Monitoring parameters relation to QoS/QoE and KPIs

Executive Summary of the deliverable

The COMBO project aims at defining concepts for Fixed Mobile Converged (FMC) networks that allow for a significant reduction of cost per bit and energy consumption. The project includes definitions of FMC use cases and Key Performance Indicators (KPIs) (Work Package 2), definition of FMC network architectures (WP3), a techno-economic analysis (WP5) and an experimental assessment (WP6).

The FMC networks will include several different types of media and infrastructure (such as fibre, copper, microwave, mobile, WiFi) and have to cope with various services with diverse requirements, such as low latency telephony and high throughput video streaming. This means that the networks must be flexible and need to be optimised to a number of different criteria. In order to achieve this, it is key to understand how measurable parameters reflect the Quality of Service (QoS) and optimisation criteria. All these are handled within Work Package 4 (WP4) of COMBO.

WP4 Task 4.1 (T4.1) deals with the QoS and Performance Monitoring (PM) aspects of the FMC networks. Performance monitoring is important for service assurance but also paramount for the performance optimization concepts – these will be developed in Task 4.2. WP4 also includes an evaluation task, T4.3, where the management concepts are assessed by simulations or by feeding WP6 with demonstration proposals.

The work undertaken in T4.1 includes a survey of existing QoS/PM tools and parameters and the definition of these parameters to support the requirements of an FMC network environment. Following the survey, which was captured in Milestone 17 (MS17) and covered tools across multiple layers and functions in addition to Quality of Experience (QoE), the goal is to begin the process of defining QoS/PM tools and parameters than can be indicative of QoE and which support the FMC environment.

This deliverable is the first step in that process. It translates input from WP2 primarily, in the form of use cases, and where available, KPIs; and provides a top-down analysis showing the relationship between QoS/PM and QoE tools and parameters

arising from those use cases and KPIs. We explored the implementation options of use cases in detail, identified QoS/PM tools and parameters for them, and where possible, identified common tools and parameters spanning multiple use cases. We also highlighted use cases with specific QoE impact. As well as addressing the scalability challenges that could be associated with converged networks, we also considered the impact of emerging network paradigms such as Cloud, SDN and NFV to identify QoS/PM aspects which might arise in the future.

This deliverable represents a preparatory work, which will be further elaborated in the subsequent deliverable D4.2, refining the QoS/PM tools under the scope of specific FMC architectures. This can be achieved when a more precisely defined list of KPIs and FMC architectures are available from WP2 and WP3, respectively.

This deliverable provides multiple key results: It provides a state of the art view of QoS/PM tools and parameters across multiple layers and functions. The work summarizes the implications and PM impacts for each use case. An example of this is UC1, where we identified a quite extensive need for traffic volume measurements, monitoring available resources for dynamic resource allocation, power consumption monitoring and securing maintained QoS. To support the use cases, we identified specific QoS/PM tools and parameters – ranging from physical layer bit error rate or signal-to-noise ratio to service availability and quality of experience –, and showed how they relate to KPIs generated by WP2. Our study on the relation between QoS and QoE highlighted some of the QoS parameters – such as network throughput, delay, delay variation or packet loss rate – which can be indicative for QoE. The deliverable also identifies gaps in connection with KPIs, including parameters related to SDN, NFV and cloud such as virtual machine resource pools and time to bring new virtual machines online. These will be fed back to WP2 and analysed further in D4.2.

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1 Introduction

An FMC network includes several different types of media and infrastructure (such as fibre, copper, microwave, mobile, WiFi etc.) which typically have different types of parameters and tools for performance monitoring and fault management. On top of these a plethora of parameters are also defined in various standardization bodies for layer 2 and above, and thus it is obviously not straightforward to understand the specific monitoring impacts for different FMC architecture proposals and how to feed optimisation algorithms with relevant network information. This document aims at providing a first analysis of performance monitoring for FMC networks by surveying existing PM tools and parameters by analysing specific monitoring impacts from use cases and KPIs from WP2. Part of this initial analysis is to identify gaps, which will be further explored in the final T4.1 deliverable D4.2 in which also the monitoring impact of the FMC network architecture proposals will be analysed.

Task T4.1 surveyed existing QoS/PM tools and parameters. The survey was captured in Milestone 17 (MS17), covering tools across multiple layers and functions in addition to Quality of Experience (QoE). A summary of that survey is captured in chapter 2 of this deliverable. Chapter 2 also introduces the two key terms QoS and QoE and describes the connection between them.

Chapter 3 translates input from WP2 Deliverable D2.1 [1], primarily in the form of use cases, providing a top-down analysis, identifying key QoS/PM tools and parameters and highlighting specific QoE impacts. Chapter 3 also explores the impact scalability/complexity and emerging paradigms such as cloud computing, Software Defined Networking (SDN) and Network Function Virtualisation (NFV) on QoS/PM.

Chapter 4 takes preliminary input from early drafts of WP2 D2.4 [3] in the form of Key Performance Indicators (KPIs), and using the results from chapter 2 and 3 of this deliverable captures the relationship between KPIs, Use Cases and QoS/PM parameters and QoE. In cases where KPIs are not supported by obvious monitoring parameters, these are identified as gaps and proposed as topics to be addressed in future WP4 activities.

Finally, Chapter 5 summarises and concludes the deliverable pointing out the key messages arising from the activities and looks ahead to the topics that need to be tackled in deliverable D4.2 of WP4 in order to propose a QoS/PM model that is tuned towards FMC based networks.

2 QoS/PM/QoE state of the art survey

When discussing performance monitoring of Internet Protocol (IP) based networks two concepts immediately emerge: Quality of Service and Quality of Experience. QoS is normally defining performance monitoring at the lower layers, i.e., the physical to the network layer or even the transport layer of the OSI reference model, while QoE is very closely connected to the application layer and the user's subjective perception of the quality of which a service is presented. QoS parameters are objective parameters that reflect the delivered service quality. QoE, on the other hand, reflects the users' perceived experience of the quality of the delivered service end-to-end and as such it is a subjective measure. QoE is purely end-to-end, meaning that the networks between source and destination can be seen as a black box. However, QoE is dependent on the QoS of the parts making up the black box.

2.1 QoS and its multitude of shapes

The concept QoS refers to a group of traffic characteristic parameters in the sense that these parameters reflect the quality with which traffic i.e. packet flows are distributed in the network. However, it can also refer to traffic engineering methods with the goal of fulfilling some level of quality for the traffic flow regarding these parameters. The current QoS can be estimated by monitoring, but it is also possible to define a level of QoS in for instance a Service Level Agreement (SLA).

For packet switched networks, both on layer 2 and 3, QoS parameters are e.g. frame or packet loss, delay, packet delay variations (PDV), out-of-order packets and bit-rate. The impact of each of these parameters on the application and thus on the QoE differ depending on the application type. For instance, in real time streaming multimedia all QoS parameter irregularities can effectively be seen as packet loss. Mobile terminals grow both in supported services and in size. It is reasonable to believe that the user's demand on perceived QoE thereby is increasing. The bigger screens itself argues for better visual quality.

There are several traffic engineering methods with the common goal of establishing a certain traffic quality level. In packet switched networks techniques like leaky bucket and token bucket protect links and network nodes from overloading and the thereof following packet loss or delay. Tagging frames or packets according to different traffic classes enables nodes to prioritise individual packet/frames or flows of packets [17][18]. IP [19] is by definition best-effort, meaning that there is no QoS. Integrated services (IntServ) [20] together with Resource Reservation Protocol (RSVP) [21] and Differentiated Services (DiffServ) [22] are two techniques to introduce QoS in this layer. IntServ reserves resources for a flow in the end-to-end path, while DiffServ tags packets on ingress and the nodes act on the tagging. MultiProtocol Layer Switching (MPLS) [23] introduces prioritised switching on the IP layer.

2.2 QoE and the relation to QoS

QoE is related to the users' or the subscribers' experience or perception of the quality of the presentation of a service. It is often referred to as QoS on the application level, but it can be discussed if this is entirely true. QoE is naturally dependent on end-to-end QoS, but is a subjective measure. Definitions for QoE in [34] and [35] include keywords and phrases such as ‘psychological measure’, ‘user behaviour’ and ‘quality of perception’, and emphasize the subjective nature of some QoE measures. User centric measurements are normally referred to in conjunction with parameterisation methods such as the Mean Opinion Score (MOS, see for instance [24] and [37]), Degradation Mean Opinion Score [25] and Media Delivery Index (MDI) [26]. Such collection of responses to QoE usually requires appropriately designed lab and field studies, which suggests that these subjective QoE metrics are unlikely to form part of an operational monitoring model.

FMC networks do not have a direct impact on QoE, the impact is indirect. An FMC network is by its nature an all IP network as indicated by Figure 1. Increased QoS on all levels up to – and probably also including – the transport layer will have a positive effect on QoE. This model, like the original OSI reference model, has its limitations though. It is dependent on each layer being fully independent of other layers, communication between neighbouring layers is performed in the interfaces. Especially wireless links introduce new challenges regarding the need for cross layer interaction. For example Transmission Control Protocol (TCP) is based on a model were links are near to perfect and have deterministic behaviour; All packet loss in a TCP session is regarded as originating from congestion in active network nodes. A not so perfect link e.g. a wireless link with packet loss deteriorates TCPs performance. A solution is to either make TCP aware of performance on intermediate links in the end-to-end path or to create link functions that cover for instance packet loss to higher layers.

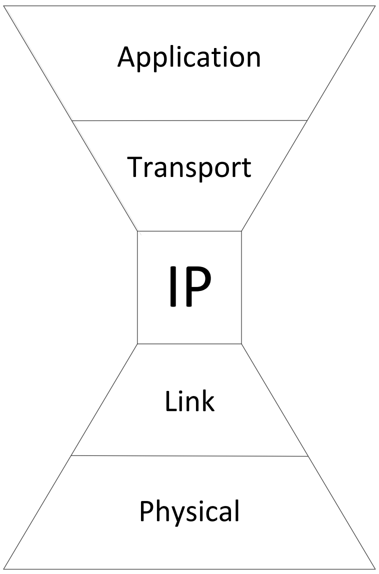

Figure 1: The Hour Glass Model, derived from the OSI reference model and the TCP/IP model

Specifics of the application layer are not within the scope of the COMBO project and a COMBO network could be seen as a carrier of IP traffic. Thus, the COMBO project is not aiming at developing or validating methods for QoE estimation. The focus is on finding and establishing QoS parameters that influence QoE and which are vital for the function of an FMC network. In order to accomplish this it is important to understand the relation between QoS below the application layer and QoE on the application layer.

The European Telecommunication Standards Institute (ETSI) guidelines [34] suggest that QoE should focus on user touch-points for the whole lifecycle of a given service, including the selection and use process. Example data relating to QoE is provided for different service types. For video services two metrics are defined which as expected relate to delay: end-to-end packet delay and lip sync (audio/video alignment).

The International Telecommunication Union – Telecommunication Standardization Sector (ITU-T) Internet Protocol Television (IPTV) requirements document [35] also defines QoE in terms of human perception and user centric behaviour. It is further noted in [36] that QoE may depend on context and user expectation. The possibility of using subjective MOS data measured for different QoS scenarios is explored with the intention of supporting a model allowing:

1. Prediction of QoE based upon QoS results
2. Derivation of QoS parameters for a given QoE requirement

[35] deals with the subject of delay, especially focusing on how users select channels in IPTV services. A key QoE implication is defined relating to channel zapping time. In addition to discussing delays within the network as a contribution towards QoE, within subjects of jitter and bit errors are also dealt with in some detail. For the latter case a proposal is made to monitor effects which are known to have implications on QoE from MOS tests.

Many methods for estimating QoE from foremost the network or IP layer QoS parameters are proposed. Already in 2002 Khirman and Henriksen suggested a method for relating objective QoS parameters with the subjective QoE regarding Voice over IP (VoIP) [31]. In [32] Kim et al show that among QoS parameters on layer 3 packet loss has a relative importance degree on IPTV of 41,7%.

