Cross-layer Optimization for Scalable Video Transmission in Next Generation Cellular Networks

Iffat Ahmed
IMT Institute for Advanced Studies, Lucca, Italy
E-mail: iffat.ahmed@imtlucca.it

***Abstract*—This paper tries to investigate that whether PHY/Application cross-layer optimization really required for video transmission over next generation wireless networks? Or would a sequential allocation where optimization is independently performed at the PHY and Application layers work similarly? How does the cross-layer and non-cross-layer optimization perform also compared to the theoretical best allocation that one could apply, if the channel states and the user quality requirements were all known in advance? Is there a way to adapt to the channel variability? How do the unicast scenario extend to the multicast case? Given that a compromise in allocation must be found between the needs of all the users in the multicast group, it may be that cross-layer optimization is insufficient. Our numerical results show that XLO significantly outperforms NXLO for both unicast and multicast video transmissions, thereby pointing out the strong need for cross-layer solutions in video transmission.**

I. INTRODUCTION

Video explosion is impressively foreseen in the Cisco report [1] which states that the video contents would be 6 million years of duration in the each month of the year 2016, across the global IP network. Thus, such an increase in usage of multimedia applications has implied a big challenge to provide adequate quality in spite of heterogeneous terminals and optimally utilize the available resources.

Scalable Video Coding (SVC) which an extension of H.264 Advance Video Coding (AVC) has a bitstream which is divided into layers, one Base Layer (BL) and multiple Enhancement Layers (EL), [2]. Such enhancement layers provide incremental quality, which are dependent of BL. On the other hand, due to the users' diverse channel conditions, we can adaptively apply channel rates with the help of Adaptive Modulation and Coding (AMC) to achieve the higher data rates and select the layer of the SVC source accordingly [3], [4].

Therefore, the main motivation is that, we need not only a generic "cross-layer" optimization, but even more challenging specifically a PHY/Application cross-layer optimization, which has to span through the entire protocol stack. This work addresses the following questions: Is PHY/Application cross-layer optimization really required for video transmission over next generation wireless networks? How do various allocations policies perform? How do the unicast scenario extend to the multicast case? Given that a compromise, the allocation must be found between the needs of all the users in the multicast group, it may be that cross-layer optimization is insufficient.

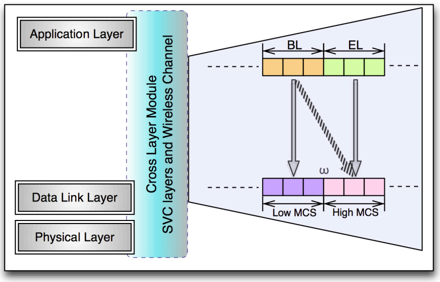


Fig. 1. PHY/Application Cross-layer allocation concept

II. ANALYSIS AND DESIGN

We formulate an analytical model based on a Markov chain representing the wireless channel, where each state is associated to a different channel quality corresponding to a set of possible choices of video layer and modulation and coding scheme. Each user i has BL requirement (θ_i), which is a uniform random distribution, based on which base station computes the optimum no. of transmit opportunies it needs to transmit BL, so that the user can correctly decode the video. The expected goodput can be defined $\mathbb{E}[\hat{g}] = \alpha t_{BL}(1-p_i) + \beta t_{EL}(1-p_i)$, where, t_{BL}, t_{EL} are the TxOps for BL and EL tranmission, respectively and p_i is loss probability. Our function is $Opt_{t_{BL}} = \arg\max(\mathbb{E}[\hat{g}])$ subject to constraints, $n_{BL} \geq \theta_i$, where, n_{BL} is the number of BL packets received. The above formulated optimization problem can be solved using Lagrange Multiplier,, details of optimization problem are described in our work [5].

