

CROSS-LAYER OPTIMIZATION OF WIRELESS NETWORK PARAMETERS IN AWGN CHANNEL FOR QoS PROVISION

Zoran Veličković

High technical school Niš

Milojko Jevtović

Yugoslav Engineer Academy

Abstract

Guaranteeing quality of service (QoS) in wireless communication systems is a challenging problem. An effective way of solving this problem is a joint optimization of network parameters with multiple ISO/OSI layers. Choice of optimization parameters is a very important activity in the design of wireless communications protocol stack that can greatly facilitate the effectiveness of the proposed algorithms. This paper presents an optimization algorithm that minimizes long-time average throughput of single-user wireless system. Optimization problem was defined as the MDP (Markov Process Decision) and an optimal solution of the minimization problem by the newly-formed cost functions is proposed. That proposed solution was tested in a simulated communication channel with uncorrelated and correlated Rayleigh fading and present AWGN (Additive White Gaussian Noise) noise. Discussed adaptation algorithm provides network parameters optimization and the satisfaction of a wide range of multimedia QoS applications. Through simulations it has been confirmed that the obtained solutions are Pareto-optimal, so that through adaptation of one QoS parameter it can be influenced on all the others. Application of MDP in multi-criteria optimization problems has proved to be justified.

Keywords: Cross-layer optimization, Markov Decision Process (MDP), Quality of Service (QoS).

INTRODUCTION

We are witnessing great interest the user to access wireless communication systems. Among other things, this interest can be justified by attractive multimedia services that this network support. However, supports for wireless multimedia services include the provision of high network throughput and a certain level of QoS (Quality of Service). In order to assess the quality of network services, ITU-T has standardized the key parameters of QoS of multimedia applications. Without considering the technical aspects, G.1010 specification is standardized QoS parameters from the perspective of users with regard to *delay*, *delay variation* and *loss of information* [1]. The parameters are classified into eight categories according to type of application, and include *voice*, *video*, *images* and *text*. According to this specification, for conversational speech, it is allowed: delay up to 150 ms, delay variation up to 1 ms and can be tolerated a maximum of 3% of lost packets. On the other hand, when download Web pages from the Internet, it is allowed the delay to 4 s,

and delay variation is not specified for this class of applications, while the mandatory requirement that all packages arrive at their destination. From the previous example can be concluded that a variety of multimedia applications have different QoS requirements. Thus, the QoS requirements of multimedia applications can be classified in those *tolerant to delay* - and demanding in terms of packet loss, to those that are *tolerant of packet loss* - and intolerant of delay. Joint optimization of network parameters over ISO/OSI layers is called *cross-layer* (CL) optimization [2]. However, the layered structure of the communication protocol stack has only a mechanism for communication of neighboring layers. Although, a historically great influence on the development of network communications, layered structure of the standard ISO/OSI protocol stack is a limiting factor in the design of the optimal protocol in a wireless environment. In [2] is described several solutions to overcome this disadvantage. The three basic architectures for free access to network parameters are in

appling: architecture with direct communication between the layers, the architecture with a shared database and a modular architecture design CL. Providers of wireless service show interest for a field of CL design to increase the level of satisfaction of their customers [3]. CL base optimization, which will be shown later in this paper, is that all types of multimedia applications provide the required QoS to the minimization of transmission power. In wireless communication systems, beside the standard set of QoS defined in [1], it is an important requirement for the minimization of transmission power. Transmission power minimization and application QoS satisfaction ensure efficient use of mobile user battery. Due to the limited radio resources, dynamic network structure, time-variable features of communication media, the fading level, and the dynamics of network traffic, the satisfaction of QoS in wireless communication systems is not an easy task. This paper discusses the CL algorithm that performs adaptation of network parameters in the function of the quality variations of the communication channel (e.g. the level of signal to noise ratio – SNR and fading) transmitting buffer occupancy and the type of network traffic in a network node. A mathematical model that optimizes network parameters to meet the QoS is based on the MDP (Markov Decision Process) is applied [4]. The aim of this paper is the maximization of long-term network throughput limitations mean the transmission power and minimize packet delay. In this paper model of one-user wireless communication system, shown in previous work, will be used [5], [6]. Method of selecting design parameters for the CL will be shown in section II, while the impact of a SNR on the structure of the optimal transmission policy will be analyzed in the third section. Overview of the results and conclusions will be presented in concluding sections.

