Ref. Ares(2013)3156493 - 02/10/2013

D2.1- Framework reference for fixed and mobile convergence

Grant Agreement number: 317762
Project acronym: COMBO
Project title: COnvergence of fixed and Mobile BrOadband access/aggregation networks
Funding Scheme: Collaborative Project – Integrated Project
Date of latest version of the Deliverable: 30-09-2013
Delivery Date: **Month 09**

Leader of the Deliverable: Dr. Eckard Bogenfeld, DTAG
File Name: COMBO_D2.1_WP2_30Sept2013_DTAG_V1.0.docx
Version: V1.0
Authorisation code: PU = Public

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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 will provide the preliminary work for fixed and mobile networks analysing their current status and evolution trends. This deliverable (D2.1) of Task 2.1 is called *Framework reference for fixed and mobile convergence*. It starts with the reference framework which shows a high-level view of the different network segments in today's fixed and mobile networks. This reference framework will be further developed to address the network evolution without an FMC approach so that it can serve as basis for comparison with the FMC network scenarios developed in WP3.

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 will be 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 will be helpful for WP3 as a reference to current networks.

Next, FMC network use cases are proposed and described. These network use cases, addressing the needs for functional and/or structural convergence, 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. The use cases are also provided as basis for the FMC architectures that are going to be specified within WP3.

Both the reference framework and the network use cases could be used to define and model future converged fixed and mobile traffic scenarios in Task 2.3 of WP2.

Finally, there is a discussion on market aspects developed in collaboration with WP5 to provide an initial view on current market descriptions and projections towards 2020.

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Other (PMC, SC, etc)			

Document History

Edition	Date	Modifications / Comments	Author
0.3	06/03/2013	First Draft with ToC	Eckard Bogenfeld
0.4	30/05/2013	Second Draft with ToC	Eckard Bogenfeld
0.5	19/06/2013	Inputs to sections “FMC network scenario elements” and “Structural versus functional convergence“	Thomas Monath
0.6	09/07/2013	New TOC, responsibilities, and draft text to section “From use case analysis to network scenarios”	Eckard Bogenfeld
0.7	11/07/2013	Added section “Common reference areas”	Jose Torrijos
	02/08/2013	Added draft text for UC04/UC05/UC10	Ali Hamidian
	05/08/2013	Added draft text for UC01/UC08	Jose Torrijos
	05/08/2013	Added draft text for sections “Convergence classification of the UCs – Overview”, “FMC UCs – Aggregation resource sharing” and UC07	Vincenzo Sestito
	09/08/2013	Added UC02 and revisions/comments of UC01	Xavier Grall
	09/08/2013	Added draft text for section “Network elements and related functions”	Lander Alonso
	09/08/2013	Added draft text for section “Reference framework” (fixed part) Proposed modification for Wi-Fi network elements refinement in Fig.3 (to be checked by FON and TT)	Joseph De Biasio
	09/08/2013	Added description of UC03	Yaning Liu
	14/08/2013	Added (draft) description of UC06	Joseph De Biasio
	15/08/2013	Adding the mobile parts of section “Reference framework”	Ali Hamidian
0.8	20/08/2013	Transfer of D2.1 into the new template	Eckard Bogenfeld
	04/09/2013	Update of Wi-Fi-related parts of the reference framework in section 2.2 (considering	Xavier GRALL

		comments from Ali) Update of UC02 description in section 3.4.2 (considering comments from Jose)	
	10/09/2013	Updates within Chapter 2.3 and Chapter 4	Eckard Bogenfeld
	12/09/2013	Updates on sections 2.4, 3.4 and appendix A.	Jose Torrijos
	13/09/2013	Added review comments to sections 2.1, 2.4, 3.1, 3.2, 3.3, and A.1	Ali Hamidian
	15/09/2013	Draft proposal for Executive Summary and Introduction	Eckard Bogenfeld
	16/09/2013	Added review comments to Executive Summary, Glossary, Introduction.	Vincenzo Sestito Ali Hamidian
	17/09/2013	Upgraded section 2.3 to avoid overlaps with section 2.2.	Lander Alonso
	18/09/2013	Added comments in section 2.2.1 Upgraded section 3.4.3 and 3.6.2	Joseph De Biasio
	18/09/2013	Update UC3 figure and add some review comments	Yaning LIU
	18/09/2013	New chapter 4 on Market Aspects	Susanne Kuehrer
	19/09/2013	Update of the UC2 figure in section 3.4.2	Xavier GRALL
	19/09/2013	Update of the UC06 and UC08 figures, Accept of comments and suggestions for the introduction, Text in chapter 3	Eckard Bogenfeld
	19/09/2013	Update UC07 figures.	Vincenzo Sestito
	19/09/2013	Updated Section 2.2 and 2.3	Ali Hamidian
	19/09/2013	Updated UC03 description	Yaning LIU
	19/09/2013	Update Chapter 4	Susanne Kuehrer
	20/09/2013	Update regarding comments, improvements, formal things, etc.	Eckard Bogenfeld
	22/09/2013	Draft proposal for the conclusion	Eckard Bogenfeld
0.9	22/09/2013	Ready for review	Eckard Bogenfeld
	26/09/2013	Merging of the reviews from Onur Eker and Dirk von Hugo; Change of graphical format of figures regarding UC02 and UC03 Minor changes in the conclusion from Ali	Eckard Bogenfeld
	26/09/2013	Accept review suggestions	Eckard Bogenfeld

		regarding executive summary and introduction	
	26/09/2013	Update from Vincenzo	Eckard Bogenfeld
	26/09/2013	Updated Section 2.3 and figures 11-13, Review	Ali Hamidian
	27/09/2013	Updated Sections 2.4, UC01,UC09 and Appendix 7.1	Jose Torrijos
	27/09/2013	Updated Section 2.3.2.2	Joseph De Biasio
0.91	27/09/2013	Updated Chapter 4	Susanne Kuehrer
	30/09/2013	Consideration of some improvements of Ali Hamidian	Eckard Bogenfeld
1.0	30/09/2013	First official version	Eckard Bogenfeld

Distribution List

Full Name or Group	Company	Date
PMC	Public deliverable (will be made available through COMBO website)	
SC		
Other		

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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
BRAS	Broadband Remote Access Server
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
D-RoF	Digital Radio over Fibre
DSL	Digital Subscriber Line
DSLAM	Digital Subscriber Line Access Multiplexer
eNodeB	Evolved NodeB
EDGE	Enhanced Data Rates for GSM Evolution
EPC	Evolved Packet Core
E2E	End to end
FTTC	Fibre to the Curb
FTTex	Fibre to the exchange
FTTH	Fibre to the Home
FTTx	FibreFibre to the x
FMC	Fixed-Mobile Convergence
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
HomePNA	Home Phoneline Networking Alliance
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
MBH	Mobile Backhaul
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
NG-BNG	Next Generation Broadband Network Gateway
NG-PON	Next Generation Passive Optical Network
NG-POP	Next Generation Point of Presence
NLOS	Non-Line-of-Sight
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
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
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
W-IP-E	Wi-Fi IP Edge
xDSL	DSL technologies
3GPP	3rd Generation Partnership Project

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 network use case (UC) description, fixed and mobile network evolution, FMC traffic modelling, and identification of requirements and Key Performance Indicators (KPIs).

This deliverable defines the general framework for fixed and mobile networks with common area descriptions as a basis for the development of future FMC network architecture and proposes FMC network use cases, identifying the today's situation, the specific needs and the opportunities for functional and/or structural convergence. Also marketing aspects are considered.

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

- In Chapter 2, the topologies and elements of the different networks are introduced, while a reference framework is created in order to have a common reference across the whole project. A 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. Four 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, ten 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.

2 Definition of the reference framework

In this chapter the topologies and elements of the different networks are introduced, while a reference framework is created in order to have a common reference across the whole project. A high-level view of the different network segments in today's fixed and mobile networks is presented and analysed. The reference framework is then used to define the main common reference areas in which fixed and mobile networks can converge.

2.1 FMC network scenario elements

In the reference framework the main top-level elements are defined and included in order to use them as a basis for the development of future FMC network architectures.

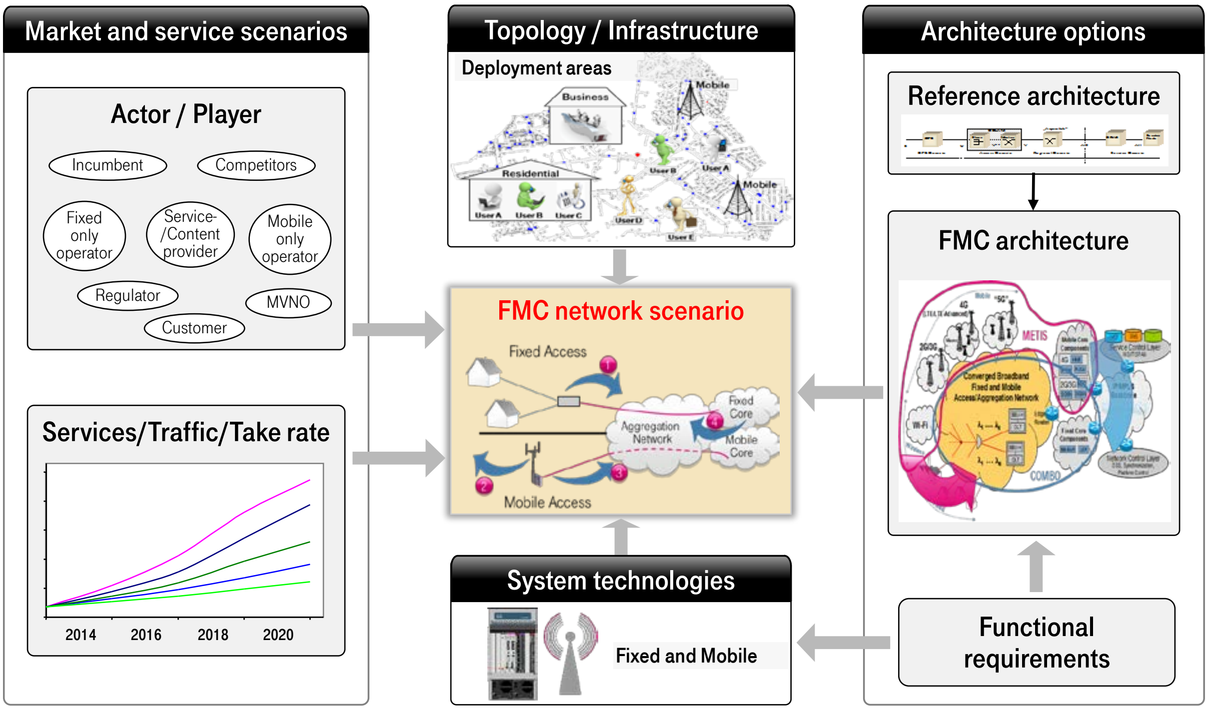


Figure 1: Main elements of a FMC network scenario (high level general view)

Figure 1 depicts the main elements of a FMC network scenario which are the market and service scenarios, topology and infrastructure, architecture options and system technologies and their relationships.

The FMC market will be formed by several actors in the playing field. These represent on one hand the demand site, i.e. mainly the customers which request the converged type of services. On the other hand the supply chain - often called also value chain – has to fulfil the demand and includes network operators as well as operators' service and content providers. The whole playing filed is influenced of course from the public interest represented e.g. by the regulation bodies.

The whole bunch of services with their specific requirements and characteristics lead together with related forecasts of evolutions to certain traffic scenarios. The requirements and demands have to be fulfilled by the FMC network.

Not only the existing deployment areas but also future infrastructures and topologies can vary in a quite wide range which creates another main influencing element.

Starting from the reference architecture several FMC evolution options are in place and these have to answer the functional FMC requirements also fulfilled by certain system technologies accordingly.

This deliverable will concentrate on topologies and architectures for the reference framework including a high-level functional view. The market and service scenarios will be further addressed in FMC traffic modelling (T2.3), assessment framework (T5.1) and business modelling (T5.3). For the network architectures, the fixed and mobile network evolution (T2.2) will set up the scene followed by the FMC architectures (WP3).

2.2 Reference framework

The reference framework in 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.

