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Transport Optimisation: initial architecture

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Abstract

This deliverable provides the initial architecture definition for the Transport Optimization subsystem (WP5) in the MEDIEVAL cross-layer architecture. Its objective is to present in detail the mechanisms which will improve the efficient transport of the video flow through the transport network. Therefore, all components in this subsystem interact with upper and lower layers in order to provide a cross-layer optimization and to trigger traffic engineering and content adaptation in different layers based on the current condition of the network. Moreover, a Content Distribution Network (CDN) is introduced for further reducing the traffic in the core network.

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Executive Summary

This deliverable is introducing the initial architecture design of the MEDIEVAL Transport Optimization subsystem. It supplements the general description of the MEDIEVAL system given in deliverable D1.1 with detailed description of the transport optimization architecture, technologies, new functionalities and internal interfaces between the different modules in this subsystem. When designing the subsystem, we envisioned a novel dynamic transport architecture for next generation mobile networks that is adapted to video service requirements. Our approach is to follow a QoE-oriented and cross-layer enabled redesign of networking mechanisms as well as the integration of Content Delivery Networks (CDN) techniques in order to optimize the transport of the video inside the mobile core network.

The deliverable starts with a summary of the key contributions in terms of novelties and initial architectural choices. It continues looking at reference technologies and challenges related to application-layer and cross-layer transport optimization. The initial Transport Optimization subsystem is introduced in detail in this document. After describing the overall architecture decisions, the components and modules, their functionalities, as well as their internal and external interfaces are presented.

One of the key components characterizing the MEDIEVAL Transport Optimization subsystem is the integration of CDN functionalities within the cellular network architecture. The CDN component is a crucial design choice which enables large scale content distribution at a reasonable cost and without overloading the operator’s core network. Caching video data close to the users is able to partly compensate the significant increase of video traffic in mobile networks, which is reported to double every year, thus having the highest growth rate of any application category.

Video streaming will be optimized with a specific focus on the selection of cache locations and peer selection based on e.g. “network distance”, availability, and content popularity. The goal is to provide video-aware transmission options to the users and the video service source. The users can choose the option with the best fit for the specific application, e.g., delay-sensitive interactive video versus video-on-demand streaming.

Another key component is the transport optimization (TO) component aiming at efficiency improvements of transport layer issues for mobile video and integrating them with other techniques implemented throughout the protocol stack. Thereby, a decentralized cross-layer optimization aims at solving congestions in the mobile network by means of various traffic engineering methods, as well as providing an optimized Quality-of-Experience (QoE) for all users.

Thereby, the cross-layer approach enables a global evaluation of the video transport and can assess the system performance in a network-wide context. It receives information from the abstract wireless interface in a technology independent manner while encoding parameters are transferred to the application via the interface provided by the Video Services subsystem. The TO component provides the framework for bridging optimizations performed at different layers and in different subsystems. Further investigation in optimizing the joint decision taking and traffic engineering techniques will be the main task in the upcoming month.

Finally, the deliverable explains the usage of the MEDIEVAL transport optimization at the example of use case 2 (“Arriving in the city”) described in deliverable D1.1. Showing several message sequence charts, the inner working of the subsystem is demonstrated, and benefits of the MEDIEVAL architecture compared to current video transmission are highlighted.

The next steps in WP5 are refinement of the internal modules, functionalities, and interfaces based on validation, prototyping and simulation work. In the CDN component, further specifications of the design and algorithms of the data distribution mechanisms between CDN nodes and the endpoint selection and discovery are planned. The upcoming work on the TO component will include joint traffic engineering among the different subsystems taking into account their impact on QoE, detailing the cross-layer optimization algorithms, and the definition of utility function where the QoE flow sensitivity is exploited.

The final architecture of the Transport Optimization subsystem will be defined and published in deliverable D5.2 in June 2012.

Table of Contents

List of Figures

Abbreviations

ALTO	Application-Layer Traffic Optimization
AM	Application Monitoring (module)
ARQ	Automatic Repeat request
BS	Base Station
CDN	Content Delivery Network (component / module)
CDNNC	CDN Node Control (module)
CM	Connection Manager (Wireless Access subsystem)
CNM	Core Network Monitoring (module)
CRC	Connection Relay and Cache
CS	Connection Specification
DM	Decision Module
DVB	Digital Video Broadcasting
E2E	End-to-End
EPSR	End Point Selection and Ranking
eMBMS	Evolved Multimedia Broadcast Multicast Services
EP	End point (of a communication link)
FEC	Forward Error Correction
FM	Flow manager (Mobility subsystem)
HARQ	Hybrid ARQ
QoE	Quality of Experience
QoS	Quality of Service
L25	L2.5 abstraction module (Wireless Access subsystem)
LTE	Long Term Evolution
MAC	Media Access Control
MAR	Mobile Access Router
MEDIEVAL	MultimEDia transport for mobIlE Video AppLications
MOS	Mean Opinion Score
MSC	Message Sequence Chart
MSE	Mean Squared Error
NEGOCODE	Network Guided Optimization of Content DElivery
P2P	Peer-to-Peer
PHY	Physical layer (of the OSI model)
PIM-SSM	Protocol Independent Multicast - Source-Specific Multicast
PoA	Point of Attachment
PSNR	Peak Signal-to-Noise Ratio
QoEVC	QoE & Video Control module (Video Services subsystem)
SME2E	Session Management & E2E monitoring module (Video Services subsystem)

SNR	Signal to Noise Ratio
SVC	Scalable Video Codec
TE	Traffic Engineering (module)
TEEPOT	Traffic Engineered Endpoint Optimization Tool
TO	Transport Optimization (subsystem / component)
UE	User equipment
VoD	Video on Demand
XLO	Cross-layer optimization (module)

1 Introduction

The current Internet, and in particular the mobile Internet, was not designed with video requirements in mind and, as a consequence, its architecture is very inefficient for handling video traffic. Enhancements are needed to cater for improved Quality of Experience (QoE), improved reliability and efficient transport optimization in a mobile network.

The purpose of this deliverable is to introduce the initial architecture design of the MEDIEVAL Transport Optimization subsystem. When designing the subsystem, we envisioned a novel dynamic transport architecture for next generation mobile networks that is adapted to video service requirements. The plan is to follow a QoE-oriented redesign of networking mechanisms as well as the integration of Content Delivery Networks (CDN) techniques.

The key components characterizing the MEDIEVAL Transport Optimization subsystem are:

1. The integration of CDN functionalities within the cellular network architecture. The CDN component is a crucial design choice which enables large scale content distribution at a reasonable cost and without overloading the operator's core network. Caching video data close to the users is able to partly compensate the significant increase of video traffic in mobile networks, which is reported to double every year, thus having the highest growth rate of any application category [25].

   Video streaming will be optimized with a specific focus on the selection of cache locations and peer selection based on e.g. "network distance", availability, and content popularity. The goal is to provide video-aware transmission options to the users and the video service source. The users can choose the option with the best fit for the specific application, e.g., delay-sensitive interactive video versus video-on-demand streaming.

2. In addition, the transport optimization (TO) component aiming at efficiency improvements of transport layer issues for mobile video and integrating them with other techniques implemented throughout the protocol stack. Thereby, a decentralized cross-layer optimization aims at solving congestions in the mobile network by means of various traffic engineering methods, as well as providing an optimized Quality-of-Experience (QoE) for all users.

   The cross-layer approach enables a global evaluation of the video transport and can assess the system performance in a network-wide context. It receives information from the abstract wireless interface in a technology independent manner while encoding parameters are transferred to the application via the interface provided by the video service module. The TO component provides the framework for bridging optimizations performed at different layers and in different subsystems. Further investigation in optimizing the joint decision taking and traffic engineering techniques will be the main task in the upcoming month.

   Regarding inter-operator scenarios, unicast and multicast transport between senders and receivers connected to different operators is enabled, aiming at further transport optimizations.

After introducing the key components and modules, the design decisions in the Transport Optimization subsystem are demonstrated at the example of the use case 2 from Deliverable D1.1 [27]. In particular, the inter- and intra-subsystem messages are described and the benefits of using the MEDIEVAL Transport Optimization subsystem for the network provider and the end users are highlighted.

The architecture described in this deliverable will be subject to future changes, based on feedback and experience gained in the upcoming months with the effective implementations, simulation results, and testbed performance evaluations. A final, revised version of the Transport Optimization architecture will be available in Deliverable 5.2 (June 2012).

The structure of the deliverable is organized as follows: Section 2 summarizes the key contributions in terms of novelties and initial architectural choices. Section 3 looks at reference technologies and challenges related to application-layer and cross-layer transport optimization.

The MEDIEVAL Transport Optimization subsystem is introduced in Section 4. After describing the overall architecture decisions, the components and modules, their functionalities, and their internal and external interfaces are presented in detail. The section also presents the physical placement of the TO components on the mobile operator network and discusses multicast considerations related to the Transport Optimization subsystem.

Section 5 explains the usage of MEDIEVAL transport optimization at the example of use case 2 described in Deliverable D1.1. Showing several message sequence charts (MSCs), the inner working of the subsystem is demonstrated and benefits of the MEDIEVAL architecture compared to current video transmission are highlighted. Section 6 presents the interfaces inside the Transport Optimization subsystem as well as interfaces with the other subsystems. The deliverable is summarized and concluded in Section 7.

2 Key Contributions

Within the MEDIEVAL project [26], many novel architectural designs, solutions and ideas have been produced, most of which have been presented in terms of contributions to standard definitions and scientific publications. In particular, MEDIEVAL's output can be found in the archives of main standardization bodies, as IETF and IEEE, in the form of standard or draft, and also in conference proceedings and journal articles.

This deliverable deals with the transport optimization for video services which is tackled through an intelligent caching coupled to a cross-layer based optimization of the video transport.

The list below represents the contributions produced within MEDIEVAL, related to the topic we deal within this deliverable.

- The CDN/P2P mechanisms for video streaming are presented in this deliverable. It aims at the optimal placement and management of CDN nodes, the optimal content location, and optimal node selection based on the specific layout of the mobile operator's core network.
- Extensions of the IETF Application Layer Traffic Optimization (ALTO) protocol to include several cost types in information transactions on endpoint costs and proposal of additional cost types and attributes. See [4].
- Extensions of the ALTO protocol to redirect ALTO responses to ALTO Relays, in order to keep network operator information confidential. See [3].
- Existing Quality of Service (QoS) mechanisms, already considered in 3GPP/LTE standard, offer guaranteed bit rate, delay and packet loss and only a limited number of users get admitted. The number of admitted users can only be increased by reducing the level of over provisioning. To go a step further, MEDIEVAL's research will focus on Quality of Experience (QoE) traffic engineering and rate adaptation by multiplexing the different users in order to stratify the QoE fairness criterion across users. In this sense, a contribution to the standard 3GPP/SA2 Rel11 is under construction between Alcatel-Lucent and DOCOMO Communication Laboratories Europe. The objective is to leverage the already approach adopted in 3GPP Rel 10 and existing work items in 3GPP/SA2.
- The architecture and the challenges of MEDIEVAL project are proposed and accepted to be published through a conference paper accepted in IEEE MediaWiN 2011 [17]. In this paper, we present the MEDIEVAL's proposed architecture and we list the envisioned challenges that should be tackled.

3 Reference Technologies and Challenges

3.1 Content Distribution Networks (CDN)

Content Distribution Networks (CDNs) are used to manage the distribution of content and services in the network. CDNs can reduce the traffic in the network (thereby also reducing network congestion) by caching popular content close to the users. Moreover, by locating the CDN servers close to the users, fast and reliable applications and services can be offered to the users. CDN networks are more than just pure network caches, but they also support content routing and accounting. They can also improve access to content that is typically uncacheable by caching proxies, including secured content, streaming content and dynamic content [13]. In general, CDNs act as trusted overlay networks that offer high-performance delivery of common Web objects, static data, and rich multimedia content. They improve the scalability of services by reducing the origin server load [11],[12]. A summary of different CDN concepts can be found in [14]. A cooperative caching management algorithm is introduced e.g. in [15].

Within the MEDIEVAL project we aim at improving cooperative cache management algorithms in order to maximize the traffic volume served from the local cache and minimize the costs in the overall network. Thereby, costs can be represent by monetary expenses (e.g. for deploying the caches), as well as other metrics like management overhead or network congestion. Thereby, a trade-off between optimizing for bandwidth or (play-out) delay must be made. For high-definition videos reducing the bandwidth usage in the network is a far more relevant objective than reducing the initial play-out delay by a few hundred milliseconds. In contrast to that, small video clips are not that bandwidth consuming and, thus, may be optimized for shorter play-out delays. Moreover, in contrast to Web-oriented CDNs, such as Akamai, setting up a CDN network inside a mobile operator's network puts different requirements on the decision *where* to place the CDN nodes, as mobile specific network architectures and protocols must be considered.

3.2 Application Layer Traffic Optimization (ALTO)

The IETF ALTO WG is designing a new service called ALTO (Application Layer Traffic Optimization) that includes a "Network Map Service", an "Endpoint Cost Service" and an "Endpoint (EP) Ranking Service". These services provide a view of the network provider's topology to overlay application clients that reflect the network provider's preferences on the choice of network locations from which to download content. The goal is to optimize the network provider's resource consumption while maintaining or improving application performance on the client side. While such service would primarily be provided by network (i.e., the ISP) and content providers, third parties could also operate this service. Applications that could use this service are those that have a choice in connection endpoints from which to get content. Examples of such applications are peer-to-peer (P2P) and content delivery networks (CDNs). Information on the IETF ALTO WG status can be found in [16]. Within the MEDIEVAL project, the Transport Optimization subsystem aims at guiding the end user on the choice of CDN nodes with respect to their location and properties, the network preferences and end user needs. The decision algorithms on endpoint choice are investigated while associated ALTO protocol evolutions are proposed.

3.3 Quality of Service (QoS) and Quality of Experience (QoE)

QoS represents a combination of several objective attributes of services, typically the bitrate, delay, error ratio, etc. There has been a common belief that by improving QoS (Quality of Service) the operators could provide high level of quality to users. In recent years this thinking has evolved to the concept of QoE (Quality of Experience). Rather than the performance statistics of the service, QoE concerns more the user experience impacted by the service performance. Especially for video applications, experience of the application is more sensitive and has more dimensions compared to traditional applications.

For video applications, which are the focus in the MEDIEVAL project, there could be a broad definition of QoE, covering all aspects of a video application, e.g., satisfaction of video quality, user interfaces, devices, etc. In the MEDIEVAL project and especially in the Transport Optimization subsystem we will refer to the perceptual quality of videos impacted by the video delivery chain as QoE.

As an original video is subject to several impairments during the delivery, the video quality perceived by users is degraded. The quality of impaired videos can be measured by performing subjective tests, in which subjects are asked to rate the videos. However this kind of methods is not feasible in service and network development work. Objective video quality assessment methods are therefore extensively developed to be applied in multiple scenarios where the perceptual quality of videos is demanded without performing time-consuming subjective test.

Based on the type of input data being used for perceptual quality assessment, the objective video quality assessment methods can be classified into several categories. One of them, that is widely used, is a media-layer method analysing video signals to assess QoE. Many methods of this type need reference videos in order to assess QoE by comparing the distortion or similarity between the reference and the impaired videos. Traditionally, MSE (Mean Squared Error) and PSNR (Peak Signal-to-Noise Ratio) are point-based methods but they are not perfectly correlated with perceptual quality measurement due to the non-linear behaviour of the human visual system. SSIM (Structural SIMilarity) [20] considers the perceptual structural information loss as the cause of quality degradation. The VQM (Video Quality Metric) [21] extracts visual features and combines their impairments to compute the QoE.

The perceptual quality of videos is rated numerically by MOS (Mean Opinion Score) levels, see Table 1. Comparing the MOS levels rated by subjects and computed by the aforementioned objective assessment methods, the performance of the objective assessment can be evaluated.

MOS	Perceptual quality
5	Excellent
4	Good
3	Fair
2	Poor
1	Bad

Table 1: MOS values and their QoE levels

Given an objective QoE assessment method, network optimizers are able to perform their decision making by taking into account the impact on resulted QoE. QoE-based optimization allows operators to maintain user satisfaction when deciding on the policy and managing their traffic.

3.4 Traffic engineering

Among well-known traffic engineering techniques, in this project we consider transcoding, which is a process to change the video format (e.g. MPEG-2/4 to H.264 and vice versa) and transrating, which is a process similar to transcoding in which files are coded to a lower bitrate without changing the video format [22].

