Cross-Layer Design based on UDP-Lite for Wireless H.264 Video Transmission

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***Abstract*—The recent UDP-Lite protocol, possibly delivering erroneous packets to the application layer, is an example of tool allowing loosening and a rethinking of the layer separation principle, enabling information exchange among system blocks. For multimedia applications, erroneous packet payloads can be valuable and better to cope with than the lost ones, and these errors can be managed at the application layer, *e.g.*, through concealment techniques. We analyze in this paper wireless H.264 video transmission through cross-layer design, by invoking different transmission strategies based on UDP-Lite, also jointly with RoHC and ARQ, and provide comparative performance evaluation.**

***Index Terms*—UDP-Lite; RoHC, H.264 video; wireless; cross-layer design.**

I. Introduction

Beyond 3G (B3G) or 4G networks and applications, with all-IP-based seamless and ubiquitous service provisioning across heterogeneous infrastructures, present a number of technological challenges: providing bandwidth efficient IP-based multimedia communications over wireless links is still a critical issue. Efficient QoS provisioning in a context with highly varying channel characteristics (bandwidth, throughput, error rates, fading, and erasure characteristics, etc.) requires an end-to-end approach going against the classical layer separation principle. In particular, vertical cross-layer cooperation may be beneficial because of both the error and erasure resilience capabilities of emerging source coding technology, of the different sensitivity to errors of the (source) encoded data bits and of the variability of wireless links. Joint source and channel coding is an example of application of such cross-layer design principle: regardless of the common application of Shannon's "separation" principle, in fact, many of the modern information technology systems, such as those involving transmission of video sources over rate constrained channels, actually violate the conditions upon which the optimality of that principle relies. For such systems, performance improvements may be achieved by moving from separate design and operation of source and channel codes to joint source-channel coding (JSCC). Unlike separation-based techniques, joint source-channel coding techniques rely on the joint or cooperative optimization of communication system components. The joint approach allows strategies where the choice of source coding parameters varies over time or across users in a manner dependent on the channel or network characteristics. Likewise, joint source-channel coding techniques allow for systems in which the choice of channel code, modulation, or network parameters varies with the source characteristics. For a tutorial description of the JSCC approach see, *e.g.*, [1]. One of the main drawbacks of the joint approach is that it requires the exchange of a variety of information among the systems layers and that these information need to be managed jointly in order to perform the system optimization [2]. This aspect has often been neglected in JSCC literature, where the assumption of perfect availability of information on the system blocks is made.

The Robust Header Compression (RoHC) framework [3], utilizing the redundancy between header fields in consecutive packets to compress RTP/UDP/IP headers, and the new UDP-Lite protocol, possibly delivering erroneous packets to the application layer [4], [5] [6], are examples of tools allowing loosening and a rethinking of the layer separation principle, enabling information exchange among system blocks. The fact that, for multimedia applications, erroneous packet payloads can be valuable and better to cope with than the lost ones, has in fact inspired the introduction of the UDP-Lite transport protocol, allowing damaged packets to go up to the application layer, where these errors can be coped with, *e.g.*, through concealment techniques. UDP-Lite can be seen as a form of "unequal error detection", where only errors in critical parts of the packet (*e.g.*, headers) are detected and determine packet loss or retransmission request. This has some similarities with the scheme proposed in [7], where the error detection task was shared between the link and the application layer, where error detection in the video payload and consequent concealment were performed by the source decoder. The potential of UDP-Lite in the framework of cross-layer design has not been widely addressed in the literature. The work in [8] addressed capacity aspects without focusing on a specific application/source. Few works, including [9], have addressed its potential for speech transmission. UDP-Lite for video transmission has been addressed in [10], where its performance is evaluated for MPEG-4 video, without considering the joint impact of RoHC and retransmission strategies. The checksum is calculated here over pseudo IP, UDPLite and RTP headers.