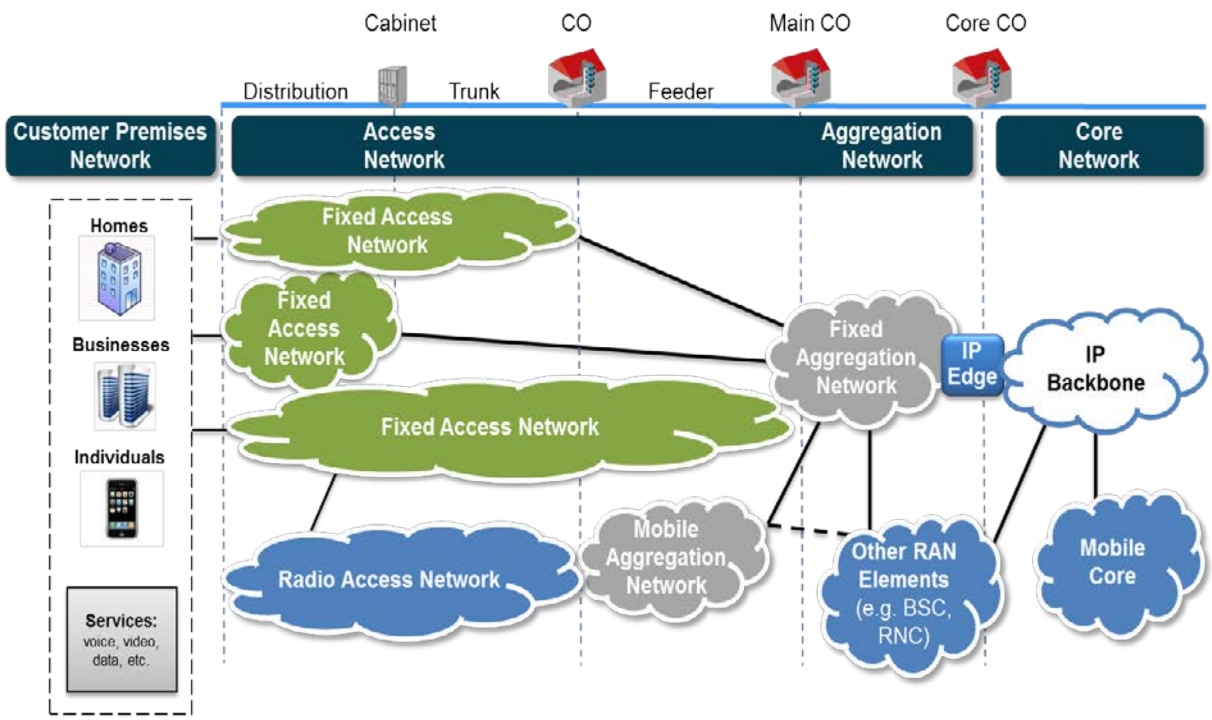


Figure 2: Schematic view of the FMC analysis field

2.2.1 Customer premises network

- Fixed residential network:

  Most telecommunication operators are today offering Triple Play services over DSL and/or FTTx 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. The IPTV service can be provided in several screen resolutions: standard (around 2-4 Mb/s per stream) and high definition (around 6-8 Mb/s per stream)
  - Voice service: Telephony provided by Voice over IP (VoIP). (The operator can also provide telephony via the Public Switched Telephone Network (PSTN) for ADSL customers, but outside the triple play bundle.)

  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). 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) which terminates the network for xDSL, 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.)
  - Network termination for FTTH
  - Set Top Box (STB) which supports the IPTV service

  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), and Tablets. Moreover, in addition to Ethernet and Wi-Fi, the home network supports very specific transport technology such as cable, Power Line Telecommunication (PLT), Home Phoneline Networking Alliance (HomePNA), ZigBee, etc. The support of such interface exists on dedicated devices (e.g., PLT equipment pair) or on a USB dongle pluggable to the RGW.

- Wi-Fi 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.). 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. By the end of 2012, there were 6.4 billion mobile subscriptions in the world, which results in a global penetration rate of around 90% [3]. It shall be noted that there is a difference between subscribers and subscriptions. In some countries, customers have several devices and each device has its own subscription. Consequently, the subscription penetration may be higher than 100% in these countries. On the other hand, in some places several people can share one single subscription.

Despite the fast growth of smartphone subscriptions, the great majority of mobile subscriptions in the world are for basic phones. By the end of 2012, subscriptions for basic phones were around 5 billion while subscriptions for smartphones were 1.2 billion. However, by 2018, it is expected that subscriptions for smartphones (expected to reach around 4.5 billion) will exceed that for basic phones (expected to decrease to around 4 billion).

The screen size of mobile devices is an important reason to whether subscribers mainly use the voice or also the broadband data service provided by mobile networks. Whereas devices with small screen sizes (e.g., basic 2G and 3G phones) mainly generate voice traffic, devices with larger screen sizes (e.g., smartphones, tablets and laptops) also generate considerable amount of data traffic.

2.2.2 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 CO is the building where each twisted copper pair is terminated on the main distribution frame. It was also the building where the first telephone switch was located. Today, the CO hosts the DSLAM for xDSL technologies.

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.

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. These stations are named Base Transceiver Station (BTS), NodeB and evolved NodeB (eNodeB). They take care of the following functions:

- Indicate the network’s presence to UEs.
- UE association.
- Transport of the UE’s communications.

2.2.3 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.

The core CO is a main CO which is at the boundary between the aggregation network and the core 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.

- Wi-Fi network

  The only possible aggregation node being specific to the Wi-Fi architecture is the Wi-Fi 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 2.2.1), 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.

- Mobile network

  In the aggregation network, the main function to perform is the transport and aggregation of the communications of a great number of subscribers. Currently, different technologies can be used for that purpose and an aggregator element is used for that purpose.

2.2.4 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.

- 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.

- 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
  - Network monitoring and management

2.3 Network elements and related functions

An FMC, being the evolution of fixed and mobile networks, will have to meet the needs of the current existing networks plus the ones to come. Currently, there are different networks deployed offering different services with different architectures. Each existing network has different elements based on the type of network it is, the services to offer and the technologies employed.

In this section, an overview of each of the elements and of the functions of each of the networks is made in order to understand their current situation. For that purpose, a table is presented first summarising the elements employed within each network and their location. The following subsections briefly describe each type of the existing network's elements and the main functions they need to perform.

2.3.1 Element summary table

The following table shows the different elements that compose each of the different type of networks that would form part of an FMC in a very simplified manner:

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	BSC	2G/3G MSC SGSN GGSN
	3G Node B	MBH aggregator Lv1 RNC HNB GW	
	LTE eNodeB	MBH aggregator Lv2	EPC MME S-GW P-GW

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

2.3.2 Fixed networks

As has been mentioned above, fixed networks currently offer triple service as a basic product including voice, data and TV. In order to be able to provide those services, the network is composed of different elements that are deployed in different network segments. In the next sections each of the main elements of the fixed network and the main functions they perform are presented.

2.3.2.1 Customer premises network elements

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.

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.

Set Top Box (STB): It 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 service to subscribers. However, they also perform other functions that allow the operator to manage and monitor them.

2.3.2.2 Access network elements

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.
- To enable the transport of those communications towards the aggregation network.

2.3.2.3 Aggregation network elements

In the aggregation segment, the main function to perform is the transport and aggregation of the communications of a great number of subscribers to direct them to their destination. The most relevant element in this area is currently the Ethernet switch. Depending on the needs the operator has, there may be more than one level of this type of device.

2.3.2.4 Core network elements

Some of the main elements located in the core network of a fixed network are:

Broadband Remote Access Server (BRAS): It is the element that behaves as the gateway for the DSLAMs in the network. Additionally, it enforces the QoS and management policies in the network.

Label Edge Router (LER): Is the element 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 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.
- Network monitoring and management.

2.3.3 Wireless networks

As it has already been described, current wireless or Wi-Fi networks have entered the metro area and Wireless Metro Area Networks (WMANs). Therefore, different scenarios are served today with these types of networks as shown in Table 1. Due to this evolution, new elements and functions have appeared in scene.

2.3.3.1 Customer premises and access network elements

Regarding the elements that traditionally have composed Wi-Fi networks, they have been just Stations (Wi-Fi enabled devices) and APs (Access Points). Wi-Fi networks have traditionally consisted of only Wi-Fi enabled devices, called Stations (STAs) and Access Points (APs). 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 following ones:

- Propagating the SSIDs of the networks offered.
- Switching the traffic from the air interface to another interface towards the network gateway.

2.3.3.2 Aggregation network elements

As Wi-Fi networks grew more complex and common, a new element was introduced, the AP controller. This element 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:

- Providing a configuration and management interface for the available networks.
- Remotely and automatically configuring the APs under each of the defined groups.
- Monitoring the status of the networks, the APs and the users.

2.3.3.3 Core network elements

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.
- Roaming enabler.

2.3.4 Mobile networks

Mobile networks have evolved over time to provide additional services other than the voice services offered in the beginning. Each major evolution step has been called a new generation of mobile networks. Rather simplified, the first generation of mobile networks was analogue and circuit-switched. The second generation became digital and supported only circuit-switched services in the early stages. However, packet-switched capabilities were introduced by General Radio Packet Service (GPRS) – also called 2.5G (indicating Generation 2.5) – in later stages. This continued in the third generation that was partly circuit-switched (for voice) and partly packet-switched (for data). Finally, the latest and fourth generation is entirely packet-switched. Currently, the 2nd, 3rd and 4th generations of mobile networks co-exist. The main network elements of the mobile network architecture of these three generations are covered below (see also Table 1).

2.3.4.1 Customer premises network elements

In the customer premises segment of the network, the mobile devices are basic mobile phones, smartphones, tablets, laptops, desktop PCs, and routers with a built-in cellular (2G, 3G, and LTE) modem or an external USB dongle. Today, most devices support both 2G and 3G but, as the number of commercial LTE networks increases, more and more devices also support LTE.

2.3.4.2 Access network elements

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 BTS, a 3G base station is called NodeB, and an LTE base station is called eNodeB. In commercial networks, it is common that one base station site can handle multiple standards, e.g., 2G, 3G and LTE simultaneously. 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.

2.3.4.3 Aggregation network elements

The mobile network elements in the aggregation segment of the network 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.

2.3.4.4 Core network elements

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.

2.4 Common reference areas

In the previous section, the general reference framework has been analysed taking into consideration the current access and aggregation segments of fixed and mobile networks. This section uses the previous reference framework 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, but typical or common values that can be found in European operators' networks.

2.4.1 Common reference areas

The reference framework 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 both mobile and fixed data using a single network.

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

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

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.

The next figure shows the previous common reference areas and its relation to the reference framework.

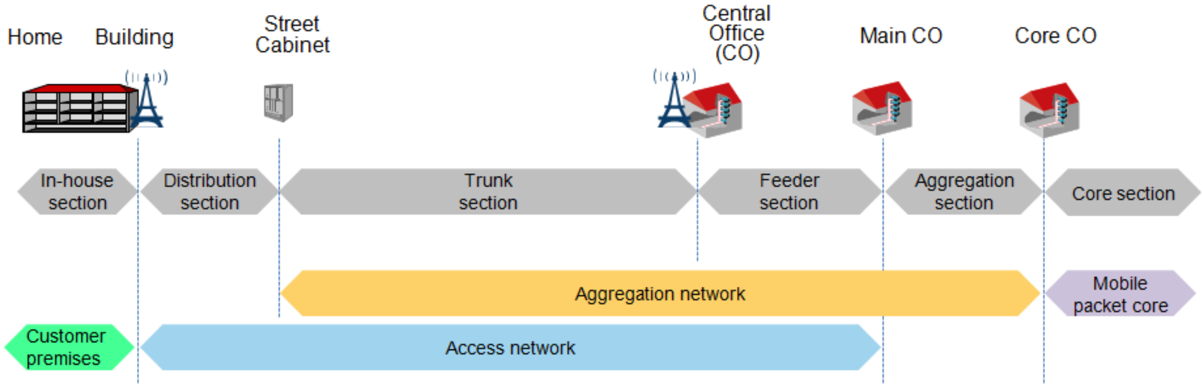


Figure 3: Common reference areas inside the reference framework

2.4.2 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. 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.

2.4.3 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 in a business building	10s - 100s			
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

2.4.4 Access network

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

2.4.4.1 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 e.g.: 1.5 km	< 7 km e.g.: 2 km	< 10 km e.g.: 3 km

Total copper line length for FTTex ADSL2+		< 2 km e.g.: 1.5 km	< 3 km e.g.: 2 km	< 4 km e.g.: 3 km
Total copper line length for FTTex VDSL2		< 1.5 km e.g.: 300 m	< 1.5 km e.g.: 400 m	< 1.5 km e.g.: 600 m
Total fibre line length for FTTH		< 5 km e.g.: 2 km	< 10 km e.g.: 5 km	< 10 km if deployed e.g.: 5 km
Cabinets				
Number of subscribers per copper access node (DSLAM) chassis FTTC	48-300 typ. 100			
Number of subscribers per cabinet FTTC		< 1000 e.g.: 200	< 500 e.g.: 150	< 300 e.g.: 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 e.g.: 15 000	3 000 - 10 000 e.g.: 8 000	< 3 000 e.g.: 1 500
Maximum number of subscribers per copper AN (DSLAM) chassis FTTex	700			
Number of subscribers per fibre CO FTTH		10 000 - 100 000 e.g.: 20 000	5 000 - 20 000 e.g.: 8 000	< 5 000 if deployed e.g: 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 a copper AN (DSLAM)	1 - 2 Gb/s			

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

Table 3: Reference parameters: Fixed access network

2.4.4.2 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 LTE macro 800 MHz cell site	< 100			
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 cell	1 sect / 1 carrier / 20 MHz			
Small cell LTE cell site radius (outdoor)	100 – 150 m			

Table 4: Reference parameters: Mobile access network

2.4.5 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

2.4.6 Mobile packet core

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

3 Definition of FMC network use cases

Chapter 3 describes a set of use cases the needs of which FMC networks shall fulfil. Four 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, ten use cases are addressed.

Table 7 shows guidance notes which helps to describe the use cases.