Moreover, we consider simple traffic engineering opportunities given by packet dropping, packet scheduling (Wireless Access subsystem) and video layer dropping. Focusing on the latter, the structure of a H.264 Scalable Video Coding (SVC) [23] video stream is such that it allows an operator to drop some sub-bit streams to ensure at least the base video quality to be played by the end user.

The H.264 Scalable Video Coding (SVC) is the name for the Annex G extension of the H.264/MPEG-4 Advance Video Coding (AVC) video compression standard [24]. SVC encodes a video into one or more subset bit-streams, exploiting three dimensions of scalability: temporal (frame rate), spatial (screen resolution) and quality (SNR/fidelity). A subset video bit stream is derived by dropping packets from the larger video to reduce the bandwidth required for the subset bit stream. H.264/MPEG-4 AVC was developed jointly by ITU-T and ISO/IEC JTC 1. These two groups created the Joint Video Team (JVT) to develop the H.264/MPEG-4 AVC standard.

Notice, that both SVC and AVC allow the possibility of dropping the least significant video frames (order of importance: I-P-B video frames), instead of performing random packet dropping.

3.5 Forward Error Correction (FEC) and Automatic Repeat reQuest (ARQ)

Video streaming is sensitive to packet loss and thus needs to be protected from (a too high fraction of) packet errors. Automatic Repeat-reQuest (ARQ) and Forward Error Correction (FEC) both serve the purpose of recovering from packet loss. With ARQ, packets detected as erroneous or lost are retransmitted. Packets are commonly acknowledged and are assumed lost if not acknowledgement arrives within a certain time interval. In contrast, FEC adds redundant information to the data to be transmitted, so that the data may be recovered (decoded) even in case some packets or lost or erroneous (up to a certain limit, beyond which too little information is available to allow decoding). In general, ARQ is more throughput efficient than FEC but adds a delay in case of the retransmission of a packet [5].

Since ARQ requires timely feedback whereas FEC does not, FEC is particularly suitable when no feedback channel exists, e.g., for some IPTV scenarios, or when feedback would be costly, e.g. for multicast scenarios where receiver-specific retransmissions may be inefficient. FEC is most commonly applied at the application level.

Raptor Codes [1][6], one of the first known classes of fountain codes with linear time encoding and decoding, offer a widely used and highly efficient FEC solution. It has been adopted in 3GPP for mobile cellular wireless broadcast and multicast applications and is also used by DVB-H [7] standards for IP datacast to hand-held devices. The FEC redundancy sent alongside with the original packets can be increased for the most important video layers (Unequal Error Protection, UEP), outperforming regular robustness schemes [8], [9]. In general, the video transport techniques adopted by the standards for broadcast video streaming applications in cellular networks are very advanced.

In particular in wired/wireless environments, joint design of FEC and ARQ may provide performance gains, where for example local retransmissions on the wireless last-hop may be skipped in case a sufficient level of application level FEC is present. The choice of FEC-level, ARQ, as well as modulation and coding schemes on the wireless link are inter-related and joint optimization may yield significant performance gains [10].

4 Transport Optimization Architecture

The Transport Optimization subsystem is composed of two main components providing CDN mechanisms for video streaming as well as cross-layer transport optimization. In the following, we first describe the global architecture of the Transport Optimization subsystem. We continue depicting the two components, their modules, and their functionalities in detail.

4.1 Global architecture

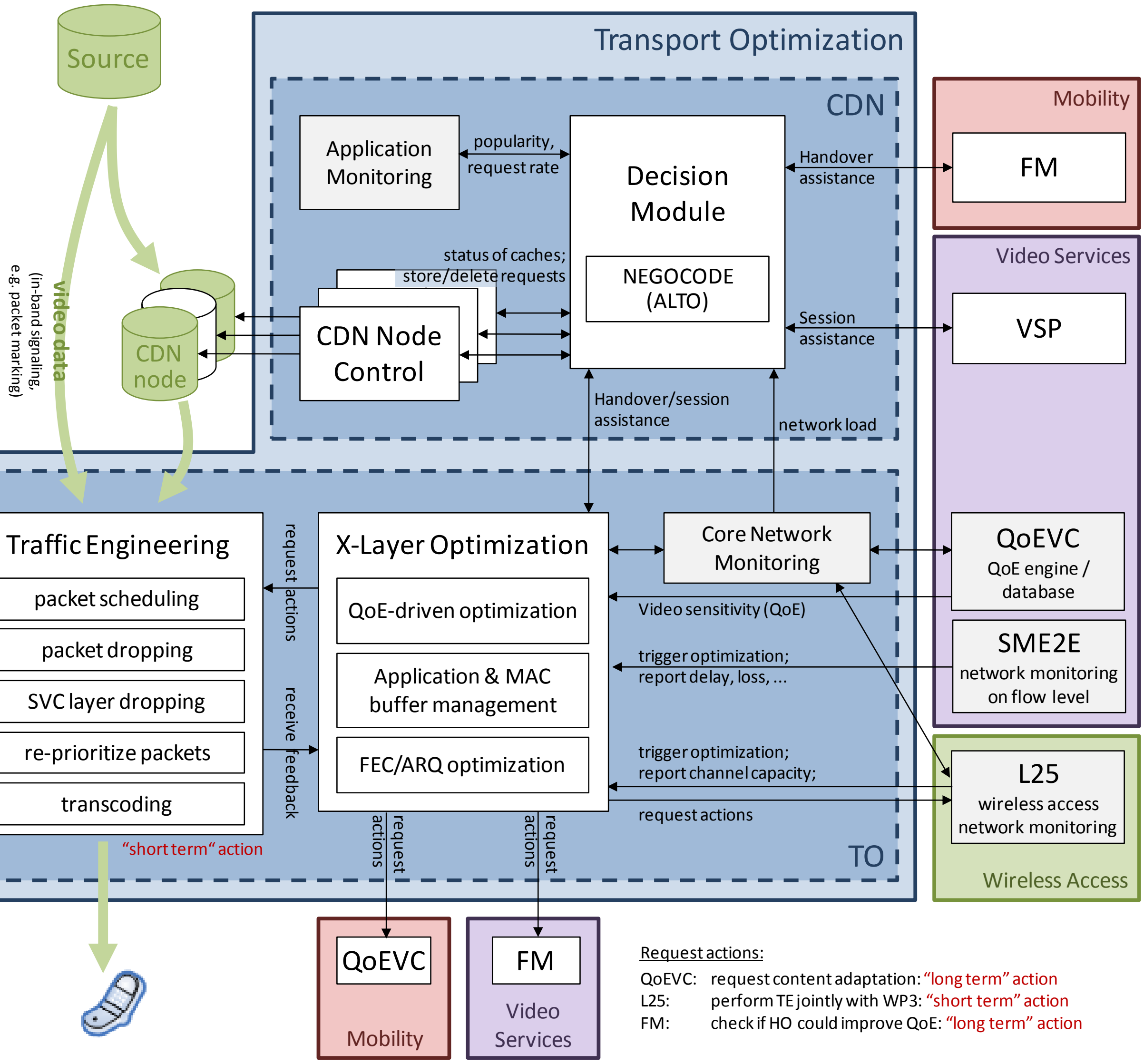

Figure 1: Global view on the architecture of the Transport Optimization subsystem

The Transport Optimization subsystem is divided in two almost independent components. The CDN component (CDN) aims at the optimal placement and management of CDN nodes, the optimal content location, and optimal selection of content location based on the specific layout of the mobile operator's core network and the guidance of the Network Operator. It is composed of a decision module (DM), a CDN node control (CDNNC), and an application monitoring module (AM).

The transport optimization component (TO), on the other hand, aims at providing optimized resource allocation and traffic engineering techniques in order to increase as much as possible the user perceived quality (QoE) while not increasing the load in the core network. The optimization of the traffic flows in the network is handled by a traffic engineering module (TE) and a cross-layer optimization module (XLO), which form a kind of control loop. Based on different input parameters ranging from the physical layer to the application layer, the XLO decides about the policy or traffic engineering technique to be applied to the video flows. The TE then executes the required actions and sends feedback about the actions taken to the XLO, which in turn will update its parameters. The XLO might also trigger other subsystems to perform traffic engineering. This could be packet dropping and scheduling at the Wireless Access subsystem for a short term adaptation, transcoding at the source (Video Services subsystem) for a longer term content adaptation, or even a handover to a different point of access (Mobility subsystem) for increasing the connectivity and throughput of the video flow. Beside these two modules, a core network monitoring module (CNM) collects and provides necessary information about the status of the core network.

4.1.1 CDN mechanisms for video streaming

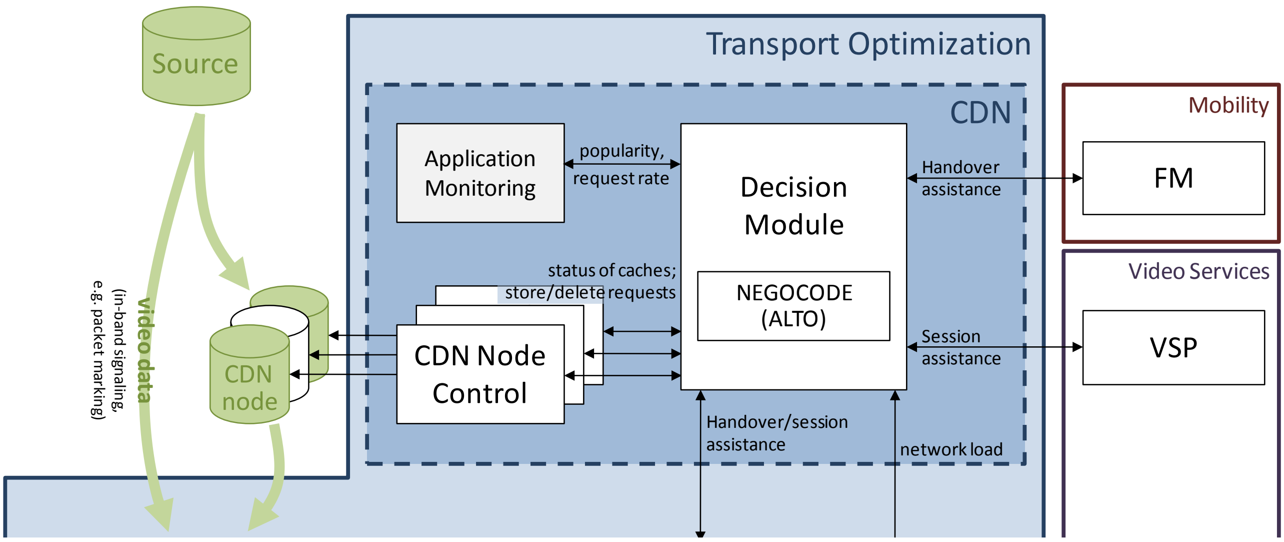

Figure 2: The CDN component

The CDN component provides a mobile CDN solution for video delivery including network based caching, network guided optimisation of content delivery and advanced multicast solutions. This includes maintaining an efficient and stable overlay topology for the control and management of the CDN nodes, performing load-balancing among the video sources and network elements, selecting optimal content locations as well as relaying connections for mobility, caching, or confidentially reasons. This requires a continuous monitoring of the current conditions of the entire system, in particular the status and distribution of the CDN nodes, as well as the popularity of content. Using the collected data it will dynamically maintain an optimal configuration of a set of servers for content distribution and select optimal sources for transmitting the video to the user.

As shown in Figure 2, the CDN component consists of three modules. The application monitoring module (AM) keeps track of the popularity of content and provides this information to the decision module (DM). The decision module is responsible for content and user related decisions, e.g. optimization of content placement with respect to demand patterns and optimization of network resources and delivery delay by maintaining traffic locality. A first step is to implement a more sophisticated selection algorithm for content locations that combines metrics like availability, bandwidth, memory capacity, and latency in a robust way. To support this, we are extending the IETF ALTO protocols to the specifics of mobile core networks and the mobility of users. ALTO requests and responses are further processed by the decision module with respect to the application needs.

The decision module interfaces both the Video Services subsystem (see [28]) and the Mobility subsystem (see [30]). If a user is requesting a video, the Video Services subsystem will send an ALTO request to the decision module to find the optimal content location for this user. Likewise, the Mobility subsystem uses ALTO requests to get a weighting of possible handover candidates in case of user mobility. These interfaces are described in more detail in Section 6.4 and in deliverable D1.1 [27].

The CDN node control module is responsible for the lower level operation and management of the content to keep the CDN operational and to maintain the required level of performance and fault tolerance, such as load balancing mechanisms among CDN nodes.

The CDN component drives optimization at several stages of content handling:

1. Pro-active off-line placement of content in the CDN nodes,
2. On-line network guided selection of content locations from which to download,
3. On-line download and placement of contents in CDN nodes,
4. Multicast content delivery, and
5. Relay-assisted delivery.

4.1.2 Resource efficient mobile transport

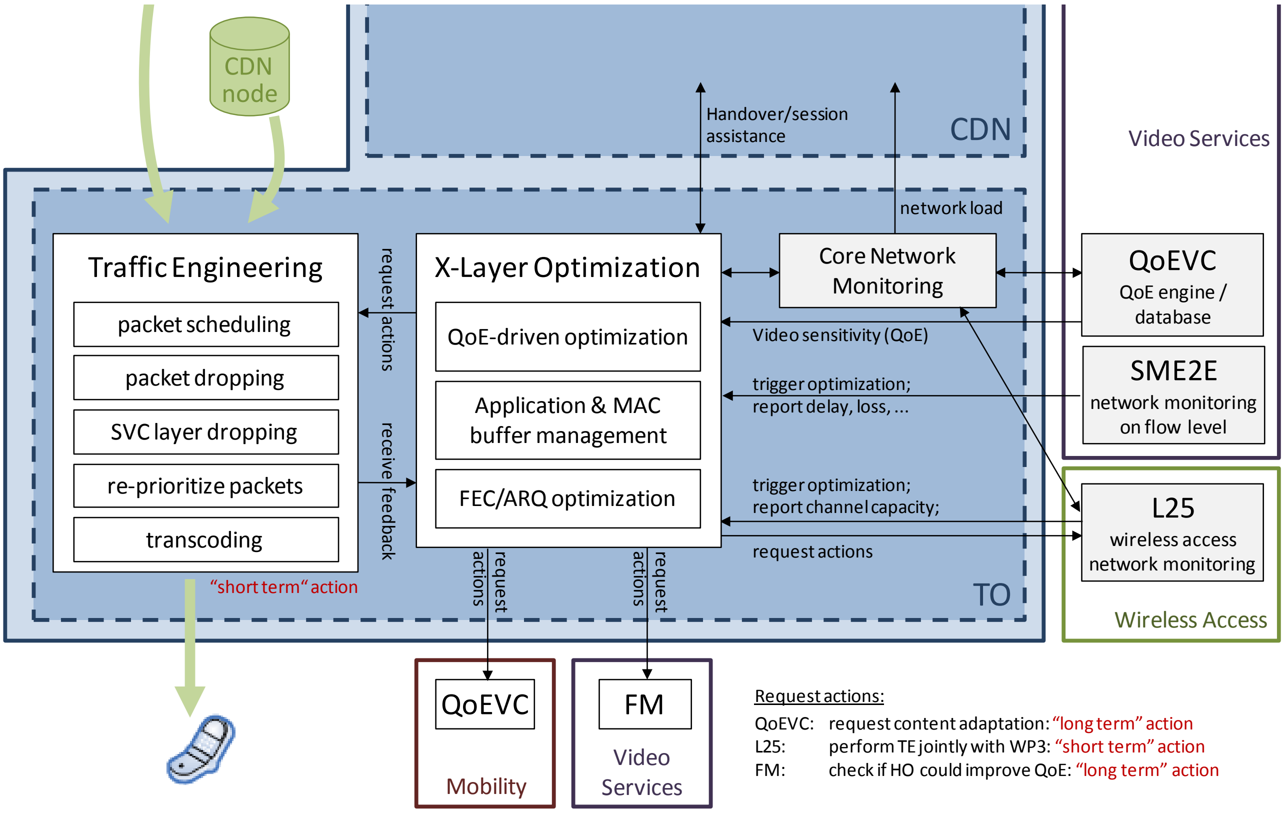

Figure 3: The transport optimization component

The traffic optimization component (TO) designs two building blocks in charge of handling problematic traffic conditions in the mobile network. The main idea is to have the cross-layer optimization module (XLO) deciding which policy/engineering technique should be applied to the problematic video flow (application flow). The output of the computation, i.e., the video rate to be ensured by means of a certain traffic engineering technique to be performed on the problematic flow, is then communicated to the traffic engineering module (TE), which executes it.

The XLO is QoE-driven, aiming at increasing as much as possible the user perceived quality. It receives inputs from different entities monitoring the network at different levels and from different viewpoints. Additionally, the Video Services subsystem sends QoS/QoE thresholds on a per-flow basis, which are used as targets when performing the required optimizations.

