Optimisation of Multimedia over wireless IP links via X-layer design

R. Fracchia[1], G. Jeney[2], M. Mazzotti[3] , E. Piri[4]

[1]Thales Communications, Colombes, FR; [2] Budapest University of Technology and Economics, Budapest, HU;
[3] Wilab – University of Bologna/CNIT, Bologna, IT; [4]VTT Technical Research Centre of Finland, Oulu, FI

E-mail: [1]roberta.fracchia@fr.thalesgroup.com, [2] jeneyg@hit.bme.hu,
[3] mazotti.matteo@unibo.it, [4]esa.piri@vtt.fi

Abstract: **This paper presents the solution designed by the ICT FP7 OPTIMIX project to enable enhanced multimedia streaming in a point to multi-point context on wireless heterogeneous systems. OPTIMIX approach is to introduce new control blocks, i.e., controllers and observer, to efficiently handle the optimization of the multimedia transmissions. The design of the controllers and of the signalling system, used to transfer feedbacks between different network entities, is described in this document. Finally simulation results as well as the test-bed that will be realized in the third year of the project are also presented.**

Keywords: Multimedia, joint source and channel coding

1 INTRODUCTION

The key issue in multimedia streaming over IP wireless links is that Quality of Service (QoS) requirements raise huge challenges not only concerning the physical bandwidth, but also the network design and services. This has to be addressed by modern communication systems where all users want to be connected dependably and efficiently.

Innovation in the area of sophisticated multimedia source coding schemes aiming to satisfy design criteria and trade-offs in terms of source representation quality, bitrate, delay, encoding/decoding complexity, etc. is a key issue in the modern world where users demand for content "anywhere and anytime". Today's approach, relying on traditional separation approaches and focusing on services delivered over homogeneous networks, does not allow meeting the on-going demands to maintain the required QoS for different users, who have different needs and requirements.

To this end, joint source and channel coding (JSCC) solutions have been proposed in the scientific literature for several decades, and have shown promising results [1]. Until recently, however, they were often considered as purely academic work, not necessarily taking into account practical considerations unavoidable in real deployment. As an example, the lacking IP network support in most initial studies resulted in JSCC optimisation strategies with a unique module for source and channel coding, which is hardly compatible with a layered approach.

The OPTIMIX project follows the path opened by FP6 IST PHOENIX project, which optimised the allocation of resources for multimedia transmission over wired/wireless links in a JSCC approach, by studying innovative solutions to enable enhanced video streaming in a point to multi-point context for an IP wireless heterogeneous system, based on a cross-layer adaptation of the whole transmission chain. The goal of OPTIMIX is to demonstrate the efficiency of having the application working as a team with the lower layers to jointly optimise the end-to-end multimedia streaming.

In this context, the OPTIMIX project develops a scheme including all the elements of major importance in a point to multi-point video streaming chain such as video coding, networking modules, MAC layer and physical layer, efficiently communicating together. In particular, OPTIMIX considers innovative techniques to improve the efficiency of video codecs when used in a wireless multi-user environment with respect to robustness, efficient compression and intelligent use of scalability schemes. Furthermore, it develops cross-layer mechanisms to enable the communication between application and transmission worlds through the use of enhanced transport and network protocols. Finally, it validates the overall system with respect to end-to-end quality optimization using a system simulator where the whole solution is implemented and preparing a test-bed with selected schemes.

2 OPTIMIX CONTROL ARCHITECTURE

The OPTIMIX project proposes a solution where the different entities involved in the end-to-end transmission are enhanced for multicast video transmissions and controlled by two new units: a Master Application (MA) Controller and a Base Station (BS) Controller. The proposed architecture, presented in Figure 1, comprises not only the data but also the control plane, which is of fundamental importance in the OPTIMIX solution: indeed, it allows the transfer of feedbacks and commands between different network entities, thus enabling the end-to-end optimization.