<table>
<tr><td rowspan="3">Description</td><td>Goal</td><td>This is the objective/end result the use case strives to or is to achieve and should be a concise statement of what the use case should achieve in a 'sunny day' scenario. (Answer also to: What do users or operators need?)</td></tr>
<tr><td>Today's situation</td><td>Today's situation (if necessary, use also a slide to show the today's situation)</td></tr>
<tr><td>Potential impact</td><td>Potential impact of this FMC proposal on network structure in terms of customer benefit or network savings</td></tr>
<tr><td rowspan="2">Convergence classification</td><td>Classification</td><td>The use case is more related to functional convergence or to structural convergence?</td></tr>
<tr><td>Arguments</td><td>The reasons for the classification, i.e., why functional convergence or why structural convergence?</td></tr>
<tr><td>Flow</td><td></td><td>The use case flow is described with all possible exceptions and/or variants. The expiration is divided into steps and each step is sequentially numbered.</td></tr>
</table>

Table 7: Guidance notes to describe the use cases

3.1 From use case analysis to network scenarios

The difference between use cases and network scenarios should be clarified first of all:

- **Use cases** define *needs*, i.e., detailed expectations from the network. These expectations will in particular help defining detailed *requirements* quantifying the expectations.
- **Network scenarios** define *solutions*, i.e., candidate network architectures. These candidate network architectures have to satisfy the expectations defined in the use cases.

So, in other words, use cases answer the question "WHAT do users and operators need?" whereas network scenarios answer the question "HOW will these needs be satisfied by the network?". The use cases are addressed here (in Task 2.1) and the network scenarios will be addressed in Task 3.2 and Task 3.3.

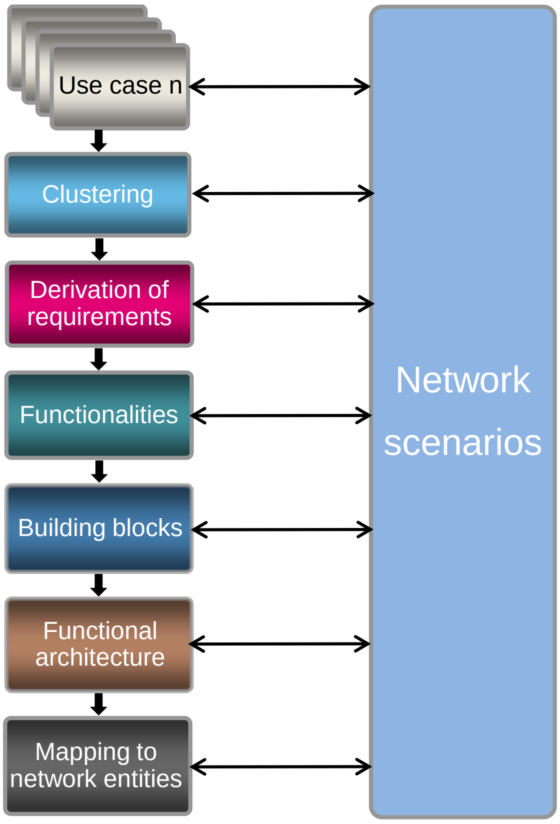


Figure 4: Use case analysis and network scenarios

Figure 4 tries to illustrate the dependencies between use case analysis and network scenarios. The use case analysis consists of

(1) Description of the use cases
(2) Clustering of the use cases
(3) Derivation of requirements from the use cases
(4) Description of functionalities to meet the requirements
(5) Identification of building blocks to realise the functionalities
(6) Creation of the functional architecture
    a. Identification of relationships (interfaces) between the building blocks to meet the use cases
    b. Specification of interfaces
(7) Mapping of the building blocks to network entities

Throughout the whole process a possible network scenario must be in mind. Of course, multiple use cases could be included into only one network scenario.

3.2 Functional versus structural convergence

Functional and structural convergence is defined as follows within COMBO:

- **Functional convergence** is defined as the convergence of fixed and mobile network functions at or below Layer 3 (the network layer).

  Functional convergence will primarily impact the control plane of future networks through harmonized or even unified control mechanisms of fixed and mobile networks. In addition, it will impact the data plane of fixed and mobile networks through an improvement of protocol stacks and a better distribution of data flows in the converged network.

- **Structural convergence** is defined as the mutualisation of fixed and mobile access/aggregation network infrastructure and hardware equipment (e.g., cable plants, cabinets, sites, equipment, and buildings).

3.2.1 Some enablers for functional and structural convergence

Functional convergence will benefit the customer by making the service independent of the access technology and the device, not through an additional service control layer but by using natively converged technologies and protocols in the network domain. Functional convergence should also give the customer the best access to the network for a given service and in a transparent manner. Achieving functional convergence, thus, requires a thorough analysis of mapping between functions, equipment and infrastructure, so as to derive a better distribution of functions among the various pieces of equipment in fixed and mobile networks. Such improved mapping of functions has to rely on technological and architectural enablers such as:

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

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

- Optical node concentration allowed by optical access technologies;
- Heterogeneous RANs combining small cells and macro cells;
- BBU hotel with resource pooling, also called Cloud RAN);

- Mobile fronthaul technologies based on Digital Radio over Fibre (D-RoF) for the connection between BBU hotels and RRUs at antenna locations;
- Multi-wavelength and multi-service optical access technologies.

Note that many different enablers could be relevant for the overall target of functional and structural convergence, and the lists given above are just preliminary. BBU hotel and D-RoF-based mobile fronthauling are examples of key enablers for structural convergence. These techniques will allow a centralized set of BBUs with resource pooling to be shared among a large number of RRUs located at different antenna sites. They are paving the way to the Cloud RAN concept and could also eventually enable the sharing of fibre access infrastructures or even shared fixed and mobile equipment at the NG-POP.

3.3 Convergence classification of the UCs – Overview

In line with the considerations reported in the previous sections, four 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 four areas, ten UCs have been addressed. The following table shows the association between each FMC area and the related UC:

FMC Area	Use Case
Unified Wireless Access Networks	UC01 - FMC access for mobile devices
	UC02 - Enhanced FMC access for mobile devices
	UC03 - Converged CDN for unified service delivery
Access Resource Sharing	UC04 - Reuse of infrastructure for indoor small cell deployment
	UC05 - Effective backhaul deployment for outdoor small cells
	UC06 - Common fixed and mobile access termination in hybrid connectivity for FMI customer services
Aggregation Resource Sharing	UC07 - Support for large traffic variations between public, residential, and business areas
	UC08 - Universal Access Gateway (UAG) for fixed and mobile aggregation network
	UC09 - Convergent access and aggregation technology supporting fixed and mobile broadband services
Operator Cooperation	UC10 - Network sharing

Table 8: FMC areas and network use cases

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

The following table resumes for each UC 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 3.4 -3.7.

Use Case	Addressed Needs	Targeted Convergence
UC01 - FMC access for mobile devices	Mobile traffic offloading through Wi-Fi network. Seamless handover between mobile and Wi-Fi access points. No UE dual attachment.	Functional
UC02 - Enhanced FMC access for mobile devices	Mobile traffic offloading through Wi-Fi network. Seamless handover between Wi-Fi access points, and Wi-Fi / mobile access points. UE dual attachment to Wi-Fi and mobile networks.	Structural Functional
UC03 - Converged CDN for unified service delivery	Offloading and caching video contents close to the users in Wi-Fi network.	Functional
UC04 - Reuse of infrastructure for indoor small cell deployment	Reuse of existing residential and business indoor infrastructure for small cell deployment. Coordination between small cell and macro sites.	Structural
UC05 - Effective backhaul deployment for outdoor small cells	Effective NLOS backhaul solutions for outdoor small cells (with both Wi-Fi and 3GPP capability) addressing PtMP, PtP and MPtP connectivity.	Structural
UC06 - Common fixed and mobile access termination in hybrid connectivity for FMI customer services	Providing the user with optimum bandwidth resource dynamically assigned via available fixed, mobile, and wireless technologies.	Functional
UC07 - Support for large traffic variations between public, residential, and business areas	A common backhaul/fronthaul infrastructure for supporting dynamic demand of IP and CPRI services transport, able to interoperate with any front haul (mobile and fixed) network element.	Structural
UC08 - Universal Access Gateway (UAG) for fixed and mobile aggregation network	A universal access gateway (UAG as NG-BNG) hosting fixed line intelligence, Wi-Fi hotspot controller functionality, and mobile baseband processing	Functional Structural
UC09 - Convergent access and aggregation technology supporting fixed and mobile broadband services	A common access/aggregation infrastructure, based on NG-PON technology, able to interoperate with fixed and mobile network elements (front-haul and backhaul)	Structural
UC10 - Network sharing	A network able to support multi-operator applications, including, policy definition per operator (SLA, QoS, QoE), allowing, consequently, for dedicated business model.	Structural Functional

Table 9: Network use cases – Needs and targeted convergence

3.4 FMC UCs – Unified Wireless Access Networks

Currently there are many references in the telecommunications sectors that forecast a huge mobile traffic growth in the coming years. Cisco Systems forecast [2] that overall mobile data traffic will grow at a CAGR of 66% from 2012 to 2017. Ericsson estimates that the global mobile subscriptions will grow from 6.4 billion by Q1 2013 up to 9.1 billion by the end of 2018. The mobile broadband subscription, which reached close to 1.7 billion in Q1 2013, is estimated to reach 7 billion in 2018. Ericsson also estimates an overall mobile data traffic growth with a CAGR of around 50% (2011-2018) [3].

There are many reasons for this growth; for example, the increasing number of smartphones, the new 4G connections, the new connected devices (phablets, tablets, e-book readers, etc.), the increasing mobile video demand (half of mobile traffic at the end of 2012 [2]), machine-to-machine communications, etc.

Mobile networks need to be upgraded in both equipment and links between communication nodes in order to deal with the expected data traffic growth. The most natural ways are to upgrade equipment to new radio technologies providing more capacity, deploy more mobile base stations, and increase the capacity of the mobile backhaul and core. However, other alternatives based on existing fixed broadband technologies can reduce the cost of the required deployments and are able to provide mobile broadband services in small coverage areas.

In 2012, Cisco Systems estimated that 33% of total mobile data traffic was offloaded onto the fixed network through Wi-Fi or femtocell devices [2]. Cisco Systems also estimates that without Wi-Fi and femtocell offload, data traffic would grow at a CAGR of 74% between 2012 and 2017, instead of the projected CAGR of 66%. However, mobile users need to configure some parameters directly in their terminal with the appropriate credentials before they are able to use a Wi-Fi connection. Additionally, seamless roaming services among different Wi-Fi operators do not exist today, neither does transparent handover between 3G/4G and Wi-Fi.

Intelligent use of existing and future mobile infrastructure in combination with other fixed networks can provide enough bandwidth for mobile broadband users with a lower cost for the operators.

3.4.1 UC01 - FMC access for mobile devices

The FMC access for mobile devices use case proposes to use Wi-Fi networks in combination with mobile networks to provide more capacity to mobile broadband users. This additional capacity could be available in small areas (i.e. not at mobile macro level) where high mobile data traffic is demanded or expected in the future. Mobile devices supporting Wi-Fi will offload mobile traffic automatically from the mobile network to the Wi-Fi network depending on the network status and on the operator preferences.

Figure 5 illustrates a mobile broadband network in which mobile data traffic is offloaded to a Wi-Fi network when the user is located in an area with Wi-Fi coverage.

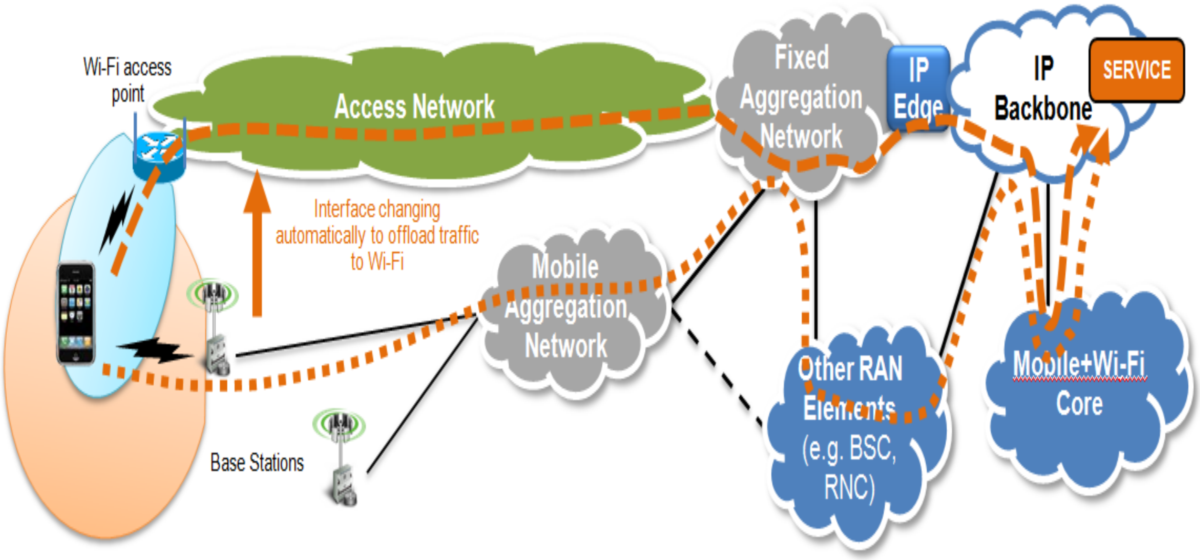


Figure 5: UC01 – FMC access for mobile devices using Wi-Fi offloading techniques

Table 10 contains the description and details for this use case.