IPTV and VoIP are both real time applications but underlying layer QoS requirements differ significantly. Not only is packet rate demands for VoIP orders of magnitude lower than for IPTV, but low latency is critical for VoIP while packet loss is the critical component for IPTV. A network that delivers IPTV with good quality can deliver VoIP with low QoE. IPTV is a simplex application while VoIP is duplex. Latency variations can, in the IPTV case, be compensated for by jitter buffers. In VoIP latency is a well-known critical QoS parameter which effectively hinders the use of jitter buffers; These introduce latency in the order of hundreds of milliseconds to be effective. Packet loss is critical for the IPTV QoE, but it is acceptable in VoIP to a higher degree.

It is reasonable to believe that these relations between lower layer QoS and QoE is valid also in a mobile environment. In simplex transmission services, like IPTV, jitter and packet loss can be compensated for but for voice low latency is a requirement. Since the physical and link layers differ significantly between wired links and radio based links for mobile terminals also the relation between QoS of the IP layer and the two lower layers differ. In the case of mobile backhauling where both types of applications are deployed by many users over a shared link the two application group's dissimilar requirements is a challenge; low packet loss and low latency at the same time.

The relation between QoS parameters on lower layers, e.g. impairments on the physical layer's impact on the IP layer, is not so deeply studied. On the physical layer all parameters that have an impact, direct or indirect, on upper layer QoS parameters must be defined as QoS parameters. For example, a change in Signal-to-Noise Ratio (SNR) in DSL affects packet delay variation and packet loss on the IP layer [13][14]. Bjergaard and Hallberg [15] compares performance metrics on the physical level with the objective QoE parameter VQM. Their models should be seen as indications of existing non-linear relations between physical layer quality and QoE metrics. VQM is a method for predicting a user's perceived experience from QoS parameters [16]. Bogovic et al discuss in [33] the relation between QoE and DSL physical layer QoS parameters. Orosz et al. [38] investigated the correlation between video QoS and QoE. By studying these parameters for a specific DSL line triple play QoE can be estimated.

In [27] Goran et al have investigated the impact of physical layer disorders on both QoS and QoE in an ADSL2+ system. Different disturbance types have different impact on QoS and QoE dependent on ADSL link setup. The number of error counters such as Errored Seconds (ES) and Severely Errored Seconds (SES) are directly correlated to the quality of an IPTV stream. Škaljo et al also estimate the impact of impairments on the physical link have on IPTV quality [28]. They, like Goran et al, use an ADSL2+ system for their experiments. Five physical layer parameters are used, among them ES. They find that not all code violation errors (CV, CRC) cause decreased QoE, which probably is due to that the disturbance hits layer 3 packets carrying other services. [29] proposes a model for capturing the cross-layer dynamics of Near-End Crosstalk (NEXT) and Far-End Crosstalk (FEXT) and the impact on packet loss. An on-going effort finding methods that correlate QoS on different layers is for example [30] where Impulse Noise impact on a flow of UDP packets is discussed. It is there shown that packet loss due to impulse noise is not only dependent on the frequency, signal level and pulse duration in time of impulse noise, but also the affected packet stream's utilisation of the VDSL2 link.

Thus, by understanding the relation between the physical layer QoS and the IP layer QoS and combine these results with available research results where IP layer QoS parameters relation with QoE it is plausible to understand the complete chain from physical layer QoS to QoE. It is not within the scope of COMBO to cover all layers in the OSI reference model. However, the understanding of the connection between parameters from various layers will be used when defining the QoS/PM tools and parameters so that the FMC model is as indicative of the QoE as possible.

2.3 Survey of monitoring parameters and methods

The milestone MS17 "Survey of monitoring parameters and methods" captured the existing QoS, QoE and PM parameters and methods, including the industry practice and current standards recommendations for both physical media and services. The survey classified the monitoring parameters and the corresponding methods and tools using different criteria:

- According to the physical medium or technology, in which optical fibre communications, copper (e.g., VDSL2 and G.fast), microwave radio links, Wi-Fi and Base-T (considering typical cables used in access networks).
- According to the protocol layer, with a deep focus on the OSI layers 2 and 3, including also 2.5 layer protocols such as MPLS.
- According to the type of service or function provided, such as mobile fronthaul, synchronization, energy consumption and protection, restoration resilience and availability features.

The survey has been also useful to agree on the definition of different terminologies related to performance management and monitoring, such as active/passive monitoring and the relationship between QoS and QoE. The definition of passive and active monitoring is the following:

- Passive monitoring: non-intrusive tools that do not affect the supervised element/ path/service (e.g., available bitrate monitoring) or methods that do not manipulate packets but have visibility of packet headers and/or payload (e.g. packet counters).
- Active monitoring: intrusive tools that disrupt or impact the link or the service under supervision (e.g., loopback facility which affects a user or a service) or methods which can manipulate or add fields to packet headers or payloads for the monitoring of an element, service or path (e.g. timestamps, flags field, etc.).

The following tables provide a summary of this work containing the main methods and parameters: they represent multiple network layers and locations/functions in one place. Table 1 focuses on methods and parameters used in specific physical media and technologies, Table 2 makes a classification according to different protocol layers and finally Table 3 outlines the main tools and parameters for different services or functions.

Physical medium and technology	Passive methods	Passive parameters	Active methods	Active parameters
Optical fibre – xPON and point-to-point (1)	• Line monitoring • Optical performance monitoring • CD, PMD testers • Optical power meters • Transceiver diagnostic interface • OTDR out of band (w/ or w/o reflective filters, point-to-pint or point-to-multipoint, co-directional or contra-directional)	• LOS, BER, frame errors, loss of synchronization, FEC, OSNR • System load • PMD, CD • Transmitted/Received optical power • Transceiver parameters (temperature, supply voltage, bias current, Tx & Rx power) • Reflectometric traces (see active parameters)	• OTDR in band (w/ or w/o reflective filters, point-to-point or point-to-multipoint, co-directional or contra-directional)	• Reflectometric traces (attenuation, reflection, end of fibre events, etc. including end-to-end loss, event loss, event reflection and attenuation slope)
Copper – xDSL and G.fast (2)	• Status parameters monitoring • Performance parameters monitoring • Data gathering function (VDSL2) • Impulse noise monitoring • Active testing and diagnostics parameters monitoring	• SNR Margin, Max attainable data rate, Line attenuation (per band), Signal attenuation (per band) • Code Violations, ES, SES, FEC, Unavailability secs, Error-free bits (EFTR), Full initialization count, Re-synchs count • Time stamped events, e.g., End of showtime, Previous end of showtime • INP equivalent (INP required to prevent data errors), symbol interarrival time	• Retraining • DELT • SELT • MELT • Loop Qualification & Monitoring (LQ&M)	• Hlog, Hlin, SNR, QLN, FEXT coupling (XLIN) • Echo measurement (fault localisation) • Cable electrical parameters at DC or low frequency

Physical medium and technology	Passive methods	Passive parameters	Active methods	Active parameters
Radio – uWave (3)	• Status monitoring • Performance monitoring over the link as a service	• Tx/ Rx frequency or radio channel • Available BW, Current BW • Available field polarization • Pmax, Pmin, Current Ptx • RSSI • Mmax, Mmin, Current Mtx and Mrx • Receiver EVM • Supply Current, demodulator unlocked alarm, clock, misaligned frames • Ethernet traffic (trx/refused, current link payload...) • Far-end Tx freq, BW, field polarization • Link Operating state, LOS, BER, EB, ES, SES, BBE, ESR, SESR, BBER, SEP, SEPI, unavailability rate, AR • MTBF, MTTR, MO, OI	• Performance prediction	• Diffraction fading, attenuation, multipath diffraction, frequency selective fading distortion, multipath propagation delay • Variation in the angle-of-arrival • Reduction of cross-polar discrimination (XPD)
Radio – Wi-Fi (4)	• Status monitoring • Performance monitoring over the link as a service	SNR Channel usage ratio (for the same channel the AP operates in) • Adjacent AP detection (for the same channel the AP operates in)	Performance management • Diagnostics	Adjacent AP detection (all channels requires stopping the service or an additional radio) •
Service – Wi-Fi	• Status monitoring • Performance monitoring over the link as a service	Nominal bandwidth of the backhaul Service status Number of clients connected Client session time • Mean delay in the connection to the core	Performance management •	• Active backhaul quality measurement methods

Physical medium and technology	Passive methods	Passive parameters	Active methods	Active parameters
Copper – BASE-T (Ethernet) (5)	• IEEE BASE-T Link Status tools • SNR margin from LDPC training operation • Physical counters	• Link status: check on link re-establishment after a link down • PMA_RXSTATUS indication - used to indicate status of the receive link at the local phy. Implementation options, but Mean Square Error and symbol errors noted • SNR	• In maintenance windows, the link can be placed out of operation, and an electrical TDR function can be performed	• Distance to open • Crosstalk • Cable length

(1) See ITU-T G.984.2, ITU-T Recommendations L.40, L.44 and L.53, SFF-8472 specification, BBF WT-287, IEEE 802.3 Physical medium attachment/dependent

(2) See BBF TR-069, TR-188, TR-197, TR-198, TR-252, ITU-T Recommendations G.997.1, G.996.2, G.993.2 amd3, G.999.4amd2, G.997.1, G.998.4, IETF RFC4706, RFC5650, RFC6765.

(3) See ITU-R Recommendations P.530-14, F1.493, ITU-T Recommendations G.821, G.826, G.827, G.828, ETSI TR 101 534 V1.1.1, ETSI TS 136 322 V8.8.0

(4) See IEEE 802.11, BBF TR-069 and BBF TR-143.

(5) See IEEE 802.3 Clauses 24.3.4.4, 40.2.8 and 55.4.2.5.7

Table 1: Monitoring parameters and methods: physical medium and technology specific

Protocol layer	Passive methods	Passive parameters	Active methods	Active parameters
Layer 2 (1)	• Remote Network Monitoring Information Base (RMON) IETF • Performance monitoring • Connectivity monitoring • Synthetic Loss Measurement • Probe monitoring • SLA monitoring	• RMON Etherstats (counters) • SMON Etherstats (counters) • Service availability, Frame loss, Frame misordering, Frame duplication, Frame transit delay, Frame lifetime, Undetected frame error rate, Maximum service data unit size supported, Frame priority, Throughput, Frame delay variation • MEF Technical Specification 10,2 • RFC1242 Benchmarking Terminology for Network Interconnection Devices	• ITU- Y.1731 SLA Monitoring • ITU-T Y.1564 Ethernet service activation test methodology • Benchmarking Methodology for Network Interconnect Devices (RFC 2544) • Connectivity fault management • Network and service testing • Network traffic management • Customer experience management • Trouble ticket management	• Frame Delay (latency) • Inter Frame Delay Variation • Frame Loss Ratio • Availability • CIR / EIR / Traffic policing parameters • MEF Technical Specification 10,2 • RFC1242 Benchmarking Terminology for Network Interconnection Devices
Layer 2.5 (2)	• Performance monitoring	• Loss and delay	• GAL (label 13) and G-ACh • Service delivery verification • Protection switching • Continuity check	• Loss and delay
Layer 3 (3)	• RMON • SMON • NetFlow • sFlow	• Packet loss ratio (one/two way) • Throughput • Delay (one/two way) • PDV • Inter Packet Gap (IPG) • Inter arrival Time • Packet rate • Burstiness, MTU • Availability parameters (Y.1540)	• ICMP echo • OWAMP, TWAMP • BFD (RFC 5880)	• Packet loss ratio (one/two way) • Throughput • RTT • Delay (one/two way) • PDV

(1) See IETF RFC 2819, RFC 4502, RFC 2613 and RFC 2544, IEEE 802.1D, 802.1Q-2011, ITU-T Recommendation Y.1564

