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Cross-layer Throughput Optimization in Slow Fading Wireless Channel

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***Abstract*—In this paper the optimizing cross-layer algorithm is presented which minimizes long-term average packet dropping subject to an average transmission power of single user wireless channel. The optimization problem is defined as Markov decision process (MDP) and the composite state space of the communication system with transition matrices of probabilities is determined. The structure of the obtained optimal policies for Rayleigh and independent and identically distributed (i.i.d.) fading channel is taken into consideration. Simulation results confirm that the proposed cross-layer algorithm provides adaptation of network parameters and makes it possible for satisfying QoS in a wide range according to application demands.**

***Index Terms*— Cost function, Cross layer design, Markov decision processes, Rayleigh fading channels.**

I. INTRODUCTION

Extraordinary interest of users for the access to wireless communication systems can be explained by attractive multimedia services they support [1]. The support of wireless multimedia services implies provision of a great network throughput as well as certain level of QoS (Quality of Services). ITU-T has standardized QoS parameters which refer to *delay, delay variation* and *information loss* from the perspective of users [2]. These parameters are classified into eight categories according to the type of application and include voice, video, image and text transfer. Thus, delay up to *150 ms* and delay variation up to *1 ms* at conversational speech can be tolerated with maximum *3%* packet los rate. On the other hand, Web-browsing can tolerate a delay up to *4 s* and a variation of the delay is not specified with information loss zero. It is evident that different applications require a wide range of QoS, from intolerant of delay to those more tolerant of packet loss. In wireless communication systems, along with the standard assembly of QoS, demand for minimization of transmit power is very important. The difficulties in providing QoS in wireless communication systems were not consider in standard protocol stack design. Reason for this can be found in the concept of the standard seven-layered ISO/OSI stack where network resources are arranged in the particular layers [3]. The data exchange is enabled only between the adjacent layers. The optimization in wireless communication systems includes most of ISO/OSI networks layers [4]. Joint optimization of network parameters of many ISO/OSI layers is called Cross-Layer (CL) design according to [5]–[7]. In this way at the same time parameters of PHY layer (transmission power, modulation type, bit error rate - BER), MAC layer (access scheme, buffer size of transmitter) and APP layer (source coding, permitted delay) can be at the same time optimized. CL algorithm which makes adaptation of network parameters in function of varying the quality of communication channel (fading level) [8], total capacity of the transmitting buffer [9] and the type of network traffic [10] in the network node is taken into consideration in this paper. A mathematical model based on Markov Decision Process (MDP) [11], [12] which optimizes network parameters is applied in order to satisfy QoS. The communication system is modeled by the composite discrete Markov process which describes behaving of the wireless communication system in various working conditions [13], [14]. The system modeled in this way can be solved numerically if dynamic programming is applied, where with optimal transmission policy for the set objective function is determined.

The aim of this paper is maximization of average long-term network throughput with limitation of the average transmission power, satisfying constant BER and minimization of the number of rejected packets. The composite model of the wireless single-user communication system which consists of Markov chains PHY and MAC-LLC layers is developed in several next sections. Thereafter, the optimization problem of the wireless communication network is defined and the optimal solution is provided. The results in the simulation environment are analyzed in extra section. Certain conclusions are suggested in the last section.

II. DYNAMICS AND THROUGHPUT

Considered a wireless communication system is the same

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as described in a previous paper [12, Fig. 1]. The communication system consists of a transmitter, which incorporates a buffer of the limited capacity and encoder-modulator and of a receiver. Loading of the buffer is done with packets from the higher ISO/OSI layers and is modeled by Poisson distribution. Transmission rate out of the buffer is adaptive, and it sustains the realization of optimization CL algorithms. The connection between the transmitter and the receiver is realized in slow Rayleigh fading channel, while information about the quality of the channel and the buffer state are being interchanged through the control channel. The average number of packets η which will be delivered to the application on a higher layer of the receiver can be determined in the following way [12]

$$\eta = \left(\lambda T_f\right) \cdot \underbrace{\left(1-P_p\right)}_{PHY-layer} \cdot \underbrace{\left(1-P_o\right)}_{LLC-Layer}, \tag{1}$$

where P_o is the buffer overflow and P_p is the packet error probability. The expression (1) binds two independent subsystems of the wireless communication system on two ISO/OSI layers: the subsystem of the transferring medium (PHY layer) and the subsystem of the buffer in the network node (MAC-LLC layer).