Description	**Goal**	Use more cost-effective solutions than traditional mobile technologies (mainly Wi-Fi) to offload mobile data traffic. This use case will require a seamless authentication between mobile and Wi-Fi technologies, allowing to select which interface is the most appropriate. In order to reduce the complexity of this use case, only one interface (Wi-Fi or mobile) will process the user traffic data at the same time. VoIP traffic will also be offloaded as any other type of packet data. Traditional mobile voice service will not be affected by Wi-Fi offloading.
	Today's situation	Today mobile users generally prefer to use rather Wi-Fi access for mobile data traffic than the mobile connections provided by mobile operators because Wi-Fi is seen as a faster technology and it is independent of the data plan signed by the customers. Wi-Fi access is well known to users and commonly they use public hotspots and Wi-Fi AP at home or in offices to get a faster connection. Many times Wi-Fi is the preferred connection as they don't use the limited capacity in current mobile data plans that operator typically offer. Mobile operators need to increase their mobile coverage and capacity and are looking for cost-effective solutions to do that.
	Potential impact	Some potential impacts are: • Mobile broadband deployment using Wi-Fi technologies in cooperation with 3G/4G technologies • Reuse current and future Wi-Fi deployment to provide mobile

		broadband services • New functions/elements will be required in the mobile devices and/or the operator's network
Convergence classification	**Classification**	This use case is related to functional convergence.
	Arguments	New elements in the network in coordination with the mobile core that are able to manage the new mobile connections in a seamless way will be needed. New functions and interfaces will be needed to integrate the new elements with the mobile core.
Flow		1. Mobile Broadband (MBB) is provided from the macro base stations to all subscribers as a general rule. 2. Increase MBB capacity at macro base level if capacity demands are more than usual. 3. Analyse availability of existing and planned fixed backhaul infrastructure for additional coverage areas inside the macro cell area. 4. Assure that the fixed network capacity is enough to support the future traffic from the small cells. Increase that capacity if needed. 5. Deployment of small areas of coverage using mobile and/or Wi-Fi technologies at micro or pico level in specific public areas in which mobile traffic demands require higher capacity (no cooperation initially). 6. Offloading traffic from the macro cell to micro/pico/small cells can be done in this phase. Conditions for traffic offloading must be defined and implemented. 7. Adapt the mobile core network and mobile terminals (if needed) to work with Wi-Fi systems providing a seamless authentication 8. Start using Wi-Fi to offload mobile data traffic in cooperation with the mobile network at macro and micro/pico level. 9. Contact other operators to allow roaming services through Wi-Fi.

Table 10: Summarised description of UC01

3.4.2 UC02 - Enhanced FMC access for mobile devices

According to the previous use case, mobile customers have the ability to access their different services (web surfing, VoIP, etc.) via Wi-Fi or mobile networks. In this use case, depicted on Figure 6, they are provided with some additional features:

- Double attachment to Wi-Fi and mobile network.
- Seamless handover between Wi-Fi AP, and also possibly between Wi-Fi and mobile accesses.
- Network assistance for the selection and utilization of the access(es).

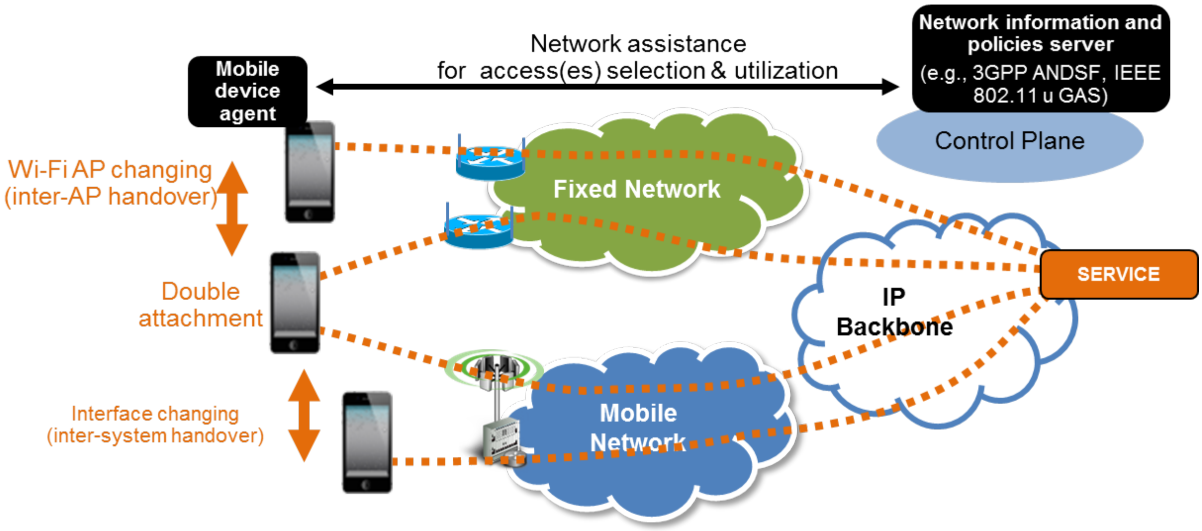


Figure 6: UC02 – Enhanced FMC access for mobile devices

The following conditions shall be met:

- Dual interface mobile devices under the coverage of Wi-Fi and/or mobile access networks with the possible ability to process dynamic information received from the network in order to use it in a smart way.
- Interworking between Wi-Fi and mobile access networks that must be operated either by the same operator or by different collaborating operators.

And 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 the possible network assistance for selecting and using the most suitable access(es) according to their needs. Thus, the Wi-Fi and mobile access networks should complete each other so the customers can benefit from higher global data rates and seamless mobility.

The following table (Table 11) summarizes the use case description:

Description	**Goal**	The goal of this use case is to enhance Wi-Fi and mobile networks cooperation by providing double attachment and mobility features with a smart network assistance to the mobile devices.
	Today's situation	A mobile device usually attaches the Wi-Fi access by selecting the most preferred SSID with the highest signal level, and without considering any other conditions (such as the backhaul capacity). When a mobile device is simultaneously attached to Wi-Fi and mobile networks, its traffic is usually forwarded only through the Wi-Fi interface. However, some devices may simultaneously use both Wi-Fi and mobile networks, but they usually statically balance the 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). The seamless handover 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).
	Potential impact	The customer should be provided with a better QoE when using Wi-Fi. The network utilization should be optimized, by balancing the user traffic on different accesses (in the time and/or in the space) and network costs should be reduced, by using Wi-Fi as a cheaper technology for completing the mobile access network coverage.
Convergence classification	**Classification**	The use case itself is related to the functional convergence, but the solution for enabling it may be either functional or structural.
	Arguments	The convergence of the use case itself regards the application services access that should be agnostic to the access network technology, and thus it can be related to the functional convergence. Regarding the solution, it may be satisfied without any neither functional nor structural convergence, but only an interworking between Wi-Fi and mobile networks, possibly only at the data/forwarding/user plane level. However, a solution with functional or even structural convergence should provide a better efficiency.
Flow		The different features may provided with different combinations, and thus different enforcement complexity level: 1. Double attachment only, with possible network assistance for access selection and utilization. 2. Inter-Wi-Fi handover only, with possible network assistance for access selection. 3. Inter-Wi-Fi and inter-system handover, with possible network assistance for access selection. 4. Double attachment with inter-Wi-Fi handover, with possible network assistance for access selection and utilization 5. Double attachment with inter-Wi-Fi handover and inter-system handover for only a selected part of the flows, with possible network assistance for access selection and utilization

Table 11: Summarised description of UC02

3.4.3 UC03 - Converged CDN for unified service delivery

Content Delivery Networks (CDNs) have been widely deployed to provide efficient content delivery services (e.g. websites, software update, video streaming, etc.). By replicating the content in network and redirecting traffic, CDNs improve the experiences for end users, reduce network traffic cost for telecom operators and reduce the cost of inter-domain traffic for Internet Service Providers (ISPs). Among these services, video is the most popular Internet application driving much of Internet traffic growth. According to the Cisco VNI report [6], consumer Internet video traffic will be 69% of all consumer Internet traffic in 2017, up from 57% in 2012. In order to reduce service latency, CDNs typically deploy servers close to the edge networks, such as data centres in ISP central offices, and the broadband gateway and STB in the residential network. CDN has been proved to be a dominant solution to deliver such content. The report also shows that Internet traffic carried by CDNs will be 51% of all Internet traffic in 2017, up from 34% in 2012. Among Internet traffic, 53% of Internet video traffic crosses CDNs in 2012 and this value will exceed 65% in 2017.

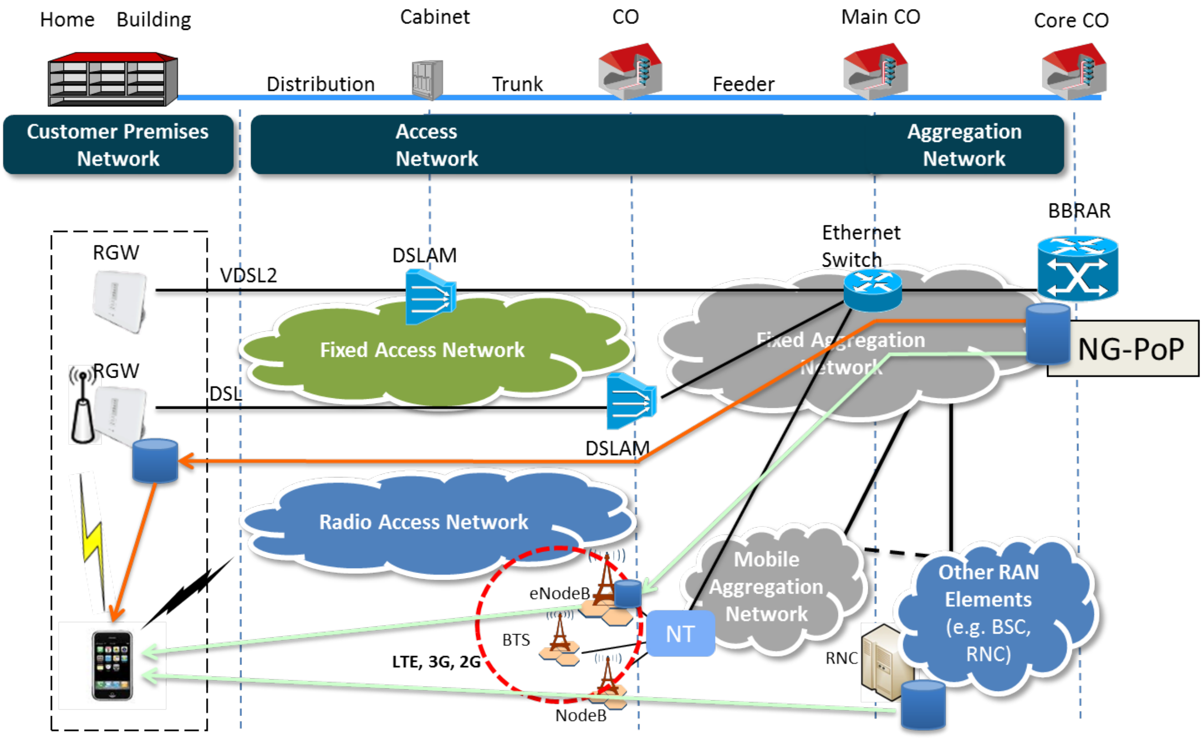


Figure 7: UC03 – Converged Fixed / Mobile CDN Solutions

With the popularity of smart phones and emerging mobile applications such as healthcare and multimedia, mobile Internet is dramatically expanding. According to recent studies [6], Internet traffic from wireless and mobile devices will exceed traffic from wired devices by 2016. Near half of Internet traffic will originate from non-PC devices by then. Video is becoming a dominant traffic in mobile networks. Hence, studies on content caching in mobile backhaul networks and new infrastructures of mobile CDNs [7] are gaining a lot of attraction recently. To optimize the backhaul traffic and improve QoS of wireless video services, network cache is designed in the access network such as Wi-Fi networks [8], radio networks [9] and femtocells [10], where caching is enabled on APs, femtocell-like base stations, 3G RNCs and LTE eNodeBs respectively. Storage and caching functions have been provided in new emerging APs in the market, but are not yet available in public Wi-Fi APs deployed by ISPs and in current mobile access network equipment. However, many caching solutions for 3G or LTE networks have been developed by companies like Allot Communications, PeerApp, Altobridge, etc.

Figure 7 above depicts a scenario where storage and caching functions are enabled in customer premises network (STBs and APs), mobile access network (RNCs and eNodeBs) and aggregate network (NG-POP). By the network caching in access network and the collaborative caching among the equipment of fixed access network, mobile access network and NG-POP, the content is intelligently duplicated closer to the mobile users. It practically ameliorates the service latency, reduces mobile backhaul traffic and improves network efficiency.

Table 12 below provides further details of this use case.