(2) See ITU-T Recommendation Y.1731, IETF RFC 6669

(3) See BBF TR-143, TR-160, WT-304, IETF RFC 5357, RFC 6802, RFC 4149, RFC 5481, RFC 5880 etc. ITU-T Recommendations Y.1540 and Y.1543

Table 2: Monitoring parameters and methods: protocol layer specific

Service / Function	Passive methods	Passive parameters	Active methods	Active parameters
Service Level Monitoring (1)	• Dynamic following of the well-known ports • Analysis of statistical distributions • Traffic monitoring • RTFM • RMON MIB • IPPM • IPFIX • PSAMP	• Packet inter-arrival times • Packet length • PDP context lifetime • Control traffic decryption success rate	• Packet fingerprint analysis • ALTO • Traffic generators • Roaming testers • Fraud detection systems	• Malware presence • Attach/ detach rate • PDP context activation/ deactivation rate • Generated traffic upload/ download bandwidth
Synchronization (2)	• Measurement of network-related parameters • Relative measurements between redundant sync paths • Installation of a temporary measurement reference • Measurement against synthetic reference (local clock)	• Packet delay • Out of order packets • Packet drop statistics • Clock accuracy • Variance • Distance (number of hops) from master • Frequency offset • Missing clock cycles • Phase transients • Asymmetry in delay • Delay variations	• SSM/ESMC Traceability signalling	• Quality Level indication (note not absolute quality, more traceability to reference)
Energy Consumption (3)	• Energy consumption monitoring	• Power • Energy • Power interval • Voltage • Current • Duty Cycle • Power cycle		

Service / Function	Passive methods	Passive parameters	Active methods	Active parameters
Protection, Resilience, Restoration and Availability (4)	• Performance monitoring	• MTBF, MTTF, MTTR, MTBO, MTRS, etc. • Availability • Loss, recovery time, full restoration time, etc. • Severe Loss Block	• Failure characterization • TDR/monitoring trails	• Outage time • Failure occurrence
Intelligent Networks/Value Added Services (5)	• Performance monitoring • QoE monitoring	• Success/Rejects rates (per service key) • Session length (per service key) • Number portability KPIs • Charging KPIs • Ringtone services • Call back application service usage • USSD service usage • Location update success/reject rates • Service continuity success rates • Success/Reject rates of reaching VAS • Rates of using home short codes successfully/ unsuccessfully • QoE MOS, DMOS, MDI,	• Regression testing when new services are introduced	• Identical to the passive parameters

(1) See IETF RFC 4594

(2) See ITU-T Recommendations G.810, G.8260, G.8273, MEF 22.1, MEF 23.1 and MEF 10.2

(3) See IEEE P802.3az

(4) See IETF RFC 2330, 3386, 3469, 4378, 3945, 4427, 4428, ITU-T Recommendations G.911, M60, M.3342, M.1301, P.10, X.641, Y.1540, Y.1541, Y.1542, Y.1561, Y.1562.

(5) See ETSI IN-CS1, IN-CS2, CAMEL (ETSI TS 123 078, 3GPP TS 29.078)

Table 3: Monitoring parameters and methods: by service/function

2.4 Survey conclusions

In this deliverable the state of the art survey was used to investigate how the different monitoring parameters and tools could support the FMC network use cases defined in WP2. This work is also important for D4.2, where an efficient performance monitoring solution for FMC networks will be defined, because that solution will be based on a selection of existing performance monitoring solutions as well as new functionality developed within the project. Part of this work is also to analyse the network scenarios that will be defined in WP3 and that are based on the use cases from WP2.

While QoE and QoS are clearly related, it is likely to be a challenge to set out a comprehensive operational QoE model given the multi-dimensional relationships between QoS parameters and user experience. From the standards review however, there are some more obvious QoS metrics which could be used to imply a given QoE for some real time services. It is proposed that QoE parameters such as those specified in ETSI [34] and ITU [35] documents as mentioned in section 2.2 are used to shape the KPIs within WP2 and to add new requirements to an FMC QoS model. These are shown below:

1. Delay budget within an FMC network architecture should be specified
2. Duration of individual error events, specified in the time domain as well as packet level. In general:
    a. Error event durations should be monitored and if exceeding a given target (e.g. ~16ms), then alarms should be generated;
    b. some targets should be explored for providing warning of trends in the duration of single error events, showing a degradation of performance which could lead to an alarm (>75% of the alarm for example)
3. Error Loss Distance
    a. should be monitored and when exceeding a given target (e.g. >1 every 4 hours), then alarms should be generated

3 Monitoring parameters overview and use cases

In this section we are reviewing the FMC use cases defined in D2.1 [1] with focus on QoS/PM aspects, and looking at emerging paradigms and the impact of scalability and complexity on QoS/PM for FMC based networks. Specific impacts on QoE will also be highlighted for FMC use cases where applicable.

3.1 Where in the network is QoS/PM placed and why

Here we take the FMC use cases from WP2 and for each of them perform top-down analysis on the various implementation options, and identify QoS/PM tools and parameters that might be used. The findings are summarised in a tabular format at the end of each section.

3.1.1 UC1 – Unified FMC access for mobile devices

UC1 proposes an enhanced FMC access network in which mobile and Wi-Fi networks are used in collaboration. In this network, mobile devices will be able to simultaneously use both Wi-Fi and mobile technologies to access to the operator's network and seamlessly move all or part of their traffic, even for the same application and session, from one access to another. Figure 2 illustrates this use case in which a UE with double attachment to both Wi-Fi and mobile networks can be seen. Additionally, a seamless handover between Wi-Fi APs as well as between Wi-Fi and mobile access technologies is shown. Finally, the network assistance for performing the access selection function is also presented and distributed between the mobile device agent and the network information and policies server.

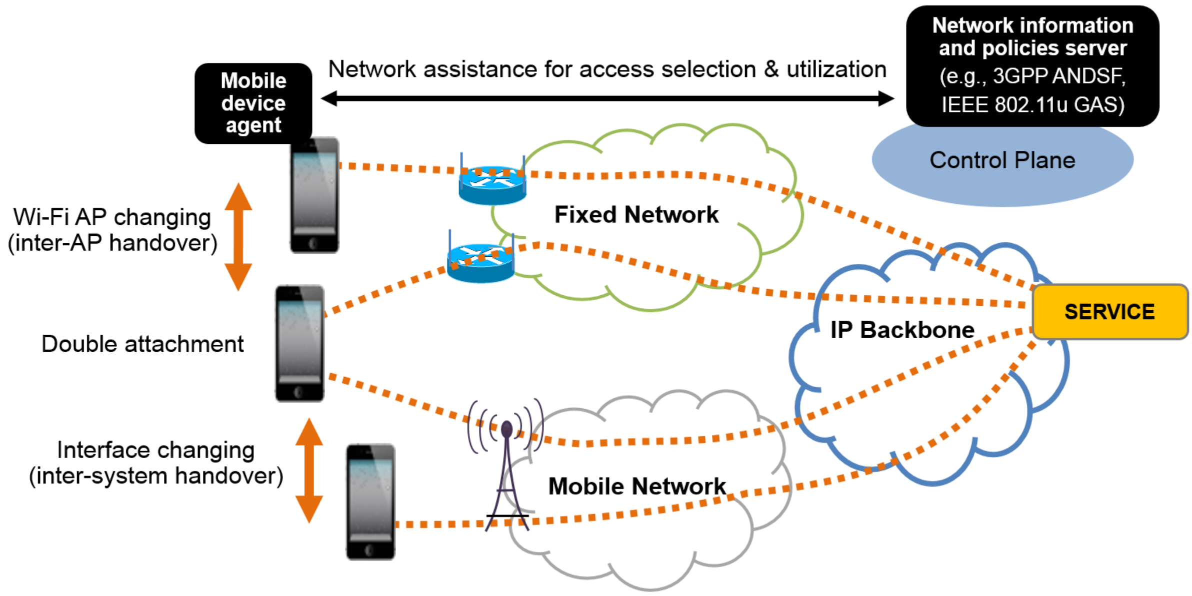

Figure 2: UC1 – Unified FMC access for mobile devices

Deliverable D3.1 [5] analyses this use case and proposes some key aspects such as a common authentication, a seamless connectivity, the connection manager, the UE capabilities, etc. and some solutions to implement them, for example: IEEE 802.11u, EAP authentication, and ANDSF from 3GPP. The D3.1 document identifies the seamless handover and double attachment as the key aspects for the use case. It also introduces a mobility manager entity in the network and multipath TCP or other approaches to resolve mobility and dual-attachment aspects, respectively. Where to locate the control entity in the network is an open issue and will be investigated in WP3.

QoS/PM aspects of UC1 are summarised in Table 4.

Function	Implications / Questions arising	PM/QoS/QoE Impact
Network discovery	• Where are the different access network available? • What is the UE consumption due to network discovery activity? • What role does the UE have in the assistance to the network discovery?	• Channel monitoring, current location, radio environment information • UE QoE and quick adaptation • Parameters transmitted to the UE for the network discovery process (e.g. visited network parameters and thresholds) and how frequently must be forwarded to the UE
Network selection	• When is it possible to use Wi-Fi and mobile? • How to assure the QoS for different services using multiple physical interfaces? • Which are the network conditions in terms of load, delay, throughput, etc.? • Which one is responsible of the selection: UE or the network? • How fast the switchover can be done? • Wi-Fi and cellular technologies have different QoS (e.g. different delays, jitter, etc.)	• Dual Wi-Fi and mobile periodic monitoring to know the network availability • Network current status, the specific needs of QoS of each service, user preferences and current policies are needed to be checked as the service could be assigned to a single interface or both, even in a dynamic way • Selection of PM parameters to be forwarded to the UE agent in case they are needed for the selection decision • QoE impact due to a high number of network reconnections (e.g. switchover between Wi-Fi and mobile interfaces in cyclic way)
Session continuity	• Intra-AP handover, inter system handover relationship with QoS/PM • How to know what the general QoS is when dual attachment is used?	• QoS/PM for multiple interfaces will be needed • QoS/PM values will be needed to be aggregated to know the current QoS at service level
Charging	• Is there an impact on charging?	• Measure time and data on each network type
Connection and mobility manager	• How to transfer a session between two access nodes? • UE agent will need to monitor all interfaces • How to enforce policies?	• QoS/PM parameters can be shared among access points or the information can be centralised • Stricter mobile and Wi-Fi monitoring of performance parameters to assure QoS and perform the appropriate switching • Enforce policies based on the UE and/or the network

Table 4: UC1 QoS/PM aspects

3.1.2 UC2 – Converged content caching for unified service delivery

UC2 refers to CDN/caching deployment, which enables a unified service delivery. Content Delivery Networks (CDNs) are based on an originating server, whose contents are distributed among a surrogate (caching) server, which in turn deliver content for the end users. In such a scenario, a rising trend for content delivery is to push the contents towards the end users, adding caching capabilities to the edge nodes or to strategic nodes of the aggregation and access networks. By distributing caching servers through customer premises, the aggregation and/or access segments of the network, operators can achieve cost savings by offloading core network traffic (e.g., inter-domain traffic is reduced). QoE is improved by e.g. lower delays. Note that, some form of caching can also apply to the Home / Small Office / Corporate network segments, but it is out of the scope of UC2. Different parameters and tools, as described in the table, can be used for Performance Monitoring, according to the different solutions in terms of number of caching nodes and their position in the aggregation and/or access network.