The transport optimization component shown in Figure 3 receives the resource requirements from the video applications (service providers) and performs the following actions to maximize the QoE experienced by video users:

(i) video rate adaptation (Video Services subsystem),

(ii) resource allocation and negotiation from the core network (Transport Optimization subsystem) to the wireless access (Wireless Access subsystem), and

(iii) optimal handover decisions by interacting with the mobility entities (Mobility subsystem).

The transport optimization approach is to act upon the following hierarchy:

1) Adapt the video content to meet the channel conditions (Video Services subsystem);
2) Handle users mobility performing offloads of the traffic (Mobility subsystem);
3) Handle congestions by means of packet scheduling, dropping and re-prioritization, as well as layers dropping and transcoding.

In our work we take into account both computational cost and performance when selecting the action to be performed on the video flow. For instance, video transcoding performs better than packet dropping in terms of QoE, but it is computationally much more expensive than the latter. Moreover, transcoding is more applicable for long-term adaptation, while packet dropping is tailored for short-term adaptations.

The adaptation of video flows in the core network with the goal of meeting a target QoS/QoE can be extended to multicast video delivery. Instead of considering a single user playing a video in the terminal, we focus on the worst user case, as for broadcast scenarios. Furthermore, we might apply techniques that well fit when serving heterogeneous set of users:

(i) H.264/SVC allows to deliver at least a base layer to the worst user and further video layers to users with better channel conditions (layers dropping can be done in the core in case multiple base stations in the same area might need lower rate), and

(ii) adaptive modulation and coding schemes at the eNodeB to allow users with good channel conditions to demodulate packets at a higher rate.

4.2 CDN component

The CDN component is used to:

- Provide a mobile CDN solution for video delivery including network based caching, peer-to-peer mechanisms, and advanced multicast solutions.
- Dynamically maintain an optimal configuration of a set of servers for content distribution with respect to the current conditions of the entire system.
- Appropriately select content locations to save network resources, inter-domain traffic and delivery delay.
- Coordinate with the Mobility subsystem to achieve handover optimization and QoE optimization.

The different building blocks of the CDN component are described in detail in the following subsections.

4.2.1 Decision module (DM)

The decision module (DM) is the central module of the CDN component. It is part of the session initiation and handover preparations. It decides when and where to store content in the CDN nodes, based on the popularity of the video files. During the session initiation, the DM also informs the mobile client about which source should be used for streaming/downloading the content, e.g. from either the (external) content provider or a cached copy from one of the CDN nodes.

Based on the information from the application monitoring module (AM) and the CDN Node Control (CDNNC) the decision module will decide whether a new request for a certain video (from the Video Services subsystem)

a) Must be denied as not enough resources are available,

b) Can only be served with lower quality or without QoS guarantees due to a lack of available resources, or

c) Can be served with the requested quality

The DM also decides on which storage location should be selected as the optimal source for transmitting the video to the user.

Particularly the DM and the CDNNC need to be closely coordinated. While the DM is responsible for content placement with respect to resource requests (content popularity, etc.), the CDNNC is responsible for CDN maintenance and may need to relocate content for this purpose.

So far, it has not been decided yet, whether the decision module is implemented as one central entity, or if its functionality will be distributed among several nodes in the core network (e.g. being attached to P-GWs).

The NEGOCODE module

The decision module includes a set of functions called Network Guided Optimization of Content Delivery that will be referred to as NEGOCODE. NEGOCODE is composed of several functions called Traffic Engineered Endpoint Optimization Tools (TEEPOT) that support:

- On-line network guided selection of content locations from which to download,
- Relay-assisted delivery.

For NEGOCODE, the storage locations or content locations are considered and referred to as Endpoints (EPs). NEGOCODE does not perform the identification of the content locations. It assumes they are already available and identified by their IP address. NEGOCODE mainly negotiates information on the cost related to the EPs with ISP managed information hosted in an ALTO server. It possibly adds other metrics on the EPs, selects and ranks them, and requests the UE to connect to a designated Connection Relay that gets the contents on behalf of the UE.

The NEGOCODE module internally uses the IETF ALTO protocol to query the ISP defined cost or ranking of the candidate EPs from which to get the content from. ALTO and NEGOCODE are not about optimizing an external P2P network but on optimizing the traffic generated by content networking applications (such as P2P or CDN) within the infrastructure of an operator network implementing ALTO.

The NEGOCODE functions (TEEPOTs):

- Implement algorithms that are generic and can be tuned to either P2P or CDN.
- Implement a more sophisticated content location selection algorithm that combines metrics like bandwidth, memory capacity, latency in a robust way.
- Provide help to handovers decision and mobility.
- Provide relaying for the ALTO protocol by receiving the ALTO response in place of the ALTO client.
- Provide relaying for the connection between the storage locations and the UE and Application Clients in the Video Services Subsystem, who are no more directly connected to the storage locations but to the relay.
- The connection relays also act as caches.

The relay functionalities are deployed inside the network and not in mobile nodes in order to offload mobile devices by taking over processing-intensive tasks as well as preventing easy access on the operator network topology and related information to third parties such as end users or application clients. This last aspect is fundamental as an incentive for network operators that are in general reluctant to deploy ALTO, because it easily unveils their internal topology state.

Compliance with the ALTO protocol:

The implementation of NEGOCODE functions is coupled with evolutions of the ALTO protocol that are being proposed at the IETF. Currently, the ALTO protocol is tailored for fixed networks and very static network information, because among other reasons there is currently no feature to protect information confidentiality.

- The ALTO extensions to support relaying are proposed in the IETF draft [3].
- The ALTO extensions to support transactions involving several cost types and to propose additional ALTO cost types and attributes are proposed in the IETF draft [4].
- The next step is to define and propose mobile core specific ALTO features, in particular, extend the ALTO protocol to mobile networks. The starting point is to consider moving users.

Functions of the NEGOCODE module

Figure 4 illustrates the main components of the NEGOCODE module and their interaction. It is assumed here that the application client already has the list of candidate locations, i.e., endpoints (EPs) for the desired content. Particular EP properties are provided by the CDN management entity.

This figure illustrates the use case of optimal selection of EPs from which to download, in case three connections are requested by the Application Client (AC), with different properties specified by the application.

Future specifications include:

- The function used to identify the endpoints, and its integration in the network infrastructure.
- The distribution and implementation of the different TEEPOTS in the network infrastructure.
- Discovery of the connection Relays associated to a UE.

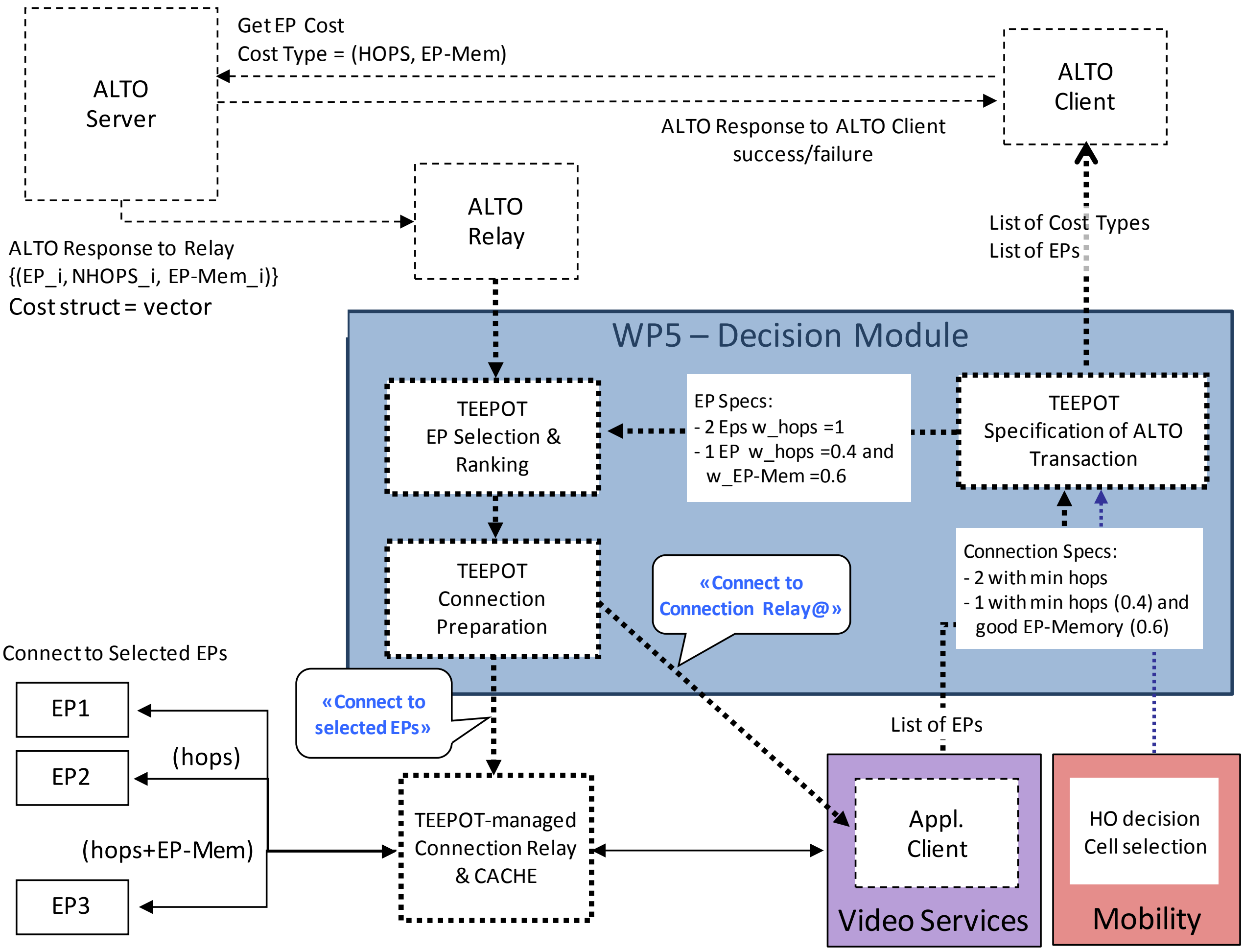

Figure 4: Main components of the NEGOCODE module and their interaction

The figure shows an example of optimal selection of EPs from which to download, when three connections are requested by the Application Client (AC), with different properties specified by the application. Dashed lines and boxes relate to ALTO protocol items and transactions. Dotted lines and boxes relate to transactions involving TEEPOTS.

4.2.2 CDN Node Control (CDNNC)

The CDN node control module (CDNNC) is responsible for management and control of the operation of the CDN nodes. It is responsible for maintaining CDN related status information such as the current load, (free) capacities, and information about stored content. This information is provided to the decision module.

The CDNNC will also receive commands from the decision module requesting it to store, move, replicate, or delete content, based on the changing popularity of content, the mobility of users or user groups, or congestion in certain parts of the core or access network that may require shifting flows and content to less congested parts of the network.

The CDNNC will also perform CDN internal decisions to move and replicate content between caches:

- for load balancing within a group of CDN nodes
- when required move content to nearby CDN nodes to be able to power off a node for maintenance or to save energy
- to adapt the content of available CDN nodes for (seamless) failover when one or more CDN nodes fail
- provide additional CDN resources (if available) and populate the corresponding caches in case of failures

- replicating/deleting CDN content to achieve the required level of resilience against failure (if needed)
- replicating/deleting CDN content within a group of CDN nodes to provide the required level performance (trade off CDN performance and required storage capacity)

This requires a close interworking between the decision module and the control module (e.g., to avoid moving content to a CDN node that will shortly be switched off for maintenance). While a location for CDN node control modules is not finally decided upon, the most likely solution is to either co-locate them with the actual CDN nodes or the decision modules.

The CDNNC module has (internal) interfaces to the actual CDN nodes, and an interface to the decision module (see Section 6.1).

If the CDN is merely used for caching, but content can always be reliably retrieved from the original server, CDN resilience is of less concern. However, if the CDN network itself is used as a distributed storage system (i.e., content is hosted within the CDN and there is no difference between original server and CDN node) providing a sufficient level of redundancy to protect against failure is important [18]. To increase resilience against failures while at the same time maintaining low storage capacity requirements, some replicated content may be stored in coded form. This coded information can be used to rebuild the content of CDN nodes [19].

4.2.3 Application monitoring (AM)

The application monitoring module (AM) receives input from the decision module about the request rate of certain videos. This information is used to calculate (and predict) the popularity of the videos. This popularity data is necessary for the decision block to optimize the content placement.

In the current version of the architecture this building block is more or less a kind of database for content popularity.

4.3 Transport Optimization component

Finding the optimal cross-layer strategy will be modelled as a constrained optimization problem where the criterion to maximize is the QoE of the video flow, under constraints related to the users' channel quality and available bandwidth, the handover candidates obtained from the mobility functions, the fill level of the MAC buffer, and the resilience to losses (Forward Error Correction (FEC), Automatic Repeat reQuest (ARQ)). Moreover, when dealing with multicast/broadcast transmissions, the number of receivers affected by QoE degradation is a further constraint to be taken into account. The overall goal is to determine the transmission rate matching the target QoE level requested for a user (unicast) or a group of users (multicast).

The transport optimization component is triggered by the mobile network as soon as a severe QoE degradation is observed. To improve it, this block performs an optimization on the video flows being delivered through the congested area, to maintain a level of QoE fairness among the streams involved. Thus, a re-allocation of the channel resources among users is performed such that the average perceived quality (via average MOS, for instance) is again maximized.

In the following sections we present in detail the modules implementing the functionalities of the transport optimization component.

4.3.1 Cross-Layer Optimization module (XLO)

In the cross-layer optimization module (XLO) we aim at computing the traffic engineering technique to be performed, as the outcome of a heuristic algorithm designed to solve an optimization problem.

As can be seen in Figure 5, the inputs of the optimization problem range from the physical layer to the application layer. Starting from the lower layers, we receive information from the Wireless Access subsystem about users' channel quality and link capacity. From the Wireless Access subsystem we receive as well information about the MAC and buffer states (at the eNodeB). In case of multicast video delivery, due to the computational costs, the buffer management function might need to track the buffer state of just some of the receivers belonging to the multicast group. From the application layer (Video Services subsystem) we get QoE-based information about video sensitivity and as well end-to-end delay and loss information.

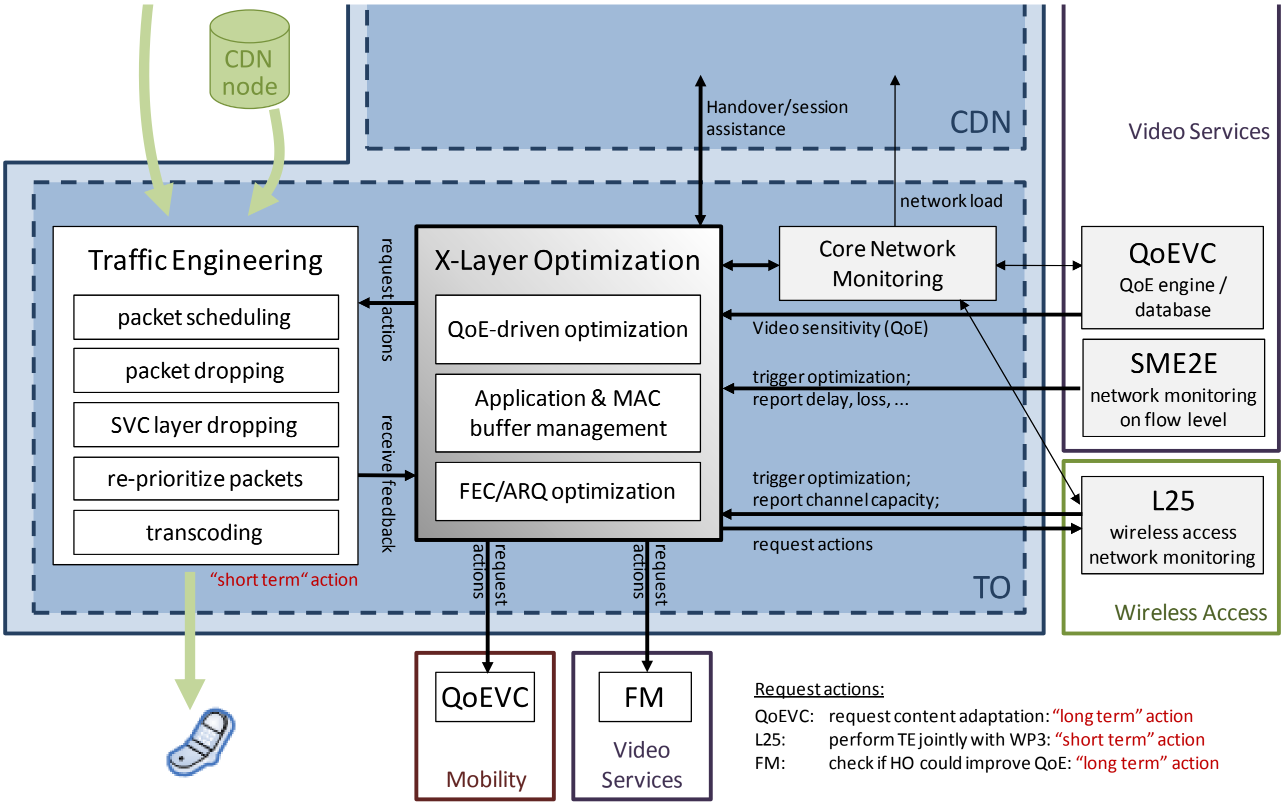

Figure 5: Cross-layer optimization module.