III. MODEL OF BLOCK-FADING CHANNEL

Existence of many propagation ways in the wireless environment causes degradation of the signal on the receiving side. This appearance is called fading and it will cause errors in received packets. Packets with errors will be rejected and depending on the received protocol their retransmission could be demanded or they could be permanently rejected. Influence of fading on the appearance of the packet error in the wireless communication system has been surveyed through packet error probability as it is given by the expression (1). This network parameter is located on the first (PHY) layer. It was shown that the instantaneous amplitude value of the receiving signal in the channel with many propagation ways has Rayleigh distribution. The most often applied model of the communication channel with slow fading is based on Markov chain which approximates the channel with the final number of states (Finite State Markov Channel FSMC) [14]. This approximation was performed by discretisation of the continual channel with fading to the finite number of states. Only the slowly variable Rayleigh channel can be well modeled by Markov chain. Therefore, the communication channel with fading can be presented by Markov chain from K state, where every state represents certain range of the fading levels on the receiving side. The probability density function (PDF) for Rayleigh channel with fading can be presented [15]

$$p_\Gamma(\gamma) = \begin{cases} \dfrac{1}{\bar{\gamma}}\exp\left(-\dfrac{\gamma}{\bar{\gamma}}\right), & \gamma \geq 0, \\ 0, \ \gamma < 0, \end{cases} \tag{2}$$

where $\bar{\gamma}$ is average, and γ instantaneous value of the channel gain. The channel gain can be divided to K not overlaped sections by using $K+1$ levels in the following

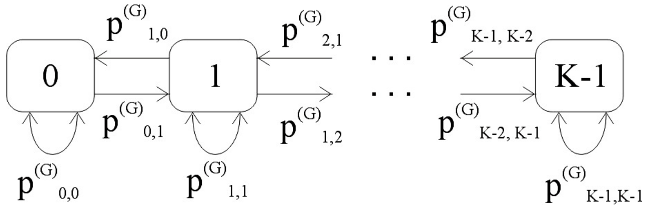


Fig. 1. Markov model of Rayleigh communication channel for K states. States are defined on the base of the fading level and the state transition probability by the expressions (6)-(10).

way $0 = \gamma_0 < \gamma_1 < \ldots < \gamma_{K-1} < \gamma_K \to \infty$. Accordingly, the communication channel is in the state g, $g \in \{0, 1, \ldots, K-1\}$, if $\gamma_g \leq \gamma \leq \gamma_{g+1}$. If G_i designates the state of the communication channel during the frame i, then the transition probability from the state g into g', $p^{(G)}(g,g')$, can be written down in the following way

$$p^{(G)}(g, g') = \Pr\left\{G_i = g' \mid G_{i-1} = g\right\}. \tag{3}$$

The steady state probability for Rayleigh communication channel is determined on the base of (2)

$$p^{(G)}(g) = \exp\left(-\frac{\gamma_g}{\bar{\gamma}}\right) - \exp\left(-\frac{\gamma_{g+1}}{\bar{\gamma}}\right). \tag{4}$$