The main purpose of the MA Controller is to adapt the source coding parameters (e.g. quantization parameters, bitrate, etc.) and the protection rates on a relatively slow-rate base according to the video source characteristics and to the state of network and radio channels.

Corresponding author: R. Fracchia, Thales Communications, 160 boulevard de Valmy, 92704 Colombes (FR), +33-146132102, Roberta.Fracchia@fr.thalesgroup.com

The BS Controller in its turn intelligently allocates the shared radio resources among the users and the different kind of traffic. We consider a very general radio access scheme, where time, frequency and space resource units are available for the communication process. Moreover, we propose to exploit the flexibility of different channel coding and modulation techniques in order to jointly adapt the radio transmission scheme to the source characteristics and to the channel states.

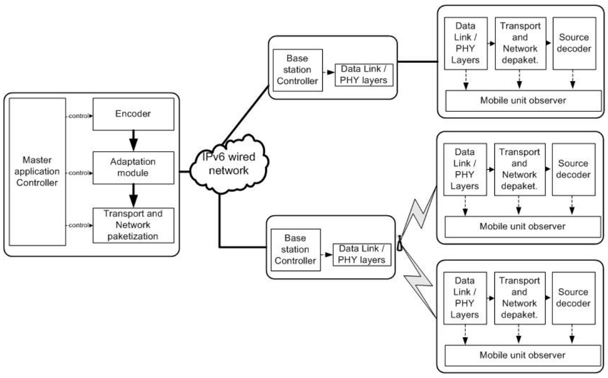

Figure 1: OPTIMIX control architecture

Remarkable results have also been obtained by enhancing the behaviour of the single modules used in the data plane. In particular:

- A Forward Error Correction (FEC) scheme has been introduced in the RTP protocol, which, being based on Rate-Compatible Punctured Convolutional (RCPC) codes, protects the transmission against bit errors introduced by the wireless channels.
- An efficient maximum likelihood decoding algorithm for low-density parity check (LDPC) codes over erasure channels has been designed. Enhancements with respect to a previously proposed structured Gaussian elimination approach are achieved by developing a set of algorithms aiming to limit the average number of reference variables from which the erased symbols can be recovered [2]. This Packet Erasure Correcting Codes (PECC) module complements RTP FEC by introducing a protection against packet losses.

Further important results are the definition of:

- A scheme for error-resilient video transmission in tele-medicine aiming to provide higher protection to the most diagnostically relevant data, by exploiting a wide range of recent advancements in video compression, error resilient video coding and transmission technologies, and including specific tools of the H.264 video coding standard, such as Flexible Macroblock Ordering for Region of Interest identification [3].
- A novel approach in high quality video coding preserving the quality obtained by a controlled image acquisition process: the key idea is to use in-loop filtering to generate a noise filtered predictor, while the output image (for viewing) is not changed, thus reducing the uncorrelated noise in the different image to be coded [4].
- A Traffic Engineering mechanism with resilience capability to a single link/node failure with recovery time of some tens of milliseconds (ms) as in SONET/SDH networks, for multicast traffic requests [5].

3 THE MASTER APPLICATION CONTROLLER

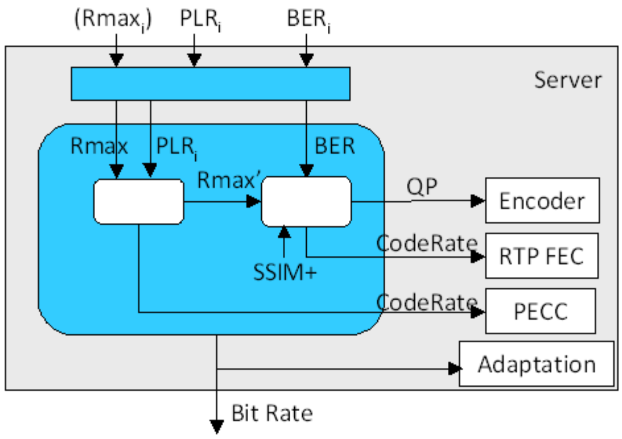

Figure 2: Master Application Controller inputs and outputs

The joint controller considered in this work needs to rely on a rate control algorithm more reactively (in the sense of quickly evolving to meet the target bitrate) than the ones traditionally used in long-term rate control for video compression. As a matter of fact, the channel conditions may vary too quickly when compared to the convergence time of the rate control algorithm, thus introducing great misbalances and several inadequately settings (as it could happen by using the long-term adaptation rate control algorithms proposed in the H.264/AVC JM [6] software).