When the video is delivered to a multicast group of users, the computation performed by the cross-layer optimizer will be slightly different from the unicast case, since changes in video flows have to be beneficial for a heterogeneous set of mobiles. However, a first possible approach is to calibrate the heuristic algorithm to the characteristics of the worst user (to be taken above a minimum admissible video rate threshold), as currently adopted by standard broadcast/multicast systems (e.g., MBMS). Enhancements can be achieved by jointly using scalable video coding (H.264 SVC) and adaptive modulation and coding schemes, promising in multicast delivery where an heterogeneous set of users is served (users with good channel quality or larger screen size can be served without being affected by users with worse channel conditions/device capabilities). The outcome of the optimization problem will lead to a certain traffic engineering technique to be performed, similar to the unicast scenario. However, in order to protect the large number of users involved in a multicast session from parallel exhaustive unicast sessions (i.e. single users affecting large groups of users whenever the same TE function is applied to simultaneous flows at a network node), packet marking might represent a quick and efficient solution.

In case of negative feedback about the feasibility of the traffic engineering technique to be performed by the traffic engineering module, a new computation is expected, taking into account the information provided by such feedback message (actual core network conditions, latency, number of users affected, etc.).

Additionally, the cross-layer optimizer sends feedback to the Video Services subsystem in order to eventually request the video stream at a lower or higher transmission rate depending on the available resources in the access network and on the capabilities of the connected mobile nodes (long-term adaptation, see Figure 5).

The outcome of the cross-layer optimizer can be used also in the Wireless Access subsystem, i.e., the wireless access (eNodeB), whenever some packet dropping is requested at a given cell (short term adaptation, see Figure 5). Finally, when needed, the cross-layer optimizer can instruct the Mobility subsystem to handle users mobility by performing offloads of the traffic (long term adaptation, see Figure 5).

In the following subsections, we highlight the main features of the cross-layer optimizer, digging into the practical meaning of each function as drawn in Figure 5 and discussing their role in the whole optimization procedure.

4.3.1.1 QoE-driven optimization

We start discussing the top function in the XLO, which represents the application layer-related function of our optimization procedure.

Video sensitivity plays a fundamental role when delivering media contents through the mobile network, from the core to the wireless access side. Each video has characteristics such that changes in the network, e.g. fluctuating data rate, packet loss, delay deadlines and jitter, might severely impact the video structure, hence the quality perceived by the end user. Video sensitivity can be expressed through a set of parameters and features, such as motion (live/static videos), content (light/complex scenes) and other QoS-based parameters.

A mobile operator can decide how to best react to network congestion or reduced available network resources based on the sensitivity of the video flow being provided to the consumers. Fast motion videos would need to optimize parameters with weights different from what more static videos need, in order to maintain a certain QoE level at the user side. Hence, for each video the required network resources and engineering techniques can be coupled according to the video characteristics, with the goal of optimizing the overall perceived quality across multiple video flows.

QoE based sensitivity profiles can be designed for class of videos, i.e. videos having similar characteristics/patterns. The relationship between video sensitivity and objective parameters, such as packet loss and video rate, needs to be exploited in the QoE Engine module in the Video Services subsystem, to be then communicated to the XLO as soon as the cross-layer optimization module is triggered to compute a new engineering solution to maintain the target QoE level required by the application. Wireless access conditions must be communicated as well, jointly with the video sensitivity evaluated by the QoE Engine to best perform the cross-layer optimization.

4.3.1.2 Application and MAC buffer management

The cross-layer optimizer needs information from the Wireless Access subsystem concerning the link state and the available bandwidth in order to compute the proper encoding video rate to be applied by the traffic engineering (TE) module. This information is sent by the terminal back to the PoA at each slot or transmission time interval. This information depicts an instantaneous image of the radio channel conditions. In order to design a TE function where the adaptation granularity is the video frame (layer filtering, frame dropping, etc.), we need to aggregate all these information over the frame rate of the stream which is variable. A rapid and sufficient solution to get aggregated information is to observe the state of the latest buffer conditions in the stream path. In our MEDIEVAL's architecture, this coincides with the MAC buffer.

The MAC buffer fullness depends on the scheduling algorithm implemented already in the base station and the radio resource management (choice of MCS scheme, etc.). Therefore, to decouple the dependency between the traffic engineering block and all the MAC/PHY functionalities (segmentation, scheduling, MCS, etc.) implemented in the base station, controlling only the fullness of the MAC buffer would be enough.

For example, by quantizing the fullness of the MAC buffer by thresholding the overflow, the optimizer will determine if it needs to lower the encoding rate. If this is the case, the TE will apply a solution depending on the stream characteristics (frame dropping, layer filtering, layers scheduling, etc.).

4.3.1.3 FEC and ARQ

FEC and ARQ mechanisms are often used to mitigate the decrease in quality of video flows due to packet delivery errors. FEC mechanisms at transport level are very efficient solution to reduce the delay compared to ARQ, as no feedback mechanism is required. However, this is usually at the expense of throughput as FEC may introduce excessive redundancy and reduce the available bandwidth. Thus is recommended for delay sensitive applications only.

On the other hand, ARQ mechanisms are more flexible as they retransmit packets only when needed. Retransmission-based techniques can operate over the wireless links within the access networks or end-to-end (TCP like) at the transport or application level. In general, ARQ has its main drawbacks in the increased delay, which may be undesirable for video applications, and also requires a return channel.

Finally, Hybrid ARQ (HARQ) tries to avoid both problems of FEC and ARQ with a combined approach: packets are protected by error-correcting codes that repair some of the errors introduced by the channel (FEC approach), and those packets, which are still in error even after FEC decoding are retransmitted upon request (ARQ approach). However, HARQ still requires feedback exchanges and retransmissions; thus, it needs to be carefully designed to avoid excessive delays.

These features should be also designed by taking into account other related similar interventions at different layers: for example, FEC at PHY layer is often necessary to deal with inefficient physical link conditions and included in the modulation specifications. Also ARQ and HARQ techniques are often part of the access standard and therefore naturally handled by interfaces in the Wireless Access subsystem.

In general, cross-layer collaboration between all the subsystems may be thought of, since the scope of MEDIEVAL involves the definition of novel techniques covering the whole mobile network, i.e., from the video source through the core network down to the access network(s). In order to join the advantages of both FEC and ARQ the MEDIEVAL approach must also take into account the unique characteristics of video traffic.

To do so, a possible approach involves the combination of HARQ and unequal error protection techniques tailored to the structure of the video flows. The overall idea is to separate the different parts of the flow, in particular to identify the most important component of the video, and apply different error control approaches. Actual retransmissions are applied only to the most important component, whereas the remainder of the flow is only protected by FEC. This structure may permit to keep any delay increase within reasonable bounds and also to adapt the error correction capabilities to counteract packet losses.

4.3.2 Traffic Engineering module (TE)

The traffic engineering module (TE) executes engineering techniques dictated by the cross-layer optimization module (XLO), in order to handle problematic flows. For instance, the action to be taken might be required to meet the video rate computed by the XLO. In case of issues related to the feasibility of the traffic engineering to be executed, due to the core network conditions or latency, the module might send a feedback message to the XLO to re-compute the optimization algorithm taking into account the updated scenario.

In the following subsections, we highlight the main features of each function of the traffic engineering module.

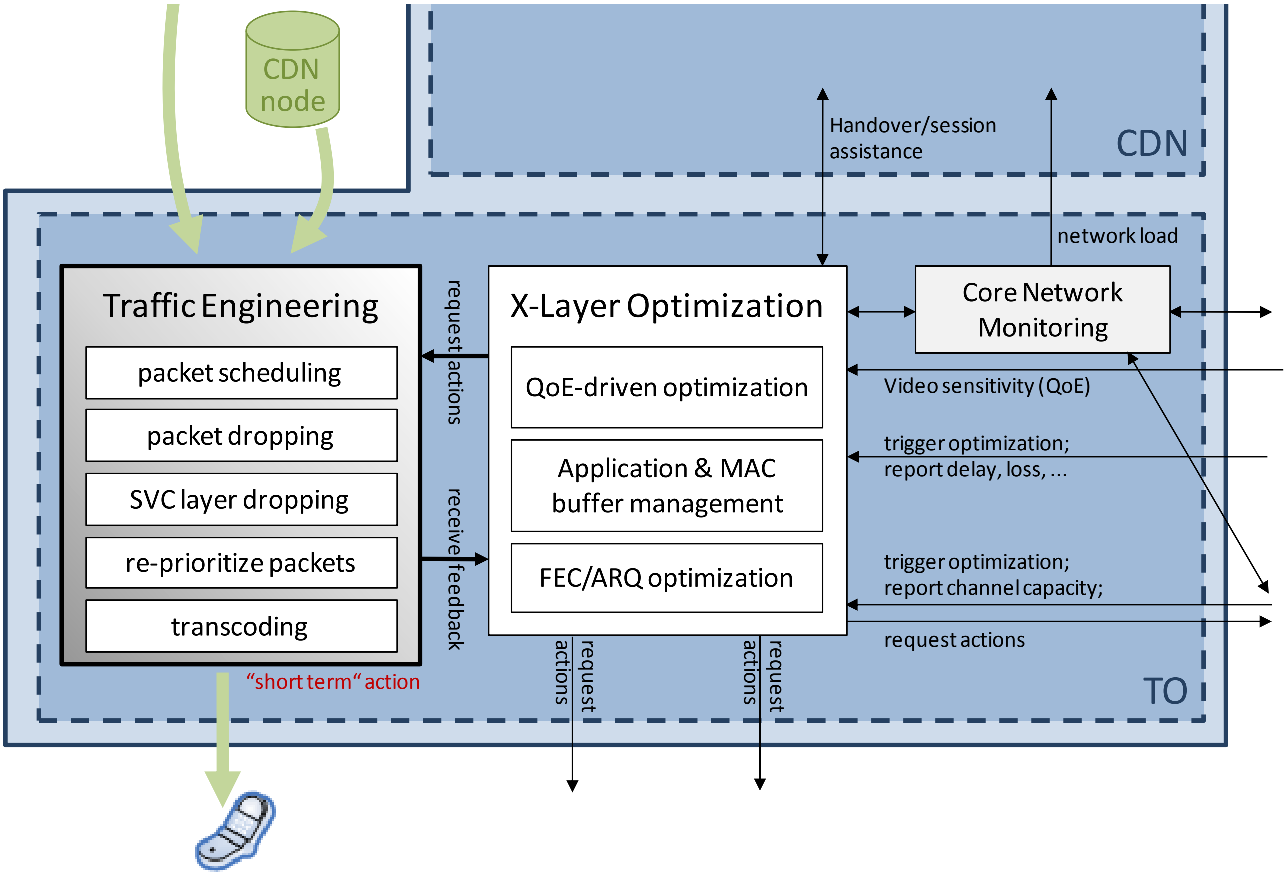

Figure 6: Traffic engineering module.

4.3.2.1 Packet scheduling and SVC layers dropping

The packet scheduling and dropping function is performed according to the decision taken by the cross-layer optimization module, i.e., the outcome of a close interaction between signalling from the Wireless Access subsystem, application layer (Video Services subsystem) and traffic conditions as evaluated by the CNM. In particular, the Wireless Access subsystem is aware of the channel conditions, and can therefore determine an estimate of the available bandwidth that the PHY layer has to fill with video flows. Such a bandwidth will be properly mapped into application layer rate, so as to have an evaluation from the Video Services subsystem which can be promptly used by the Transport Optimization subsystem.

Packet marking techniques, i.e. packets are marked for instance in the IP header to differentiate the importance of packets inside the same video layer and among different layers (i.e., intra- and inter-layers), will be used to inform the access network on how to schedule packets and drop them in case of congestion (or drop entire video layers in the worst case).

Given the tight collaboration with the wireless subsystem (i.e., with the point of attachments (PoAs)), we foresee the possibility of having XLOs implemented at the PoAs, as long as a distributed implementation of the optimizer is proven to be feasible.

Moreover, when scalable video coding techniques are in use, the bandwidth estimation performed by the access network is properly mapped into application layer rate by dropping scalable layers, in case of SVC streaming. In fact, scalable coders, [23], have been developed to partially address the issues of user terminals heterogeneity, adapting the video quality to the time-varying bandwidth by using the SNR (Signal to Noise Ratio) scalability scheme and avoiding the re-encoding operation. Packets with various priority levels are generated. Receiving only the highest-priority packets allows getting an acceptable quality, which increases with the number of lower-quality packets correctly received. One of the main drawbacks of this approach is that any low-priority packet is useless unless all associated higher-priority packets have been received.

For this reason and in order to maximize the QoE, the video dependency is exploited in order to schedule the different layer's packets. For example, assuming that the terminal suffers from a video freezes, which is known very damaging to the QoE, the TE could decide, that it would be better to send to the terminal a certain amount of base layer packets in advance and then, if there is a room, to send the quality packets next time. In this way, we possibly could avoid video freezes during the next period/slot.

In this TE block, criteria will be included in the determination of how to schedule packets and drop the lower priority ones in case of congestion, both based on traffic characteristics and subscriber profiles.

According to the channel state and the fullness of the MAC buffer (last buffer in the stream path) obtained from the Wireless Access subsystem, we decide the transmission policy of different layers and which layer should be dropped. The Video Services subsystem should transmit all layers corresponding to the maximum quality or bit rate negotiated with the terminal. In some cases, the TE should downgrade the bit rate in order to adapt to the bandwidth. When, the bad situation, e.g. bandwidth is low, is leveraged, we should increase the QoE of the terminal therefore the network should be able to send the enhancement packets.

4.3.2.2 Transcoding

Transcoding refers to a process that first decode the bit stream into uncompressed format followed by re-encoding the uncompressed stream into a compressed format either same as before but with different compression attributes or to different format. It is mainly in use to adapt the input bit stream into a format supported by the target device or bit rate supported by the network. The main attributes to be changed at the transcoder are thus the format, frame rate, frames SNR, and spatial resolution, an example for format changes could be MPEG-2 to H264 or WAV to MP3. The output stream quality is thus considered less or equal to the input stream quality.

The use of transcoding to cope with available network resources and terminal capabilities in real-time requires high processing and memory. Therefore, it is less attractive than adaptation at the source. In cases that the terminal does not support the existing format, it makes sense to perform such adaptation mechanisms, but should be avoided when possible. The MEDIEVAL approach is based on SVC encoding, which allows layer dropping of higher layers to achieve the same required adaptation with minimal resource consumption at the network (excluding format adaptation). The layers are marked by the source or network elements and identified at the network entities to perform packet scheduling or dropping based on the marked priority. Transcoding is sometimes used in centralised gateways as suggested in [2].

