughput of a P-GW is measured according to the data traffic that it is able to process. Typically is up to 500 Gb/s (source: Ericsson SSR 8020).

7.2 Regulation on Electronic Communications Markets in Europe

After the privatization of many former state-owned incumbents in the 1990s until 2000, the European Council asked for a better regulation to support the shift to a digital knowledge-based economy by providing fair access to world-class communications infrastructure and services.[25]

In 2002, the EU Regulatory Framework for electronic communications was introduced, which aimed at “establishing a harmonised regulatory framework for networks and services across the EU and at seeking to respond to convergence trends covering all electronic communications networks and services within its scope.” [24] Based on the requirement of the framework directives, which requires the adoption and regular view of a Recommendation on Relevant Product and

Service markets, a first set of recommendation was adopted in 2003 and a second one in 2007. Based on the latter one, the Regulatory Framework was revised in 2009 "to ensure more effective competition and better rights for consumers." [25]

In this context it has to be mentioned that, additional to the EU regulation, "according to the current regulatory European framework, National Regulatory Agencies are entitled to identify markets not included in the Recommendation, and may as well have to define the concrete boundaries of the included markets." [26]

In the regulatory framework a Market is "the prerequisite for assessing whether a particular market is characterised by effective competition or should be subject to ex ante regulation. … The objective is to identify whether competitors are capable of constraining each other's behaviour and preventing the others from behaving independently of consumers within the market." [25]

Ex ante regulation is defined in Article 16 of Directive 2002/21/EC and addresses the lack of effective competition that is expected to persist over a time horizon; therefore NRAs have to analyse the market forward looking. [25]

Basis for the market analysis executed by the NRAs are the "Commission guidelines on market analysis and the assessment of significant market power under the Community regulatory framework for electronic communications networks and services". [32]

Based on the SMP Guidelines, "there are in the electronic communications sector at least two main types of relevant markets to consider, those for services or facilities provided to end-users (retail markets) and those for upstream access to facilities and networks which are necessary for operators to provide competitive access services to end-users (wholesale markets). Further on, different product markets are defined at both wholesale and retail level depending on demand and supply-side characteristics." [25]

A further "justification" for ex ante regulation can be found in the study about "Future electronic communications markets subject to ex-ante regulation: [27]

"The purpose of ex-ante regulation is to reduce and, where possible, remove any detriment to consumers. Detriment can arise for a number of reasons but this report is concerned only with detriment, which arises from significant market power in any of the up or downstream markets.

Although the detriment is experienced at the retail level, the fundamental cause of restrictions and distortions of competition is typically experienced at an upstream wholesale level. Since it is preferable to treat the disease rather than its symptoms, there is a strong policy preference under the Framework to apply any necessary remedies at the level where the fundamental bottleneck occurs. The Commission has therefore focused on identification of wholesale markets, so that regulation can be applied at the retail level only where unavoidable".

The electronic communications markets will be identified by three cumulative criteria: [27]

- The presence of high and non-transitory barriers to entry

- A market structure which does not tend towards effective competition within the relevant time horizon
- The insufficiency of competition law alone to adequately address the market failure(s) concerned

Following markets are addressed by regulation on European and national level: [28]

- Market 1: Access to the public telephone network at a fixed location for residential and non-residential customers
- Market 2: Call origination on the public telephone network provided at a fixed location
- Market 3: Call termination on individual public telephone networks provided at a fixed location
- Market 4: Wholesale (physical) network infrastructure access (including shared or fully unbundled access) at a fixed location
- Market 5: Wholesale broadband access
- Market 6: Wholesale terminating segments of leased lines
- Market 7: Voice termination on individual mobile networks

As already mentioned before, the European Commission is required by the framework directives to have a regular view on the market regulation and developments and to come up with recommendations for change.

Currently the Commission is working on the second review of the Recommendation on Relevant Markets, which sets out a list of predefined markets subject to ex-ante regulation. The process started with a public consultation at the end of 2012, includes surveys [29], research papers [30] and an external study [27], as well as position papers from stakeholders such as ETNO [28], ECTA [31] and BEREC [26]. In all these documents new technological developments were analysed considering their potential implications on regulation.

The study conducted on behalf of BEREC [26] pointed out that “since the last review of the Recommendation, technological evolutions together with competitive pressure have modified the way end consumers access electronic communications services. Bundling has become the standard form of purchasing these services for a majority of end consumers, requiring attention at the wholesale level in case existing wholesale product would not be sufficient to provide the higher number of services expected, including mobile or broadcasting. In addition, convergence has facilitated entry by alternative operators, surpassing traditional bottlenecks related to telephony networks, moving to all IP environment, or even providing electronic communications services based on Internet protocols (over the top). Finally, fixed-to-mobile substitution seems to be significant although with important divergences among Member States.