The controlling process results in deciding every Group of Picture (GOP) (i.e., every second) the best compression and eventually protection parameters given the available bitrate and transmission conditions (network and/or channel state information). The MA Controller takes in as input the available bandwidth (Rmax), the packet loss rate (PLR) and the bit error rate (BER) from various clients as depicted in Figure 2. The available bandwidth can be estimated by the server or indicated by the BS Controller (in this case we assume the wireless link is the bottleneck of the communication), while PLR and BER are measured by the clients. These values, different for each server-to-client communication, are then transformed by a cost function into the requirements of a target user:

$$(Rmax^*, PLR^*, BER^*)=f(Rmax_i, PLR_i, BER_i)$$

As an example, the stream can be encoded following the requirements of an average user or a gold user.

The obtained loss probability PLR^* is used for the selection of the PECC module code rate against packet losses. Then, considering the remaining bandwidth and the BER*, the MA Controller jointly selects the code rate of the RTP FEC protection and the Quantization Parameter used by the video codec [7].

Alternatively, if pre-coded files are used, the maximum rate available for video is communicated to an adaptation module in charge of adapting the pre-coded video stream to the requirements.

In addition, the MA Controller can indicate the BS about the average bitrate of the encoded GOP: the BS, knowing in advance the amount of required resources, can perform an accurate resource allocation. However, it has to be noticed that this information is not mandatory since the bitrate could be measured at the BS.

Finally, priorities of the different layers (for the H.264/SVC codec) or of the single frames (for the H.264/AVC codec) are reported in the Differentiated Services (DS) field of the IPv6 header.

4 THE BASE STATION CONTROLLER

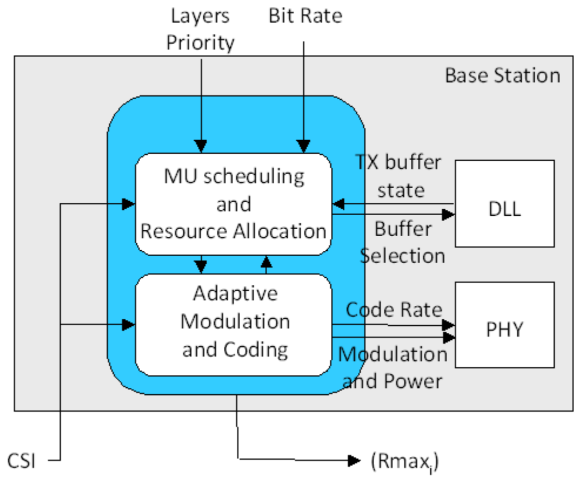

Figure 3: Base Station controller inputs and outputs

The main role of the BS Controller is to manage the shared radio channel among multiple users. In particular, it has to schedule the downlink transmissions and assign the common resources to the users, according to their channel conditions, the multimedia stream characteristics and the QoS requirements specified by the MA Controller. Due to the intrinsic variability of mobile radio channels, the BS Controller has to perform its optimization algorithms very frequently, on a time basis ranging from some ms to few tens of ms, depending on the considered system.