For determination of transition probabilities for the model with K states, expressions (6)-(10), the number of crosses in one second (N_g) between γ and γ_g should be determined

$$N_g = \sqrt{\frac{2\pi\gamma_g}{\bar{\gamma}}}\, f_D \exp\left(-\frac{\gamma_g}{\bar{\gamma}}\right), \ g \in \{0, 1, \ldots, K-1\}, \tag{5}$$

where f_D is the maximum of Doppler channel frequency. The channel gain γ_g in relation to the level for observed state of the channel g. The maximum Doppler frequency for the given movement rate of the terminal v and the bearing frequency f is determined $f_D = f \cdot v/c$, where c is the speed of light. Presupposing that the fading is slow enough, i.e. that the channel remains unchanged during time frame T_f, and that the state transition is performed after every frame and only between the adjacent states, the state transition probability for the channel with K states can be written down as [15]:

$$p^{(G)}(g, g-1) = \frac{N_g T_f}{p^{(G)}(g)}, \quad g \in \{1, \ldots, K-1\}, \tag{6}$$

$$p^{(G)}(g, g+1) = \frac{N_{g+1} T_f}{p^{(G)}(g)}, \quad g \in \{0, 1, \ldots, K-2\}, \tag{7}$$

$$p^{(G)}(g, g) = 1 - p^{(G)}(g, g-1) - p^{(G)}(g, g+1), \quad g \in \{1, \ldots, K-2\}, \tag{8}$$

$$p^{(G)}(0, 0) = 1 - p^{(G)}(0, 1), \tag{9}$$

$$p^{(G)}(K-1, K-1) = 1 - p^{(G)}(K-1, K-2). \tag{10}$$

The transition matrix of the communication channel with correlated fading for the case from K state, $P^{(G)}$, is formed on the base of the expression (6)-(10). The model of Markov chain for the channel with slow Reileight fading is presented in Fig. 1. The transition matrix of this model has a quadrate structure as presented in (11). For the sake of simplifying: $p^{(G)}(g, g\text{-}1) = p^{(G)}_{g,g-1}$

$$P^{(G)} = \begin{bmatrix} p^{(G)}_{0,0} & p^{(G)}_{0,1} & 0 & 0 & \dots & 0 \\ p^{(G)}_{1,0} & p^{(G)}_{1,1} & p^{(G)}_{1,2} & 0 & \dots & 0 \\ \dots & \dots & \dots & \dots & \dots & 0 \\ 0 & 0 & \dots & p^{(G)}_{K-1,K-3} & p^{(G)}_{K-1,K-2} & p^{(G)}_{K-1,K-1} \\ 0 & 0 & \dots & 0 & p^{(G)}_{K-1,K-2} & p^{(G)}_{K-1,K-1} \end{bmatrix}. \quad (11)$$

IV. MODEL OF THE BUFFER OF THE LIMITED CAPACITY

The influence of the communication node in the total number of transmitted packets in the wireless communication system is surveyed through the parameter P_o in the expression (1). The important cause of loosing packets in the communication node can also be the buffer of limited capacity on the transmitting side. Of course, in addition to the capacity of the transmitting buffer, the arriving dynamics of packets into the buffer has a considerable influence on the number of rejected packets.The arriving dynamics of packets into the buffer is modelled in this paper by Poisson distribution. In this way the burstly packet traffic obtained during realization of most multimedia applications is simulated. By changing the parameters of the buffer loading model, various types of multimedia services can be simulated. Every packet which arrives into the buffer when it is filled up will be rejected. Loading or unloading of the buffer, happens in equal discrete time frames T_f. It is evident that the speed of sending packets from the buffer has a direct influence on the packet rejecting probability. So, if unloading of packets from the buffer happens faster, the buffer won't be fully occupied and packet rejecting will be lower. The possibility of sending packets through choosing of the modulation scheme [8] with great number of constellation states (MQAM modulator) is used in this paper. The subsystem of the limited buffer in a network node can be modeled by Markov chain whose states are determined by the number of packets in the buffer. The state space of the Markov chain used for description the buffer whose capacity is B packets $\mathcal{B} = \{B_0, B_1, \dots, B_B\}$. The state of an empty buffer is marked with B_0, while the full buffer is marked with B_B. In order to define Markov chain completely, along with the space of the state, it is necessary to determine the transition probability of this subsystem $p^{(B)}(m,n)$ from the state m into the state n. Transition matrixes of the subsystem probability of the buffer are determined by the following expression