Furthermore, the challenges posed by NGA roll out need a certain degree of flexibility in the precise definition of fixed wholesale markets. The necessity of access to backhaul services, the location of the unbundling point in the context of NGA, or the appearance of active and passive wholesale services depend on the concrete deployment model chosen in each Member State.

The development of NGA infrastructure-based competition arising from alternative technologies (*e.g.* cable, mobile via LTE) is also an important trend, which, in some markets, is already having a significant impact on the structure and way broadband markets evolve."

In the new recommendations the EC included all input received from stakeholders and studies and pointed out: [25]

"Since the adoption of the Relevant Markets Recommendation in 2007, several technological developments have been observed, which have an impact, currently or in a forward-looking perspective, on the relevant markets defined in the Recommendation. These developments include roll-out of LTE, the upgrade of cable infrastructure and deployment of fibre.

Furthermore, the use of broadband is increasingly substantial, to the extent that it is surpassing narrowband use, which has resulted in an increase in the supply and demand of services and applications via the Internet, including Over-The-Top (OTT) services.

Moreover, IP technology is taking over circuit switched networks, which has implications in particular for fixed telephony services. Adding to this, there has been a substantial increase in inter-platform competition, with the upgrade of cable technologies and local fibre deployment."

In particular following areas/technological trends were tackled:

- PSTN and VoIP
- LTE
- Copper and fibre networks
- OTT
- Bundling
- NGA

To accommodate these technological trends in a new regulation, a redefinition of the boundaries between current Markets 4, 5, and 6 - respectively, wholesale (physical) network infrastructure access (including shared or fully unbundled access) at a fixed location, wholesale broadband access and wholesale terminating segments of leased lines, irrespective of the technology used to provide leased or dedicated capacity) – are to be redefined as new Markets 3 and 4. New Market 3 is subdivided into Market 3(a), 'Wholesale local access provided at a fixed location', and Market 3(b), 'Wholesale central access provided at a fixed location for mass-market products'. The proposed new Market 4 is defined as 'Wholesale high-quality access provided at a fixed location'. [24]

As BEREC pointed out in their response to the EC recommendations [33], “retail market segmentation would now essentially be premised on the different types of products demanded by end users, in particular products sought by mass-market customers and high-quality products (the latter being included in new Market 4, with services such as leased lines or ’carrier-grade’ Ethernet services, and where appropriate high-quality wholesale access products).”

They further state, that “with regard to the current Markets 4 and 5, the European Commission proposes a move from the current active-passive distinction (which is the basis for the differentiation between physical and non-physical access products in Markets 4 and 5), to a distinction based on the characteristics of products (local-central point for handling traffic, contention and control over the transmission network). This redefinition in particular leads to the explicit incorporation of virtual forms of unbundling within the new Market 3a.”

In this context they further highlight that “in 2010 and 2013, the European Commission adopted two Recommendations (the NGA and the Non-Discrimination Recommendations), which deal with the existing markets for wholesale (physical) network infrastructure access (current Market 4) and wholesale broadband access (current Market 5). The Recommendations refer to a set of remedies that NRAs should consider when regulating wholesale broadband, and which must be duly taken into account by NRAs in the context of their national analyses. BEREC sees a need for clarification by the European Commission, in particular with regard to certain bitstream access products that belong to current Market 5 and are therefore covered by the NGA and Non-Discrimination Recommendation. Indeed, if part of those products falls under the new Market 4 (rather than under the new Market 3b) in the future, it is uncertain whether they will still be covered by these Recommendations.”

So changes in these markets will have an effect on regulation of FMC architectures.

The EC states in its recommendations [24] that “in most cases, if the retail market is competitive (absent regulation), there is no need for wholesale market regulation. But BEREC [33] here recommends that there should be made a clarification with reference to the case of termination markets, “where there may be a need for regulation, even where there is effective competition in the downstream market (because of the Calling Party Pays principle where in the absence of wholesale regulation, a competition problem at the retail level can be identified only if one considers a notional retail market, rather than the actual access and calls retail markets.”

When considering all these remarks, it can be assumed that certain aspects of the FMC architectures developed within the COMBO project can be subject to regulation.