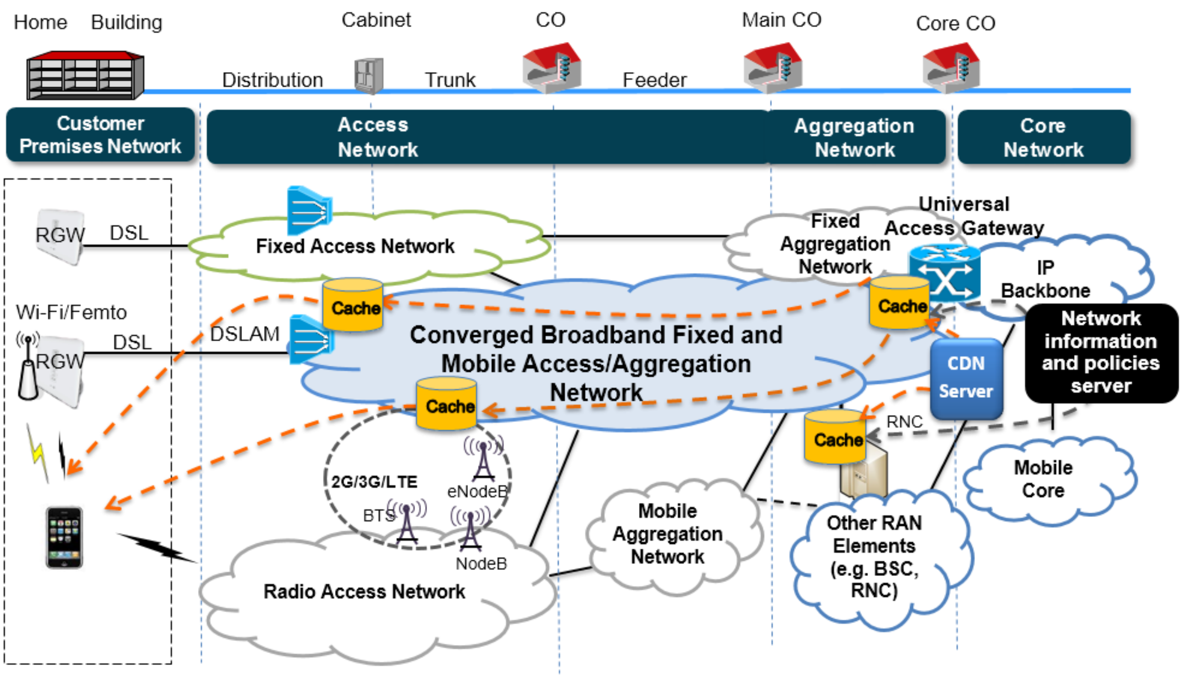

Figure 3: UC2 – Converged content caching for unified service delivery

Note that the position of caching servers plays an important role in relation to the number and typology of users, who can potentially be served by the converged caching scenario. Determining the position of caching servers in the network strongly depends on the characterization of local traffic. Placement must take into account statistical models. This can guarantee the usefulness of content replication in a specific position of the network. In Figure 3 caching servers can be found distributed across the FMC network. However, their location, as well as the Universal Access Gateway location (see UC6), are chosen as an illustration only. The final architecture of the solution must still be defined.

QoS/PM aspects of UC2, with a specific emphasis regarding FMC, are summarised in the following table.

Function	Implications / Questions arising	PM/QoS/QoE Impact
Frequently accessed contents	• Where to place the servers? How close are caches to the end users? • Can the servers be shared among the fixed and the mobile network? • Will the servers need to store multiple copies of the same content? (E.g., for different screen resolutions?) • How beneficial can convergence be in terms of cache sharing? • How much storage will be needed? • Can server capacity improve QoE (E.g., less loss, fewer bottlenecks?) • Do lower delays improve performance of on-demand media streaming?	• Measure average latency (user waiting time), i.e. delay between content request and beginning of content reception • Measure average content download time, i.e. total time to retrieve content object • Monitor core traffic and of inter-domain traffic evolution to assess whether caching allows to lower their respective amounts • Measure the hit ratio in various servers • Improved QoE through reduced content access time
Specific services/ applications	• To what kind of services/applications does caching apply to?	• Is it necessary to implement deep packet inspection in order to identify relevant applications? • Perform delay measurements per application type
Caching strategies	• What type of caching strategy should be applied (proactive vs. reactive caching) and for which applications? • What type of cache replacement policy should be implemented? • What caching technology should be implemented (e.g. collaborating caching, dedicated data servers, distributed/P2P CDN)? • How does FMC impact caching strategies?	• Monitor content-related parameters: - Cache hit ratio - Cache ageing time • Monitor network-based parameters: - Availability of bandwidth from the source to the cache and from the cache to the end-user (the latter being more critical) - Monitor average latency • Monitor average content download time

Table 5: UC2 QoS/PM aspects

3.1.3 UC3 – Reuse of infrastructure for small cell deployments

When considering deployment of small cells, one must also plan for the backhaul connectivity for these small cells. The backhaul connections can be either wired (based on copper or fibre) or wireless.

Considering indoor small cell deployment, residential and business buildings often have existing fixed/wired copper and/or fibre infrastructure that can be reused to provide backhaul connectivity. Thus, as illustrated in Figure 4, this use case highlights the opportunities to reuse that infrastructure in order to reduce costs and deployment time for cost-sensitive small cells. The small cells can be e.g. pico Base Stations (pBSs) with integrated Base Band Units (BBUs), or Remote Radio Units

(RRUs) with centralised BBUs; in the latter case, CPRI is an implementation option (this will be handled in further detail in upcoming deliverables). In residential buildings, the pBS is located inside or next to the Residential Gateway (RGW) to apply mobile coverage in the home network. The backhaul will be dominated by the available fixed access technology, like VDSL2, G.fast, base-T or PON. In many aspects, the physical small cell's backhaul connection will determine the possible level of radio coordination and if architectures such as centralized Radio Access Networks (RAN) are possible.

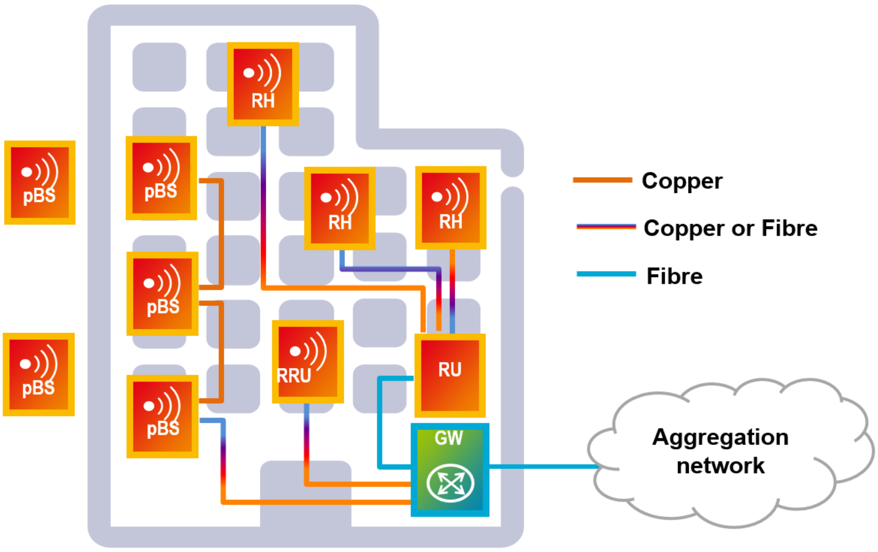

Figure 4: UC3 – Reuse of infrastructure for small cell deployments

The performance monitoring and QoS aspects of this use case are summarised in Table 6.

Function	Implications / Questions arising	PM/QoS/QoE Impact
Media and connection impact on QoS	• What is the QoS impact on services used by mobile subscribers when different types of media (copper, fibre, or wireless) and different types of connections (backhaul or fronthaul) are used? • What is the minimum achievable bit rate, delay and delay variation per type of connection? • How to achieve a consistent level of synchronisation over the different types of connections?	• Measure the average bit rate, delay and delay variation in the different media and types of connections. • Measure the average packet delay & delay variation in the different types of connections.
Service delivery	• How stable will the mobile connection be?	• For sensitive services monitoring of transmission errors, packet loss and delay variations. • QoE is dependent on cell coverage and handover
Traffic load adaptation	• How to adapt active cells to the required traffic load? • What is the quality of the backhaul to the next aggregation point?	• Available data rate and delay on the line • Obtain details on the transmission channel, by e.g. TDR for copper.

Table 6: UC3 QoS/PM aspects

3.1.4 UC4 – Universal access bundling for residential gateway

In UC4, the point of convergence between fixed and mobile access is located in the RGW in combination with a hybrid connection gateway (HCG). The RGW is thus called a converged residential gateway (CRGW). The objective is to dynamically manage and fulfil the user service demands.

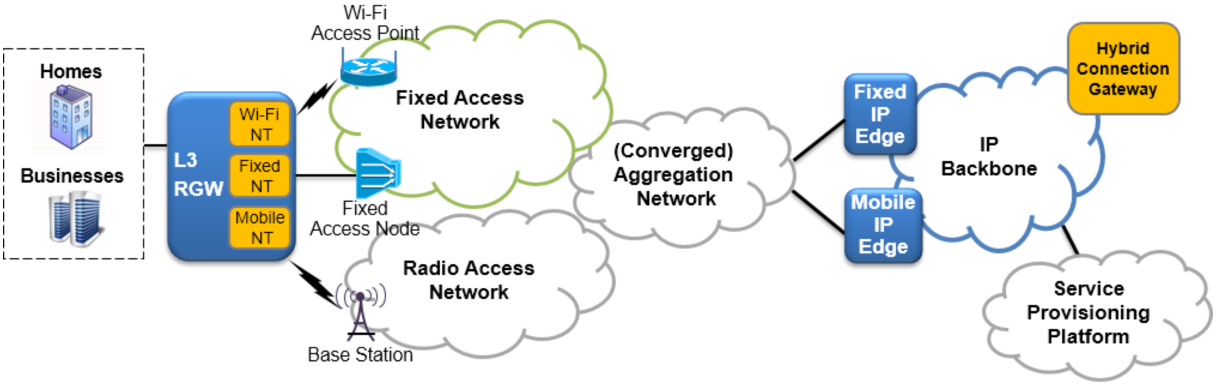

Figure 5: UC4 – Universal access bundling for residential gateway

All traffic to and from the RGW is tunnelled over three main routes: the fixed access, a nearby Wi-Fi AP and the mobile network, according to a specified prioritisation, see Figure 5. The tunnelling can be obtained by e.g. MPLS, IP over IP or multipath TCP. The HCG acts as the tunnel termination point in the network for all three paths. On the other side of the tunnelling, the RGW orders the packets in the flows. The fixed network will often be the preferred path as it is generally more stable. In the case of residential customers, using Wi-Fi access means that neighbours share a portion of their access capacity to even out individual traffic peaks – which are assumed to be only lightly correlated. The HCG should also coordinate the handover between networks on the outside as users enter or leave the local network. For a converged aggregation network, the natural position of the HCG is in the aggregation region. If, on the other hand, the access links are connected to different aggregation networks the HCG can either be moved higher up in the network or individual HCGs be interconnected by tunnelling.

From a performance management perspective, the connectivity and QoS parameters for the three tunnelling paths need to be monitored. The preferred packet routes are then decided by the HCG according to SLA or connectivity demands. More specifically the parameters needed are listed in Table 7.

Use Case Consideration	Implications / Questions arising	QoS/PM Impact
Connectivity demands	• What type of services and what are the QoS requirements? • What are the available connectivity links for the different paths?	• For each tunnel path, monitor - Configured capacity - Available capacity - Delay/delay variation - Packet loss
Resilience	• What is required in relation to the SLAs?	• Monitor the availability of each tunnel • Level of resilience affects QoE
Packet ordering in tunnel termination points	• What are the delay differences and delay variations in the paths?	• For each tunnel path - Delay (two-way) - Delay variation

Table 7: UC4 QoS/PM aspects

3.1.5 UC5 – Support for large traffic variations between public, residential, and business areas

This use case, UC5, relates to network infrastructure convergence by sharing the resources of the aggregation network for mobile, residential and business users. Focus is on the need to handle large variations in traffic demand at different times of the day and week.