In this paper, after an illustrative analysis of the performance of UDP-Lite with a simple Binary Symmetric Channel (BSC) model, we address wireless H.264 video transmission through different UDP-Lite based transmission strategies, also jointly with RoHC [3] [11] and Automatic Retransmission reQuest (ARQ), and we provide a comparative performance evaluation.

II. UDP-Lite Transmission strategies

We assume we transmit H.264 video packets over RTP/UDP/IP (see Figure 1 for the corresponding packet structure). Hence, we have at the UDP layer packets composed of the different packet headers $H_{UDP}, H_{RTP}, H_{NAL}, H_{Slice}$ with respective lengths $l_{UDPH}, l_{RTPH}, l_{NALH}, l_{sliceH}$, and of a payload representing video information of length $l_{payload}$, resulting in a total length l_{packet} for the packet.

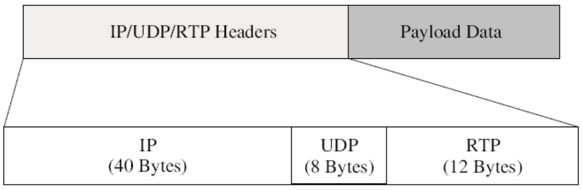

Fig. 1. RTP/UDP/IP packetization.

```
 0              15 16             31
+--------+--------+--------+--------+
|     Source      |   Destination   |
|      Port       |      Port       |
+--------+--------+--------+--------+
|    Checksum     |                 |
|    Coverage     |    Checksum     |
+--------+--------+--------+--------+
|                                   |
:              Payload              :
|                                   |
+-----------------------------------+
```

Fig. 2. UDP-Lite header.

In the UDP protocol the integrity of the packet is checked through Cyclic Redundancy Check (CRC), applied over the whole packet. The packet is discarded in both the cases of errors in the packet header and in the payload. The UDP-Lite protocol enables CRC coverage of a limited portion of the packet, enabling erroneous packets to go up to the application layer, where these errors can be coped with, *e.g.*, through concealment techniques. In the UDP-Lite header the length field of the UDP header is replaced by a checksum coverage field that specifies which part of the payload is used in the checksum calculation, starting from the beginning of the packet. The UDP-Lite header structure is reported in Figure 2. If used with full checksum coverage, UDP-Lite is semantically identical to UDP. UDP-Lite should be supported by a "permeable" MAC layer [12] to avoid that packets with bit errors due to the effect of the physical layer are dropped at the MAC layer, *i.e.*, before the UDP layer.

We analyze in this section the reduction in packet loss rate achieved by the UDP-Lite protocol, when different portions of the packet are covered by CRC. Since this packet loss reduction comes at the expense of residual errors in the uncovered fields, we also take into account in the analysis the residual error rate present in the portions of the packet not covered by CRC.

In the following section we will link these observations with the global end-to-end quality achieved for video transmission over a realistic wireless channel.

We assume here for simplicity transmission over a BSC channel characterized by an error probability P_e.

When CRC is performed on a data portion of length l and packets are discarded if the check detects errors, we can evaluate the packet loss rate as: $P_L = 1 - (1 - P_e)^l$.

For UDP, where CRC is performed over the whole packet, larger packet sizes result then in higher packet loss rates.

By considering transmission of an H.264 video source, Table I reports different UDP strategies, each corresponding to a different CRC coverage, and the relationship between the bit error probability and the associated Packet Loss Rate (PLR). The analysis assumes BSC and that all the errors present in the fields covered by CRC are detected.

In the numerical results below, we assume $l_{UDPH} = 8$ Bytes, $l_{RTPH} = 12$ Bytes, $l_{NALH} = 1$ Byte , $l_{sliceH} = 6$ Bytes, $l_{packet} = 1028$ Bytes.