SELECTION OF PARAMETERS OPTIMIZATION

Mapping multimedia applications at the level of the loss packets - delay is shown in Fig. 1 [1].

The size and shape of individual applications meet the limits in the number of lost packets, i.e., the allowed delay. Given the fact that wireless communication protocol stack has a large number of parameters in each layer, CL design can potentially make use of all available parameters in order to satisfy the QoS. Although, the potential adaptation parameters can be done on a very large collection, it is often not optimal. Available resources for the implementation of CL algorithms restrict the number of network parameters that can participate in the optimization. The most common network nodes do not have powerful enough processor, memory and energy resources for the implementation of complex CL algorithms. From the previously presented, it can be concluded that the choice of CL optimization parameters is extremely important issue. Therefore, the optimization parameter selection takes place through the following three steps [7]:

- *Abstraction* of specific parameters for a given layer. Primary in this step is to identify parameters that have a significant impact on the desired characteristics. The number of selected network parameters should be reduced to a measure that allows the applied algorithm, i.e., the available hardware resources.
- *Identification* of parameters that optimize a given objective function. Thus, in this paper is optimized network bandwidth for a given power level transmitters.
- *Reconfiguration* layer includes distribution of selected values of network parameters to all layers involved in the optimization. It is the individual layers' responsibility to translate the selected parameters back into layer-specific parameters.

These steps need to be repeated by the speed at which a particular application requires. The identification of network parameters that have a significant impact on the performance of layers is a key step in the design of CL algorithms. So, through a process of abstraction is the reduction of the number of network parameters involved in the optimization, which is a very important aspect in practical implementation. On the other hand, the abstraction hides the technical details and allows design CL generic algorithms that can efficiently applied in different systems.

According to the role of the selected network parameters, they can be classified into four

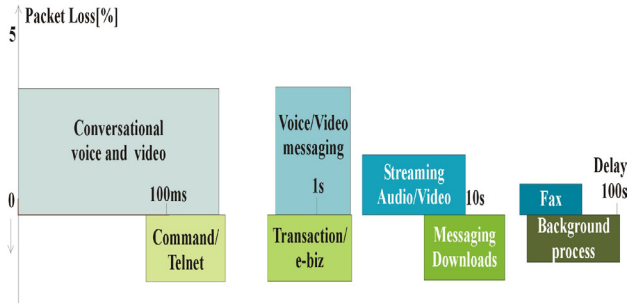


Fig. 1. Mapping applications to the desired QoS in the plane of packet loss - delay [1].

categories:

- *Direct Tunable* (DT) parameters. These parameters are directly accessible by CL algorithm. An example could be a number of OFDM carriers in OFDM systems, or a choice of modulation techniques at the PHY layer of the cellular network.
- *Indirectly Tunable* (IT) parameters. These parameters CL algorithms can not be changed. However, the adaptation of DT parameters can have an impact on them. An example of this type of parameters is BER (Bit Error Rate), which can not be set because it is directly a function of the selected modulation scheme.
- *Descriptive* parameters (D). This kind of network parameters CL algorithm can be read, but they can not be adjusted. An example of these parameters can be number_of_frames/s and the image size of a video stream.
- *Abstract parameters* (A). These parameters are abstraction previous three types of parameters used in the CL algorithm.

CL algorithms can be jointly optimized PHY layer parameters (transmitter power, modulation type, bit rate, BER), MAC-DLC layer (access scheme, size, and transmitting the buffer occupancy) and APP layer (source coding and allowed delay). CL optimization algorithms that consider network resources with the PHY and MAC layers of DLC [8] are the most frequently implemented. In proposed CL algorithm, parameters with PHY, MAC-DLC and APP layers are used to optimize the network utility in order to meet the QoS. The two lowest layers of the protocol are modeled on the basis of Markov chain and can be found in previous works [5],

[6]. Network traffic to the APP layer is modeled by Poisson distribution which can simulate different classes of multimedia applications.

Table 1: Transmission modes of IEEE 802.11a standard.