For the sake of generality, we consider a Multiple-Input Multiple-Output (MIMO) radio architecture with Orthogonal Frequency Division Multiple Access (OFDMA) scheme and we focus on optimizing the downlink transmission. Given the extremely high computational burden of optimal scheduling and resource allocation procedures, we opt for low-complexity sub-optimal approaches [8][9]. The optimization task is stated as a sum-rate (SR) or a weighted sum-rate (WSR) maximization problem subject to several constraints, such as: i) the total transmission power, ii) the target data rate for the total H.264/AVC stream or for the different layers of an H.264/SVC stream indicated by the MA Controller; iii) the amount of data present in the user transmission buffers coupled to the priorities signalled by the MA Controller. The solution of this problem is computed through dual-Lagrangian optimization techniques.

Adaptive modulation and coding (AMC) schemes can also be applied to satisfy BER/FER requirements for the different video priorities.

5 THE SIGNALLING SYSTEM

OPTIMIX signalling system is based on the joint use of Triggering Framework and IEEE 802.21[10]. The main entity of Triggering Framework, Triggering Engine (TRG), is present in the server, BSs and clients to allow exchanging information, triggers, between trigger sources and consumers at any layer of the network protocol stack. IEEE 802.21[11] is used in OPTIMIX clients and BSs to provide timely values of physical and data link layer parameters to the other entities in the network: IEEE 802.21 information is converted into triggers, which are handled by TRG as all other triggers.

Although Triggering Framework allows using filters in the subscriptions, the feedback message exchange causes overhead for the total network traffic. In order to mitigate the feedback overhead, a client-side aggregation mechanism for Triggering Framework has been developed. Trigger aggregation bundles multiple triggers into one trigger, which is periodically sent to the consumers subscribed to it.

Triggers sent from the clients to the MA Controller are thus aggregated triggers sent every second and including the packet loss rate evaluated at the RTP layer and BER. Packet loss rate is evaluated at the trigger transmission time, while BER indications are provided by the physical layer, via the IEEE 802.21 parameters report events, every 20 packets. The aggregated trigger contains the average value of all the BER values received by the TRG module in the client since the previous trigger transmission: indeed, the fast variations of the channel are handled by the BS Controller, while the MA Controller works on a longer time scale thus not requiring very frequent updates on this metric.

Moreover, single triggers are transmitted between the controllers: the MA Controller sends the required bitrate to the BS Controller, while the BS Controller can optionally send the wireless link bandwidth to the MA Controller.

Besides client-side aggregation, the OPTIMIX architecture introduces a network-level aggregation realized by Feedback Aggregation Servers (FASs) into the IP network core and exploiting IPv6 anycasting [12]. In anycast, a packet sent to an anycast IPv6 address is delivered to only one member of the anycast group: in OPTIMIX the anycast group is composed by the FASs and the server itself. The clients thus simply send their triggers to the anycast address and these messages are received by the "closest" node (i.e., a FAS or directly the server). The FASs collect triggers and store them in queues where each queue represents a significant service class according to the services available for the mobile entities in the given network. In accordance with the service parameters (maximum feedback delay, etc.) every queue has different timers to process the feedback data packetizing them into IP packets. These generated IP packets contain feedbacks from multiple sources so the network-level aggregation decreases the overhead in the IP core and makes possible to bundle feedbacks of same type into one IP packet.

6 EVALUATION BY SIMULATION

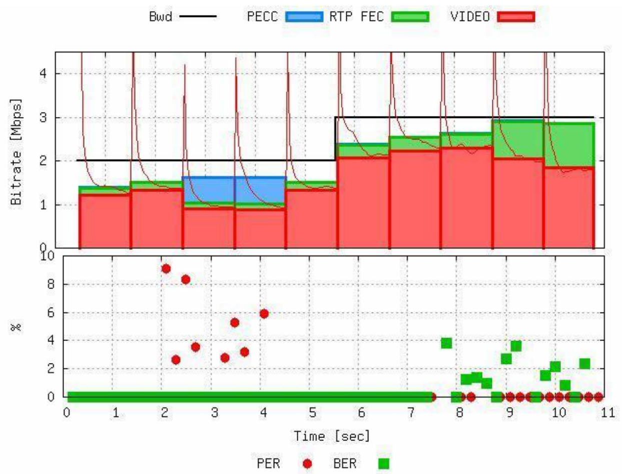

Figure 4: Master Application Controller adaptation

A system simulator integrating all the modules composing the OPTIMIX system and allowing both unicast and multicast transmissions has been developed and is available on the OPTIMIX web site [13]. This simulator is used by the consortium to test and refine, when needed, the designed algorithms. Moreover, it is a complete and easy instrument for the assessment of the results achieved by the project.