$$p^{(B)}(m,n,u_m) = \begin{cases} A_{n-m+u_m}(\lambda),\ m-u_m \le n < B_B, \\ 1 - \sum\limits_{k=0}^{B_B+m+u_m-1} A_k(\lambda),\ n = B_B, \\ 0,\ others, \end{cases} \quad (12)$$

where $A_k(\lambda)$ is the probability that k packets arrive into the buffer during the frame T_f, and $u_m \le m$ is the number of packets which unload when the buffer is in the state m. For the sake of simplifying: $p^{(B)}(m,n,u_m=const) = p^{(B)}_{m,n}$. Transition matrix of probabilities $P^{(B)}$ of Markov process which models the buffer of the final length for one value of the parameter u_m has the quadrate structure (13). For applying in the wireless communication system with adaptive unloading rate of the buffer it is necessary to determine transition matrices of probabilities for all values of adaptive rate. In this way 3D transition matrix of probabilities is obtained where the third dimension depends on the number of possible adaptations of the unloading rate of the buffer

$$P^{(B)} = \begin{bmatrix} p^{(B)}_{0,0} & p^{(B)}_{0,1} & p^{(B)}_{0,2} & \dots & p^{(B)}_{0,B} \\ p^{(B)}_{1,0} & p^{(B)}_{1,1} & p^{(B)}_{1,2} & \dots & p^{(B)}_{1,B} \\ p^{(B)}_{2,0} & p^{(B)}_{2,1} & p^{(B)}_{2,2} & \dots & p^{(B)}_{2,B} \\ \dots & \dots & \dots & \dots & \dots \\ p^{(B)}_{B,0} & p^{(B)}_{B,1} & \dots & p^{(B)}_{B,B-1} & p^{(B)}_{B,B} \end{bmatrix}. \quad (13)$$

The standard IEEE 802.11a/e provides for several different modes of work on PHY layer which secure adaptation of unloading rate of the buffer.

V. COMPOSITE MARKOV MODEL OF THE COMMUNICATION SYSTEM

The state space of the communication system (S) is composite, determined by states of the communication channel g and the buffer in the communication node $\mathcal{B}$ [12]

$$S = g \times \mathcal{B}, \quad (14)$$

where $\{\times\}$ represents an operator of Cartesian product. On the base of (14), the state space of Markov chain of the communication system is determined in the expression

$$S = \{s_1, s_2, \dots, s_Q\}, \quad (15)$$

where

$$Q = K \cdot (B+1). \quad (16)$$

Fig. 2 shows the composite Markov model for a communication system with 8 channel states and 16 buffer states that was used in simulation in this paper. Therefore, state of the communication system for frame i, S_i, is determined by two components: state of the buffer B_i and state of the communication channel G_i

$$S_i = (B_i, G_i). \quad (17)$$

The packet number for empting the buffer when the communication system is in the state S_i is marked with U_i.

CL optimization algorithm described in the following section implies that both transmitting and receiving sides have information about the state of the communication system for every frame *i*. For the complete determination of Markov chain it is necessary to determine transition values this time for the whole communication system.

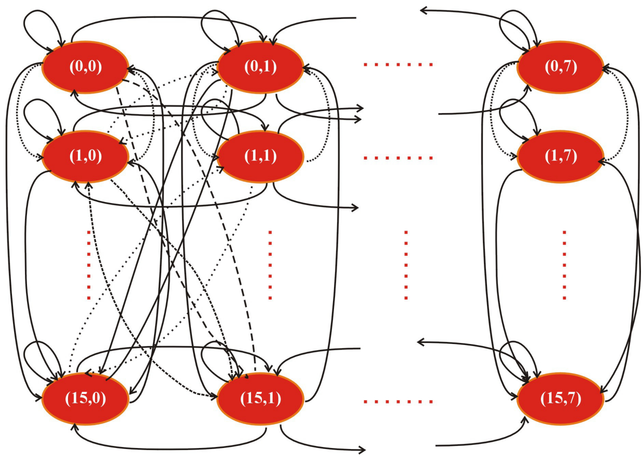


Fig. 2. Markov model of the considered communication sistem, K=8, B=16.

