Quality of Experience Driven Cross-Layer Optimization for the Future Mobile Internet

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Extended Abstract

Application-awareness has been identified as one of the requirements for a future Internet. We address this requirement with a quality-of-experience based cross-layer optimization framework. In our approach, we jointly optimize upper and lower layers of the protocol stack with the aim of maximizing user perceived quality of service..

Motivation

The Internet has become the main network technology supporting communications and Web services in all areas of our society. Despite its popularity, the Internet suffers from several deficiencies originating from its basic design principles. Targeted as a network for robust data transport over a fixed infrastructure, its suitability for today's variety of services including real-time traffic and mission critical applications is limited. In order to perform this role efficiently, a fundamental redesign of the Internet architecture is being discussed.

Further, the Internet has stretched out from the fixed line infrastructure to cellular networks. There, access to the Internet was offered as an add-on for second generation mobile networks. Today, the Internet protocols are an integral part of third generation mobile communication systems such as UMTS. Also, other competing wireless technologies have emerged such as WLAN and WIMAX which make use of the Internet technology.

Quality of Service is one of the still unsolved pressing problems in the Internet. Despite significant research and standardization efforts the best-effort characteristic of the Internet prevails. In the core network, QoS is addressed by simple overprovisioning today. However, to cope with the rise in traffic volume and the requirements of emerging applications (e.g., real-time, interactive) as well as the use of networks with different physical layer characteristics (e.g., wireless), comprehensive solutions have to be developed and deployed in order to transform the Internet from a commodity best-effort network to a commercial telco-grade one.

The increased usage of a wide variety of wireless multimedia services is putting an ever increasing demand for high data rates on the mobile access networks, which are considered as the bottleneck link. However the time varying transmission conditions of the wireless channel and the dynamic changes of application requirements of multimedia applications make the optimization of the network resources a challenging task. Cross-Layer Optimization is an approach that addresses these issues by exchanging key parameters across the layers in order to operate the system in an optimum state.

In order to address the emerging variety of multimedia applications in the Internet, each posing different requirements on the quality of service parameters, we optimize the resources from an application viewpoint. In this way, we take the user perceived quality of service, i.e., quality of experience (QoE) as our optimization metric.

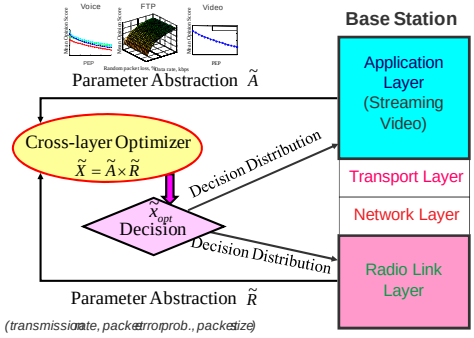
Objective

It is the objective of our work to come up with efficient mechanisms to jointly optimize different protocol layers in order to maximize the QoE or to allow a maximum number of user applications with a given QoE expectation.

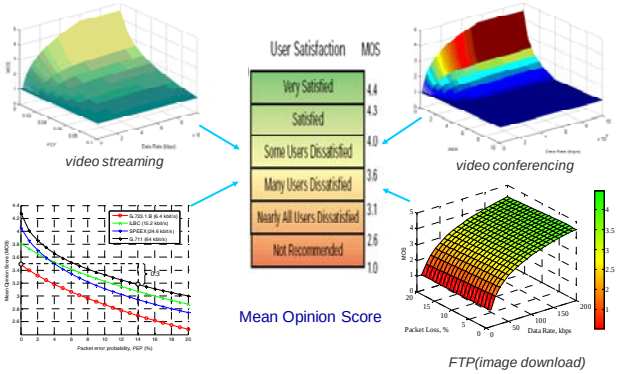
Approach

Cross-Layer Optimization has to consider the following steps

- Parameter abstraction: simple models of the considered layers to be considered for optimization
- Common metric to compare the QoE of diverse applications (utility function)
- Optimization algorithms
- Realization of the optimal setting in the respective layers



We have defined a MOS (Mean Opinion Score) related utility function for each application showing the sensitivity of each application's QoE with respect to other system parameters such as transmission rate, packet error rate, or delay. This utility function is used to maximize the QoE across all users and in turn feedback respective decisions of parameter settings to the respective layers.

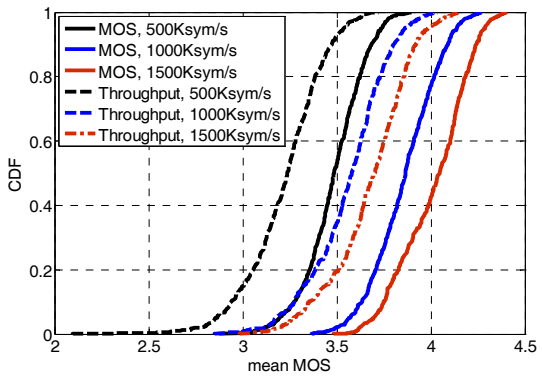


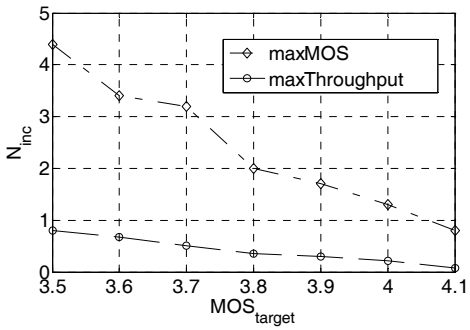
We have applied our Cross-Layer Optimization scheme to a mobile communication system running at a base station serving diverse applications to the users in a cell. We consider mainly two layers: application layer and radio link layer. The radio link layer is characterized by its possibility to influence resource allocation to a user (e.g., adaptive modulation and coding, assignment of users and data to TTIs) depending on its current status (e.g., CQI value of user). The application layer is characterized by the utility function showing for example the effect of a rate reduction or of changing delay on the QoE. Application layer settings to be influenced include for example the media codec selection or target transmission rate. The latter can be performed on the network layer by simple packet dropping, layer dropping (for layered coding) or transcoding. The cross-layer optimization function is considered to run at or close to the base station.

Results

We have applied our CLO approach to a communication system with seven users each served by a different application attached to one base station with varying channel conditions. In particular, we have 3 voice users, 2 FTP users, and 2 video users. The optimization goal is to maximize the mean MOS across all users.

The figure below on the left side shows simulation results of our MOS based approach compared with an approach where we maximize the overall system throughput not taking QoE into account. The optimization interval is 1 sec. We can see that the QoE can be improved for 50% of the users for about 0.3 on the MOS scale from 1 to 4.5, which is quite significant. The figure on the right side illustrates another view on our results. Instead of maximizing QoE, we keep the QoE at a certain level and see how many additional users could be added.





Summary

The presented Cross-Layer Optimization approach shows its effectiveness in a multi-user multi-application scenario for a wireless access network. It illustrates possible achievements in the resource management in a future Internet taking multiple system layers and in particular application-awareness resp. QoE into account for the overall optimization.

In general this cross-layer optimization scheme can be applied for any optimization process with the network wherever decisions have to be made on QoS based on application resp. QoE awareness.

For a future Internet it has to be carefully considered to what extent the existing layering should be broken up or if cross-layer information exchange as in our work is enough to realize application awareness in a future Internet design.

References

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