Modulation Type	R _b [Mbps]	R _c [Mbps]	R _s [Mpsps]	u b/sy
BPSK	6	12	12	1
BPSK	9	12	12	1
QPSK	12	24	12	2
QPSK	18	24	12	2
16QAM	24	48	12	4
16QAM	36	48	12	4
64QAM	48	72	12	6
64QAM	54	72	12	6

Adaptation of code and modulation scheme of PHY layer is the basic parameters which can be implemented by CL optimization algorithm. Selection of optimization network parameters is based on the information of first and the second layer. On the PHY layer information of the quality of the communication channel are considered, while the MAC-layer DLC consider information on communication buffer. Modern protocols offer a number of various modulation scheme as a choice of CL algorithms. Table 1 shows the adaptive capabilities of the PHY layer, which offers 802.11a standard. R_c is the speed of data, R_b and R_s encoding bit and the symbol rate for some types of modulation. First column is defined by the type of modulation, and the back of the column is defined by the number of bits per symbol of the selected modulation scheme.

CL OPTIMIZATION PROBLEM

Minimum level of necessary transmission power P in the communication channel with AWGN noise and the presence of fading are given by (1), and refer to systems with MQAM modulator and ideal coherent phase detection:

$$P(u, g, P_b) \geq -\frac{WN_o}{\gamma_g} \cdot \frac{\ln(5 \cdot P_b) \cdot (2^u - 1)}{1.5}. \quad (1)$$

P_b is required bit error probability, parameter W is the channel bandwidth, γ_g gain of communication channels with the fading of the state $g \in (0, 1, 2, \dots, K-1)$ [11]. N_o is AWGN noise power density, and u the number of bits per QAM symbol (last column in Tab.1). This means that the values of parameters that

characterize the communication channel during the frame are invariant. It is evident that for the increased level of AWGN noise should provide a greater level of transmitting power. On the other hand, the better communication channel fading conditions require a lower transmitting power. From expressions (1) it can be concluded that the adaptation of transmission power by fixing the symbol rate and BER can be made a variation of the symbol constellation MQAM modulator (parameter u). If with P_i denote necessary transmitting power of the frame i , for wireless communication systems is extremely important to limit the long-term mean value of maximum transmit power:

$$\limsup_{T \rightarrow \infty} \frac{1}{T} E \left\{ \sum_{i=0}^{T-1} P_i \right\} \leq \bar{P}. \quad (2)$$

On the other hand, an important QoS parameter for multimedia applications is the maximum allowable packet delay. Packet delay is defined as (Little's theorem):

$$D_i = \frac{B_i}{\lambda}, \quad (3)$$

where λ is the mean number of packets received in the buffer, and B_i the number of packets in the buffer for the time frame i . The mean value of maximum long-term packet delay can be defined as follows:

$$\limsup_{T \rightarrow \infty} \frac{1}{T} E \left\{ \sum_{i=0}^{T-1} D_i \right\} \leq \bar{D}. \quad (4)$$

Previous equation (2) and (4) are defined by competing network requirements in terms of restrictions on long-term mean transmission power and packet delay. Minimization of average transmit power affects on the average number of discarded packets, network throughput, as well as to delay the packets. Thus, it is not possible to optimize the function for one parameter and that it does not affect to the other. Finally, the maximization of network throughput is realized by minimization of the number of discarded packets L_o with a given average transmission power and allowable packet delay. Minimization problem can be expressed in the following way:

$$\arg \min_{U_0, \dots, U_{T-1}} \limsup_{T \rightarrow \infty} \frac{1}{T} E \left\{ \sum_{i=0}^{T-1} (L_o(B_i, U_i)) \right\} \quad (5)$$

$$U_i \in \{0, 1, 2, \dots, B_i\}, \forall i = 0, 1, \dots, T-1, \quad (6)$$

with conditions:

$$\limsup_{T \rightarrow \infty} \frac{1}{T} E \left\{ \sum_{i=0}^{T-1} P_i \right\} \leq \bar{P} \quad (7)$$

and

$$\limsup_{T \rightarrow \infty} \frac{1}{T} E \left\{ \sum_{i=0}^{T-1} D_i \right\} \leq \bar{D}, \quad (8)$$

where $\bar{P}$ is the maximum of allowable average power transmission, while $\bar{D}$ is the maximum allowable average packet delay. Parameter U_i is the number of packets that are empty buffer during the frame i . One solution of this multi-objective problem (5) - (8) is, instead of the original problem, minimizing weight function of all three criteria. In this way, the minimization problem is defined as *long-term average cost MDP*:

$$\limsup_{T \rightarrow \infty} \frac{1}{T} E \left\{ \sum_{i=0}^{T-1} C_I(B_i, G_i, U_i) \right\}, \quad (9)$$

where C_I is a *direct cost* to be paid in the state of the communication system (b, g) applying the control action (u, P):

$$C_I(b, g, u) = P(u, g, P_b) + \beta_1 \cdot L_o(b, u) + \beta_2 \cdot D(b). \quad (10)$$