Description	**Goal**	To be able to employ existing fixed / mobile infrastructure in order to enable offloading and caching frequently requested content. This function will cache the video content available close to the users. Collaborative caching among fixed / mobile access network and NGPOP helps to reduce the mobile backhaul traffic, to improve the performance of the fixed network, and to ameliorate the service latency.
	Today's situation	• CDN is widely deployed in fixed network • In customer promises networks, storage and caching functions have been provided in STBs and new emerging APs • Mobile CDN is primitively designed and deployed • Network caching is proposed to be enabled on RNC or eNodeB in RAN • Mobile users offload data traffic from 3G/4G to Wi-Fi network
	Potential impact	• Mobile broadband deployment using Wi-Fi technologies in cooperation with 3G/4G technologies • Reduce mobile backhaul traffic and improve performance of fixed network • Improve service latency and user experience • New functions/elements will be required in the mobile devices and/or the operator's network
Convergence classification	**Classification**	This use case related to functional convergence.
	Arguments	New elements in the fixed / mobile access networks that have the caching function and management of caching on different network nodes. New functions and interfaces will be needed to integrate the new elements.
Flow		1. Analyse the coverage need and create business case 2. Analyse the availability and feasibility of network caching on fixed / mobile access networks 3. Investigate the convergent needs and propose convergent solutions 4. Implement the caching on fixed / mobile access networks and design caching algorithms 5. Design and implement the collaborative algorithm among fixed / mobile network equipment and NGPOP 6. Start enabling caching on network equipment in the cooperation with fixed / mobile network operators. 7. Implement converged CDN solutions

Table 12: Summarised description of UC03

3.5 FMC UCs – Access Resource Sharing

The following sections describe three FMC use cases with focus on an efficient utilization of access resources. The first two use cases aim at a structural convergence with a reuse of the existing access infrastructure for small cell rollouts which is important from an operator's point of view since a deployment of a dedicated small cell feeder network is economically challenging and time consuming. On the other hand the third use case addresses a functional convergence of fixed, mobile, and wireless access with the target to provide an optimal user bandwidth.

3.5.1 UC04 - Reuse of infrastructure for indoor small cell deployment

Figure 8 below illustrates the reuse of existing residential and business indoor copper and fibre infrastructure when deploying indoor small cells. The main drivers for this would be to save cost and deployment time. A description of this use case is summarized in Table 13.

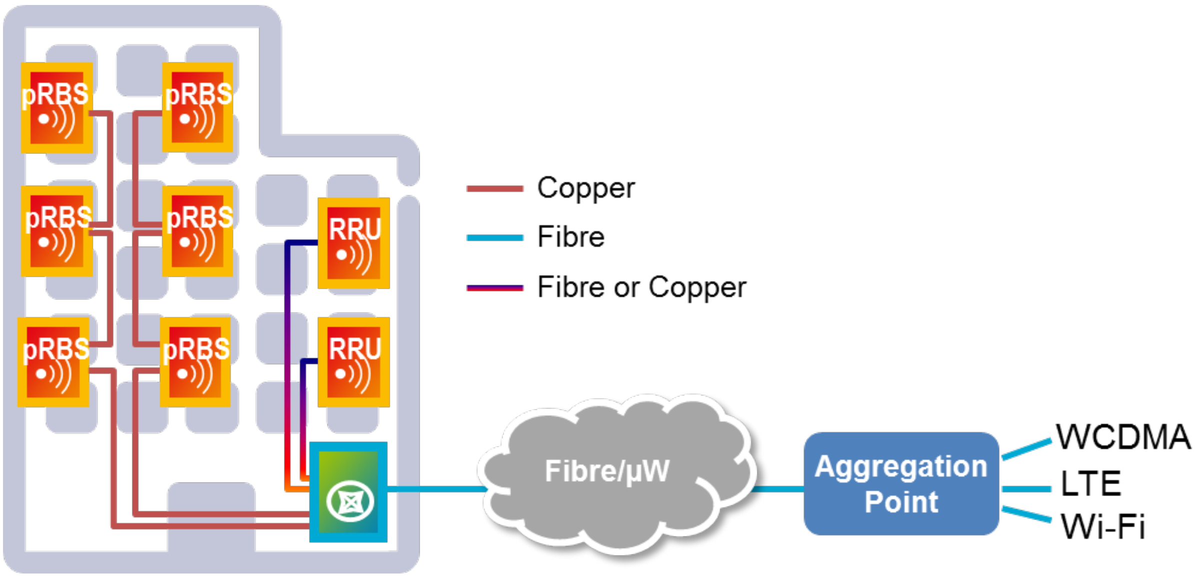


Figure 8: UC04 – Illustration of reusing existing infrastructure for indoor small cell deployment

Description	**Goal**	To reduce deployment time and costs by reusing existing residential and business indoor copper/fibre infrastructure
	Today's situation	Today, there is a need for wide deployment of indoor small cells. This task is rather costly, so, in order to increase the incentives for this investment, the deployment costs need to be reduced.
	Potential impact	The positive impact of this proposal is that makes it easier and cheaper for operators to deploy indoor small cells; in addition, existing fixed copper/fibre infrastructure will be used more efficiently resulting in potentially lower cost for end-users

Convergence classification	**Classification**	The use case is more related to structural convergence
	Arguments	The main part of this proposal is related to reusing fixed infrastructure for fixed-mobile indoor small cells
Flow		1. Analyse capacity and coverage need and create business case 2. Analyse availability of existing and planned fixed backhaul infrastructure 3. Contact real estate owners and/or municipalities regarding small cell sites 4. Contact other operators and decide on potential for and level of network sharing 5. Implement small cell backhaul solutions

Table 13: Summarised description of UC04

3.5.2 UC05 – Effective backhaul deployment for outdoor small cells

Figure 9 below illustrates the deployment of outdoor small cells using NLOS radio backhaul solution. The suitable point-to-multipoint NLOS topology is typically hub-and-spoke with the possibility to extend the spokes with additional hops. In order to reuse existing infrastructure, it is beneficial to co-locate the hub with a macro cell site and/or a fixed infrastructure distribution node. A description of this use case is summarized in Table 14.

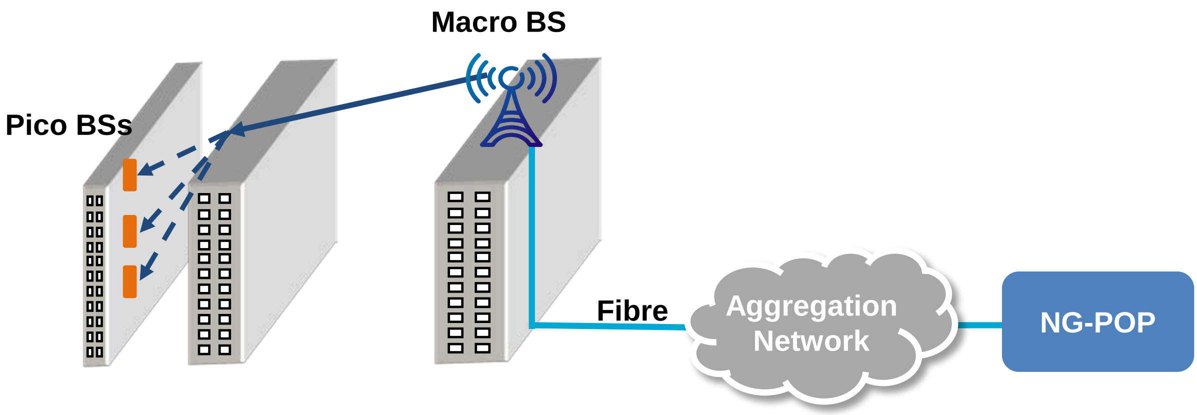


Figure 9: UC05 – Illustration of outdoor small cell deployment using an NLOS backhaul solution

Description	**Goal**	To quickly and easily deploy backhaul/fronthaul connection for outdoor small cells
	Today's situation	Today, it is difficult to deploy outdoor small cells in areas with neither existing fixed backhaul nor LOS for wireless backhaul
	Potential impact	The positive impact of this proposal is that it gives operators more flexibility by providing yet another option for backhaul

Convergence classification	**Classification**	The use case is more related to structural convergence
	Arguments	The main part of this use case is related to backhaul infrastructure for outdoor small cells
Flow		1. Analyse MBB capacity and coverage need and create business case 2. Analyse availability of existing and planned fixed backhaul infrastructure 3. Contact regulators regarding availability of spectrum for LOS and/or NLOS wireless backhaul 4. Contact real estate owners and/or municipalities regarding small cell sites 5. Contact other operators and decide on potential for and level of network sharing 6. Implement small cell backhaul solutions

Table 14: Summarised description of UC05

3.5.3 UC06 - Common fixed and mobile access termination in hybrid connectivity for FMI customer services

The target is to provide the user with dynamic optimum bandwidth and efficient resource via available fixed, cellular mobile and Wi-Fi technologies. Such access bundling is achieved by using several transmission channels simultaneously (e.g. fixed xDSL, Wi-Fi hotspot and cellular radio) (see Figure 10). An additional element is required in the network, called Hybrid Connection Gateway, which is in charge of redirecting/collecting IP flows to and from multiple paths for a given end-user (see the description in Table 15).

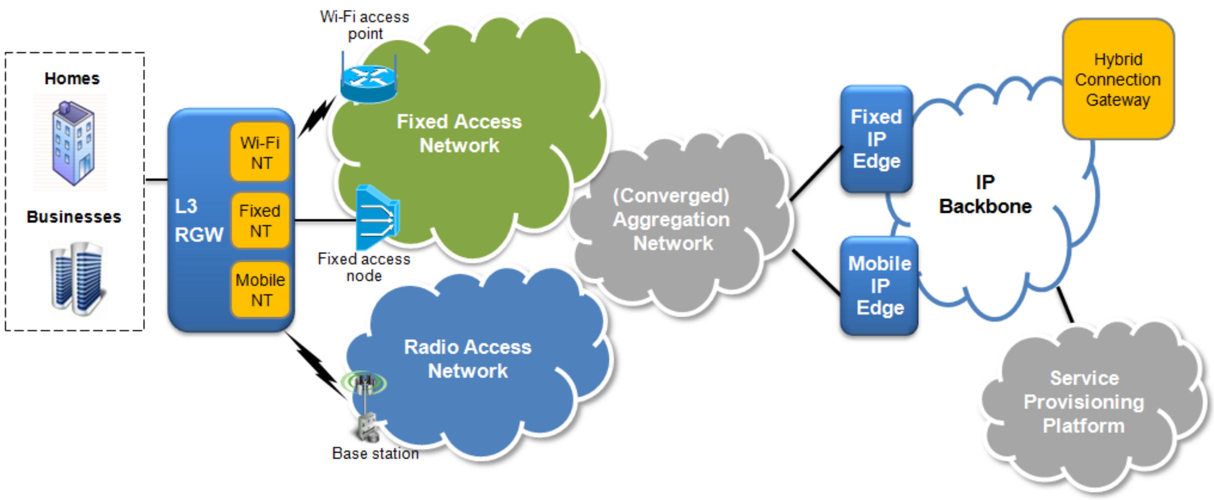


Figure 10: UC06 – Hybrid connectivity

Table 15 contains the description and details for the use case UC06.

Description	**Goal**	To use resources of fixed, mobile, and wireless access as flexible and efficiently as possible (from a network operator's perspective)
	Today's situation	Currently, the RGW is connected to the fixed access network only. Dual attachment through a 3G interface may exist, in order to secure the uplink in case of fixed access network outage.
	Potential impact	The positive impact of this proposal is that it improves service availability and performance for the customer. It also allows the operator to choose the access network to be used according to its constraints.
Convergence classification	**Classification**	Functional convergence
	Arguments	The service is independent of the structural convergence in the aggregation network.
Flow		1. The first step is to support LTE/3G access technology as a redundant link for fixed access. In this sub-case, no need of the multipath gateway. The protection is initiated by the RGW, with a tear down of the active sessions. 2. The second step introduces the Hybrid Connection Gateway and some additional requirements in the RGW, in order to support two access technologies and to take benefit of the increased overall bandwidth. 3. The third step should consider more than 2 access technologies (e.g. several mobile or wireless connections, etc.)

Table 15: Summarised description of UC06

3.6 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; use cases described hereafter, aim, then, to stress the need for a further integration between fixed and mobile backhauling networks, which allows to optimize infrastructure and functionalities supported, taking into account current and future service applications.

The following macro aspects are addressed:

- sharing of the network infrastructure, extending either the current aggregation domain towards the access (fixed / mobile) or enhancing the access domain extent towards the main central office;
- sharing of network infrastructure enabling for dynamic allocation of connectivity resources among mobile, residential and business services;

- definition of a universal gateway function, at the main central office (i.e. the edge of the aggregation network), integrating both fixed and mobile controller functions and allowing, when needed, for IP off-loading from mobile gateways.

3.6.1 UC07 - Support for large traffic variations between residential and business areas

The following pictures represent, respectively, the current situation of backhauling infrastructure often split per fixed / mobile services and the expected evolution, where a common aggregation infrastructure is used for a dynamic (optimized) allocation of resources over time. Figure 11 shows today's situation, where conventional IP-based backhauling implies one dedicated BBU for each RRU at the cell site. On the other hand, Figures 12 and 13 show the potential impact of CPRI-based BBU centralization where, keeping a common CPRI fronthaul / IP backhaul network, one BBU can be shared over the time by more than one RRU, resulting in less number of needed BBUs. Thus, as opposed to today where a BBU is statically associated to an RRU, it will be possible to create an association between a BBU and an RRU dynamically. For example, one and the same BBU can serve RRUs in business areas during business hours and RRUs in residential areas during non-business hours. A description of this use case, including more details, is found in Table 16.