This tool simulates the transmission (with video bits actually generated and sent) of H.264/AVC or H.264/SVC videos and accurately models all the OSI layers from the application to the physical layer.

We show here the performance of the MA Controller on an NLOS scenario, where mobile clients are in a commercial or industrial environment and demand the Foreman reference sequence. Users, equipped with an IEEE 802.11g device, move at a very low speed (indicatively 1 km/h) but changing often location and room. These results are thus obtained by setting the standard deviation of the log-normal shadowing of the Rayleigh block fading channel to 4 dB, the coherence time to 0.5 s and the signal-to-noise ratio E_S/N_0 (where E_S is the energy per OFDM symbol and N_0 is the one-sided noise power spectral density) to 30dB. For the IEEE 802.11 transmission a QPSK modulation is considered.

In Figure 4, we evaluate the behaviour of the MA Controller and its appropriate reaction to changing network conditions. The upper figure reports the available bandwidth (black line) and the generated bitrate composed by video bitrate, PECC and RTP FEC redundancy. In addition, BER and PLR are reported in the lower figure as a function of the simulation time.

In the upper figure, we can observe that the parameters selected by the MA Controller vary every second, since the controller works on a GOP time scale. Moreover, the figure shows that the total generated bitrate is at the same time always lower than the target and close to it, thus efficiently exploiting the available bandwidth. The MA Controller also accurately reacts to changes in the bandwidth availability (see time=5.7s).

Furthermore, we can notice that the MA Controller selects a default code rate of 8/9 for RTP FEC even without bit errors, in order to guarantee a minimal protection. No PECC protection is instead introduced when PER=0. At t=2s a fault in the wired network is simulated: several packets are lost and the PER approaches 10%. At the first following adaptation phase (i.e., at t=2.3s) the MA Controller reacts by introducing protection: 1/3 of the total bitrate is devoted to PECC repair packets. Fault is recovered at t=4.1s and PECC protection removed. At t=7.5s the wireless channel condition changes and errors start to affect the received packets: after a small delay due to the feedback transmissions the MA Controller reacts by increasing the FEC protection rate to 2/3.

7 THE TEST-BED

The test-bed of the OPTIMIX solution, which will be realized by the end of the project, is illustrated in Figure 5.

The OPTIMIX server includes all the modules considered by OPTIMIX: the source encoding module, the MA Controller and the Adaptation module, the extensive signalling framework to handle feedbacks from the users, RTP, RTSP, RTCP to handle the streaming session and to packetize the frames, the SRTP module introducing ciphering and the PECC module introducing protection against packet losses. The server is finally equipped with camera and microphone, generating data flow to encode on the fly and streams encoded offline.