Weights β_1 and β_2 are positive numbers and the role of Lagrangian multipliers and determine the relative relationship between packet delay and the number of discarded packets [6].

SIMULATION RESULTS

This section presents numerical results obtained by applying an optimal MDP algorithm presented in the previous section. The simulation was performed for the following values of network parameters: $\lambda=3000$ packets/s, $L=1000$ bytes/packet, $B=15$ packets buffer capacity, bit error rate $P_b=10^{-6}$, channel bandwidth $W=100$ kHz, T_s is the symbol duration, and frame T_f was determined with 100 symbols. In this paper, we tested the behavior of an optimal algorithm with different AWGN noise levels in the fading communication channel. Rayleigh fading channel is modeled by eight states as in [11]. The communication channel with correlated and uncorrelated Rayleigh fading is discussed. The structure of optimal policies for certain values of the parameters β_1 and β_2 have been made in previous work [8], and [12]. Fig. 2, shows the packet delay values obtained in the function of transmitting power for different levels of AWGN noise at the reception. In Fig.

2a, are shown the results for the communication channel with uncorrelated fading, while in Fig. 2b, shows the results for time-correlated Rayleigh fading.

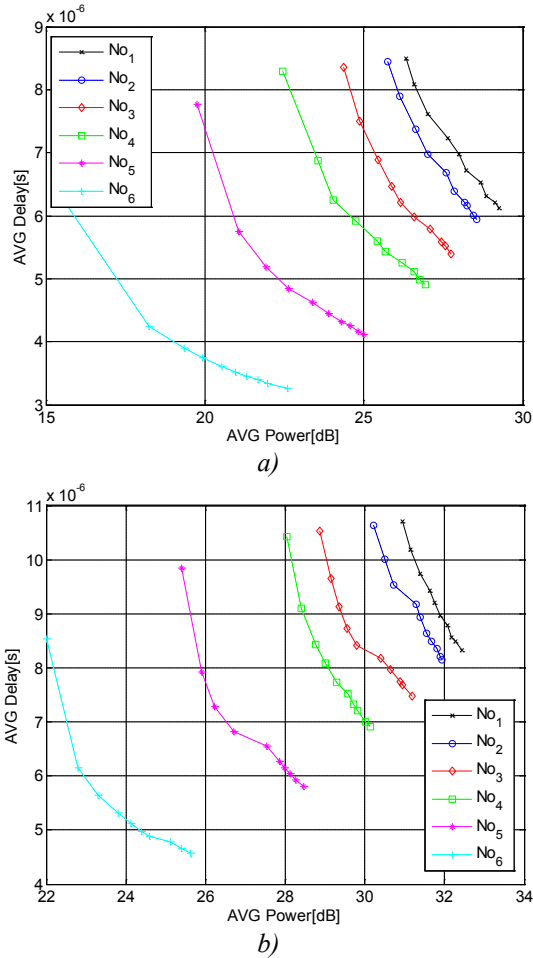


Fig. 2. Average packet delay in the function of average transmission power for different levels of AWGN noise in the communication channel with a) uncorrelated b) correlated fading.