The basic cross layer model is illustrated in Fig. 1. The BL packets can be transmitted with any MCS available, but EL packets can only be transmitted with the MCS above a certain threshold ω. For the sake of analytical tractability, we make the following assumptions. We consider two different modulation schemes with a QAM constellation; in particular, we have $\mathcal{Z} = \{QSPK, 16QAM\}$, that is, depending on the channel quality. Similarly, we consider two video layers of $\mathcal{L} = \{BL, EL\}$. The goodput and delay of a user can be defined as:

$$\mathcal{G}_i|\mathcal{S}^k_{\zeta\ell} = g^k_{\zeta\ell}(i) \cdot P^k_{\zeta\ell} \quad and \quad \mathcal{D}_i|\mathcal{S}^k_{\zeta\ell} = d^k_{\zeta\ell}(i) \cdot P^k_{\zeta\ell} \tag{1}$$

Given the state of the channel $\mathcal{S}^k_{\zeta\ell}$, at time k, user is able to receive packet from layer $\ell \in \mathcal{L}$ with the rate $\zeta \in \mathcal{Z}$. Thus, we

---

Thanks to my superviser Dr. L. Badia and support by the FP7 EU project MEDIEVAL

can define the overall system goodput and delay as follows:

$$\mathcal{G} = \frac{1}{N}\sum_{i=1}^{N}\sum_{k=1}^{T}\mathcal{G}_i|\mathcal{S}^k_{\zeta\ell} \quad and \quad \mathcal{D} = \frac{1}{N}\sum_{i=1}^{N}\sum_{k=1}^{T}\mathcal{D}_i|\mathcal{S}^k_{\zeta\ell} \tag{2}$$

where, N is the total number of users and T is the total number of TxOps. For unicast scenario, it is straightforward that each user has its own goodput and delay, however, for multicast scenario, users need to cooperate regarding their heterogenious BL needs and channel conditions, therefore, for multicast, an aggregated channel condition are considered at each TxOp, and average strategy is applied for BL requirements, i.e., $BL_{avg} = \frac{1}{N}\sum_{i=1}^{N} Opt_{t_{BL}}(i)$ and so $\theta\_BL_{avg} = BL_{avg}\cdot\lambda$, where, $\lambda \in [0,1]$ is a threshold parameter to compute the amount of base layer which must be received by the receiver, after λ, we can allocate video packets (either BL or EL) according to three allocation policies defined in subsequent section. The system also computes optimum number of EL packets to be transmitted to all the users, therefore, the computation of the optimum number of EL packets is:

$$Opt_{t_{EL}} \Longrightarrow \begin{cases} T - BL_{avg} & \text{iff } BL_{avg} > \frac{T}{2} \\ BL_{avg} & \text{Otherwise} \end{cases}, \tag{3}$$

The allocation of BL packets can now be defined as

$$alloc\_BL^k_i(\theta_{BL_{avg}}) = Opt^k_i(\zeta,\ell)\ \forall(\zeta,\ell)\in\mathcal{Z}\times\mathcal{L} \tag{4}$$

$$alloc\_EL^k_i(Opt_{t_{EL}}) = Opt^k_i(\ell,\zeta) \iff \zeta > \omega \tag{5}$$

here $Opt^k_i(\ell,\zeta)$ is the same for both $alloc\_BL^k_i(\theta_{BL_{avg}})$ and $alloc\_EL^k_i(Opt_{t_{EL}})$, which is defined as (6)

$$Opt^k_i(\ell,\zeta) \Longrightarrow \begin{cases} \arg\max[\mathcal{G}_i \mid \mathcal{S}^k_{\zeta\ell}] \\ \arg\min[\mathcal{D}_i \mid \mathcal{S}^k_{\zeta\ell}] \end{cases} \tag{6}$$

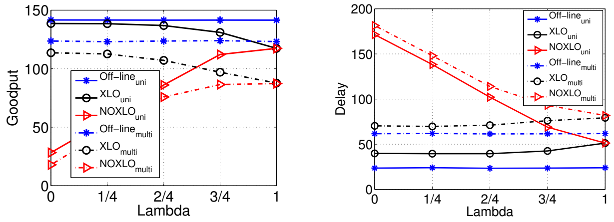
A. Allocation Policies

We consider three allocation policies: (i) *Offline* (theoretical upper bound); (ii) *NXLO*(sequential selection, as Non-cross Layer); (iii) *XLO* (joint cross-layer optimization).