4.3.3 Core Network Monitoring module (CNM)

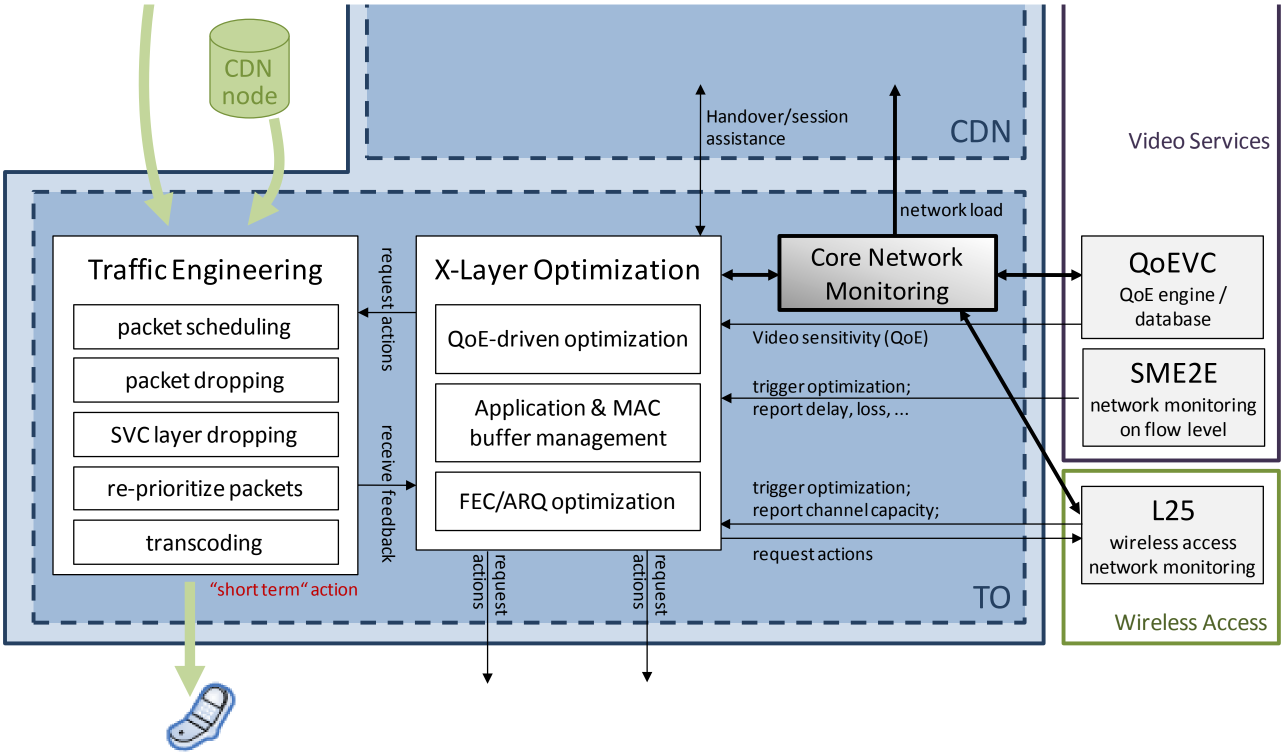

Figure 7: Core network monitoring module

The core network monitoring module (CNM) supports the cross-layer optimizer module (XLO) to solve the problematic flows having QoE degradation.
Here, we describe some required features in the MEDIEVAL project which are already supported by some commercial tools (e.g., the wireless network guardian of Alcatel Lucent[1]):

- Monitors every subscriber's data experience.
- Analyzes and identifies the root-cause issues that are contributing to a subscriber's degraded experience.
- Determines whether an issue originates within a cell site, on a backhaul link, within the packet core network, across devices, or with a misbehaving application.
- Identify a wide range of performance issues associated with the subscriber's data session, including issues such as poor cell performance, inability to launch a data session, DNS failures, poor-performing device and more.

These indicators support the transport optimization functionalities: The CNM generates some alarms, e.g. congestion, which activates the optimization block.

At this stage of the project, the CNM based on existing tools seems to be sufficient to fulfil the different requirements of the project, i.e., core network monitoring is out of scope from the MEDIEVAL research point of view. Yet, the integration of such monitoring, in particular considering the interfaces with network monitoring modules in other layers, is crucial for the envisioned transport optimization.

[1] http://www.alcatel-lucent.com/wps/portal/products/detail?LMSG_CONTENT_FILE=Products/Product_Detail_000590.xml

4.4 Physical placement of the functional entities

The following figure and list gives a first draft of the physical placement of the functional entities. The physical placement of the modules is still considering several variants. This is partly due to the late start of WP5 in month 4. Thus, the final specification of physical placement will be provided in deliverable D5.2 (June 2012).

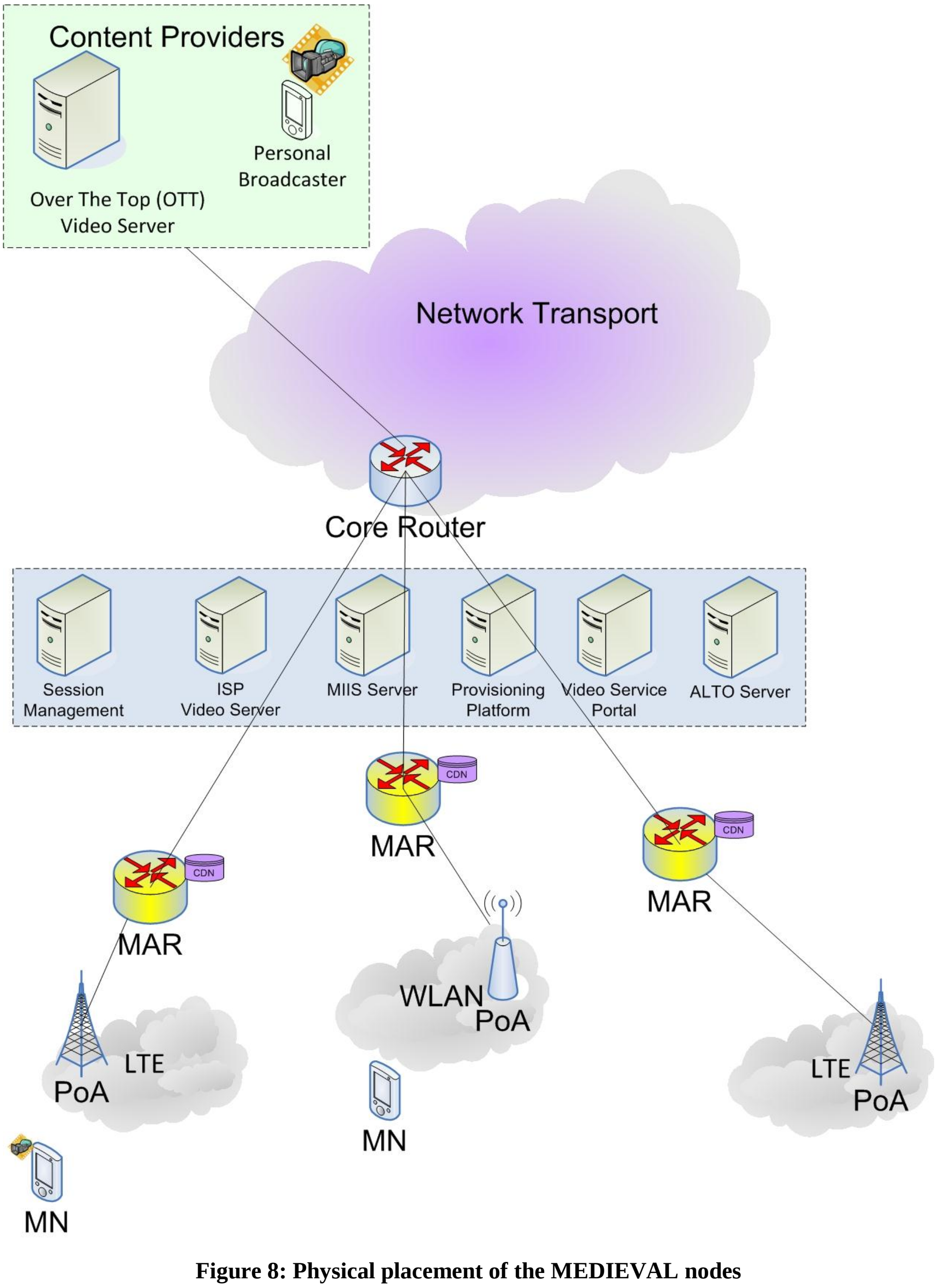

Figure 8: Physical placement of the MEDIEVAL nodes

Decision module:

- Dedicated server in core network (including the central ALTO information server), or
- Attached to the MAR (P-GW or PCRF) with a central ALTO information server

CDN node control:

- Attached to the MAR (P-GW)

CDN nodes:

- Attached to the MAR (P-GW, S-GW)

TE:

- In the PoA
    - LTE eNodeB (TE is performed by the Wireless Access subsystem by using the function "Video Frames Selection and Interface Configuration", VFSIC)
    - WiFi access point (TE is performed by the Wireless Access subsystem using the function "802.11aa and Dynamic Configuration", WMDC)
- In all gateway nodes (SGSN/GGSN, P-GW/S-GW)

XLO:

- LTE eNodeB and WiFi PoAs
- All gateways (SGSN/GGSN, P-GW/S-GW)

Network monitoring:

- Any main switch or router

4.5 Multicast support

The MEDIEVAL project uses multicast for some scenarios such as Mobile TV and personal video broadcast. The project targets a number of innovations to support multicast, namely in the Wireless Access subsystem concerning multicast support in 802.11 and LTE, as discussed in D3.1 [29], and in the Mobility subsystem concerning multicast mobility for receivers and potentially also sources, see D4.2 [31]. The LTE architecture supports multicast (or rather broadcast) traffic through the eMBMS specification, which is based on IP multicast in the operator core network. Modifications to and extensions of eMBMS in the Wireless Access subsystem need to be coordinated with the multicast support in the Transport Optimization subsystem.

For this reason, interfaces of the Transport Optimization subsystem need to support multicast traffic. In particular, session setup through the NEGOCODE protocol, as well as the interfaces to the Video Services, Wireless Access, and Mobility subsystem need to be multicast aware and support the same information and control primitives.

In the XLO, multicast support requires more fundamental modifications than just interface support. Since the cross-layer techniques of packet dropping, SVC layers selection, adaptive coding and modulation trade off QoE and consumed resources; these decisions need to take into account the number of affected users as well as the heterogeneity of users in the different multicast / broadcast scenarios.

Since multicast is mainly used for live streaming, the CDN itself is usually not involved and for this reason need not support multicast. It may however be part of such multicast streaming trees to store live content in the CDN (pre-fill the caches) for later individual consumption, or support functionality such as pause and rewind of a live video stream. This option is to be investigated at a later stage in the project.

In the core network, multicast functionality is provided by IP multicast through PIM-SSM, as in eMBMS. Depending on whether the content source is in a multicast enabled network, multicast trees are anchored directly at the source, or are rooted at the MBMS-GW co-located with the mobility access router MAR (see D1.1 [27], Section 6.1.2.5). In case IP multicast is used (e.g., for life streaming) but content needs to be also stored in the CDN to provide access at a later point in time, one or more CDN nodes may join the multicast tree as multicast receivers.

Another point of investigation is whether to provide functionality of dynamically switching between multicast and unicast for the same session depending on the number of receivers. Such functionality can be used to optimize the overhead for multicast delivery, but only provides gains when the multicast group sizes vary significantly over time and overhead is a major concern. At this stage, it is not clear if these potential gains outweigh the additional complexity of integrating such functionality into the overall architecture.

Note that the CDN nodes may use an overlay multicast solution to exchange traffic among them, for example to replicate or move content. However, since this traffic is internal to the CDN and only affects the CDN nodes, this design decision does not affect any other Transport Optimization modules or outside interfaces.

The following list gives an overview of the components and interfaces affected by multicast:

- Traffic engineering module: Scheduling, layer/packet dropping, and transcoding mechanisms may need to take into account the number of affected receivers. As an example, it may be reasonable to give preferential treatment to multicast flows with a large receiver set compared to unicast flows, since a large number of users benefit from the flow.
- Cross-layer optimization module: FEC/ARQ design and QoE optimization may need to take into account the number of affected receivers; buffer management may need to track the buffer state of some or all receivers of the multicast group.
- Core network monitoring module: It needs to be aware of the type of traffic that is monitored (unicast/multicast); depending on where information is gathered, this may involve keeping track of specific multicast sessions, group membership etc. or can be on an aggregate level (see Section 4.3.3).
- Decision module: When taking flow based decisions (handover) or receiving flow-based information (session establishment), the decision module needs to be aware of the type of flow (unicast/multicast). For example, multicast session initiations may be granted a better QoS level, preferential treatment concerning content location and load balancing, etc., depending on the number of users benefiting from the multicast flow.
- Interfaces: Since the Video Services, Wireless Access, and Mobility subsystems all deal with multicast, all interfaces between the Transport Optimization subsystem and other subsystems need to be multicast aware (decision module ←→ Video Services and Mobility subsystem; cross-layer optimization ←→ Video Services, Wireless Access, and Mobility subsystem).

5 Usage Scenarios

The following section provides information regarding possible service use cases and its relation to the Transport Optimization subsystem and the MEDIEVAL architecture. The purpose of this section is to validate the interfaces and architecture. The section covers the use of ALTO services, PoA's selection, and simultaneous use of LTE & WiFi networks for different flows, flow mobility between access networks, congestion with QoE maximisation handling and more.

In the following, we describe the use of CDN mechanisms and transport optimization functions at the example of use case 2 "Arriving at the city" which is introduced in the MEDIEVAL deliverable D1.1 [27].

<u>Step 1:</u>

John is going to Cannes to view the Cannes Film Festival. He lives in Italy and the best way to go there is by train. So right now he is taking the bus to the train station.

His smart phone is on and attached (registered) to the LTE network of the operator he is subscribed to (Home Operator). He is waiting for a bus (his company strongly suggests to use public transportation rather than taxis when at home). While he is waiting he starts to watch a video on his screen to distract himself (VoD video service).

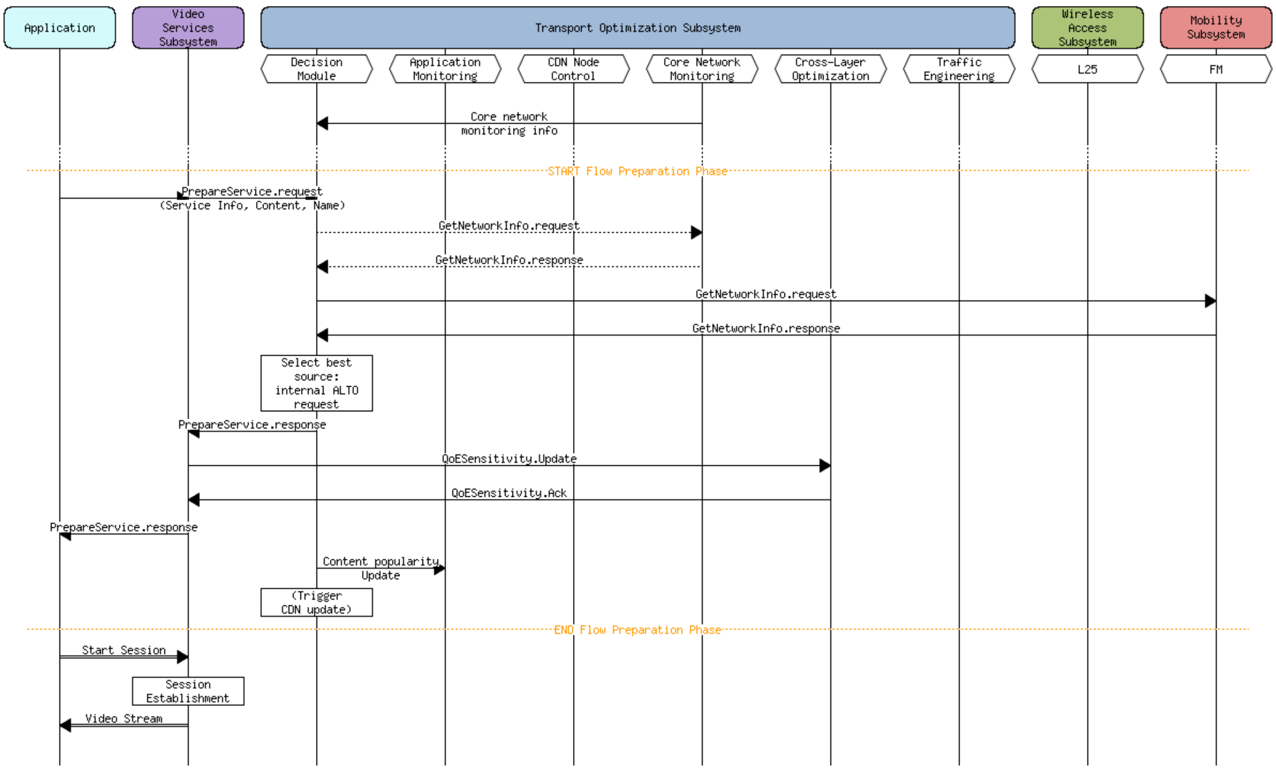

Figure 9: Session setup MSC from Transport Optimization point of view

John has opened the application/browser and sends an http content retrieval request. In the session setup, from the transport optimization point of view, there is no difference whether this is an external YouTube link or internal ISP content. Also, it does not matter, whether this is a chunk of 2 seconds or an entire clip.