The highest level of AWGN noise (worst quality channel) is indicated by No_1 , and the lowest with No_6 (the best quality). Graphs were obtained for the following parameter values $N_o = [2 \cdot 10^{-6} \ 10 \cdot 10^{-6} \ 30 \cdot 10^{-6} \ 50 \cdot 10^{-6} \ 80 \cdot 10^{-6} \ 100 \cdot 10^{-6}]$. Generally, with Fig. 2, may conclude that with increasing average transmission power leads to reduction in average packet delay for both discussed types of fading. This trend is evident for all values of parameter N_o . So if uncorrelated fading (Fig. 2a), the value of a package of $6\mu s$ delay, when the noise level No_6 , requires a level of transmission power of the $\bar{P} = 16dB$. On the other hand, for the same value of delay when the noise level No_5 ($No_5 > No_6$) is required the level of transmission power of the $\bar{P} = 21dB$. It should be noted that the average transmission power in case of

correlated fading (Fig. 2a) was significantly greater than the power of Rayleigh uncorrelated fading (Fig. 2b). At the same time, delays packets are

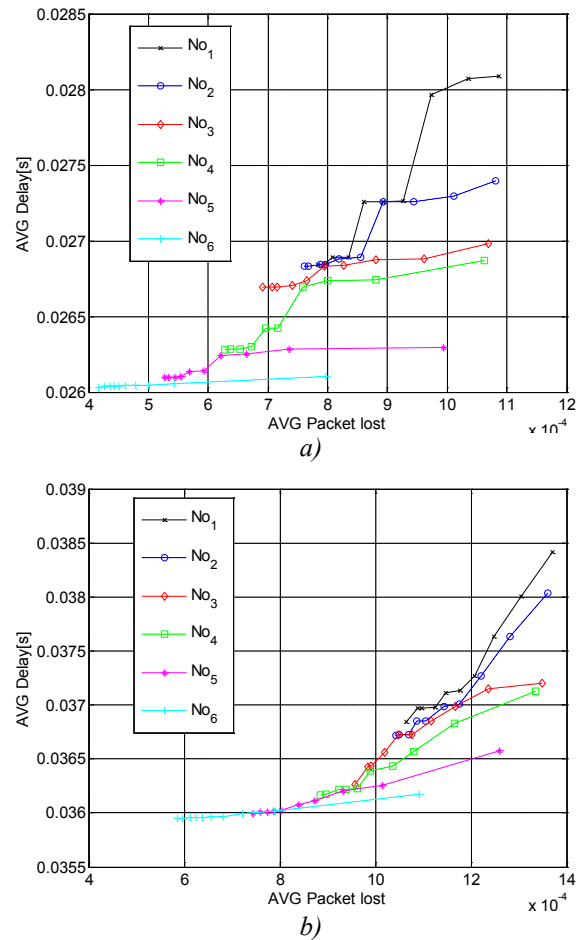


Fig. 3. Average packet delay in the function of average transmission power for different levels of AWGN noise in the communication channel with a) uncorrelated b) correlated fading.

also higher for the case of correlated fading. For both considered types of fading, with increasing levels of AWGN noise at the receiver, requires the higher level of transmission power in order to maintain the same average packet delay. Comparing the graphs in Fig. 2a/b, intuitively it can be concluded that at high values of transmission power, all curves converge to the corresponding minimum value of delay. It should be noted that every point on the curves is one of the optimal transmission policy (the parameters β_1 and β_2) for the given conditions. In Fig. 3 are shown the results of the number of discarded packets in the function of transmitting power to the same channel conditions as in Fig. 2. Fig. 3a shows the results for the uncorrelated, while Fig. 3b shows results for the channel with correlated Rayleigh fading. For both types of considered fading, with an increase in

transmission power, decrease the number of dropped packets.