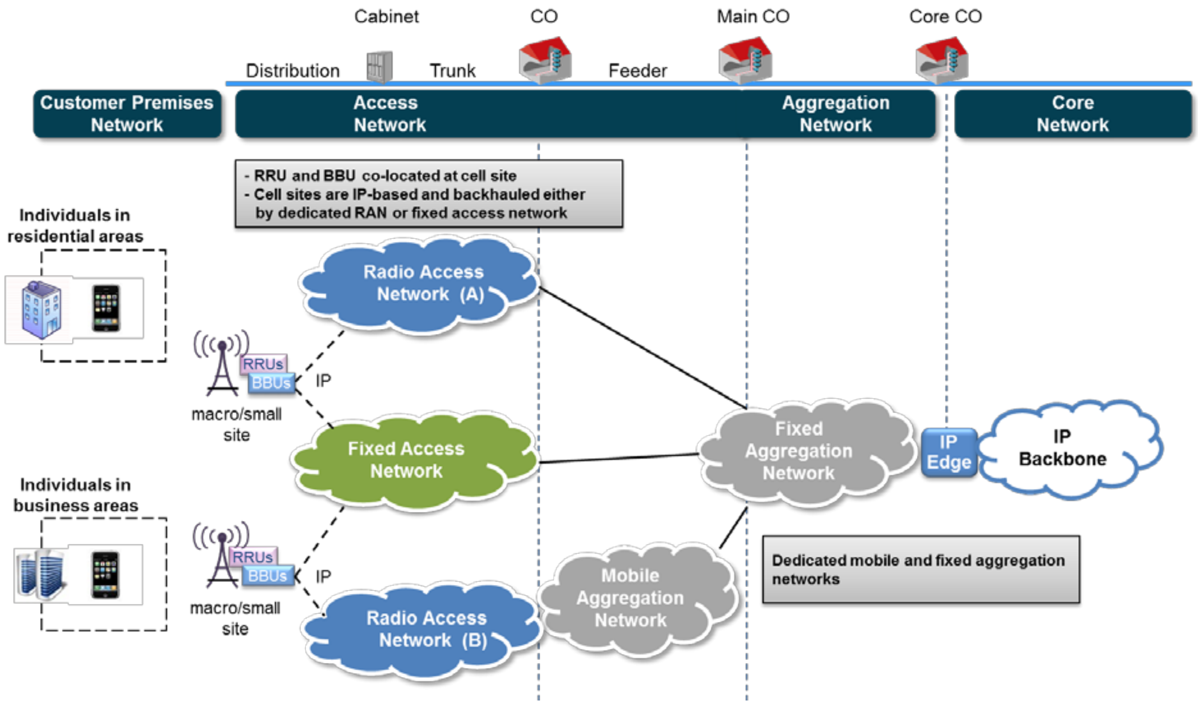


Figure 11: UC07 – Today's situation

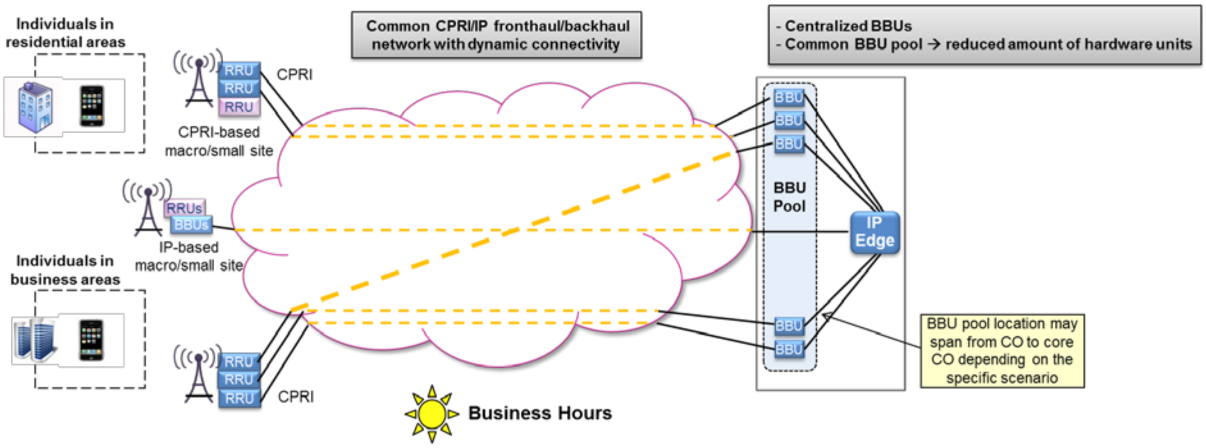


Figure 12: UC07 – Potential impact – “business hours” connectivity

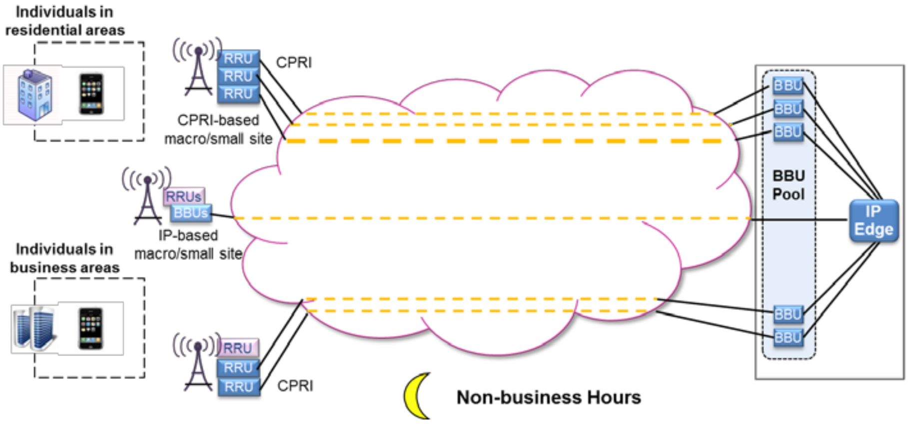


Figure 13: UC07 – Potential impact – “non-business hours” connectivity

Description	**Goal**	Achieving CapEX and OpEx reduction, respectively, driven by: 1. a common fixed-mobile aggregation network, able to interoperate with any front-haul network element or access network (fixed / mobile); 2. dynamic handling of network resources, optimized for the different conditions of traffic demand during the day, related to mobile, residential and business services (IP and CPRI based).
	Today’s situation	1. Radio units and baseband units have low utilization during certain hours of the day. 2. Backhauling infrastructures are often separated per fixed/mobile services.
	Potential impact	The positive impacts on the network include: 1. optimized convergence of fixed/mobile services over a common aggregation network (unique carrier grade OAM & resilience), with an expected lower “cost per bit”; 2. less number of BBUs will be required to support the same number of subscribers; 3. less energy will be consumed by shutting off radio units

		whenever possible, for example, in business areas during the night; 4. chance to address network sharing among service providers.
Convergence classification	**Classification**	Structural
	Arguments	The main part of this use case is the convergence of fixed/mobile over a common backhaul/fronthaul infrastructure, able to aggregate both IP and CPRI services (for BBU centralization)
Flow		1. Analyse CapEx and OpEx associated to: a. backhaul network for both fixed and mobile applications; b. cell sites (BBUs, power, conditioning, rent). 2. Identify capacity needs during different periods of the day/week (e.g. "business" and "non-business" hours) for the different backhaul/fronthaul network elements and create the business case. 3. Identify the needed backhaul/fronthaul common network in terms of throughput, client services to be carried, technologies to be deployed, trying to leverage, as much as possible on the existing infrastructure (e.g. fibre ducts, aggregation NE sites). 4. Implement the needed functionality for handling traffic variations at central office, including "optimized" BBU hotel (i.e. reduced amount of BBUs) and load-adaptive functions to shut down resources (e.g. RRUs) when not required.

Table 16: Summarised description of UC07

3.6.2 UC08 - Universal Access Gateway (UAG) for fixed and mobile aggregation network

The motivation of this use case is the integration of fixed and mobile gateway functionality in order to realize an efficient transport/control and optimize costs by reducing the number of network elements (Figure 14).

Current mobile core network is quite centralized and all data traffic has to cross the GGSN or P-GW as gateway to the national IP network to reach public Internet domain.

For any traffic not related to operator managed services, it is not necessary to cross the centralized GGSN/P-GWs. If the S-GW/P-GW is distributed and located in a central office closer to the user (NGPOP), this traffic can then access the national IP network and reach final destination in the Internet sooner, enhancing thus the latency and saving transport resources.

By distributing the mobile gateways closer to the end user, all traffic which does not need specific treatments (e.g. per user DPI) will be delivered to the IP core network. This allows saving transport resources within the mobile core network:

- In early LTE deployments, the mobile core network EPC is centralized, with a few centralized gateways gathering all traffic from all LTE cells. This choice is inspired by the current network architecture for 3G, and based on dimensioning studies.

- Lower latency (no additional tunnelling required anymore) and savings in the transport network towards EPC.

Note that transport resources to application servers / Internet peering points will still be required.

Optionally, by implementation of storage and processing resources this use case could be enhanced as an enabler for content delivering function (CDN) or offer an access (open API) to OTT service providers for their own resource and traffic management.

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

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

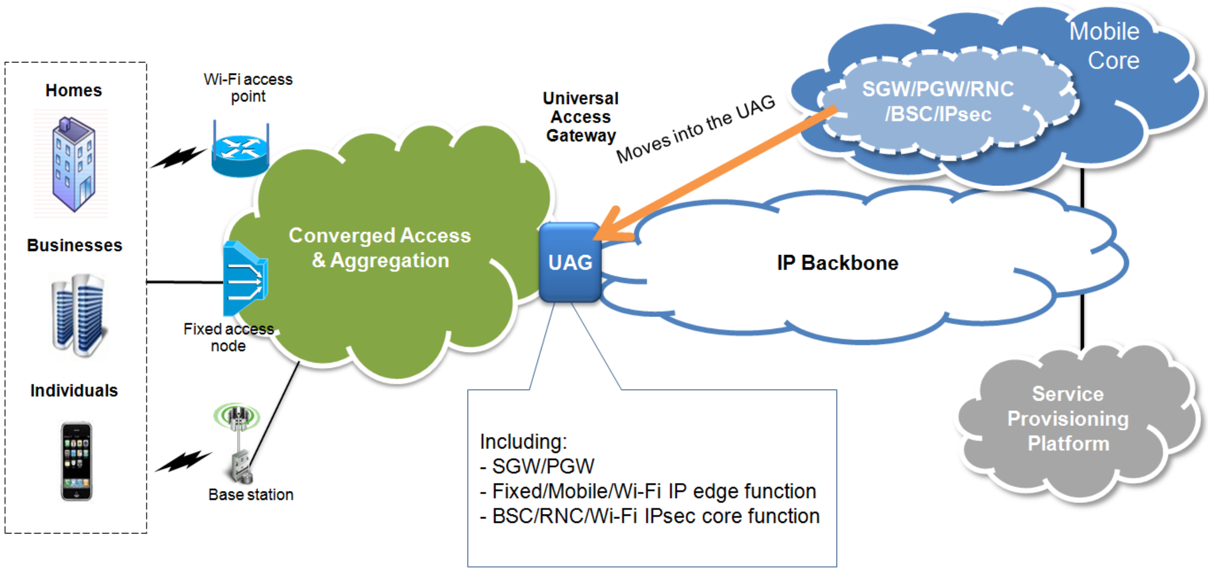


Figure 14: UC08 – Universal Access Gateway concept

The case is characterized by a fully integrated production including reduced network elements and related operations. It addresses functional and structural convergence:

- Existing mobile network functions move also to UAG but except mobile control plane elements like MME, HSS, and AAA servers.
- Full structural convergence of former different network elements like Access Router (AR), IPSec, S-GW/P-GW.

Table 17 contains the description and details for the use case UC08.

Description	**Goal**	Integration of fixed and mobile IP edge functionality in order to realize an efficient transport/control and optimize costs by reducing the number of network elements.

	Today's situation	Distinction between mobile and fixed network elements Tunnelling of mobile data path from antenna location to S-GW and mobile core network In current LTE deployments the mobile core network EPC is centralized, with a few centralized gateways gathering all traffic from all LTE cells.
	Potential impact	• Overcome performance limitations on access router caused by significant traffic increase • Fully integrated production including reduced network elements and related operations • Content delivery optimization based on access to all end user connectivity's (fixed, mobile / Wi-Fi) • Option to introduce backwards compatibility regarding 2G / 3G network elements/ functions for example BSC, RNC • Lower latency and savings in the transport network towards EPC
Convergence classification	**Classification**	Functional and structural convergence
	Arguments	• Existing mobile network functions are replaced except mobile control plane elements like MME, HSS, and AAA • Full structural convergence of former different network elements like AR, IPSec, SGW/PGW.
Flow		1. Depending on available access capacity either IP packets, MAC layer data or the CPRI/ORI signal for mobile base stations is sent from UAG 2. Next step is to integrate EDGE/3G processing functions, Wi-Fi IP Edge on a single UAG

Table 17: Summarised description of UC08

3.6.3 UC09 - Convergent access and aggregation technology supporting fixed and mobile broadband services

Fixed and mobile broadband networks have been designed and evolved independently using different technologies and protocols. From the last years, mobile networks have started to use high capacity links of fixed networks to provide enough capacity to the mobile base station and to interconnect the mobile packet core to them. However, mobile networks use these dedicated communication links transparently and only to carry mobile data traffic, so there is no deep integration.