A redirector/proxy module in the Video Services subsystem retrieves the http request, parses it, and triggers a session setup. The session setup is composed of a number of stages, and involves Video Service and Transport Optimization entities see Figure 9: The VSP first sends a `PrepareService.request` message to the DM, which is then requesting information from the Mobility subsystem about the current PoA resources. In addition, core network monitoring information is available from the CNM module. Next, NEGOCODE functions are invoked (see Figure 10) in order to obtain the best source for the requested content. If the content is available in the CDN (in the requested bitrate and format), the locator (e.g. the IP address) of the CDN is returned to the QoEVC; otherwise the locator of the original source is returned.

Next, the QoEVC will search internally whether this content already has sensitivity metadata. If not, it may trigger a background process that derives it for further users' use. The QoEVC will send the video sensitivity and other parameters to the XLO. If sensitivity metadata is not available, the average reference curves will be provided to the XLO.

The DM then sets up the session with the relevant FM, and provides information on the service and content to the Mobility subsystem. After finishing the setup, the DM acknowledges the video service portal (VSP) of session setup/update complete by sending a `PrepareService.response` message.

Based on this information (including the locator of the video), John's request is redirected to that address. At this stage, John's browser starts retrieving the adaptive streaming information and John can start watching the video. Finally, the DM triggers a content popularity update in the application monitoring module.

The selection of storage locations, called endpoints, using NEGOCODE is explained in detail in the next paragraph (see also Figure 10):

The video that John watches is an old movie called "MEDIEVAL Story" and directed by Ms. MN who attends Cannes. The movie is being disseminated by a content provider on several spots in the world. Not uniformly though as the video is only popular in its home country and among fans of Ms. MN in the world. John has also started to download 2 videos about the place he stays near Cannes that he needs and may watch sometime.

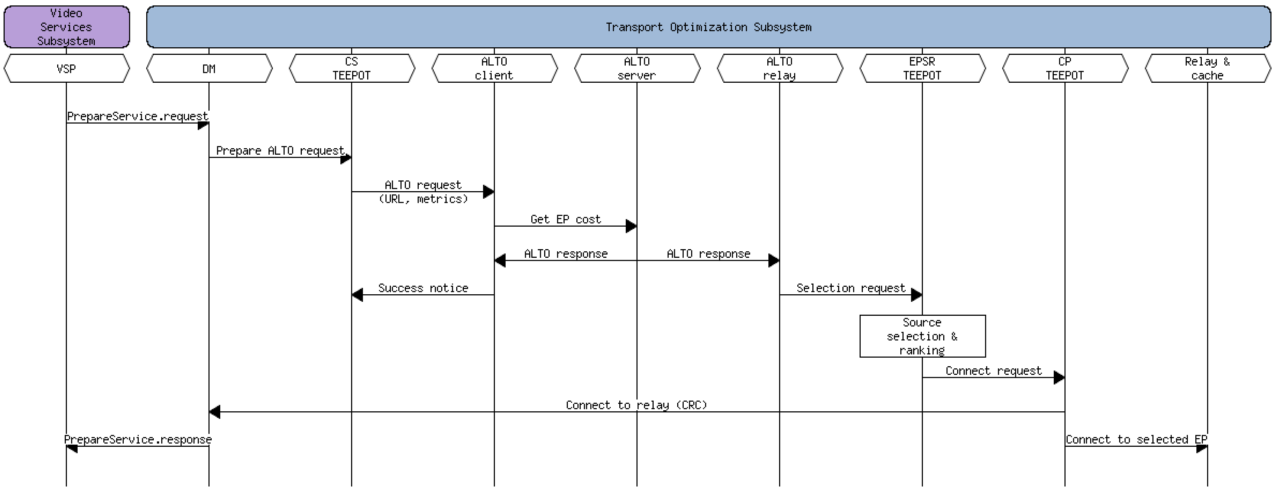

Figure 10: Selection of endpoints using NEGOCODE

John's UE is MEDIEVAL-capable and once a set of locations hosting the 3 videos has been identified, it is sent to the decision module, together with John's preferences on minimal latency for "Medieval Story" and minimal losses for the 2 other videos. The connection specification (CS) TEEPOT in the decision module specifies that 3 connections are needed: 1 minimising latency (metric2) and routing cost (metric1), 2 minimizing routing cost and packet loss (metric 3).

The CS TEEPOT in the decision module is co-located with an ALTO Client to whom it forwards the request in a format compliant to an ALTO protocol request. The request contains the IP addresses of the sets of locations and associated metrics on which to provide values.

If the ALTO server responds successfully, the CS TEEPOT gets a success notice from the ALTO Client and sends to the endpoint selection and ranking (EPSR) TEEPOT a request including a set of endpoints with associated metrics and metric weights.

In the meantime, the ALTO server sends the information requested by the ALTO client to the ALTO relay while the ALTO client only gets noticed on the “transaction success”. The ALTO relay forwards the information to the EPSR TEEPOT that is ranking and selecting a number of connection endpoints. The resulting set is sent to the Connection Preparation (CP) TEEPOT.

The CP TEEPOT contacts:

- A selected Connection Relay & Cache (CRC) whom it tells to connect to the identified Endpoints and get the identified content from,
- The application client whom it tells to connect with the CRC identified by e.g. its IP address.

John gets the 3 requested videos with a nice QoE, thanks to a selection of endpoints driven by the hosting ISP that optimises its resources. Thanks to ALTO relays, no information on the ISP’s transport network is unveiled to the application client. The selected CRC supposedly can temporarily cache the videos, likely to be watched by other people journeying between Italy and Cannes. As this caching becomes persistent, the CRC may be included in the set of CDN nodes.

Step 2:

The bus arrives; John moves inside, where he sits and continues watching the video. During the whole trip John continues watching the video without losing his connection or his video showing any disruption.

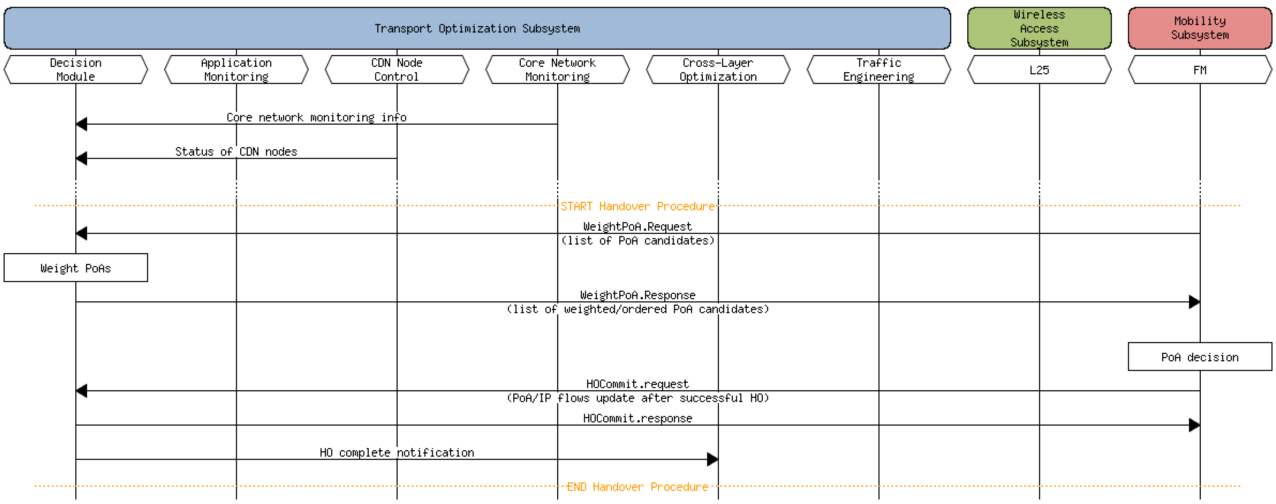

Figure 11: Handover MSC from Transport Optimization point of view

During the trip the Mobility subsystem will receive information about available PoAs from the Wireless Access subsystem. Before performing a handover to a new PoA it will send a `WeightPoA.request` to the decision module (see Figure 11). The decision module knows which CDN nodes are located closest to the PoA candidates. It also knows about the status of the core network (from measurements performed by the CNM) and the relevant CDN nodes (provided by the CDNNCs). Based on this data, the DM weighs the PoA candidates. For example, a PoA will receive a low weigh if its corresponding CDN node has a high load. Also, one candidate might be ranked low, if the link to the CDN node was reported to be congested.

The weighted list of PoA candidates is then returned to the Mobility subsystem, which will consider these weights in its decision to select the new PoA to connect to. The final decision is then reported back to the DM, such that e.g. resource at the CDN nodes could be adapted accordingly or some cross-layer optimization could be performed.

Considering the status and location of the CDN nodes will enhance the decision on which PoA to choose, thus improving the overall QoS/QoE for John. The required handovers will be smoother and John will hardly notice that his smart phone is connecting to different PoAs during his trip.

Step 3:

John starts a new application (e-mail), while connected on LTE and the video flow keeps running in the background.

The new service triggers a new session setup, during the session setup, the PoA of the new service may result in a different optimal PoA to the service (due to network available resources or congestions at the current PoA), the new flow thus may be initiated on a different PoA at the LTE network while in parallel the existing video service is attached to another LTE PoA. While the two PoAs are associated to two different services, the network allocates both PoAs to be associated to the video service which has higher priorities over the background email session. The video service now is able to use both PoA simultaneously to achieve higher rates while the email uses the available resources in a best effort manner.

Step 4:

John arrives at the train station (he is still watching the video and handling e-mail, so there are two active flows) and connects to the WiFi network. The video flow is moved to WiFi (what is commonly referred to as WiFi offload). E-mail data packets remain being received on the LTE network. This flow handover is inter-technology/intra-domain: the Hotspot WiFi is managed by the same operator that the LTE network.

After detecting a new PoA, namely the WiFi hotspot, the Wireless Access subsystem informs the Mobility subsystem of the new handover candidate network. Instead of taking the handover decision on its own, the Mobility subsystem will exploit the cross-layer functionalities provided by MEDIEVAL requesting a weighting of the available PoA from a network perspective.

In our use case, the decision module confirms that the traffic conditions inside the observed network are good and both PoA are weighed high. Based on this observation, the Mobility subsystem decides on moving the video flow to the WiFi network which provides a higher bandwidth.

Step 5:

The train arrives and John moves inside, where he sits and continues his trip. The train is equipped with a WiFi on-board network. Due to a status of network congestion in the WiFi hotspot of the train station, John's smart phone switches the video-streaming to the WiFi network offered by the train while maintaining the e-mail flow anchored to LTE. This intra-technology handover is intra-domain (the WiFi over the train is operated by the same operator as the WiFi hotspot).

The core network monitoring module provides the XLO module with traffic information, signalling in particular when an area becomes congested (WiFi hotspot in the station). In our use case, the congestion happening at the WiFi hotspot in the railway station is signalled to the XLO module (see Figure 12).

At this stage, the XLO needs information from the Video Services subsystem about the E2E network information, e.g. E2E delay, and from the Wireless Access subsystem about the access network availability and capabilities (presence of a WiFi spot available and not fully used in the train). Once the optimization algorithm is executed, a TE function is selected and performed either in the core network, or in the PoA (simple frame dropping), or at the content provider (new video format fitting the updated conditions) or it checks for possible handover candidates.

In our use case, the optimal solution taken by the XLO is to switch the video flow of John from a WiFi PoA (at the station) to another one available and less used (in the train). Thus, the TE action is performed via the Mobility subsystem, moving the flow from one PoA to another one. This result cannot be achieved by current video delivery architectures since only the MEDIEVAL architecture monitors the traffic conditions at different network levels. Thus, it is able to select the best solution available at each level of the protocol stack and at each network node involved.

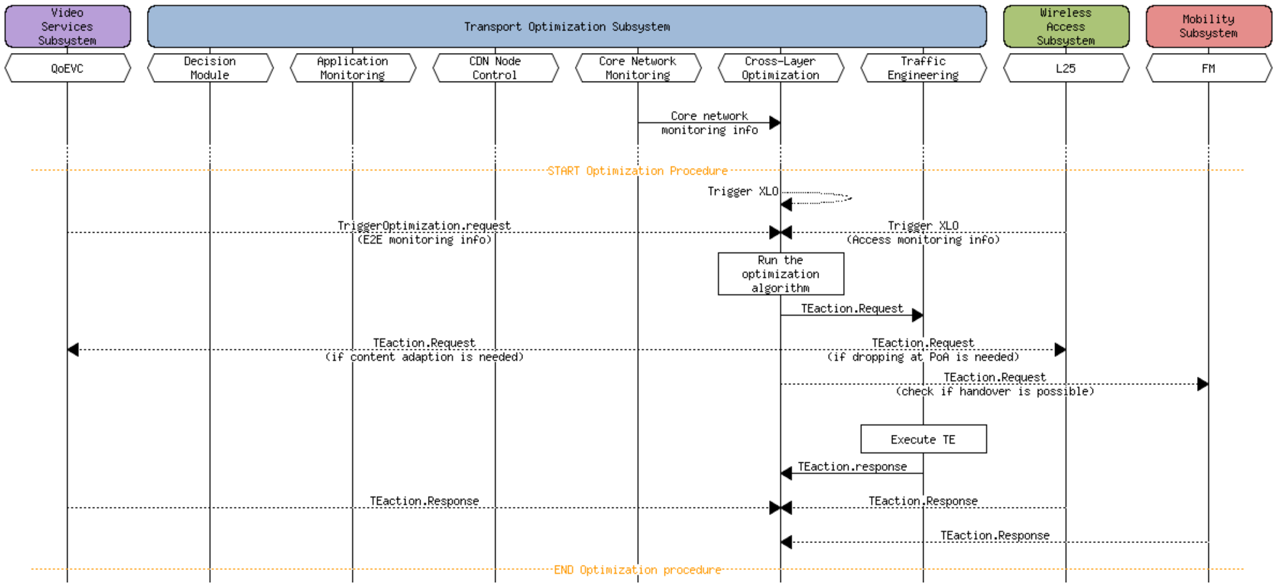

Figure 12: Traffic optimization MSC

<u>Step 6:</u>

John arrives at Cannes, in France. Even if WiFi is available at the train station, his mobile (based on interactions with the network) connects to the LTE network as the video requirements are better met by the available provider. This way he connects to the local French provider (inter-domain/inter-technology handover) and gets into a taxi.

The LTE provider was chosen because the local WiFi network at the train station was already congested due to the crowd. The LTE network provides QoS and the video service preferences cause the XLO to hand over the service to the LTE network which could provide better performance to the user: Transferring the resources to LTE involves mechanisms which allow simultaneous use of both networks (i.e. make before break) to support smooth mobility. Only after LTE session setup was completed and the QoE/QoS was guaranteed, the WiFi session is terminated.

<u>Step 7:</u>

After arriving at the Cannes film festival, John is waiting in the queue. He starts watching a live feed on his mobile (through Mobile TV video service), as are most of the people who are also queuing. Everybody is trying to watch what is happening inside and on the red carpet interviews.

The video is accessible through multicast.

Since other users already access the live video feed, the data is already broadcast by the base station. John joining as additional user does no consume any additional resources, neither in the access network nor in the backhaul, or core. The core network monitoring module obtains information from the CNM_L25 interface between the CNM and the wireless access network about the increased number of users accessing the multicast stream. If necessary, this information is then used to update the layer dropping / packet dropping rules of the traffic engineering module and the QoE optimization and HARQ parameters in the cross-layer optimization module due to the increased number of users benefiting from the content.

In the core network, the live stream is transported via IP multicast (PIM-SSM). Since the content source is within the multicast enabled core network of the mobile operator, the root of the multicast tree is at the content source. Since the content is also stored for offline viewing, and it is expected that there will be high demand for that content, nearby CDN nodes join the multicast session as clients and proactively buffer the stream. This decision is taken by the CDN decision module.

6 Interfaces

In this chapter we provide an overview of the internal and external interfaces (see also Figure 13). In this deliverable our goal is to give an overall idea of what such interfaces are designed for. External interfaces are described in detail in deliverable D1.1 [27]. Internal interfaces are not yet described in detail due to the late start of WP5 (in month 4), thus the final and fully detailed specification of the internal interfaces will be provided in deliverable D5.2 (June 2012).