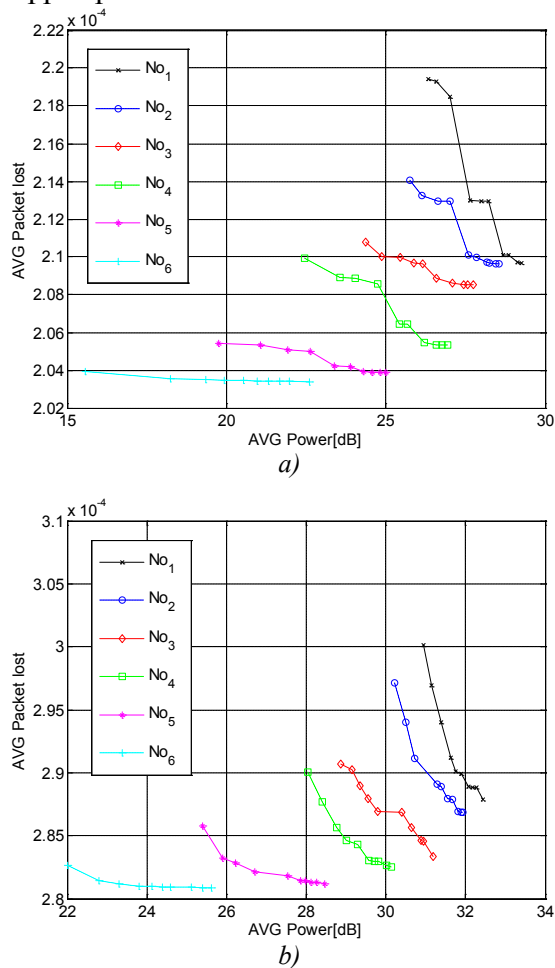


Fig. 4. Average number of lost packets in the function of average transmission power for various levels of AWGN noise in the communication channel with a) uncorrelated b) correlated fading.

Less favorable conditions in the communication channel with correlated fading can be clearly seen from Fig. 3. For the same average number of lost packets with correlated fading channel it's necessary to provide a higher power transmit level of the uncorrelated fading channel. Fig. 4 shows the graphic average packet delay in function to the number of discarded packets. Figure 4a refers to the channel with uncorrelated Rayleigh fading, while the Fig. 4b refers to the communication channel with correlated Rayleigh fading. With the increasing number of discarded packets, the packet delay increases. The worse channel conditions have a greater delay for the same value of discarded packets. The expected result that the channel with correlated fading conditions has worse results in relation to the

uncorrelated fading channel is confirmed in this figures.

CONCLUSION

Depending on the level of white Gaussian noise (AWGN) and the available transmission power, adaptation code and modulation scheme can achieve stringent QoS requirements. It was shown that in the communication channel with correlated fading should provide a greater level of transmitting power to provide the same QoS parameters than the channel uncorrelated Rayleigh fading. With increasing SNR a reduced level of transmit power is required for both discussed types of fading. Set MDP optimization problem is solved by minimization of cost function in an efficient manner. The obtained results are confirming the effectiveness of the proposed solutions.

REFERENCE

- [1] ITU-T Recommendation G. 1010: End-user multimedia QoS categories – ITU-T, 2001.
- [2] V. Srivastana, M. Motani, "Cross-layer design: a survey and the road ahead," *IEEE Commun. Mag.*, vol. 43, no. 12, pp. 112–119, Dec. 2005.
- [3] S. Thakolsri, S. Khan, E. Steinbach, W. Keller, "QoE-Driven Cross-Layer Optimization for High Speed Downlink Packet access," *Journ. of Comm.*, vol. 4, no 9, pp. 669-680, Oct. 2009.
- [4] M. L. Puterman, "Markov Decision Processes: Discrete Stochastic Dynamic Programming," New York, NY: John Wiley & Sons, 1994.
- [5] Z. Veličković, M. Jevtović, "Adaptive cross-layer throughput optimization in wireless fading channel and limited buffer capacity", Ref. tst_o_II.3.pdf, p.p. 9-12, ICEST 2010.
- [6] Z. Veličković, M. Jevtović, "Adaptive Cross-layer Optimization in Wireless Block-Fading Channel for QoS provision", WASET: ICCNMC 2010, Venice, Italy, paper accepted.
- [7] S. Khan, Y. Peng, E. Steinbach, M. Sgroi, W. Keller, "Application-Driven Cross-Layer Optimization for Video Streaming over Wireless Networks," *IEEE Communications Magazine*, pp. 122-130, Jan. 2006.
- [8] P. Popovski, M. A. Ingram, C. B. Peel, S. Hara, S. Toumpis, Editors, "Cross-Layer Design for the Physical, MAC, and Link Layer in Wireless Systems", *EURASIP*, 2009.
- [9] H. S. Wang and N. Moayeri, "Finite-state markov channel—a useful model for radio communication channels," *IEEE Trans. Veh. Technol.*, vol. 44, pp. 473–479, Feb. 1995.

- [10] A. K. Karmokar, D. V. Djonin, and V. K. Bhargava, "Optimal and suboptimal packet scheduling over correlated time varying flat fading channels," IEEE Trans. Wireless Commun., vol. 5, no. 2, pp. 446–457, Feb. 2006.