It is important to mention here that there is not only one probability for transition from the system state S_{i-1} into the system state S_i, but that the number of possible transitions determined by adaptive possibilities of unloading the buffer in the communication node. Therefore, set of actions, which can be performed for every state of the system is determined by adaptive possibilities of coding and choice of modulation techniques in the communication system. For the observed communication system the set of actions represents the number of packets through which the buffer in the communication node can be emptied during one frame. By fixing the symbol rate and adaptation of parameters of signal constellation in MQAM modulator the rate of emptying the communication buffer can be adapted. Transition probabilities of the communication system $p^{(S)}$ in realization of the action u can be determined in the following way

$$p^{(S)}(s \mid s', u) = p^{(G)}(g, g') \cdot p^{(B)}(b, b', u)\,, \tag{18}$$

where $p^{(G)}$ and $p^{(B)}$ are transition probabilities of the subsystem which describe the communication channel, that is, state of the communication buffer, respectively. The quadrate matrix of transition probabilities for the whole communication system for one value of the parameter u is given in (19)

$$P^{(S)} = \begin{bmatrix} p_{0,0}^{(S)} & p_{0,1}^{(S)} & \cdots & \cdots & \cdots & p_{0,Q}^{(S)} \\ p_{1,0}^{(S)} & p_{1,1}^{(S)} & \cdots & \cdots & \cdots & p_{1,Q}^{(S)} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ p_{Q-1,0}^{(S)} & p_{Q-1,1}^{(S)} & \cdots & \cdots & \cdots & p_{Q-1,Q}^{(S)} \\ p_{Q,0}^{(S)} & p_{Q,1}^{(S)} & \cdots & \cdots & \cdots & p_{Q,Q}^{(S)} \end{bmatrix}. \tag{19}$$

For the system with adaptive modulation transition matrix of probabilities is also 3D matrix where the third dimension depends on adaptive possibilities of the communication system. It is evident that dimensions of this matrix $P^{(S)}$ which describes the communication system are considerably greater than those of matrices which described the communication subsystems. Great dimensions of 3D matrices demand a lot of processing time and considerable memory resources. This can be one of the reasons for finding suboptimal solutions so that they can accommodate to available resources in the network node.

VI. OPTIMIZATION PROBLEM

If P_i marks the necessary transmit power of the i-th frame, it is extremely important for wireless communication systems to limit the maximum of the long-term average transmission power $\overline{P}$

$$\lim_{T\to\infty} \sup \frac{1}{T} \mathrm{E}\left\{ \sum_{i=0}^{T-1} P_i \right\} \le \overline{P}\,. \tag{20}$$

As it was mentioned in the introductory part, multimedia communications demand great network packet throughput. If we presuppose that a packet has L bits and that it will be rejected if at least one bit is wrong, the packet error probability (PER) P_p can be determined in the following way

$$P_p = \sum_{j=1}^{L} \binom{L}{j} P_b^j \cdot (1 - P_b)^{(L-j)}. \tag{21}$$

In this paper, protocols which keep BER constant (P_b = const) will be considered, so that according to (21) it will result in constant PER. Increasing of network throughput for the case of constant PER can be realized through minimization of the number of rejected packets produced by the buffer overflow in the communication node. The average number of rejected packets L_o depends on the capacity, dynamics and fulfillment of the buffer