Figures 3 and 4 report the PLR versus bit error probability for these numerical values. Figure 3 refers to the case where ARQ is disabled, whereas Figure 4 refers to the case where a maximum of two retransmissions is allowed by the protocol. We can observe that, for instance, for an error probability at UDP layer $P_e = 10^{-4}$ the expected packet loss rate with UDP is $P_L = 10^{-1}$, *i.e*, one packet out of ten is discarded. For the same value of P_e the expected packet loss rate goes down to $P_L = 10^{-3}$ and lower when different UDP-Lite strategies are adopted. Of course this is at the expense of errors present in the payload of forwarded packets. Figure 4 shows that when retransmissions are possible the residual packet loss rate is further reduced, at the expense of increased delay and overhead.

III. Simulation set-up

This section reports the simulation set-up for our study on the impact of different UDP-Lite strategies on the end-to-end video quality for H.264 video transmission over a realistic wireless channel.

A single transmitting antenna and a single receiving antenna are considered. A radio interface based on OFDMA is adopted. OFDMA parameter setting are reported in Table II.

TABLE II
OFDMA simulation settings

Number of carriers	48
Number of pilot carriers	4
Number of total carriers	64
Number of subchannels	48
Number of time slots	72
Number of time blocks	6

TABLE I
TRANSMISSION STRATEGIES

	UDP strategy	Packet loss rate	Residual bit error rate in forwarded packets with the assumptions made
A	UDP-Lite with CRC on UDP header only	$1-(1-P_e)^{l_{UDPH}}$	P_e in $l_{RTPH} + l_{NALH} + l_{sliceH} + l_{payload}$, 0 elsewhere
B	UDP-Lite with CRC on UDP and RTP headers	$1-(1-P_e)^{l_{UDPH}+l_{RTPH}}$	P_e in $l_{NALH} + l_{sliceH} + l_{payload}$, 0 elsewhere
C	UDP-Lite with CRC on network headers and Network Abstraction Layer Unit (NALU) headers	$1-(1-P_e)^{l_{UDPH}+l_{RTPH}+l_{NALH}}$	P_e in $l_{sliceH}+l_{payload}$, 0 elsewhere
D	UDP-Lite with CRC on network headers, NALU headers and slice headers	$1-(1-P_e)^{l_{UDPH}+l_{RTPH}+l_{NALH}+l_{sliceH}}$	P_e in $l_{payload}$, 0 elsewhere
E	UDP	$1-(1-P_e)^{l_{packet}}$	0

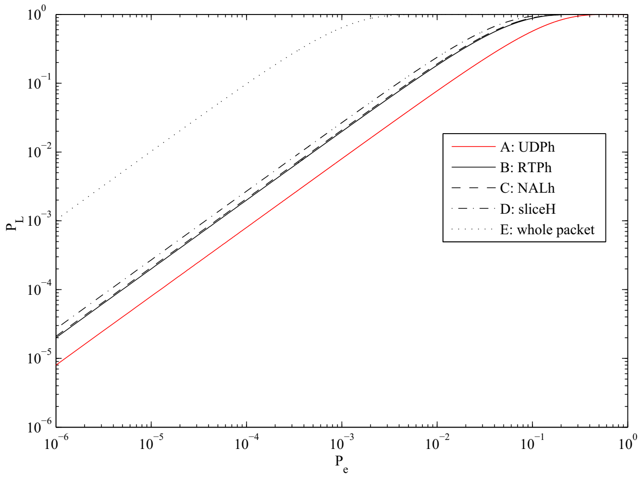

Fig. 3. Packet loss rate vs. bit error probability at the link layer, no ARQ.

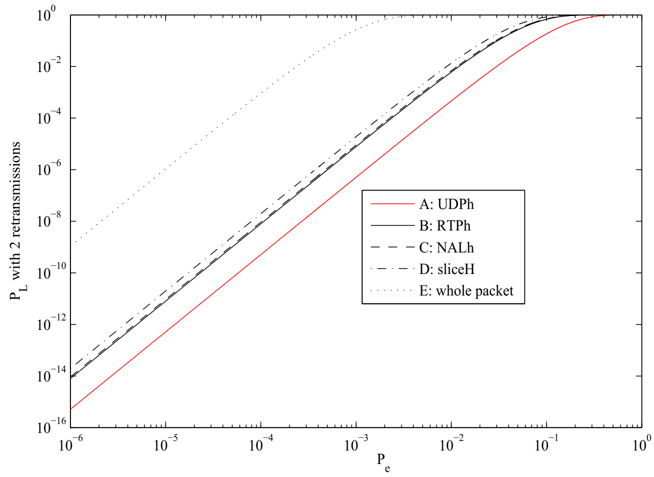

Fig. 4. Packet loss rate vs. bit error probability at the link layer, ARQ with max 2 retransmissions.