Figure 15 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 final customers or it can be used to provide the backhaul to the technology 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.

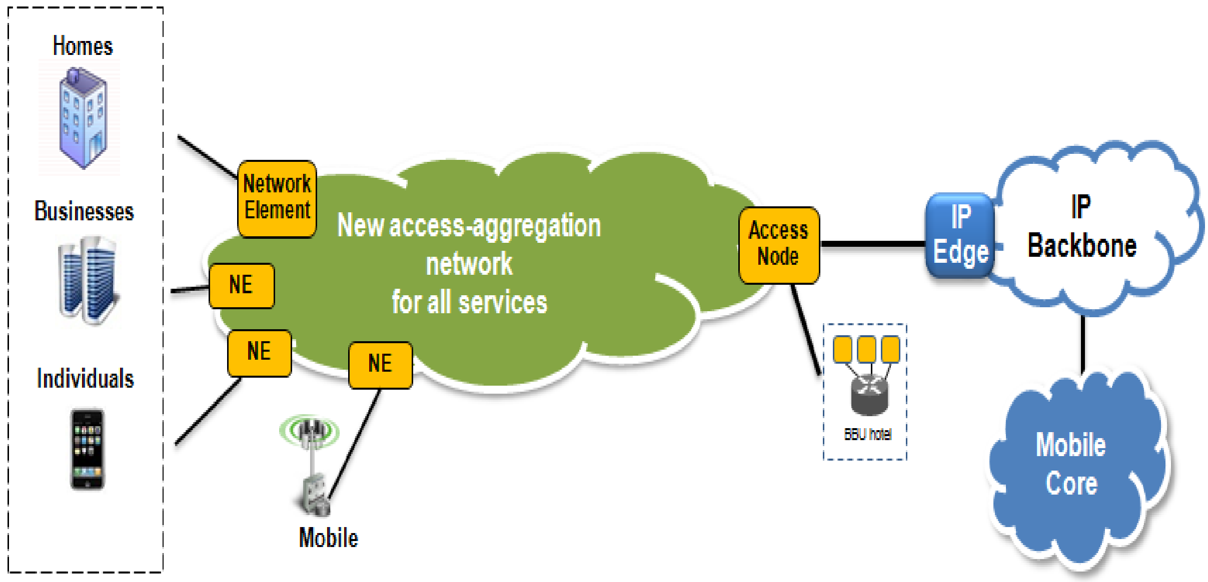


Figure 15: UC09 – Convergent access and aggregation technology supporting fixed and mobile broadband services

The next table (Table 18) contains the description and details for the use case UC09 in which it is proposed that a single network provides all broadband services.

Description	**Goal**	Use a single network technology as a universal technology for a single model of access and aggregation network able to support types of communications services: residential, business and mobile backhauling.
	Today's situation	Currently, fixed and mobile networks have their own network infrastructure with many different technologies. Multiple technologies in the same network segment used to provide connectivity services to different type of customers lead to a high CapEx and OpEx due to the required investment to purchase, upgrade and operate.
	Potential impact	Some potential impacts are: A single network for all services will provide CapEx and OpEx savings: one technology, economy of scale, same equipment, evolution, technicians, provision, configuration tools, installation, etc. Able to support legacy services: voice, TDM, VPN, etc. • Multi-operator enabler.

Convergence classification	**Classification**	This use case is mainly related to structural convergence.
	Arguments	A single network technology with the same functions in the same elements is structural convergence. BBU hotel concept is more related to functional convergence as current base stations' functions are placed in different elements and locations; however it is not the main target of this use case.
Flow		1. Start to deploy new long reach and high capacity technologies in aggregation nodes. 2. These new access-aggregation nodes can be used to provide backhaul connectivity to existing services: backhaul to FTTx residential customers, FTTH to enterprises and mobile backhaul to base stations. 3. Migrate legacy access and aggregation technologies for residential/business/mobile backhaul when new capacity is needed. 4. Centralize base band processing in BBU hotels at this phase in cost-effective areas (e.g. dense urban areas) if it is needed according to the operator strategy. 5. Final migration and shutdown of legacy technologies in access-aggregation.

Table 18: Summarised description of UC09

3.7 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.

At the same time, network sharing is a complex task, partly because it requires competing operators to set aside competitive concerns and, instead, cooperate and focus on the cost-saving possibilities. In other words, network sharing requires cooperative competition or so called "cooptition". 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].

The goal of the use case in this section is to highlight network sharing as a way to address the issues of spectrum availability, shortage of licenses, tougher competition in the telecom sector and global financial pressure.

3.7.1 UC10 – Network sharing

Today, mobile operators may lease fixed line capacity for their backhaul networks. In an FMC scenario, this type of sharing may be an even more natural thing to do.

Furthermore, networking sharing in an FMC scenario may facilitate mobile-only operators to enter the fixed market or vice versa. For example, a mobile-only operator that lacks LTE license can share its sites with a fixed-only operator that has got an LTE license for the purpose of entering the mobile market.

Figure 16 below illustrates how operators can save costs by sharing their networks, for example, using a third-party network company. A description of this use case is summarized in Table 19.

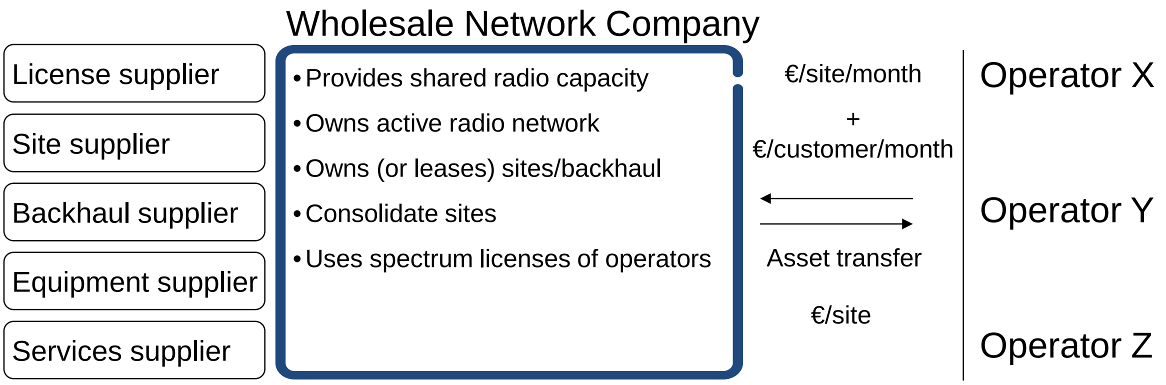


Figure 16: UC10 – Illustration of network sharing using a third-party network company

Description	**Goal**	To provide multi-operator network capabilities in order to reduce costs and support more flexible business models by utilizing existing infrastructure for both fixed and mobile communication
	Today's situation	Today it is possible to share networks but in order it make it more efficient network solutions should allow for fair resource sharing per operator
	Potential impact	Multiple operators can share infrastructure and thereby cost; existing fixed copper/fibre infrastructure will be used more efficiently resulting in potentially lower cost for end-users
Convergence classification	**Classification**	The use case is more related to structural convergence but functional convergence aspects are also included
	Arguments	The main part of shared networks is shared infrastructure and equipment but there will be a need for common management solutions in order to, for example, enable dynamic traffic management (see UC07)
Flow		1. Analyse existing infrastructure 2. Analyse capacity and coverage need 3. Initiate contact with other operators 4. Decide on level of network sharing 5. Decide on business model for network sharing 6. Implement network sharing for equipment and/or functions

Table 19: Summarised description of UC10

4 Market aspects

In this section an initial general overview of the actual market situation of the different network types will be given as well as an overview of the main market drivers for the development of converged networks. More detailed information on business ecosystems, business models and value networks of the different network types will be provided in Deliverable 5.1 - *Assessment framework and evaluation of state of the art architectures*.

4.1 Overview of current 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. The data provided in the subsequent sections show the actual trends in the separated networks and the need for further convergence.

4.1.1 Fixed

According to the most recent data published by Organization for Economic Co-operation and Development (OECD) from December 2012 [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 17). 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.

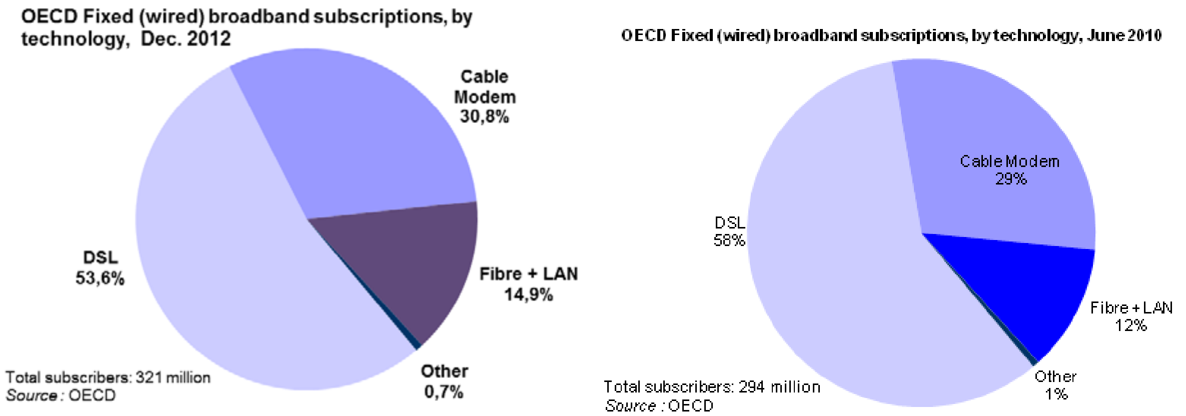


Figure 17: Global fixed(wired) broadband subscription

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 grown approximately 8 percent year-on-year during Q1 2013, exceeding 6.4 billion. The number of mobile broadband subscriptions grew even faster over this period at a rate of 45 percent year-on-year, reaching around 1.7 billion. The amount of data usage per subscription also continued to grow steadily. About 50 percent of all mobile phones sold in Q1 2013 were smartphones.”

They further stated that these factors combined have led to the total amount of mobile data traffic doubling between Q1 2012 and Q1 2013. Figure 18 shows the global monthly data and voice traffic in mobile networks by depicting very clearly that mobile data subscriptions will grow steadily and so driving the growth in data traffic. While voice traffic growth is only 4 percent, data traffic is doubled in one year.

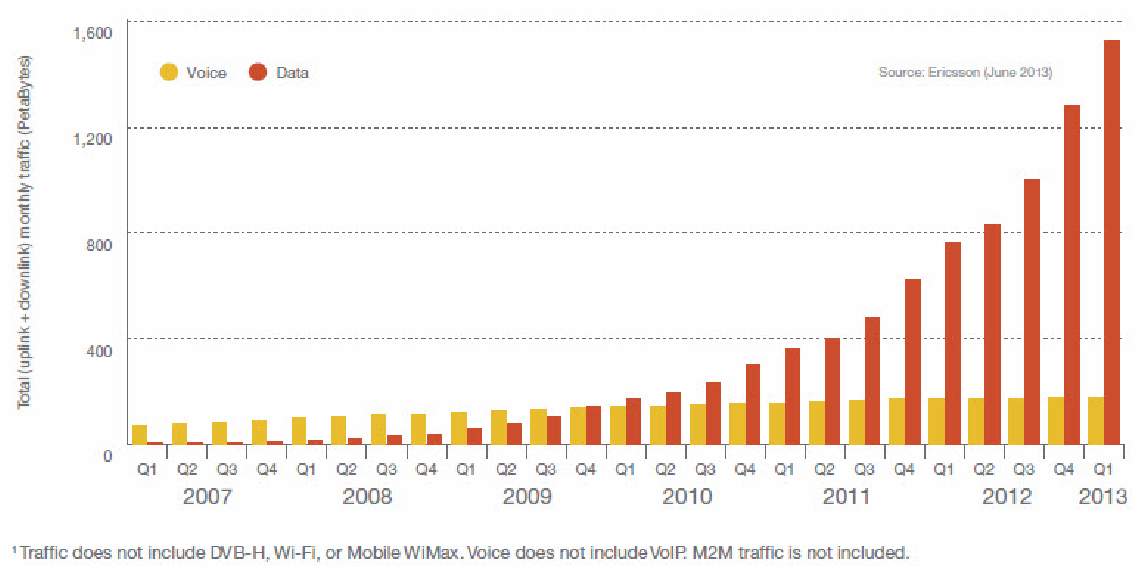


Figure 18: Global total data traffic in mobile networks, 2007-2013

As per Ericsson, the currently used mobile technologies are 2G, 3G and LTE. GSM/EDGE technology (2.5 G) has by far the widest reach and covers more than 85 percent of the world’s population. LTE (4G) is currently being deployed and despite being in the early days of rollout (estimated coverage worldwide in 2012 10%, in 2018 increase to 60% predicted), LTE networks can already provide downlink peak rates of around 100 Mb/s. Today, peak speeds experienced by users are often limited by device capabilities. The evolution of LTE, also referred to as LTE-Advanced, will enable peak data rates exceeding 1 Gb/s per site.