$$L_o(b,u) = \mathrm{E}\left\{ \max(0, A + b - u - B) \right\}, \tag{22}$$

where B is the capacity of the buffer in packets, b the number of packets in the buffer which is unloading with u packets and loading with A packets per frame. The expectation is with respect to the number of packets arriving in frame. The maximum long-term average number of rejected packets can be presented in the following way [12]

$$\lim_{T\to\infty} \sup \frac{1}{T} \mathrm{E}\left\{ \sum_{i=0}^{T-1} L_o(B_i, U_i) \right\},. \tag{23}$$

when $U_i \in \{0,1,2,...,B_i\},\ \forall i = 0,1,...,T-1$.

The optimization problem can be defined as minimization problem in the following way:

Minimize the maximum of long-term average rejected packets L_o of the wireless communication system subject to an average transmission power constraint $\overline{P}$ and constant BER.

Minimization problem can be presented in the following way:

$$\underset{U_0,\dots,U_{T-1}}{\arg\min}\ \underset{T\to\infty}{\lim\sup}\frac{1}{T}\mathrm{E}\left\{\sum_{i=0}^{T-1}\left(L_o\left(B_i,U_i\right)\right)\right\}, \quad (24)$$

when $U_i \in \{0,1,2,\dots,B_i\}$, $\forall i = 0,1,\dots,T-1$, subject to

$$\underset{T\to\infty}{\lim}\ \sup\frac{1}{T}\mathrm{E}\left\{\sum_{i=0}^{T-1}P_i\right\}\le \overline{P}, \quad (25)$$

where $\overline{P}$ is the maximum tolerable average transmit power. Parameters B_i and U_i present the number of packets in the buffer, i.e. the number of packets for which the buffer is being emptied respectively during the frame i.

The direct solution for the optimization problem (24), (25) can be a very hard task. One of the solutions of the multi-objective minimization problem is, instead of the original problem, to minimize the weight function of all criteria. In this way the minimization problem is defined as the long-term average cost MDP [11]. We aim to minimize

$$J_{avr} = \underset{T\to\infty}{\lim}\ \sup\frac{1}{T}\mathrm{E}\left\{\sum_{i=0}^{T-1}C_I\left(B_i,G_i,U_i\right)\right\}, \quad (26)$$

where C_I is immediate cost incurred in state (b, g) when control action (u, P) is taken, i.e.

$$C_I(b,g,u) = P(u,g,P_b) + \beta\cdot L_o(b,u), \quad (27)$$

The weight factor β is positive number with the role of Lagrangian multiplier and indicate the relative importance of average lost packets over the average transmission power. Considering the fact that the state space of the system is finite, it means that the cost is also limited. We are interested in the stationary communication system where transition probabilities and the cost do not depend on time, so that the system can be minimized by using dynamic programming techniques. The solution for the optimization problem (24), (25) is *policy*. Policy represent rules established in advance for defining actions which should be taken in the moment foreseen for deciding. The solution of MDP is in fact the set of rules the wireless communication system is governed by under the set conditions. The optimal stationary policy π^* is obtained by solving the following problem

$$\pi^* = \underset{\pi}{\arg\min}\ J_{avr}(\pi). \quad (28)$$

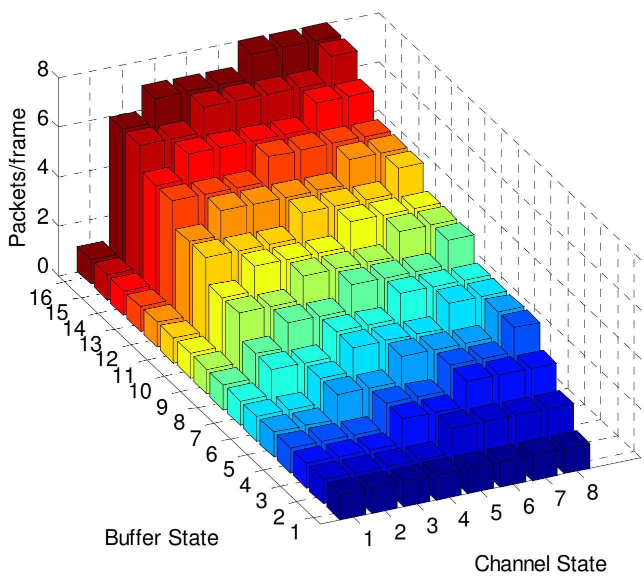
VII. Simulation Results

The numerical results are obtained for the simulation parameters sumarized in Table I.