As shown in Figure 6, during business hours and during the working days of the week, demand for example on mobile networks may be geographically concentrated around industrial zones or large cities, while mobile networks in rural areas may be less loaded. However, in the evening, or during weekends, when workforce and commuters return home, the demand on mobile network resources changes and the residential/rural areas become more congested while the resources in the business zones become less loaded. One key implication of this use case is that some RRUs will be put into sleep mode. In a geographic region where RRUs can be placed into a sleep mode, at least one RRU will need to remain online so that new users can be detected, and to allow the flexible restoration of service and the graceful bring up of RRUs from sleep mode.

In addition to structural convergence, in order to transport the mix of traffic including mobile and fixed line as well as supporting a centralized RAN model, some protocol convergence is also a possibility. Thus the impact of transporting IP based services from fixed line users across a fronthaul/CPRI based topology or vice versa, will need to be considered from a QoS/PM perspective. Figure 7 summarizes this situation.

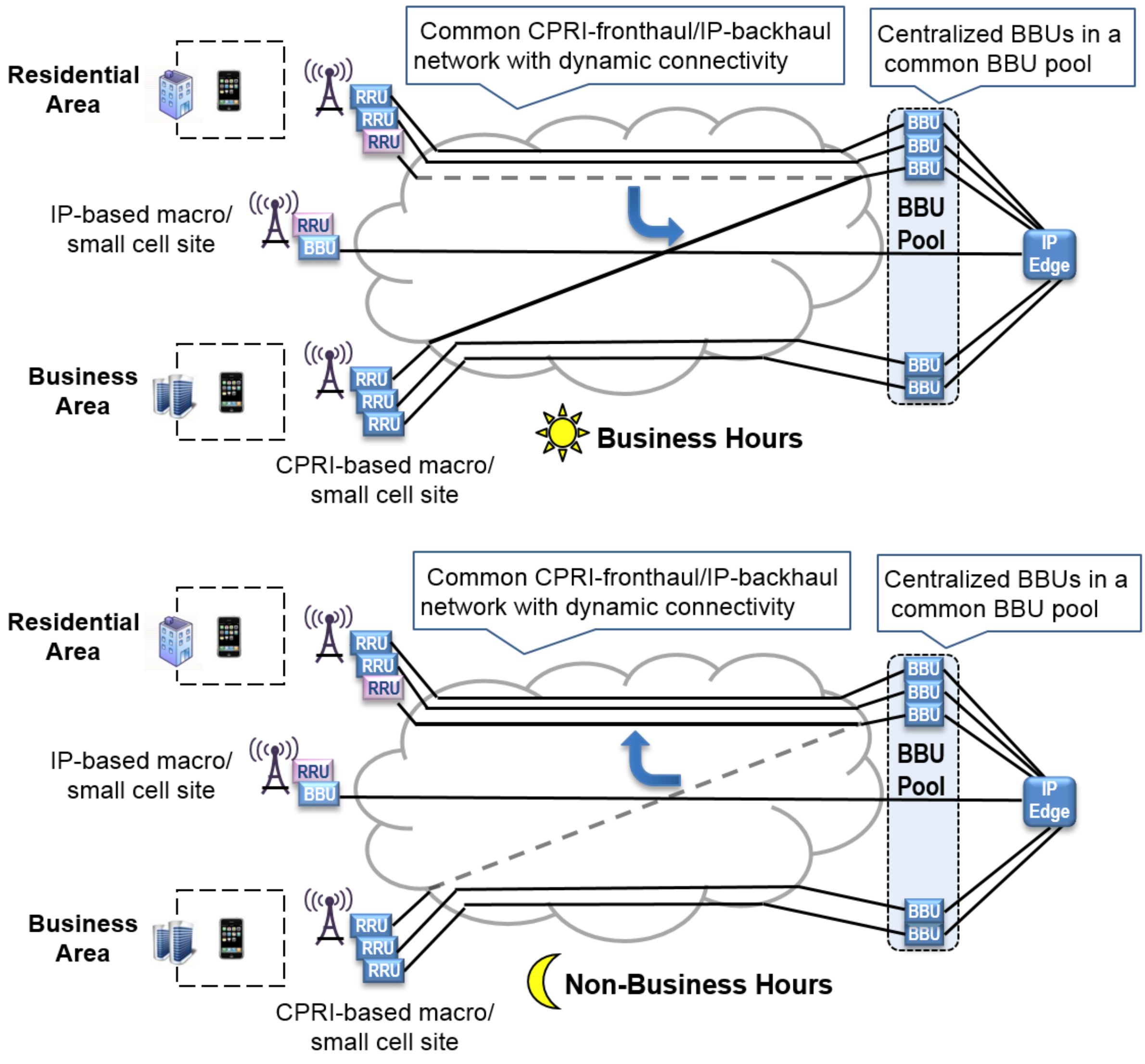

Figure 6: UC5 – Dynamic resource reallocation at business and non-business hours

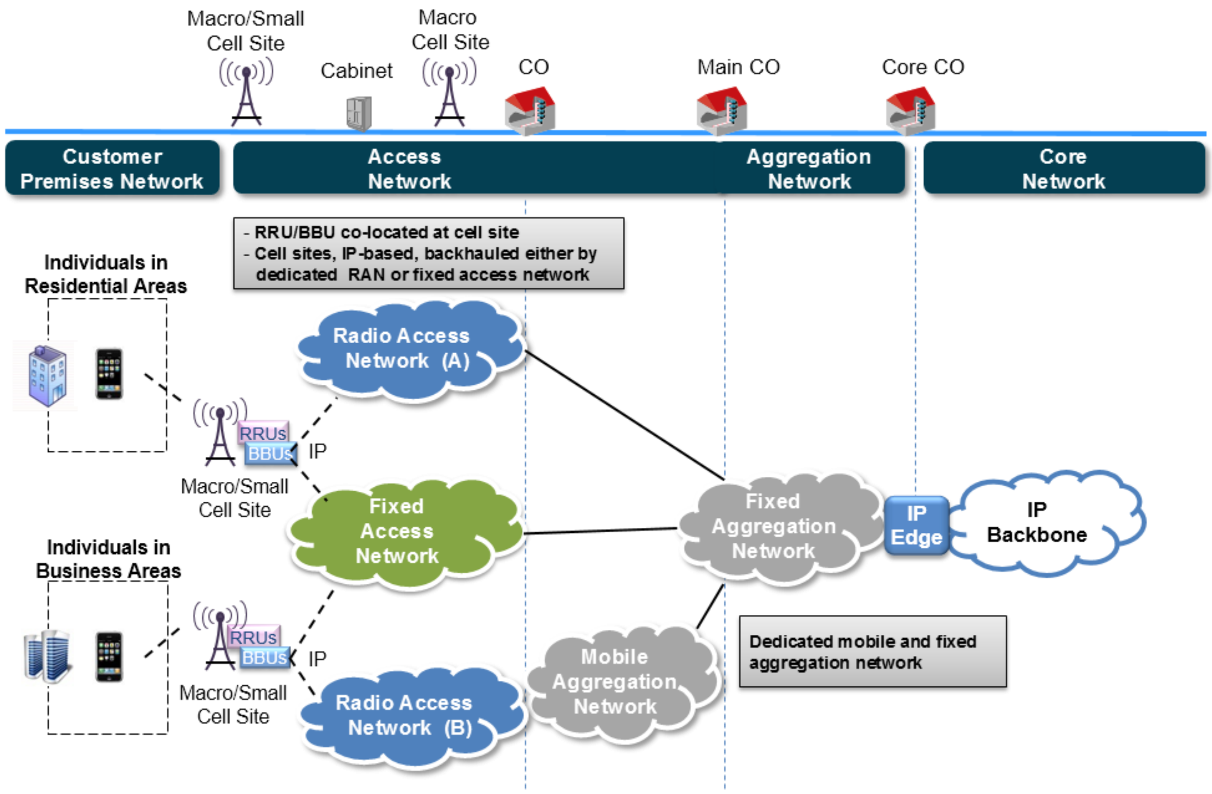

Figure 7: UC5 – Support for large traffic variations between public, residential, and business areas

Additionally, due to the selective switch-off in areas with temporarily decreased traffic, the power consumption is decreased; however, the QoS and availability will likely deteriorate. Therefore, QoS/PM should cater for monitoring the anticipated impact. The QoS/PM aspects of this use case are summarised below.

Function	Implications / Questions arising	PM/QoS/QoE Impact
Identify which cells to put into sleep mode	• From an OpEx saving point of view, is it preferable to put into sleep mode high power macro BSs with large coverage or low power pico BSs with small coverage? Or should a selected combination of pico and macro BSs be put into sleep mode?	• Measure the traffic volume that needs to be supported and choose which nodes to put into sleep mode, for optimal OpEx savings while maintaining the requested QoS. • Transition to sleep mode will have an impact on QoE
Dynamic allocation of resources	• Does it mean turning on/off e.g. specific radio access nodes? • How are automated tasks (e.g. software updates) affected?	• Measure time to bring back resources online • Dynamic resource reallocation affects QoE

Function	Implications / Questions arising	PM/QoS/QoE Impact
Virtualization	• What BBU functionalities can be virtualised? • How fast switchover / reconfiguration can be done?	• Monitor VM resources in BBU Pool – and for example raise warnings when certain percentage of BBUs in use • Measure and report on switchover times
Monitoring	• Which control channels to monitor and how - S1? • Requested load/bandwidth • Number of users • Time of the day/week/month • Energy • Manual reconfiguration • Automatic Reconfiguration • Delay across aggregation/switch devices • Delay variation introduced per device	• Time based statistics and binning/collection • Monitor power monitoring at base-stations, power at aggregation switches, power at server rooms etc. • Monitor time taken to switch • Monitor time taken to detect reason to switch, then time to switch? • Delay/latency and PDV monitoring •
Protocol Convergence	• How to measure QoS and identify faults? Monitor CPRI? • L2/L3 over CPRI/Fronthaul • CPRI/Fronthaul over L2/3 or alternative	• Check that the BER of either service is not impacted • Impact on delay profile of CPRI traffic • Delay, jitter and frequency accuracy performances compatible with 3GPP protocols constraints (e.g. HARQ_LTE).
Port operating modes	• Interface utilisation at edge and at aggregation nodes •	• Monitor percentage of utilisation of interfaces • Monitor number of active interfaces vs. sleep interfaces and report.

Table 8: UC5 QoS/PM aspects

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

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

Mobile packet core functionality can be moved into the UAG. In this sense, the UAG could potentially include SGW and PGW as well as fixed, mobile and Wi-Fi IP edge functionalities or co-ordination instances from the mobile core as described in UC1, UC2 and UC4.

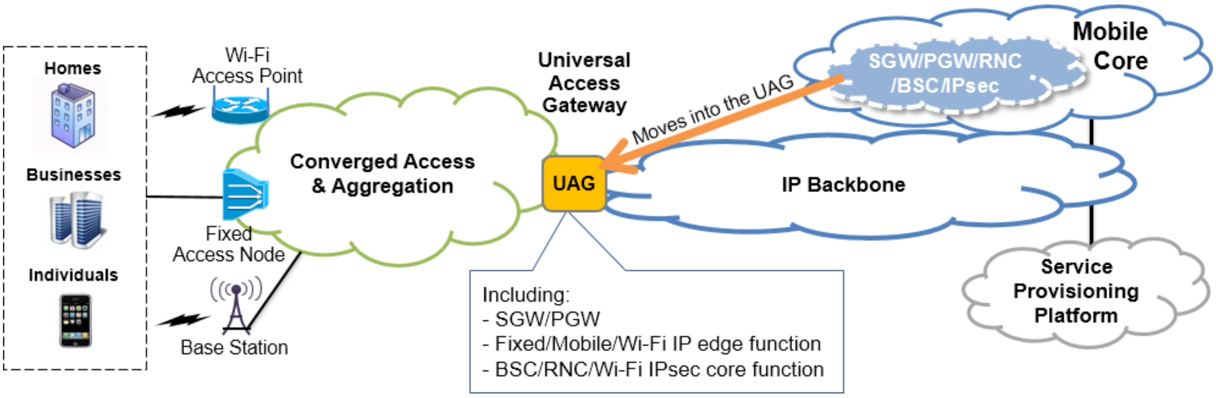

Figure 8: UC6 – Convergence of fixed, mobile and Wi-Fi gateway functionalities

The principle architecture should support radio coordination features such as CoMP. Additionally, the UAG could comprise further functionality such as the BBU hoteling function for example, as detailed in D2.2 [2].