Ericsson revealed in the report, that currently, a 4G connection generates 19 times more traffic (although representing only 0.9 percent of mobile connections, they account for 14 percent of mobile data traffic) than a non-4G connection.

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.

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 Developments

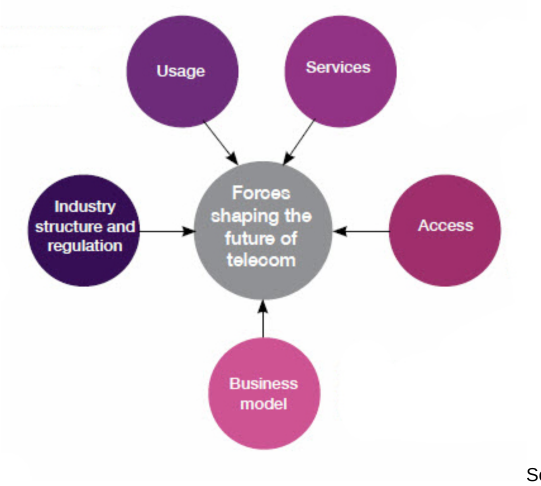
As unisonous stated in various statistics, studies and publications of public authorities like OECD [11], ITU [14], ETNO [15], etc. as well as private companies such as consultant companies like Booz & Co. [16], Arthur D. Little [17], Roland Berger [18], etc. or network manufacturers such as Ericsson [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 19):

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 19:.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)

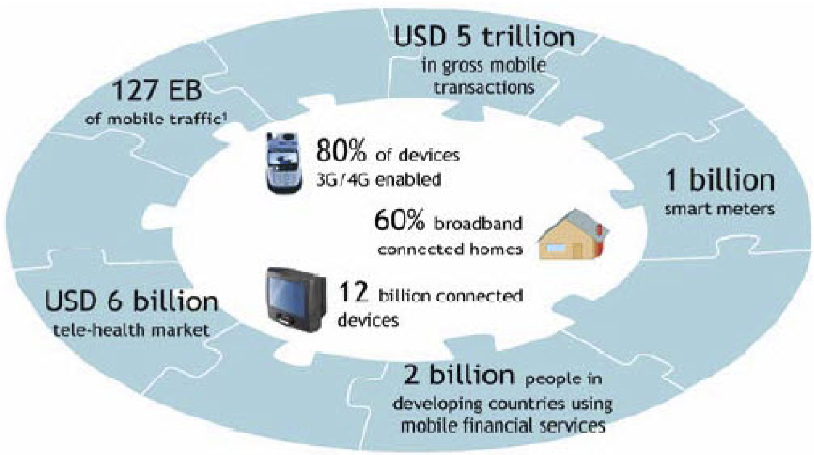
They further emphasize that this radical shift will not imply by any means the disappearance of fixed network. On the contrary, “network topologies will rely more and more on Wi-Fi and FTTH/GPON, FTTB as mobile networks simply will not be able to handle the data traffic volumes and speeds required by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

4.2.1 Drivers and barriers

As already mentioned before the main driver - need for more capacity in Internet access - 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. Another driver for FMC is the necessity of cost reduction in operator networks as well as the need for new revenue models.

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.”

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 20).



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

Figure 20: Key Figures in 2020

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.

But they emphasized 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 21).

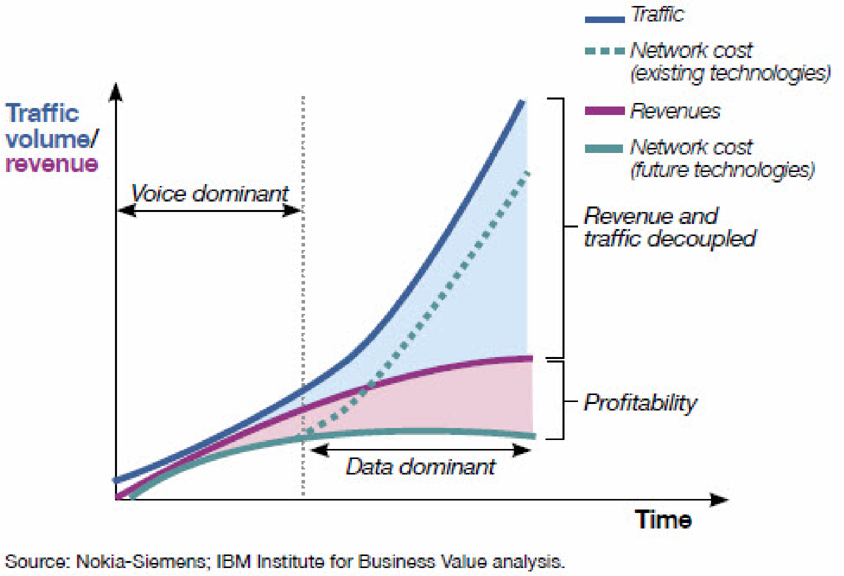


Figure 21: Revenue and traffic are disassociated in an increasingly data-dominant world

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.

The importance of FMC had already been pointed out in the European Research project ECOSYS in a study in 2009 (see Figure 22) showing that market shares would decrease for separate operators [21].

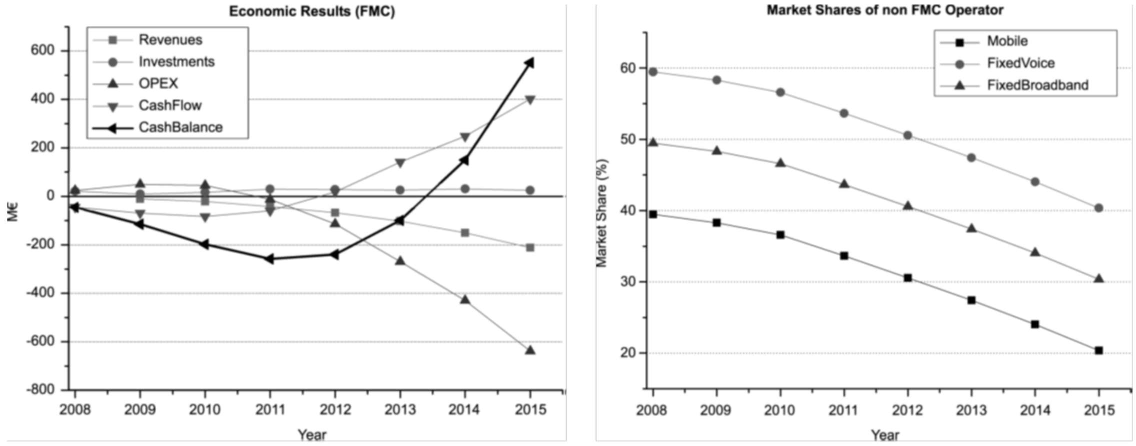


Figure 22: Economic results in FMC and development of market shares of non FMC Operators

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. 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.

In the previous chapters, the reference framework (chapter 2) and the different FMC network use cases defined (Chapter 3) had been described explicitly, showing exactly that they are tackling the issues mentioned above, trying to overcome the limitations of today's networks. Chapter 4 tried to complete the picture of the framework reference for fixed and mobile convergence by providing a large market analysis based on the assumption and market research results of different official organisations, private companies and the project partners. 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.

Based on this market analysis and the related future predictions further economic analysis (cost analysis and analysis of business ecosystem and business models) of the reference framework and the FMC network use cases will be executed in WP5 (the complete analysis of the state-of-the-art frameworks will be completed in Deliverable 5.1 - *Assessment framework and state of the art architectures*).

5 Conclusions

This deliverable will serve as the basis for the overall COMBO project since it is the reference point for all WPs.

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, using different reference parameters, such as the number of households, the reach distances, and the number of sites.

Furthermore, FMC network use cases are proposed and described. These network use cases, addressing the needs for functional and/or structural convergence, are the pre-stage to identify the requirements and key performance indicators for COMBO. The use cases are also provided as basis for the FMC architectures.

Finally, this deliverable gives 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.

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7 Appendix

7.1 Common Reference Areas

Section 2.4 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 (e.g. 1.5 km), below 7 km (e.g. 2 km) and below 10 km (e.g. 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 (e.g. 1.5 km), below 3 km (e.g. 2 km) and below 4 km (e.g. 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 (e.g. 600 m) than in dense urban and urban areas (e.g. 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 (e.g. 2 km), below 10 km (e.g. 5 km) and below 10 km (e.g. 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 (e.g. 200), below 500 (e.g. 150) and below 300 (e.g. 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 (e.g. 20.000), from 5 000 up to 20 000 (e.g. 8 000) and below 5 000 (e.g. 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 100 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 23). The size of the two areas could be quite variable, depending on the specific geographical region.

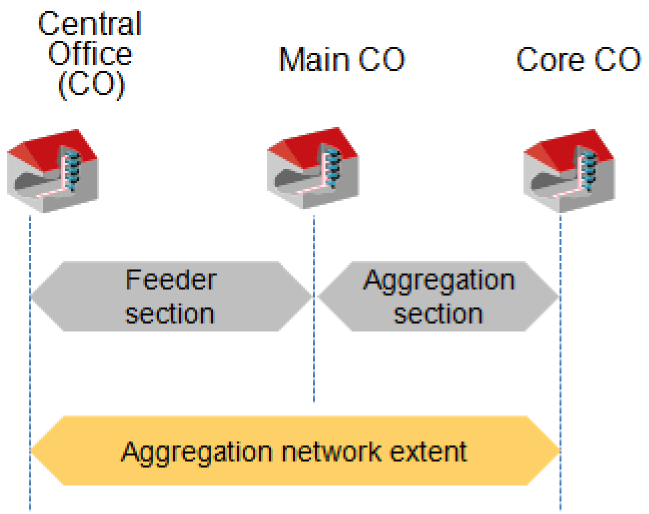

Figure 23: Aggregation network extent

- 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 24.A): collocated.
  - the AN and the first level of aggregation are in different CO inside the same metro area (see Figure 24.B): dozens of kilometres.

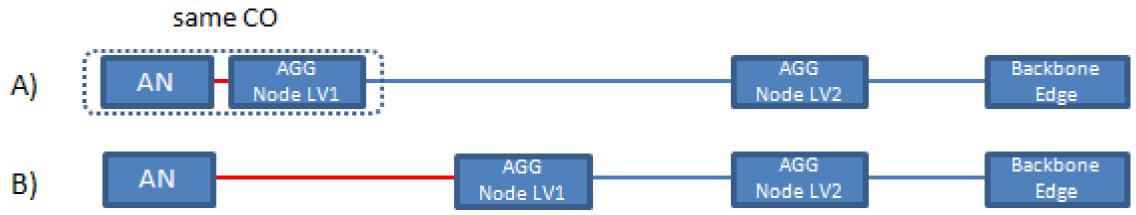

Figure 24: Link length between access node and aggregation node

- 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 25.A): collocated.
  - the first and the second levels of aggregation are in different CO inside the same metro area (see Figure 25.B): dozens of kilometres. In dense urban, urban and rural areas the typical reach is less than 10, 30 and 50 km respectively.

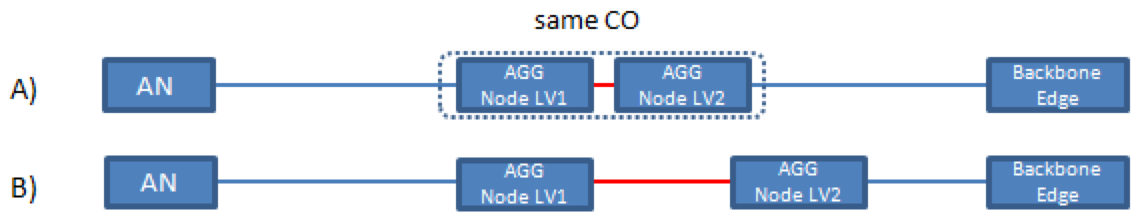

Figure 25: Aggregation level 1 to level 2 link length

- 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 26.A): collocated.
  - the second level of aggregation and the backbone edge are in different CO inside the same metro area (see Figure 26.B): dozens of kilometres. In dense urban, urban and rural areas the typical reach is less than 10, 30 and 50 km respectively.

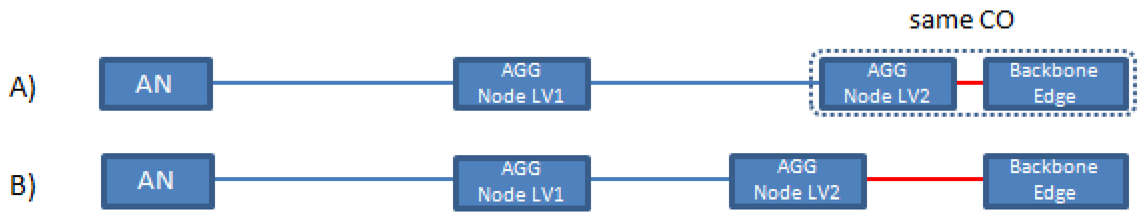

Figure 26: Aggregation level 2 to backbone edge link length

- 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).

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