A fixed RCPC code with rate 1/2 is used throughout the simulation.

We used the simulator developed in the framework of the European project OPTIMIX [13], with the application layer controller active for rate-control and triggering engine aggregation for signaling side information across layers. Packet Erasure Correcting Codes (PECC) were used against erasures with a target bit rate of 500 bits/s. Random bandwidth update was enabled. No adaptation is used at the base station (BS), hence preset parameters were kept constant throughout the simulations to better highlight the impact of the strategies under study. The total bandwidth is 20 MHz, the coherence Bandwidth is 1.25 MHz. Coherence time is 0.1 s. Log-normal slow fading (shadowing) is also considered with coherence time of 2 s.

Table III reports the video parameters considered.

TABLE III
H.264/AVC ENCODER PARAMETERS

Video Sequence	Foreman
Resolution	QCIF (176x144)
Frame Rate	15 fps
Profile	Baseline
Intra Period	5
Quantization Parameter	35 (I Slice), 36 (P Slice)
Slicing Mode	33 MB's per Slice

The video sequence has been encoded through the JM AVC video codec and decoded with a slightly modified version for

TABLE IV
PACKET CHECKSUM COVERAGE

	Content Description	Checksum coverage (Bytes)
A	UDP-Lite header	8
B	UDP-Lite + RTP headers	$20 = 8 + 12$
C	UDP-Lite + RTP + NAL headers	$21 = 8 + 12 + 1$
D	UDP-Lite + RTP + NAL + Slice headers	$27 = 8 + 12 + 1 + 6$
E	Full Packet	1028

improved error resilience.

IV. SIMULATION RESULTS AND DISCUSSION

Table IV reports, for the different UDP-Lite strategies, the different portions of the packet covered by checksum at the UDP layer. Extending the CRC coverage increases the packet loss rate, although it reduces the number of erroneous packets forwarded to the application layer and an appropriate trade-off has to be achieved.

In [8] this trade-off is afforded analytically in terms of achievable capacity. However, in a cross-layer framework for video transmission, end-to-end video quality and not capacity is actually the main target. For this reason we report in the following simulation results for the different strategies in terms of video quality.

Figures 5 and 6 show simulation results with the different strategies reported in Table IV, for transmission of H.264 video over a wireless channel characterized by Rayleigh fading and log-normal shadowing, and a physical layer based on OFDM with the parameters described in the previous section. Simulations are performed with an OMNET++ simulator realistically representing the different layers of the protocol stack, including signaling across the layers. The figures report video quality results (in terms of peak-signal-to-noise-ratio, PSNR) for different channel conditions expressed as signal-to-noise ratio. Packet length is 1028 bytes for the simulations shown in the figure. Simulation results were collected for seven different channel SNR conditions and averaged over not less than five simulations with different channel realizations.

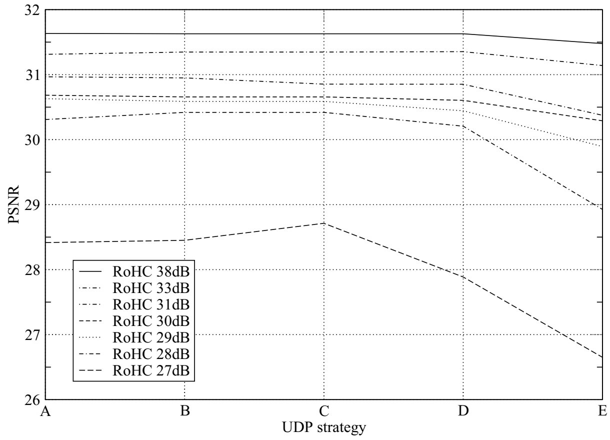

Fig. 5. Video quality for different UDP-Lite strategies, RoHC applied.