The impact of the functional distribution on scalability and performance must be evaluated in COMBO, especially, the impact on the latency behaviour. The performance monitoring and QoS aspects of this use case are summarised in the table below:

Function	Implications / Questions arising	PM/QoS/QoE Impact
Monitoring	• What is the impact of the functional distribution on scalability and performance?	• Throughput, delay, packet delay variation and packet loss monitoring
Reach	• Can we reach the distance specified?	• Optical power budget
Traffic mix	• What is the proportion of the mobile vs. fixed line traffic?	• Deep packet inspection

Table 9: UC6 QoS/PM aspects

3.1.7 UC7 – Converged access and aggregation technology supporting fixed and mobile broadband services

UC7 aims at specifying a converged access and aggregation network based on a single universal technology (see Figure 9). This could be done by using for example TDM/TDMA technology for mass-market access such as a typical FTTH deployment and over the same network enable backhaul (e.g. DSLAM, Mobile) and future WDM overlay services for fronthaul (or other very demanding services beyond 1Gb/s). The converged access and aggregation network should be able to support all different services aimed for residential, business and mobile backhauling.

To have the same network technology requires to be possible to handle high data rates with a low delay and low delay variation. This points in the direction of an all-optical infrastructure. The high demands of this structure mean, for a general roll out, that it is some years in the future. In 2017 it is expected that 80-90% of all consumer traffic consist of video and other streaming media [6].

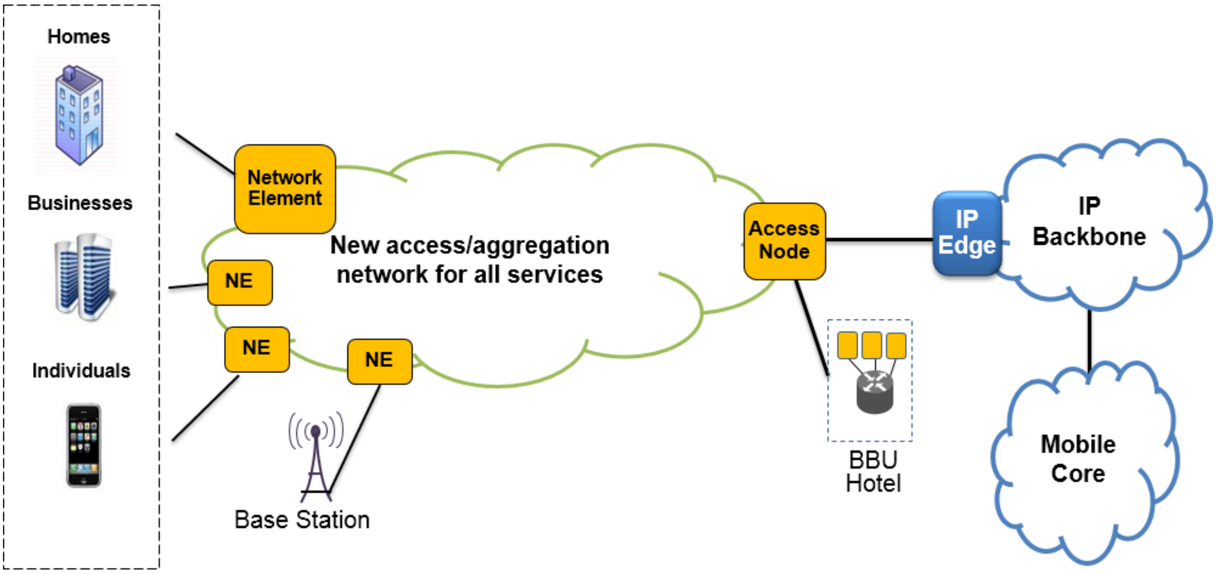

Figure 9: UC7 – Converged access and aggregation technology supporting fixed and mobile broadband services

Hence, to ensure the quality of both IPTV and OTT delivery, parameters on all layers related to QoE must be monitored regularly. IPTV and OTT demand high QoS mainly downstream. Even so, upstream QoS requirements are important for other services, such as cloud access or backup, and should not be neglected. Another demanding service on such networks is the mobile fronthaul. Here, data rate, delay and delay variation are crucial for CPRI, which demands both a very high data rate of minimum 614 Mb/s per line in each direction and a low round trip delay. There are also specific requirements for the X2 interface in the mobile network for handling mobile device handover between eNodeBs.

Typical parameters that should be monitored and implications and questions arising for this use case are given in Table 10.

Function	Implications / Questions arising	PM/QoS/QoE Impact
Support of video services	• What parameters are relevant for QoE for IPTV, OTT, video conference and VoD services?	• To keep high level of QoE through SLA • Monitor end to end path for e.g. data rate, delay variation and packet loss is needed for all services • Monitor latency for real time video services.
Services based on IP best-effort transport	• What parameters are relevant in addition to the ones for downstream delivery?	• Similar monitoring needs as for video services including upstream monitoring.
Support of LTE	• What are the requirements for CPRI, OBSAI and X2?	• To transmit the radio signals digitally it is required to have good knowledge of data rate, delay and delay variation. Further, the X2 protocol has requirements on the round trip delay.

Table 10: UC7 QoS/PM aspects

3.1.8 UC8 – Network sharing

UC8 proposes a multi-operator environment where competing operators can cooperate and share their network resources, such as antenna sites, radio resources, backhaul connectivity, etc., in order to use the resources more efficiently and obtain additional savings in an FMC network scenario. This can be considered analogous to code sharing flights in the aviation business, where sharing a single plane full of passengers is beneficial to operating two planes of two companies on the same route, both with few passengers. When a network failure arises, it should be possible to guarantee a premium service to one or more operators, depending on the subscribed SLA from the Wholesale Network Company as a provider.

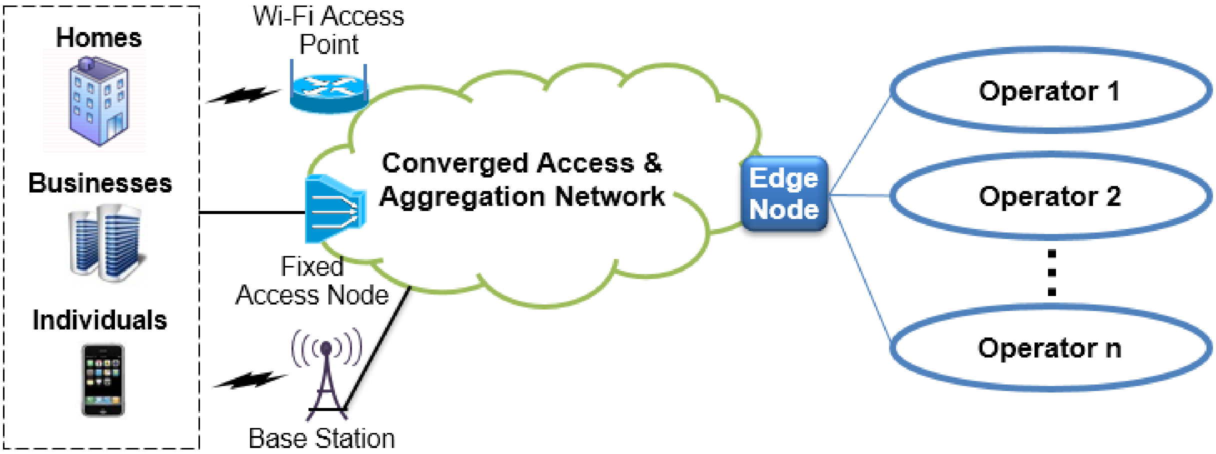

Figure 10: UC8 – Network sharing

Function	Implications / Questions arising	PM/QoS/QoE Impact
Monitoring	• Fair use of the low level monitoring information	• Only PM information related to the specific shared resource will be available to operators
	• Visibility of PM data	• Each operator shall see only its own PM data. The network resource operator could see all operators' PM data
	• Sensitive PM data	• Sensitive shared PM data will need to be handled with confidentiality
	• Efficient PM	• The wholesale company is the one to monitor the use of the network resources such that each operator gets resources according to its SLA. Each operator can in turn monitor that the resources it is getting are in line with its SLA.
	• Typical PM parameters and areas to monitor in a shared resource	• Throughput, delay, jitter, packet loss, availability, reliability and usage monitoring. Parameters will depend on the specific resource to monitor.

Table 11: UC8 QoS/PM aspects

Figure 10 illustrates how different operators can, for example, share a single network deployed by a third-party network company. It highlights the physical network provider as one of the main actors where QoS/PM needs to be considered. The physical network provider will also be a key actor for the physical performance monitoring. Operators also have the possibility to supervise the shared network resources by themselves, but at Layer 2 or higher. Deliverable D3.1 [5] identifies some possible solutions for network sharing, such as network virtualization and SDN mechanisms.

The performance monitoring and QoS aspects of UC8 are summarised in Table 11.

3.2 Scalability and Complexity: Centralisation/Decentralisation of QoS/PM

The monitoring tasks in some of the above described use cases are initiated individually, but in most situations monitoring should be performed regularly. Furthermore, the location of the monitoring equipment or measurement points differs for the individual parameters. In order to design a performance management solution that is efficient and scalable it is key to understand the trade-off between centralized and decentralised monitoring agents and how these affect the overall complexity. This section includes a discussion on Simple Network Management Protocol (SNMP),which is the most common protocol for reading and writing network parameters, and elaborates on monitoring scalability, complexity and centralization/decentralization. These are all factors that need to be considered in the monitoring analysis of the proposed FMC network architectures in D4.2 but also for the performance optimization studied in task T4.2.

In an FMC scenario the natural monitoring points in the network are shifted, as governed by the modified network architecture. The question of function virtualisation and software defined networking is discussed in more detail in section 3.3.

3.2.1 Performance monitoring by SNMP

In a network, many of the monitored parameters can be read remotely over a private management network using SNMP, which is a protocol for remote management of network elements. Currently the protocol is in its third version (SNMPv3) that is described by RFC 3411–RFC 3418 and also known as STD 62 [12]. This protocol makes it possible for the network provider to centralise the monitoring of the network entities and to collect the data at a central node.

SNMP itself does not define which information (which variables) a managed system should offer. Rather, SNMP uses an extensible design, where the available information is defined by MIBs (Management Information Bases), a virtual database used for managing the entities in a communications network. The MIB describes the structure of the management data of a device subsystem by using a hierarchical namespace containing Object Identifiers (OIDs) where each identifies a variable that can be read or set via SNMP. Carrier grade hardware usually offers SNMP as one of the available options to manage the deployed network elements. An application would be in charge of managing the different elements of the network by connecting to them through SNMP and performing different operations.

3.2.2 Scalability and complexity

Measurement of QoS and QoE parameters has always been a challenge, but the introduction of new use cases and emergence of FMC architectures are likely to compound this problem. Regular measurement of performance parameters may not be scalable for large networks. For most networks, capacity is not the problem since inband control data requires low bandwidth. Since reading and delivering a parameter (e.g. by SNMP) requires a small amount of network resources, there is a limit on the number of parameters that can be read from any single node. Therefore, large networks, e.g. metro or even national networks, cannot have a completely centralised monitoring. Instead, the monitoring system must collect local data for restricted parts of the network, using distributed monitoring nodes or agents. The data can then be collected in a centralised database.