8 Glossary

Acronym / Abbreviations	Brief description
AAA	Authentication Authorization and Accounting
ADSL	Asymmetric DSL
AN	Access Node
AP	Access Point
API	Application Programming Interface
AR	Access Router
ASPs	Application Service Providers
ATM	Asynchronous Transfer Mode
B2B2C	Business to Business to Consumer
B2C	Business to Consumer
B2C2C	Business to Consumer to Consumer
BBU	Base Band Unit
BEREC	Body of European Regulators for Electronic Communications
BRAS	Broadband Remote Access Server
BS	Base Station
BSC	Base Station Controller
BTS	Base Transceiver Station
CAGR	Compounded Annual Growth Rate
CapEx	Capital Expenditure
CAPWAP	Control And Provisioning of Wireless Access Points
CDN	Content Delivery Network
CO	Central Office
CPE	Customer Premises Equipment
CPRI	Common Public Radio Interface
DPI	Deep packet inspection
DMA	Digital Media Adapter
DNS	Domain Name System
DSL	Digital Subscriber Line
DSLAM	Digital Subscriber Line Access Multiplexer
ECTA	European Competitive Telecommunications Association
eNodeB	Evolved NodeB
EDGE	Enhanced Data Rates for GSM Evolution
EPC	Evolved Packet Core
E2E	End to end
ETNO	European Telecommunications Network Operators
FMC	Fixed-Mobile Convergence
FMI	Fixed-Mobile Integration
FTTC	Fibre to the Curb

FTTex	Fibre to the exchange
FTTH	Fibre to the Home
FTTx	FibreFibre to the x
FXS	Foreign eXchange Subscriber
GGSN	Gateway GPRS Support Node
GPON	Gigabit-capable Passive Optical Network
GPRS	General Radio Packet Service
GSM	Global System for Mobile communications
GW	Gateway
HeNB	Home eNodeB
HNB	Home NodeB
HSS	Home Subscriber Server
KPIs	Key Performance Indicators
IBM	International Business Machines
IMS	IP Multimedia Subsystem
IP	Internet Protocol
IPSec	Internet Protocol Security
IPTV	Internet Protocol Television
ISP	Internet Service Provider
ITU	International Telecommunication Union
LAN	Local Area Network
LER	Label Edge Router
LOS	Line of sight
LTE	Long Term Evolution
MAC	Media access control
MBB	Mobile Broadband
MME	Mobility Management Entity
MPLS	Multiprotocol Label Switching
MSC	Mobile Switching Center
MPtP	Multipoint-to-Point
M2M	Machine to Machine
NAS	Network Attached Storage
NE	Network Element
NGA	Next Generation Access
NG-PON	Next Generation Passive Optical Network
NG-POP	Next Generation Point of Presence
NLOS	Non-Line-of-Sight
NRA	National Regulatory Agency
NSPs	Network Service Providers
OAM	Operations, administration and management
ODN	Optical Distribution Network
OECD	Organization for Economic Co-operation and Development

OLT	Optical Line Termination
OpEx	Operational Expenditure
OTN	Optical Transport Network
OTT	Over-The-Top
iPBX	Internet-based Private branch exchange
PC	Personal Computer
PDP	Packet Data Protocol
P-GW	Packet Data Network (PDN) Gateway
PLT	Power Line Telecommunication
PM	Performance Monitoring
PPP	Point-to-Point Protocol
PSTN	Public Switched Telephone Network
PtMP	Point-to-Multipoint
PtP	Point-to-Point
QoE	Quality of Experience
QoS	Quality of Service
RADIUS	Remote Authentication Dial-In User Service
RAN	Radio Access Network
RGW	Residential Gateway
RNC	Radio Network Controller
RRU	Remote Radio Unit
SAU	Simultaneously Attached Users
SGSN	Serving GPRS Support Node
S-GW	Serving Gateway
SLA	Service Level Agreement
SMP	Significant Market Power
SOHO	Small Office – Home Office
SSID	Service Set Identifier
STA	Station
STB	Set-Top Box
TDM	Time Division Multiplexing
UAG	Universal Access Gateway
UC	Use case
UE	User Equipment
UMTS	Universal Mobile Telecommunications System
USB	Universal Serial Bus
VDSL	Very high speed DSL
VoIP	Voice over IP
VPN	Virtual Private Network
WDM	Wavelength Division Multiplexing
WiMAX	Worldwide Interoperability for Microwave Access
Wi-Fi	Wireless Fidelity

xDSL	DSL technologies
3GPP	3rd Generation Partnership Project

9 List of Tables

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