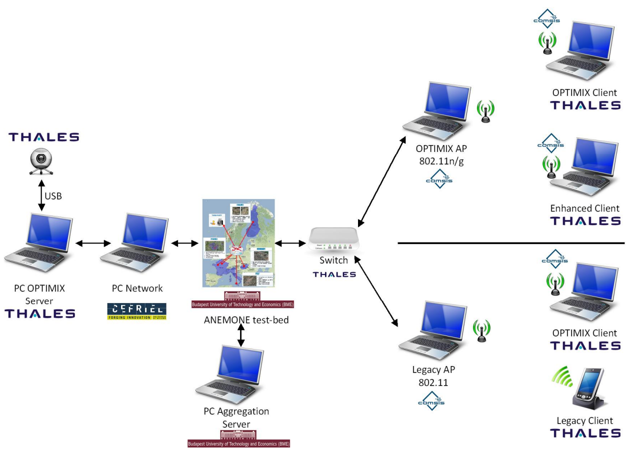

Figure 5: OPTIMIX test-bed

The PC server is connected to the PC Network, which is, in its turn, connected to the ingress of the ANEMONE [14] test-bed. The PC Network, which introduces configurable losses and delay, has two goals: first, by varying these two parameters it allows to verify the end-to-end optimization mechanisms in different network conditions; second, it guarantees a model of a real IPv6 network in case the access to the ANEMONE test-bed could not be available (e.g., due to tunnelling problems from the location of the exhibition). The ANEMONE test-bed aims at providing a global interconnection of IPv4/IPv6 networks and a support for delivery of IPv4/IPv6 services over a native IPv6 core built upon the GEANT infrastructure [15]. The PC aggregation server adds aggregation capabilities to reduce the overhead introduced by feedbacks sent by the clients.

The ANEMONE test-bed is connected to two different IEEE 802.11g/n access points (APs), one presenting basic functionalities and the other one supporting header compression, adaptation, signalling framework (both IEEE 802.21 and Triggering Framework) and BS controller. Since the full development of the BS Controller functionalities can not be realized by the end of the project, a QoS-aware frame scheduling is supported by an adaptation module at the application layer of the BS, further reducing the bandwidth occupancy of the video stream if needed. Both the APs use enhanced IEEE 802.11n/g boards developed by the partners.

At the client side, three 802.11n boards are associated at clients of different capabilities (two OPTIMIX clients and one enhanced client) while a legacy client is equipped with a classical 802.11g WiFi connection. The "legacy client" is a basic device without additional features while the enhanced client has advanced features (e.g., RoHC, PEC, RTP FEC, etc.) but no support of the signalling framework. The OPTIMIX client implements the complete OPTIMIX solution.

The OPTIMIX test-bed follows forward to validate the improvements developed in the OPTIMIX project by evaluating the performances of clients for the same received signal strength. Several configurations will be compared to show the gain introduced by the different OPTIMIX modules.

1. Legacy server, legacy BS and legacy client. This is the reference configuration: pre-coded stream are transmitted without any additional functionality .
2. OPTIMIX server, legacy BS and legacy client. The BS and the clients are standard 802.11g devices without enhanced transmission or reception schemes. This scheme allows showing the gain introduced by the MA Controller even without feedbacks from clients.
3. OPTIMIX server, legacy BS and OPTIMIX client. Client and server have been developed following the joint optimization scheme, while the access point does not present optimization modules: this configuration allows in particular showing, by comparison to configuration 2, the impact of RTP FEC, PECC, enhanced MAC/PHY schemes at the receiver. Moreover, we will show:
   - The benefit of the MA Controller by comparison versus configuration 2: comparison of optimized versus default parameters for encoding, RTP FEC, PECC, Adaptation Module
   - Introduced signalling overhead by comparison versus configuration 2.
4. OPTIMIX server, OPTIMIX BS and enhanced client. The client is not optimized, but presents enhanced reception schemes, e.g. a robust video decoder). Moreover, in this case the client could partially benefit from application and BS control when multicast transmissions are tested and feedbacks are sent by the optimized users of the same cell. A degradation of the performance is anyway expected. This configuration allows in particular to show, by comparison to configuration 2 and 3, the impact of:
   - RoHC, both for data (downlink transmission) and feedbacks (uplink transmission)
   - Adaptation at the BS
   - BS Controller
   - Enhanced MAC/PHY schemes at the transmitter.
5. OPTIMIX server, OPTIMIX BS and OPTIMIX client. All the nodes of the transmission chain are involved in the joint optimization scheme (server, AP, and client). This configuration is representative of the OPTIMIX communication chain and the results achieved in OPTIMIX. It will show the combined effect of the MA Controller and the BS Controller.