1) Offline Policy: It takes into consideration the slots which have best channel condition amongst $\mathcal{Z}$ above a certain threshold ω for EL and remaining slots for BL, upon the condition that the required BL packets have been transmitted. If the remaining slots are below a certain threshold ω, then only BL packets can be transmitted with either high or low MCS, while EL cannot. Furthermore, if the BL is completed and the only available slots are below ω, then the EL packets are dropped and no more transmissions are executed.

2) NXLO: In the non-cross-layer policy the base station first picks the SVC layer packet to be sent, that is, BL or EL packet based on θ_BL_i (for unicast) and θ_BL_{avg} (for multicast), and then checks the PHY (MCS) of the user in the current time slot.

3) XLO: In this policy the channel status is checked first to get the best MCS, then the base station jointly selects the BL/EL and MCS based on θ_BL_i or θ_BL_{avg}, for unicast or multicast scenarios, respectively.



(a) Goodput vs. lambda (b) Delay vs. lambda

Fig. 2. Unicast/Multicast comparison

We simulated these policies in multicast and unicast environment, and results are averaged over large number of runs. In the multicast scenario, the same number of BL packets must be transmitted to every user. For this reason, the number of BL packets cannot be optimal for all users, but is the result of a deal among different needs. Figs.2(a)-(b) show the results for both unicast and multicast results regarding aforementioned three allocation policies. It can be noticed that the performance of multicast is slightly lower because, all the users in a group have to coordinate and might have to compromise for each other. Another point is that when λ is 1, NXLO and XLO converge and the policy differentiation does not matter for both multicast and unicast results. Further, for goodput and delay, XLO performs near optimal (offline) as in Figs.2

III. CONCLUSIONS

The proper joint-selection of BL and EL according to the channel conditions of the user can significantly impact its goodput. A cross layer (PHY/Application) solution with respect to adaptive rates for SVC layers in the multicast environment is studied. The resulting numerical performance is evaluated via simulations in terms of goodput and delay in unicast/multicast. We observed that joint selection of both video layer and modulation scheme can improve the QoE compared to the sequential selection. Additionally, the joint selection (XLO) provides quasi-optimal/theoretical best (offline policy) results. Evaluation and comparison of both unicast and multicast environments is also investigated, in the latter, a compromise among the heterogeneous user requirements must be found, therefore the solution quality will be generally worse than the unicast case, where individual quality requirements can be better tracked.

REFERENCES

[1] “Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 20112016,” Tech. Rep., May 2012.

[2] H. Schwarz, D. Marpe, and T. Wiegand, “Overview of the scalable video coding extension of the h.264/avc standard,” *IEEE Trans. on Circuits and Systems for Video Tech.*, vol. 17, no. 9, pp. 1103 –1120, sept. 2007.

[3] J. Villalon, P. Cuenca, L. Orozxo-Barbosa, Y. Seok, and T. Turletti, “Cross-Layer Architecture for Adaptive Video Multicast Streaming Over Multirate Wireless LANs,” *IEEE JSAC*, vol. 25, no. 4, May 2007.

[4] J. Widmer, A. Capalbo, A. Anta, and A. Banchs, “Rate allocation for layered multicast streaming with inter-layer network coding,” in *IEEE INFOCOM*, march 2012, pp. 2796 –2800.

[5] I. Ahmed and L. Badia, “Analysis of management policies for multicast transmission of scalable video content in next generation networks,” in *IEEE IWCMC*, 2013.