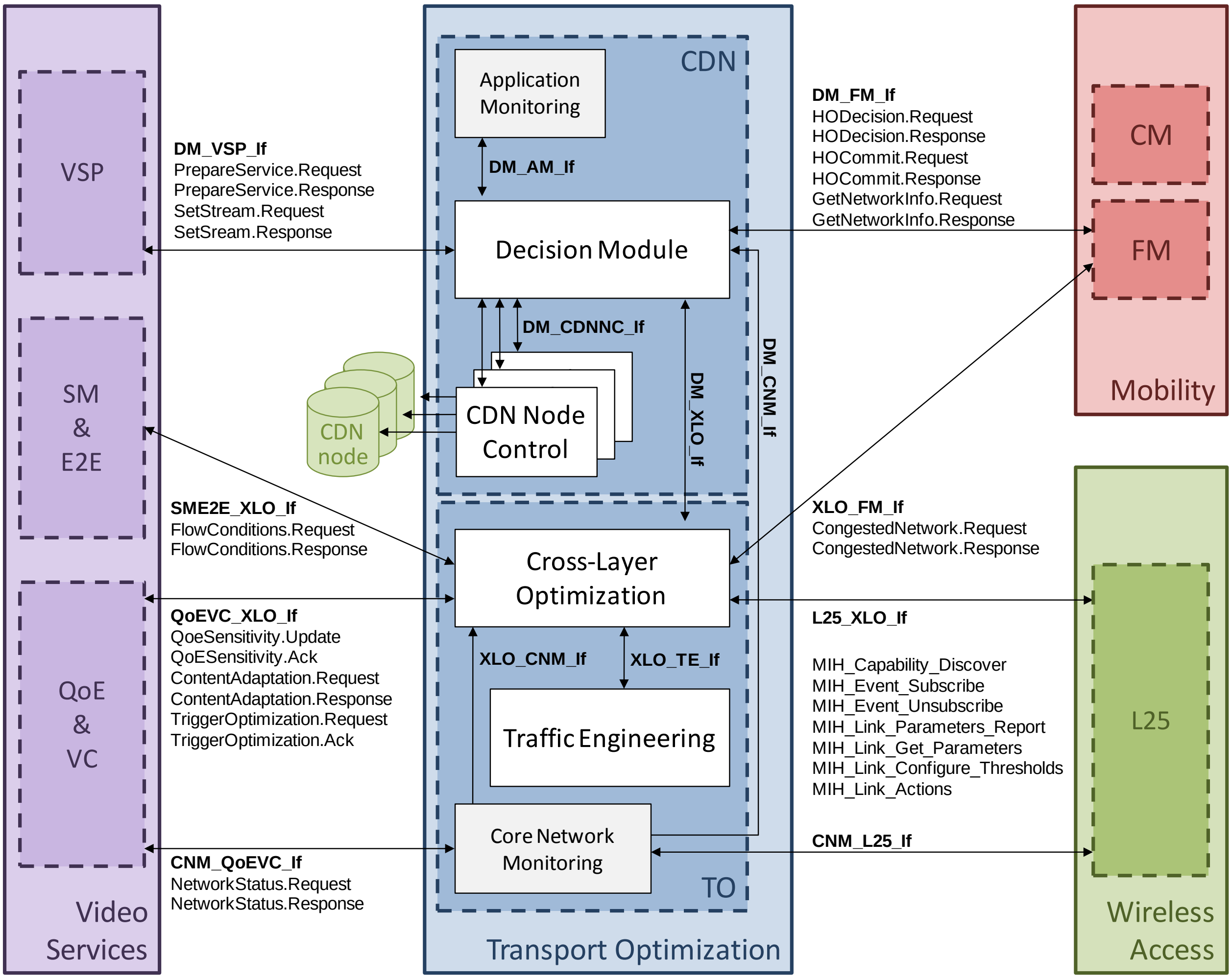

Figure 13: Interfaces of the Transport Optimization subsystem

6.1 Transport Optimization internal interfaces

In the following sections we describe the internal interfaces of the Transport Optimization subsystem, as depicted in the blue block in Figure 13.

6.1.1 Interface DM_XLO_If

This interface forwards information about HO complete and termination of the video session to the cross-layer optimizer, for an optimal handover decision to be taken when interacting with mobility entities. The interface is multicast aware, thus the cross-layer optimizer will run the heuristic algorithm according to the constraints introduced by either the unicast or multicast scenario.

In the other direction, the decision module receives a message from the cross-layer optimization module if a handover was triggered to the Mobility subsystem.

6.1.2 Interface DM_CDNNC_If

The interface between the CDNNC and the DM is used to provide status information of the CDN nodes, i.e. their availability, load, and cached data. The CDNNC will receive commands from the DM concerning content storage, like store/delete requests to accommodate the caches in the CDN nodes to changes in the popularity ranking of the content

6.1.3 Interface CDNNC_CDNnode_If

The interface to the CDN nodes is used to issue node specific control commands and query status information.

6.1.4 Interface DM_AM_If

The interface between the application monitoring (AM) and the decision module (DM) is used to transmit the following data:

- DM → AM: request for video X from region Y (to update the popularity of the video X in region Y)
- AM → DM: top ranked videos and their (predicted) popularity for the different regions

The AM has no other interfaces with other building blocks.

6.1.5 Interface DM_CNM _If

This interface provides information about the current network conditions (in particular the network load) to the decision module which are then used for selecting the optimal CDN node. These involve measurements performed by the core network monitoring module itself on core router and link status, as well as measurements performed by other modules on E2E-monitoring (Video Services subsystem) and on access network monitoring (Wireless Access subsystem) that are delivered to the network monitoring module for collection and aggregation.

This information is necessary to optimize the decision on where to cache which content and from where to stream content to users. The NEGOCODE TEEPOTS need additional mobile core network information; this is not supported by the ALTO protocol as it is not related to the ISP routing preferences and not accessible to the ISP. A typical example is the memory of CDN endpoints especially if it is provided at a short time scale.

6.1.6 Interface XLO_TE_If

The cross-layer optimization module communicates to the traffic engineering module the action to be performed on the problematic video flow (e.g. packet/layers dropping). The engineering technique to be executed is eventually communicated to the Video Services, Wireless Access or Mobility subsystem. For instance, whenever the outcome of the optimization procedure turns to be “packet dropping” at a target PoA, then this request will be communicated to the Wireless Access subsystem which will act as a TE by executing such action at the PoA (edge of the core network).

Moreover, the fullness state of the MAC buffer (cross-layer optimization module) is communicated to the layer filtering (traffic engineering module). In this context we have a loop-based approach, since after selecting some packets, the MAC state is updated and retransmitted to the layer filtering block, and so on.

6.1.7 Interface XLO_CNM_If

The core network monitoring (CNM) monitors a set of parameters related to flows, e.g. available bandwidth or quality of the flow in term of loss. When congestion occurs, the CNM activates the cross layer optimizer to solve the problem.

When congestion is not detected, the cross layer optimizer is activated through the Video Services subsystem in case of QoE degrading. In this case, the cross layer optimizer is helped by the different parameters measured and monitored by the CNM.

6.2 Interfaces with Video Services (WP2)

The interfaces between Transport Optimization subsystem and the Video Services subsystem (see [28]) are designed to improve the handshake between the Video Services subsystem and the network mechanisms addressing the goal of maximizing the QoE retrieved by the users. The handshake allows the Video Services subsystem to inform the XLO about the video sensitivity requirements. It also allows the services to search cached content in the network and to coordinate content adaptation when resources are changed in the network.

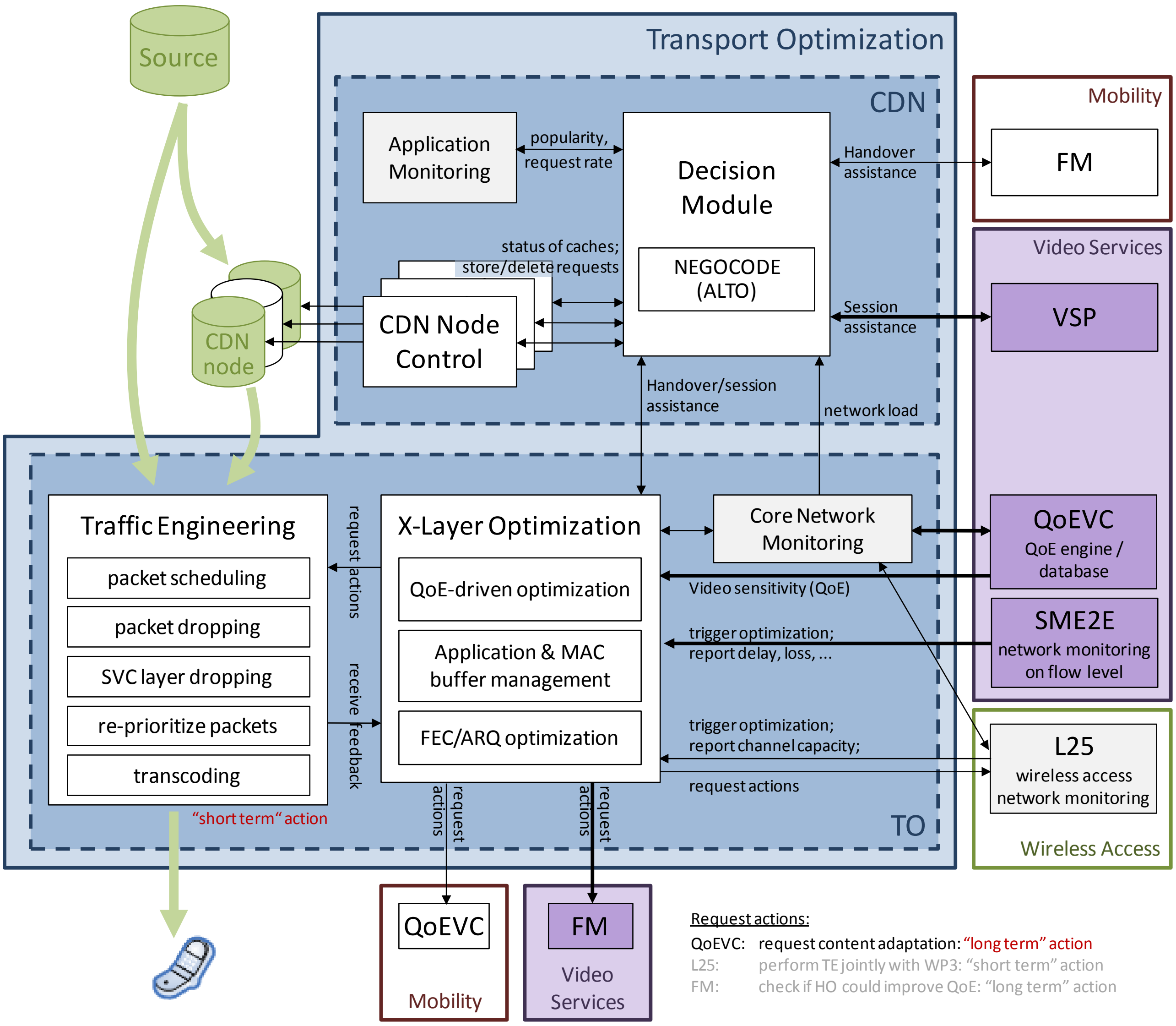

Figure 14: Interfaces with the Video Services subsystem

6.2.1 QoEVC_XLO_If

The cross-layer optimization module receives video sensitivity information (QoE-based measurement) in the form of a utility function from the QoE & video control module (QoEVC) in the Video Services subsystem. This utility function describes, for instance, the relationship between the perceived quality and a set of objective parameters, such as data rate and packet loss. The XLO uses this function (sub-block QoE-driven optimization) to evaluate the impact on QoE when computing the optimization problem.

While this offline video sensitivity computation and communication from the QoEVC to the XLO is feasible for VoD, for live video (streaming) the QoE engine will provide a set of average sensitivity values (taken from a large set of videos analyzed) on the relationship between perceived quality and, for instance, data rate. This average is an approximation which gives a statistical reference on the relationship between the two measures to the XLO.

The QoE sensitivity information is sent during the session initiation from the QoEVC to the XLO, or as soon as the video stream starts. Moreover, this QoE signalling should be repeated during the video session, at a certain time interval (depending on the dynamicity of the video), to catch the changes of the QoE sensitivity of the video played (including possible advertisements, news, etc.) and promptly update the XLO procedures.

As soon as the TO is not able to maintain from the network point of view a certain QoE level for a video flow, the XLO indicates to QoEVC that the QoS provided by the network is degrading or over-provisioned. Thus, a request for content adaptation (send video in a different format) is sent to the QoEVC in the Video Services subsystem, in order to avoid or limit the amount of packets being dropped at the network, if though the throughput is too high for the network to handle it by dropping packets with accordance to the provided priorities by the QoEVC.

Based on the E2E monitoring done in the Video Services subsystem, it may be identified that a certain flow does not allow acceptable delivery over the network, thus the QoEVC may trigger the XLO to request focused resource shifts to improve the conditions of the suffering service.

6.2.2 SME2E_XLO_If

Through this interface, the cross-layer optimizer receives information on the flow conditions (end-to-end (E2E) delays and losses) on the application's point of view from the session management and E2E monitoring module. This information is then used, possibly in combination with the core network monitoring information from the network, to best cope with problematic flows by means of traffic engineering mechanisms decided upon the computation of the cross-layer optimizer.

6.2.3 DM_VSP_If

When the user is looking for specific content through let say the video service portal (VSP) in the Video Services subsystem, the VSP is establishing an handshake with the DM to identify the list of available content for specific selected service. Then, the DM (through the NEGOCODE functions) is looking for the best matching cache (in case of VoD) to serve the selected content, and provides the VSP with the IP address and other information needed to retrieve the content.

6.2.4 CNM_QoEVC_If

Provide information about the core network status from the network monitoring block to the QoEVC in the Video Services subsystem.

The CNM monitors the network's status and provide useful information to the QoEVC in order to adapt the content taking into consideration the network status, information such as buffer states, delays, lost and momentary service throughput will be provided. The QoEVC will collect that information, process it, and decide about the best adaptation mechanisms with respect to the specific service, in that case for live video it may adapt the encoding rate, or change the amount of FEC packets.

6.3 Interfaces with Wireless Access (WP3)

Interfaces with the Wireless Access subsystem are about the exchange of information between the core and access networks to gather, on one side, the parameters from the lower layers, i.e. from the L25 abstraction layer, to best perform the optimization at the cross-layer optimizer (thus acting as MIH user), and, on the other side, to communicate to the Wireless Access subsystem (L25) optimal traffic engineering actions to be performed at the PoAs.

In this section we give a high-level description of the interfaces between the Wireless Access subsystem (see [29]) and the Transport Optimization subsystem.

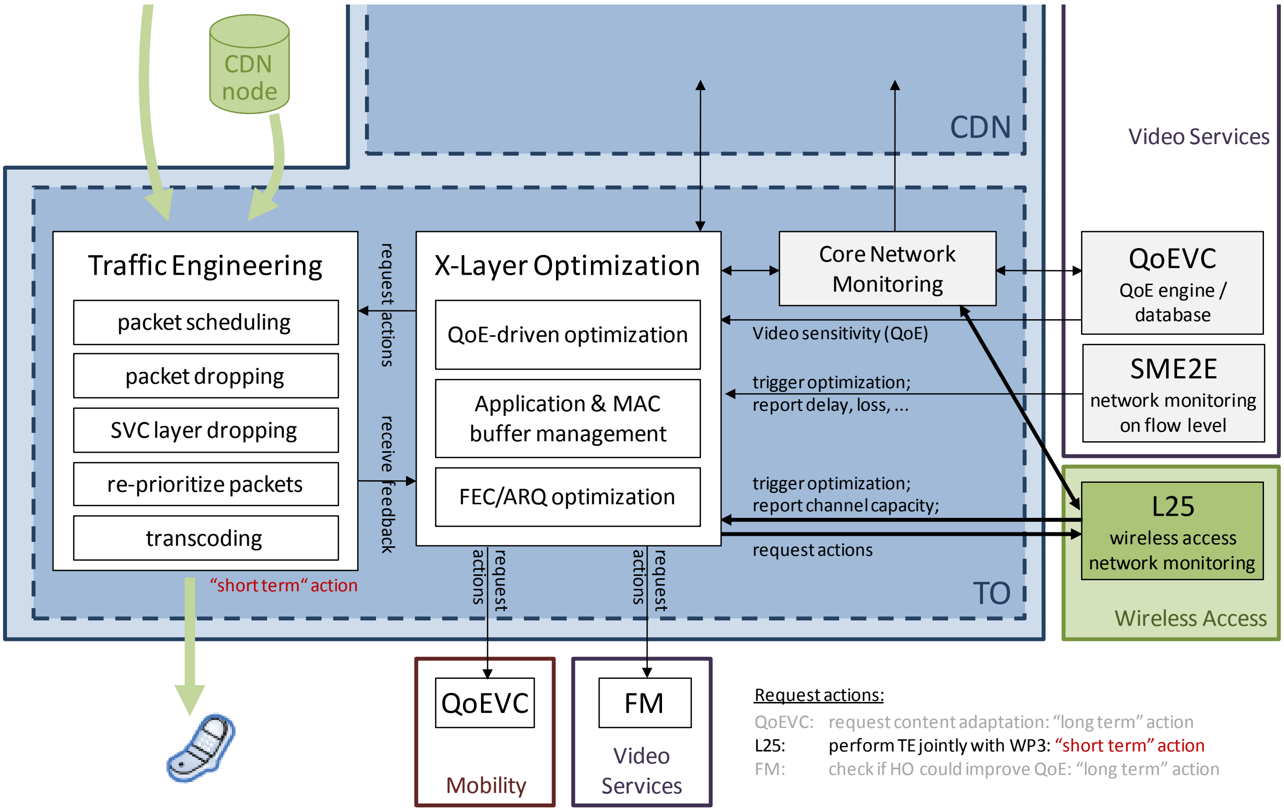

Figure 15: Interfaces with the Wireless Access subsystem

6.3.1 L25_XLO_If

The cross-layer optimizer, here considered as MIH user of the L25 component, receives information from such component on available radio access networks and radio parameters, like SNR, packet loss, QoS levels, number of queues and buffer states that are necessary for performing the cross-layer optimization.