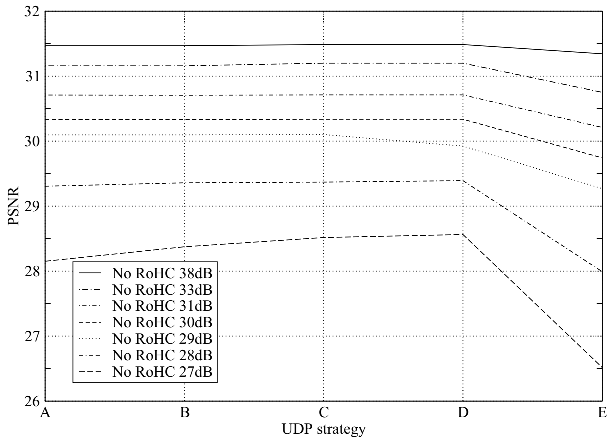

Fig. 6. Video quality for different UDP-Lite strategies, no RoHC.

Figure 5 represents the case where RoHC is adopted in conjunction with UDP-Lite/UDP, whereas Figure 6 represents the case where RoHC is not adopted in conjunction with UDP-Lite/UDP. Unidirectional mode is used for RoHC, with RTP/UDPLite/IPv6 profile for header compression. The 60 Bytes header is compressed to 8 Bytes, *i.e.*, 1 Byte for RoHC header, 0 Byte for IP header, 4 Bytes for the compressed UDP-Lite header (2 Bytes for UDPLite coverage and 2 Bytes for UDP-Lite checksum) and 3 Bytes for the compressed RTP header. Hence 8 Bytes checksum coverage is used over the RoHC compressed packet.

We can observe that UDP-Lite outperforms UDP in the considered scenario and that it can be convenient to extend the protection to the RTP header and the H.264 network abstraction layer (NAL) header when RoHC is not applied.

Figure 7 reports the case where ARQ is adopted, with a maximum of 4 retransmissions. We can observe that retransmissions result in improved quality only for the worst channel condition considered.

V. CONCLUSION

We analyzed in this paper wireless H.264 video transmission through cross-layer design, by invoking different transmission strategies based on UDP-Lite, also jointly with RoHC and ARQ. Comparative performance evaluation based on end-to-end video quality shows that UDP-Lite outperforms UDP in the considered scenario and that it can be convenient to extend the protection to the RTP header and the H.264 network abstraction layer (NAL) header when RoHC is not applied. Retransmissions as a consequence of UDP-layer detection are only beneficial in the worst channel conditions considered,

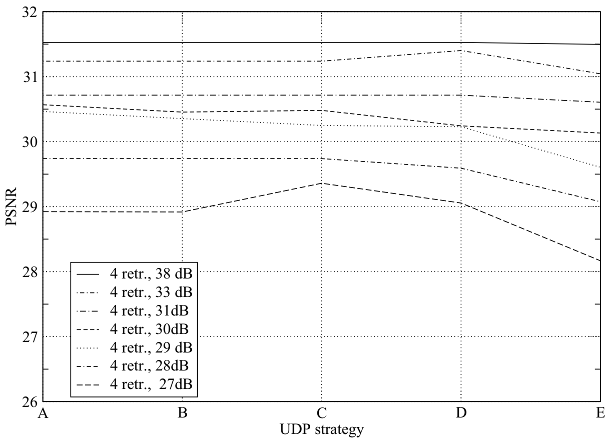

Fig. 7. Video quality for different UDP-Lite strategies, max 4 retransmissions, no RoHC.

suggesting that retransmissions could be enabled only below a certain threshold on channel conditions.

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