There is also a difference in the complexity of the monitoring equipment. For many parameters read from physical layer (e.g. available capacity or error rates), the data is stored in remote equipment as MIB data, e.g. counters. Reading these requires only an SNMP/Get bulk call to the monitoring equipment. This can also apply for higher layers' passive parameters. In general, passively monitored parameters require little computational effort. There are, however, more demanding monitoring methods, such as deep packet inspection, which may be considered as necessary for implementing caching in CDN or energy aware networks. These can be even more complicated when a stream or a flow carries encrypted data. Active monitoring such as TDR or ICMP echo also increases the complexity of the system. The main consideration with such methods is normally that they might affect real traffic on the links. In some cases, like TDR, the end equipment must interrupt the normal traffic streams during the measurements.

3.2.3 Centralisation/decentralisation

Traditionally performance monitoring has often been controlled by a centralized management system. All monitored network parameters will then be available in one common location and thus a lot of information is available for making centralized decisions. The data can also easily be displayed in an Operations Support System (OSS) Graphical User Interface (GUI). A problem with centralizing all of the monitoring is however that the complexity of the task grows with the number of monitored nodes.

Depending on the purpose of monitoring, data can also be stored in decentralised nodes. In large networks it may be useful to decentralize the management and evaluation tools in order simplify analysis of specific parts of the network. These decentralized management agents should preferably have Self Organizing Network (SON) capabilities to minimize the need for human intervention and thus the Operating Expenditure (OpEx).

In order to get an overview of the complete network, a centralised management node can collect pre-processed, higher-level data from the decentralised nodes. Thus, for large FMC networks it is foreseen that performance monitoring will be a combination of centralized management and decentralized management agents.

3.3 Impact of emerging paradigms, such as Cloud Computing, SDN and NFV on QoS/PM

This section explores the impact of new technologies in relation to QoS/PM. The analysis performed earlier and the survey from Milestone MS17 is useful for looking at existing use tools/parameters, but new concepts such as cloud computing, software defined networking, and network function virtualization may cause some new requirements or changes to the current best practice.

These emerging paradigms' impact on convergence is considered in WP3 Deliverable D3.1 as these emerging paradigms can be used in the network scenarios design. Likewise, within WP4 they are explored with emphasis on the implications of QoS/PM.

3.3.1 Cloud Computing

Cloud services can be categorized into specific use cases, including services such as Infrastructure as a Service (Iaas), Platform as a Service (PaaS) and Software as a Service (SaaS). In these cases, users run their software applications or business packages on remote servers and store their data in data centres, which are likely to support multiple different customers/users using the same infrastructure. Instead of the users running their platforms and applications locally, they use a thin client to access and modify their data using cloud services. For a more in-depth discussion on the actual impact of cloud services please see D3.1 [5]. For the purposes of the present deliverable, we can consider the characteristics of cloud services more generally.

The standardization of cloud services by groups such as NIST (in the USA) [7] and ITU [8] all address elasticity. Cloud services are assumed to be used in an on-demand model, where a path to the service is provisioned or scaled up when needed, and scaled back down or taken down when the service is no longer needed.

Such paths to the service may need to support dynamic bandwidth provisioning, adaptive quality of service SLAs and different levels of performance monitoring. This differs from existing services such as VPNs, which also rely on elasticity being provided by the network operator. Dimensioning is currently performed thanks to efficient traffic monitoring, and equivalent bandwidth schemes.

The implications of Cloud Computing therefore on QoS/PM could include in the first instance:

1. The need of a newer definition for QoS/PM suitable for elastic services, whose requirements can change over time. An inelastic definition of the SLA would result in underprovisioning or overprovisioning, which are unsuitable or inefficient.
2. The impact of IaaS, PaaS and SaaS on the end user service performance. In particular, security is affected, because the user data shares the same infrastructure with other users. Application response latency is also affected, because the application is running remotely.

3.3.2 SDN

Software Defined Networking (SDN) is currently under discussion in several standardisation bodies and a precise definition is still missing, because of different opinions within the industry. In simple terms, one could say that SDN relates to splitting the control plane from the data plane, and implementing part of the control plane outside of the equipment in charge of the data plane.

Several of SDN aspects are relevant for the COMBO project. First of all, the definition of a “southbound” API relying on the OpenFlow protocol [9], which allows the forwarding infrastructure to be controlled by an external intelligence source. The forwarding databases and look-up tables in switches and routers can in theory be de-layered and controlled by the OpenFlow Controller and modified to configure specific paths for different flow types.

Another notable characteristic of SDN is the ability of partitioning the network infrastructure into slices that can be used by different customers or groups of users. The following are a few issues with SDN that are relevant to COMBO.

1. The need for new APIs for instantiating SDN-controlled QoS/PM tools and for monitoring SDN controlled nodes.
2. The need for a new QoS/PM model that deals with network slicing. In particular, for defining which resources would be shared among slices and which should be instantiated per-slice. Note that this aspect is also related to the cloud service discussion about elastic SLA support.
3. If SDN enabled networks rely on a centralised controller, then the performance of the channel, the access and the response of the controller will affect the entire

network – it is highly likely that the channels to the controller will be a key performance indicator within the network being monitored. WP4 is collaborating with WP2 and WP3 for feeding requirements back in order to formulate the KPIs and network scenarios.

3.3.3 NFV

Network Function Virtualisation – just like Cloud Computing – is a hot topic in industry debate and discussions. It is driven primarily by the operator community, which wishes to implement network functions on generic servers and not on specific equipment, as is generally the case in telecom networks. The generic servers could also be implemented in data centers. NFV is expected to help in reducing cost, complexity, energy consumption and OpEx, and to promote better interoperability. The ETSI standards organisation currently has an active NFV group comprising operators and vendors [11].

The characteristics of NFV can be summarised as:

1. Virtualisation eliminates dependency between a network function and its hardware. NFV takes functions from existing devices in the network, realizes them in software, and then migrates them to be hosted in alternative (centralised) locations.
2. Discrete Virtual Network Functions such as the list below are likely to be implemented in virtual machines that are hosted in data centre servers: Network Address Translation, Authentication, IPSec, Firewalls and Cache facilities.
3. Some functions are no longer performed in the place where they once were – functions become mobile.

Moreover, some functions within the network will not be virtualised, because they are either hardware-bound or needs to be optimised for performance. Examples of such features are media and/or rate conversion of physical interfaces (such as optical to electrical and 1 Gbit/s to 10 Gbit/s interfaces), aggregation of lower port into higher ports, modulation schemes that rely on physical signals, synchronization needing oscillators and critical time devices. Hardware-bound performance monitoring tools related to these areas can be virtualised only to some extent, since they are tightly linked to the physical media or the physical instance.

From an analysis of how NFV might affect the QoS/PM model, two points emerge: the concept that QoS/PM can be virtualised itself, and how to measure the QoS/PM of a virtualised system (measurement of host servers and of virtual servers).

As far as QoS/PM virtualisation is concerned, there may be a need for specific QoS/PM based Virtual Networking Functions that are implemented in Virtual Machines (VMs). Otherwise, all VMs supporting the functions mentioned above will need to contain an element of QoS/PM – both models may be present. Depending on the implementation model and the way VMs are chained together, they may have differing levels of visibility of the whole service, path or network – i.e., their view of the world might be limited.

As for measuring QoS/PM of a virtualised system, NFV requirements include mechanisms to support QoS metrics and ensure that these metrics are met for the service level agreement [11]. If the NFV migrates network functions to a centralised location, then it is likely that those centralised locations become the critical place which need to be monitored for QoS/PM. This may allow simplification of devices that remain physically present, and perhaps put more emphasis in these locations on passive rather than active monitoring.

VMs need to be turned on, managed, and they become something to be monitored since they directly affect the QoS and QoE. These tasks include:

- Monitor how fast VMs are spun up and brought online
- Manage the detection of failed VMs and dynamic instantiation or relocation of replacements (current implementations of large data centres are already designed this way)
- Measure the latency impact of implementing function in VMs
- Monitor VM resources: server capacity and current resource levels; support warning thresholds, etc.

It will be interesting to monitor VM resources and the impact on the environment such as energy consumption per VM or to at least understand the contribution of a pool of VMs. It will be necessary to somehow monitor the environment and correlate that with the VM resources used.

3.4 Summary of Performance Monitoring and use case analysis

All use cases defined by WP2 have been analysed from a performance monitoring point of view and specific monitoring implications have been highlighted as well as specific impacts on monitoring, QoS and QoE. In D4.2 the network scenarios will be analysed from and since the network scenarios build on the use cases the analysis in this document will be uses as a basis for the work in that deliverable. When defining monitoring for those network scenario it is also important to consider the scalability/complexity and decentralization/centralization trade-offs as discussed in this section.

Finally the monitoring impact of emerging technologies have been discussed and some specific monitoring tasks have been highlighted that are foreseen to be important for those technologies.

4 Mapping from KPIs to QoS/PM and QoE

So far we considered the QoS/PM aspects of current networks and functions, use cases from WP2, scalability, complexity and the impact of emerging technologies. We now aim to consider further input from WP2 in the form of key performance indicators related to QoS and PM for FMC networks; this input is part of D2.4 [3]. It should be noted that just a preliminary list of KPIs were available when this deliverable was written. The idea is that this analysis should be used as a starting point to the work in D4.2 where a complete list of KPIs from WP2 will be available.

This is still true for the second version of this deliverable where the KPI mapping has not been updated since that will be handled in D4.2. This means that for the second version of D4.1 the KPIs in the table will not be the same list of KPIs as for the updated WP2 deliverables. The mapping between KPIs, measurement points, use cases and QoS/PM tools will however still give valuable input when working with the updated KPIs in D4.2.

The aim of this section is to identify relationships between KPIs and use cases, and to eventually map and identify the likely QoS/PM tools and/or methods that will be needed to meet the KPIs. When preparing this table, we started from section 2 of this document. The table below captures these relationships and where needed highlights potential gaps in the toolsets currently available.

KPI	Measurement point	Use Case relationship	QoS/PM Tool/Method
Network availability	Access node	UC1, UC2, UC3, UC4, UC5	1) Layer 1 a) Optical: LOS, BER, PMD, CD, OTDR, SNR b) Copper: SNR, Monitor Code violations c) Radio – uWave/Wi-Fi: SNR, Available BW, Modulation index where applicable d) BASE-T Electrical: Link status, PMA RXSTATUS indication SNR e) General – loopback testing 2) Protocol Layers are device dependant a) Loopback capability at different layers b) Frame Error rate
Terminal equipment availability	Terminal Equipment	UC1, UC4	3) Physical layer loopbacks on devices can be used to check physical layer availability 4) Device forwarding capability/correct configuration a) Layer 2: IEEE 802.1ag – CFM, ITU-T Y.1731 b) Layer 2.5: BFD c) Layer 3: BFD, ICMP Echo Request (ping)
Device set-up time	Terminal Equipment		***Gap candidate*** *– How to monitor device set-up time, in a standard, well defined way* Could this be based on Intelligent Networks/Value Added Services – Success/Reject times etc. – (See table 3)
Service set-up time	Service probes	UC1, UC4	5) Intelligent Networks/Value Added Services (See table 3) ***Gap candidate*** *– Useful to explore Service set-up time Methods in future activity*
Connection set-up time	Access node	UC1, UC4	6) Intelligent Networks/Value Added Services (See table 3) ***Gap candidate*** *– Useful to explore Connection set-up time Methods in future activity*

KPI	Measurement point	Use Case relationship	QoS/PM Tool/Method
Transmission rate/ bandwidth	Terminal Equipment, network probe	UC1, UC2, UC3, UC4, UC5, UC6	7) Physical layer – port rate reporting a) Measured Bit rate 8) Packet/Forwarding a) Y.1731 throughput testing, Y.1564 stepped bandwidth tests b) RFC 2544 c) Traffic Management – Policing/Shaping profiles vs. measured d) RMON, SMON at Layer 2 and 3 using packet counters and derived frame rates etc.
Delay	Terminal Equipment	UC1, UC2, UC3, UC4, UC5, UC6, UC7, UC8	9) Protocol Layers a) Layer 2 – ITU-T Y.1731 b) Layer 3 - TWAMP 10) QoE Related a) Mapping from QoS to QoE or do we need other QoE tools
Jitter	Terminal Equipment	UC1, UC2, UC3, UC4, UC5, UC6, UC7, UC8	11) Physical layer monitoring a) Jitter monitoring is likely a gap at least in real-time physical signal integrity b) Do we really need it? 12) Packet Jitter – Packet Delay Variation a) ITU-T Y.1731 b) PDV Estimation using IEEE 1588
Bit error rate	Terminal Equipment	UC1, UC2, UC3, UC4, UC5. UC7	13) Physical layer methods a) See table 1 14) Protocol layer methods a) Use RMON and Packet metrics to derive BER from Frame Error Rate
Packet loss rate	Terminal Equipment	UC1, UC2, UC3, UC4, UC6, UC8	15) RMON, SMON, ITU-T Y.1731
Connection loss rate	Terminal Equipment, network nodes	UC1, UC2, UC3, UC4	16) For typical connections this may be a ***gap candidate*** a) Or can this be monitored i.e. by a BRAS/BNG – counting the number of lost PPPoE/DHCP sessions – either way not captured in Section 2, so could be a gap
Service availability	Terminal Equipment, network nodes	UC1, UC2, UC3, UC4, UC5, UC6	17) Monitor protection switching events and response times (see table 3) 18) Monitoring of parameters such as MTBF, MTTF, MTTR etc.