Thus, it receives information about the availability of the wireless accesses (available access technologies and access networks in the neighbourhood) and the dynamic variations of the wireless access link parameters such as the quality and, whenever it is feasible, its capacity.

Moreover, the optimizer receives information about specific Jumbo Frame functionalities such as aggregating non-related traffic (or traffic from different flows), as well as providing indications necessary for the transport of Jumbo Frames, such as frame size and queue delay.

The terminal capabilities (size of the screen, available network interfaces), its active links and flows, or the counting of receivers in case of multicast might be also communicated through this interface.

Finally, this interface receives information about the mobility scheme support and about the availability of multicast support in the access networks.

On the other way around, when the cross-layer optimizer communicates the outcome of the optimization to the traffic engineering module, it can trigger the wireless access (eNodeB) when it requires to jointly perform an action, such as for instance packet dropping or re-prioritization of packets at the eNodeB (or Wi-Fi PoA).

Moreover, the Transport Optimization subsystem can change the priority marking (specifying QoS requirements of the flows) of video packets when needed (through the TE module), which will be then used by the Wireless Access subsystem for eventually scheduling or dropping the packets at the wireless access.

6.3.2 CNM_L25_If

The core network monitoring module communicates with L25 module to get the status of the wireless access, either it is LTE or WiFi, and uses this information to monitor the whole network (core and access parts). This information can be then used by the cross-layer optimizer to run the optimization algorithm when needed by the video delivery chain.

6.4 Interfaces with Mobility Subsystem (WP4)

Interfaces with the Mobility subsystem (see [30]) are related to handover procedures. The Transport Optimization subsystem supports the mobility management to select optimal handover candidates from the network point of view. Also, the XLO may trigger a handover in case of network congestion.

All interfaces with the Mobility subsystem are API based protocols.

6.4.1 DM_FM_If

On this interface, the flow manager (FM) of the Mobility subsystem will inform the decision module about the preparation of a (vertical or horizontal) handover by sending a list of potential handover candidates and associated IP flow list mapping to the DM. The list is a pre-selected list of various PoAs signalled from the Wireless Access subsystem and it is sorted by the handover decision algorithm in the FM taking into account the resources availability and IP flow requirements.

The decision module responds to the above request with a weighted list of these candidate PoAs based e.g. on availability, proximity, and current load of the CDN nodes. These weights will then be considered by the FM to finally select the handover target network.

Upon handover execution, the FM informs the DM about the new PoA / IP flow distribution, such that the DM can trigger any required action, like an update of the distribution of content in the CDN nodes.

6.4.2 FM_XLO_If

The cross-layer optimization tries to improve the flow of the video data inside the network. In case of congestion or limited resources, the module will propose several traffic engineering techniques to be performed in order to solve or improve these limitations and provide an optimal overall QoE to all users. The possible actions include also a handover to another PoA in order to, e.g., avoid a congested base station or route the data on a different data path through the network.

The handover will take some time to be completed, thus this action is regarded as optimization one a “long term” time scale (compared to “short term” actions like packet dropping)

If it is not possible to maintain a certain QoE due to e.g. congestion at a CDN node, the XLO can trigger the FM using this interface to initiate a handover to another PoA. Therefore, the XLO will send a list of IP flows that should be improved. The FM will then check if other PoAs are available that could be used as alternative to the current PoA. If so, the FM will initiate a handover process as described in Section 6.4.1, i.e., send a list of handover candidates which will be weighted by the DM.

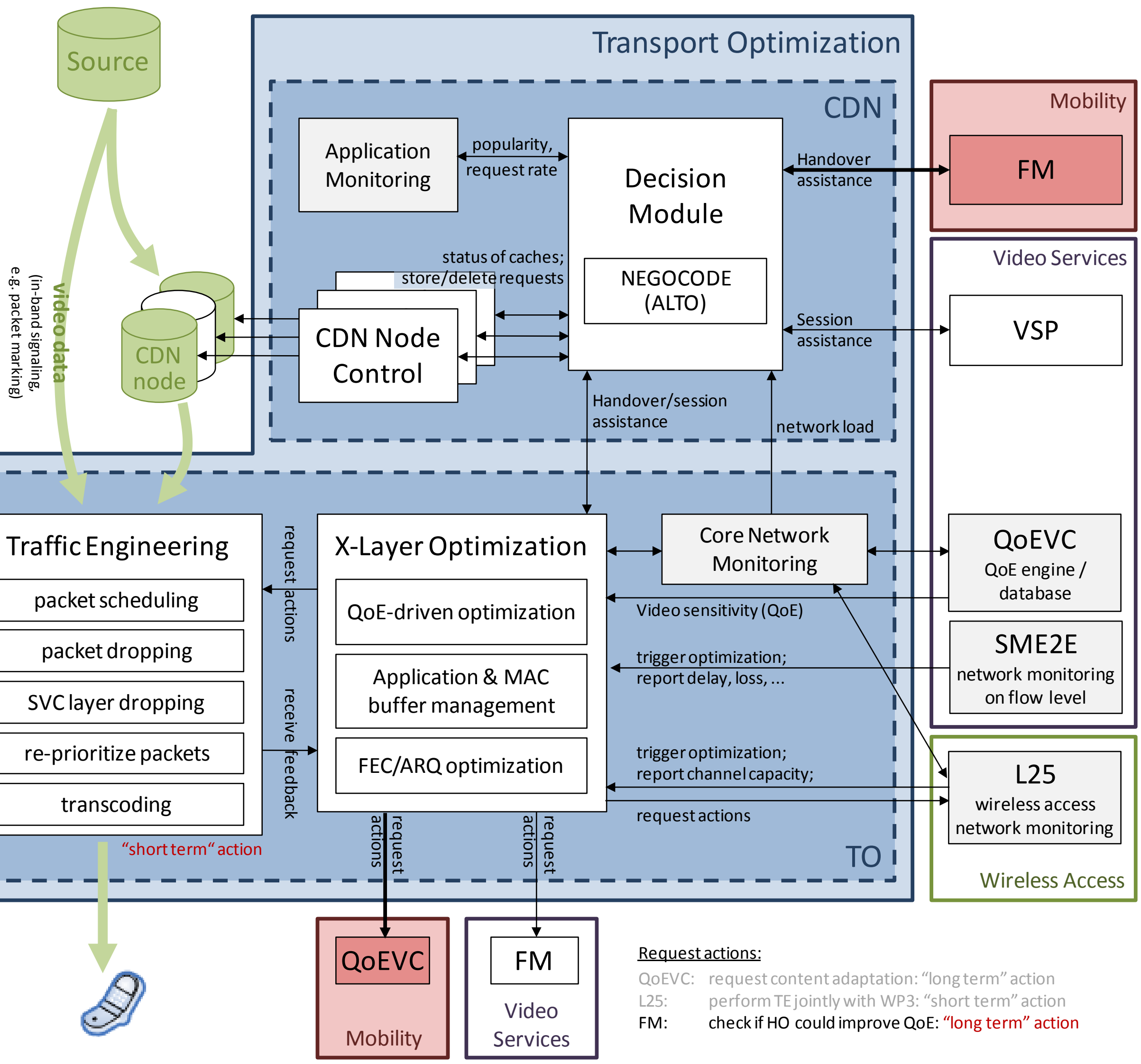

Figure 16: Interfaces with the Mobility subsystem

7 Summary and Conclusion

The MEDIEVAL project aims at defining and implementing network functionalities and associated protocols for an enhanced video delivery over mobile networks. Starting from the current standardization activities in 3GPP and IETF, the project evolves today's cellular network architecture, integrating sophisticated and intelligent cross layers network functions able to recognize video characteristics, to classify IP traffic accordingly and to adopt network delivery services of selected policies for improved video traffic delivery.

In this project, the Transport Optimization subsystem covers the decision and TE mechanisms to optimize video streaming through CDN techniques, optimal source selection and tracking and cross-layer transport optimization inside the mobile core network.

7.1 Challenges

Several challenges appear and the Transport Optimization subsystem addresses the following:

- Integration of content distribution functionalities in the mobile network including:
    - Selection of optimal locations for CDN nodes.
    - Proactive push of content to caches to maintain a low access delay.
    - Network-aware selection of optimal locations from which to download content, considering network layer information and mobility of users.
    - P2P-inspired content exchange among caches to further reducing of server load.
- QoE based cross-layer design to adapt the wireless access parameters to the transport network and video traffic requirements.

To address these challenges, the Transport Optimization subsystem is divided in two blocks intended to implement the following solutions:

- The CDN component (CDN) drives optimization at several stages of content handling:
    - CDN.1: Pro-active off-line placement of contents in the CDN nodes,
    - CDN.2: On-line network guided selection of content locations from which to download,
    - CDN.3: On-line download and placement of contents in P2P or CDN Client nodes,
    - CDN.4: Multicast content delivery,
    - CDN.5: Relay-assisted delivery.
- The transport optimization component (TO) includes XLO and TE and acts upon the following hierarchy:
    - TO.1: Adapt the video content to meet the channel conditions (Video Services subsystem);
    - TO.2: Deal with users mobility performing offloads of the traffic (Mobility subsystem);
    - TO.3: Deal with congestions by means of packet scheduling, dropping and re-prioritization, layers dropping and transcoding.

7.2 Results

In the past and first 8 months of this work package, WP5 has output the following:

- At the Transport Optimization subsystem level:
  - Design of the overall transport optimization architecture, putting together the different partner's visions.
  - Design of the interfaces between the Mobility and the Transport Optimization subsystem for handover issues. Harmonizing the interfaces and components with the other MEDIEVAL subsystems.
  - Work on the physical placement of the transport optimization components. Definition of a MSC for TO internals and communication with other subsystems.
- In the CDN component
  - CDN.2: A functional architecture has been defined for a set of functions called NEGOCODE that includes an algorithm to select content locations that combines several metrics such as bandwidth, memory capacity, and latency in a robust way.
  - CDN.1 and CDN.4: Multicast considerations and interfaces, investigation of efficient layered multicasting through coding, initial performance analysis of coded storage on data resilience.
  - CDN.5: Introduction of Connection Relays between the storage locations and the Application Clients, who are no more directly connected to the storage locations but to a Connection Relay.
  - The implementation of the NEGOCODE functions is coupled with evolutions of the IETF ALTO protocol that have been proposed: introduction of ALTO relays associated to Connection Relays, for purposes of network provider confidentiality see draft [3]; extensions to support transactions involving several cost types and additional ALTO cost types and attributes, see draft [4].
- In the TO component
  - Definition of the cross-layer transport optimization module and the related interfaces within the TO and with the other subsystems. The XLO problem is being modelled under a general framework of stochastic optimization (Markov Decision Process).
  - TO.1: Integration of the cross-layer mechanism for QoE-driven traffic management and design of the supporting interfaces with the Video Services and Wireless Access subsystems.
  - TO.3: Optimisation for video delivery over multiple interfaces simultaneously, i.e. 3GPP + WiFi. Specifically: first definitions for uplink algorithms, where the UE implements cross layers adaptation for SVC and AVC streams, including layer dropping and feedback messages to the source to adapt streams attributes. Definition of priority queues to handle content aware scheduling policy on the uplink. First design of multicast scheduling in collaboration with the Wireless Access subsystem.

7.3 Next steps

The plans of WP5 for the next 12-month period are to further investigate the following aspects:

- CDN: Further work on the decision module. Detailed inter- and intra-subsystem communication. Revisions to the interfaces with the other sub-systems, based on validation, prototyping and simulation work, as well as on the internal refinement work performed inside of each of the subsystems.
- CDN.1, CDN.3, CDN.4 and TO.3: Design of CDN storage and data distribution mechanisms between CDN nodes, extension of multicast streaming and CDN robustness algorithms, initial investigation of feasibility of integration with AL-FEC/ARQ.
- CDN.2, CDN.5: Further specification of the algorithms to select the Endpoints and adapt to the evolution of the Endpoints performance. Specification and distribution of the associated functions in the TO architecture and in the network infrastructure. Discovery of the Connection Relays associated to a UE and specification of their interaction with ALTO Relays and other entities.
- TO: Handling the problem of layer scheduling and filtering in terms of stochastic optimization based on Markov Decision Process and performance assessment of the algorithm. This requires building a utility function where the QoE flow sensitivity is exploited. Analysis of the scalability of the method and definition of less complex algorithms if needed.
- Definition of utility functions taking into account PHY parameters and QoE-rate relationship to start the implementation of the cross-layer optimization algorithm. Special focus will be given to ARQ/FEC implications in such optimizer and eventually to multicast implications (possibly jointly with the Wireless Access subsystem).
- Cross-layer communication with the Wireless Access and the Transport Optimization subsystems.
- TO.1: Continue the implementation of the QoE-driven optimization and deploy the optimization component and interfaces in the physical architecture. Work on traffic engineering techniques (mainly using SVC coding) for rate adaptation taking into account their impact on QoE. Enhance the QoE optimization to smooth the QoE fluctuation of users moving across cells.
- TO.3: Continue the work on Optimisation techniques for video delivery over multiple interfaces on the uplink. Complete SW design and define the implementation part for demonstration.

Standardization plans include:

- IETF
  - Extension of the ALTO protocol to the specifics of mobile core networks and the mobility of users, promotion of the Provider-confidential ALTO concept based on ALTO Relays and Connection Relaying.
- 3GPP:
  - Follow-up on QoE and traffic management support and contributions around the interfaces supporting QoE-driven traffic management.
  - In 3GPP SA2: promotion of approach to video-oriented transport optimization. In fact several proposals are currently under discussion to enable the Evolved Packet Core Network, e.g., reacting upon network congestion (User Plane Congestion Management) and dynamically adapting the active PDN connections. Along these lines the MEDIEVAL project is further investigating novel mechanisms to perform traffic engineering not only based on network congestion but also on application information and, in particular, taking into account the QoE perceived at the user side.

8 Annex: Publication efforts

D. Munaretto, "Opportunistic Scheduling and Rate Adaptation for Scalable Broadcast Video Streaming", in *Proc. IEEE WoWMoM*, Jun. 2011

This abstract aims at introducing the role that QoE will cover in next generation cellular networks and which methods mobile operators should consider to meet customer expectations. Starting from current trends in standardization, we further discuss two key objectives currently being dealt with in the MEDIEVAL research project: quasi-real time evaluation of the perceived QoE by end users and application requirements in terms of network resource usage. The online QoE computation algorithms combined with application layer optimizations give a promising solution. To this end the authors propose to exploit the ALTO protocol and its extensions for the mobile core and to evaluate key metrics (QoE-based video metrics and network metrics) in simulation and live text experiments.

N. Amram, B. Fu, G. Kunzmann, T. Melia, D. Munaretto, and M. Zorzi, "QoE-based Transport Optimization for Video Delivery over Next Generation Cellular Networks", in *Proc. IEEE MediaWiN*, Jun. 2011

Video streaming is considered as one of the most important and challenging applications for next generation cellular networks. Current infrastructures are not prepared to deal with the increasing amount of video traffic. The current Internet, and in particular the mobile Internet, was not designed with video requirements in mind and, as a consequence, its architecture is very inefficient for handling video traffic. Enhancements are needed to cater for improved Quality of Experience (QoE) and improved reliability in a mobile network. In this paper we design a novel dynamic transport architecture for next generation mobile networks adapted to video service requirements. Its main novelty is the transport optimization of video delivery that is achieved through a QoE oriented redesign of networking mechanisms as well as the integration of Content Delivery Networks (CDN) techniques.

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