8 CONCLUSION

The end-to-end approach proposed by OPTIMIX project aims at providing to the end user a versatile and adaptable secure infrastructure that can satisfy the needs of rich multimedia based applications. This structure is meant to offer transmissions that will be more bandwidth efficient and more robust, but also to take into account the heterogeneity of multiple users' requirements and capabilities.

OPTIMIX proposes a cross-layer solution where optimization of high layer protocols (implemented by service providers) and radio resources (implemented by telecommunication operators) is realized by different controlling units and which can be progressively deployed, thus resulting of particular interest for the main business actors.

Finally, it is noteworthy that OPTIMIX decided to avoid the design of new solutions when standardized mechanisms could be adapted to the project needs: for example, IEEE 802.21 in the signalling solution and IPv6 anycast that, even if not conceived in the context of the project, can be successfully exploited.

9 ACKNOWLEDGEMENTS

This work has been carried thanks to INFSO-ICT-214625 OPTIMIX project, which is partially funded by the European Commission within the EU 7th Framework Programme and Information Society Technologies.

The authors want to acknowledge all the OPTIMIX partners for their support in the system design, in the development of the system simulator used to obtain the results presented in this paper and in the test-bed.

References

[1] G. Cheung and A. Zakhor. Bit allocation for joint source/channel coding of scalable video. IEEE Trans. Image Processing, 9(3):340 – 356, March 2000

[2] G. Liva, B. Matuz, E. Paolini and M. Chiani, "Pivoting algorithms for maximum-likelihood decoding of LDPC codes over erasure channels," in Proc. of IEEE Globecom 2010, Miami, USA, 2010.

[3] M. Martini and C. Hewage, "Flexible Macroblock Ordering for Context-aware Ultrasound Video Transmission over 802.16e", International Journal on Telemedicine and Applications, 2010.

[4] E. Wige P. Amon , A. Hutter, A. Kaup, "In-loop Denoising of reference frames for losseless coding of noisy image sequences," in Proc. of IEEE ICIP 2010, Hong Kong, 2010.

[5] G. Panza, A. Capone, D. Pinarello and P. Belotti., "Fault Resilience in Next-Generation Networks", in Proc of Future Networks and Mobile Summit 2010, Florence, Italy, 2010.

[6] JM 12.1 reference model for H.264 Advanced Video Coding. http://iphome.hhi.de/suehring/tml/.

[7] C. Bergeron and C. Lamy-Bergot, "Modelling H.264/AVC sensitivity for error protection in wireless transmissions", in Proc. of MMSP, pp.302--305, Victoria, Canada, 2006.

[8] K. Seong, M. Mohseni and J.M. Cioffi, ``Optimal Resource Allocation for OFDMA Downlink Systems'', in Proc of ISIT 2006, Seattle, USA, 2006.

[9] A.I. Perez-Neira, P. Henarejos, V. Tralli and M.A. Lagunas, ``A low-complexity space-frequency multiuser scheduling algorithm'', in Proc. of International ITG Workshop on Smart Antennas, Berlin, Germany, 2009.

[10] E. Piri, T. Sutinen and J. Vehkaperä, "Cross-layer Architecture for Adaptive Real-time Multimedia in Heterogeneous Network Environment," in Proc. of European Wireless, Aalborg, Denmark, 2009.

[11] IEEE 802.21 WG, ``IEEE Standard for Local and Metropolitan Area Networks. Part 21: Media Independent Handover Services'', IEEE Std 802.21-2008, Jan. 2009.

[12] C. Partridge, T. Mendez, W. Milliken, ``Host Anycasting Service'', RFC1546, November 1993.

[13] OPTIMIX, http://www.ict-optimix.eu.

[14] ANEMONE, http://www.ist-anemone.eu

[15] GEANT: European multi-gigabit computer network for research and education purposes, http://www.geant.net.