Table 12: Mapping of KPIs, to Use Cases and QoS/PM Tools

In most cases, QoS methods and parameters are readily available to support the use cases and the KPIs. The key tools which are likely to be needed are shown in the table above. However, there are some cases where the KPIs and use cases do not easily relate to a given QoS tool or the parameters associated with those tools. In addition, during the preparation of this deliverable, the emerging technology analysis has highlighted some possible KPIs that could apply in future in relation to cloud, SDN and NFV. Such cases are identified as gaps and explored in further depth below:

1. Set-up time of devices, services and connections
   a. In the QoS tools survey considered in section 2, no tool seems to be relevant for monitoring these particular KPIs
   b. Perhaps the most relevant set of QoS/PM tools may be related to those tools identified in relation to Intelligent networks and value added services in section 2, table 3
   c. It could be considered that these set-up times are more akin to connections involving mobile devices and therefore perhaps some methods may be explored from the 3GPP suite of specifications – and brought into the FMC tool set for such monitoring in FMC networks
2. Connection loss rate
   a. This KPI may be something that a BRAS or BNG typically supports by default – however no such tools was identified in the survey we performed or during the analysis of use cases from WP2. We assume that the mechanisms for monitoring lost connections may be done in implementation specific ways – therefore some common and agreed methods need to be identified.
   b. 3GPP specifications are good candidates to identify the suitable tools to support this – since such a KPI seems to be related to mobile connection loss rate
3. KPIs possibly emerging from WP4 that could be fed back to WP2
   a. Cloud Services
      i. If the service is elastic, can the QoS/PM support scale up and down in sympathy with the service – is there a view that the KPIs might themselves be elastic
      ii. KPIs relating to security aspects i.e. number of failed authentication attempts or similar should be considered
      iii. Application layer delay/latency – more QoE associated than network or packet associated perhaps delay KPI needs to be further refined or split into categories
   b. SDN
      i. KPIs may be needed which are associated with availability, performance and bandwidth capabilities of centralised network controllers
   c. NFV - Virtual Machine related KPIs covering:
      i. Resource pools and percentage of utilisation
      ii. Time to bring new VMs online
      iii. Time to migrate VMs between locations
      iv. Environmental monitoring – in correlation with the performance of the virtual machines

The gaps identified in this section need to be addressed in future work, and communication between WP4 and WP2 should be considered in order to ensure that KPIs finally produced by WP2 take the input above into account. D4.2 will then take the updated WP2 list of KPIs and include those in the monitoring analysis for the network scenarios.

5 Summary and conclusions

The purpose of this deliverable was to create a QoS/PM state-of-the-art overview and use this to analyse the PM impact on the WP2 use cases and KPIs. This deliverable serves as a basis for analysing the network scenarios as defined by WP3. The preparatory work in D4.1 is important for the finalization of the deliverable D4.2, which focuses on monitoring of FMC networks, supporting the overall FMC solution as proposed by COMBO. The T4.1 work will also be used as input to the performance optimization work explored in T4.2.

The preparation of this deliverable allowed considerable collaboration between WP2 and WP4, exploring the WP2 use cases in-depth, with focus on QoS/PM aspects. For this we used the information from the internal milestone MS17 research, and provided a state of the art view of QoS/PM tools and parameters across multiple layers and functions. Our study on the relation between QoS and QoE also highlighted some of the QoS parameters – such as network throughput, delay, delay variation or packet loss rate – which can be indicative for QoE.

The analysis indicated specific implications and PM impacts for each use case (Table 4 through Table 11). An example of this is UC1, where we identified a quite extensive need for traffic volume measurements, monitoring available resources for dynamic resource allocation, power consumption monitoring and securing maintained QoS.

In parallel activities we analysed emerging technologies: SDN, NFV and cloud, and considered scalability and complexity questions, such as distributed performance measurement and deep packet inspection. These all added to the list of QoS/PM tools and parameters which we believe are contributing to FMC networks. With more virtual functionality it becomes increasingly important to monitor the virtualization infrastructure, too.

Through the use case analysis we explored how QoS/PM tools and parameters relate to, and support the monitoring of KPIs. For each KPI we also proposed measurement points, either at the terminal equipment, at an access node or at reference points within the network core. With this we can start to gain confidence that a QoS/PM model can be worked out which supports the final FMC topologies and functions that the COMBO project develops (Table 12).

In the KPI analysis we identified several gaps – including device/connection/service set-up times or connection drop rate – which need to be considered in more detail in future activities. The identified gaps include parameters related to SDN, NFV and cloud, such as virtual machine resource pools and time to bring new virtual machines online.

It is important to emphasise that the work undertaken in D4.1 is fundamentally preparatory. The next stage in Task 4.1 is to analyse the architectures that emerge from WP3 and the full list of KPIs from WP2. The aim is to prepare a QoS/PM model and guidance for the FMC network topologies and functions that the COMBO project proposes. D4.2 “Performance monitoring for FMC networks” planned for M18 will address this, and is expected to explore the challenges and benefits associated with the QoS/PM model for FMC networks, and to discuss the changes or developments beyond state of the art – which are needed to make the QoS/PM model proposed a suitable proposition, tackling the gaps identified in the preparation of this deliverable. D4.2 will also explore an initial information model or MIB for QoS/PM aspects of FMC networks.

In summary, Deliverable D4.1 highlights the following key points:

1. Use cases developed by WP2 all generated specific QoS/PM tools and parameters. In order to support them, for each use case multiple tools and parameters are needed. The deliverable provides a list of these in Table 12 – ranging from physical layer bit error rate or signal-to-noise ratio to service availability and quality of experience –, and shows how they relate to KPIs generated by WP2.
2. Some monitoring aspects were not accurately considered during the state of the art review in MS17, but are needed to support use cases from WP2, and therefore need to be further researched in preparation of D4.2 – specifically how to monitor fronthaul networks and how to provide SLA monitoring of CPRI topologies.
3. An important aspect of QoS/PM for FMC networks relates to the adoption of SDN and NFV. These are potentially disrupting technologies, which could cause major differences in how functions and networks are monitored. During the analysis we identified some new KPIs, such as virtual machine resource pools and time to bring new virtual machines online. These will be fed back to WP2 and analysed further in D4.2.

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7 Glossary

Acronym / Abbreviations	Brief description
2G	2nd Generation (mobile service)
3G	3rd Generation (mobile service)
ANDSF	Access Network Discovery and Selection Function
BBU	Base Band Unit
BER	Bit Error Rate
BFD	Bidirectional Forwarding Detection
BS	Base Station
BSC	Base Station Controller
CD	Chromatic Dispersion
COMBO	COnvergence of fixed and Mobile BrOadband
CoMP	LTE Coordinated Multipoint – dynamic coordination of eNodeBs
CPRI	Common Public Radio Interface
DELT	Double Ended Line Test
EAP	Extensible Authentication Protocol
EFTR	Error-Free Throughput
EFS	Error-Free Seconds
EIR	Equipment Identity Register
eNB	Evolved Node B (base station)
ES	Errored Seconds
ESMC	Ethernet Synchronization Message Channel
FEC	Forward Error Correction

Acronym / Abbreviations	Brief description
FEXT	Far End Crosstalk
FMC	Fixed Mobile Convergence (Converged)
GPRS	General Packet Radio Service
G-ACh	Generic Associated Channel
GAL	Generic Associated Channel Label
Hlin	Linear channel characteristic function
Hlog	Logarithmic channel characteristic function
IaaS	Infrastructure as a Service
ICMP	Internet Control Message Protocol
IEEE1588	Institute of Electrical and Electronic Engineers 1588 (Precision Time Protocol)
IP	Internet Protocol
IPFIX	Internet Protocol Flow Information Export
IPPM	Internet Protocol Performance Metrics
IPG	Inter Packet Gap
ITU-T	International Telecommunications Union- Telecommunication Standardisation Sector
KPI	Key Performance Indicator
LTE	Long Term Evolution (3GPP standard)
LOS	Loss Of Signal
MDI	Media Delivery Index
MEF	Metro Ethernet Forum
MELT	Metallic Line Test

Acronym / Abbreviations	Brief description
MIB	Management Information Base
MME	Mobile Management Entity
MPLS-TP	Multi-Protocol Label Switching – Transport Profile
MTBF	Mean Time Between Failures
MTBO	Mean Time Between Outages
MTTF	Mean Time To Failure
MTTR	Mean Time To Repair
MTU	Message Transfer Unit
NFV	Network Function Virtualisation
NGPON2	Next Generation Passive Optical Network 2
OBSAI	Open Base Station Architecture Initiative
OTDR	Optical Time-Domain Reflectometer
OSNR	Optical Signal-To-Noise Ratio
OWAMP	One Way Active Measurement Protocol
PaaS	Platform as a Service
PDN	Packet Data Network
PDP	Packet Data Protocol
PDV	Packet Delay Variation
P-GW	Packet Data Network Gateway
PHY	Physical Layer Device (interface component)
PIANO+	European Commission Framework 7 Program – PIANO+
PM	Performance Monitoring

Acronym / Abbreviations	Brief description
PMD	Polarization Mode Dispersion
PSAMP	Packet Sampling
QLN	Quiet Line Noise
QoE	Quality of Experience
QoS	Quality of Service
RAN	Radio Access Network
RGW	Radio Gateway
RGW	Residential Gateway
RNC	Radio Network Controller
RMON	Remote Network Monitoring
RRH	Remote Radio Head
RRU	Remote Radio Unit
RSVP	Resource Reservation Protocol
RTFM	Real-time Traffic Flow Measurement
RTT	Round-Trip Time
RU	Radio Unit
SaaS	Software as a Service
SDN	Software Defined Networking
SELT	e Ended Line Test
SES	Severely Errored Seconds
S-GW	Serving Gateway
SLA	Service Level Agreement

Acronym / Abbreviations	Brief description
SNMP	Simple Network Management Protocol
SNR	Signal-to-Noise Ratio
SMON	Switch Monitoring
SR	Symbol Rate
SSM	Synchronization Status Message
TDR	Time-Domain Reflectometer
TWAMP	Two Way Active Measurement Protocol
STB	Set-top box
UE	User Equipment
USSD	Unstructured Supplementary Service Data
VAS	Value Added Service
VDSL2	Very-high-bit-rate Digital Subscriber Line, 2nd generation
VoD	Video on Demand
VoIP	Voice over Internet Protocol
VQM	Video quality model
WDM-PON	Wave Division Multiplexing-Passive Optical Network
Wi-Fi	Wireless Local Area Network – Commercial name
Xlin	Linear Crosstalk Coupling

8 List of Tables

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