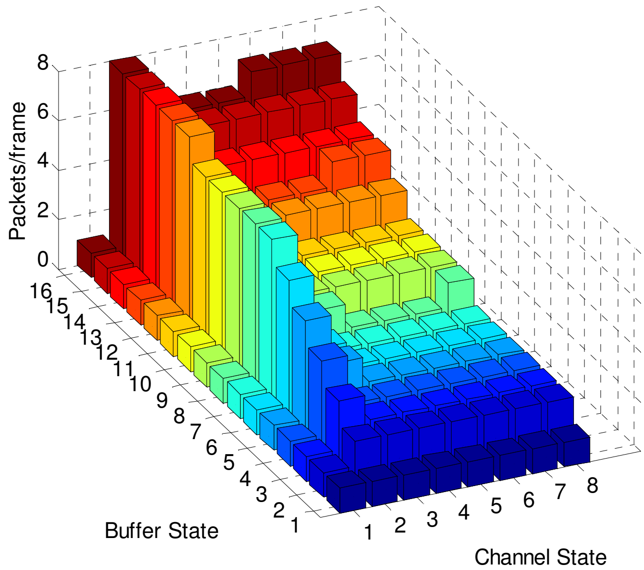
TABLE I. TEST SETUP.

Item	Setting
Average packet arrival rate λ	1000 packets/s
Packet length L	100 bits
Capacity of the buffer B	15 packets
Average Bit Error Rate P_b	10^{-6}
Channel bandwith W	100 kHz
Noise power density N_o	$2\cdot10^{-5}$ W/Hz
Duration of the symbol (fixed) T_s	10^{-5}s
Frame duration	100 symbols
Average channel gain	$\bar{\gamma} = 0.8$
Channel gain levels γ_g $g\in\{0, 1, \dots, 7\}$	0; 0,168; 0,231; 0,376; 0,554; 0,784; 1,109; 1,663.

Based on the simulation parameters, the transition matrix (11) is determined by equations (4) - (10). Then, on the basis (12), the transition matrix (13) is formed. The transition matrix of the entire communication system (19) is determined by equations (14) - (18). For Poisson PDF of the arrival packets, the average rejected packets are determined according to (22). Instead of the original optimization problem (24), it is easier to solve the corresponding MDP problem (26) with cost function C_I (27). For different values of the parameter β, the Pareto-optimal average packets loss and average power is determined. In order to analyze the influence of fading on transmission policy, the communication channel with correlated and independent and identically distributed (i.i.d.) slow fading over time is taken into consideration.



a)

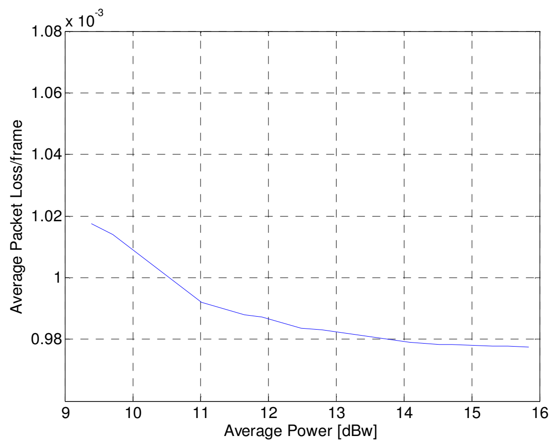


b)

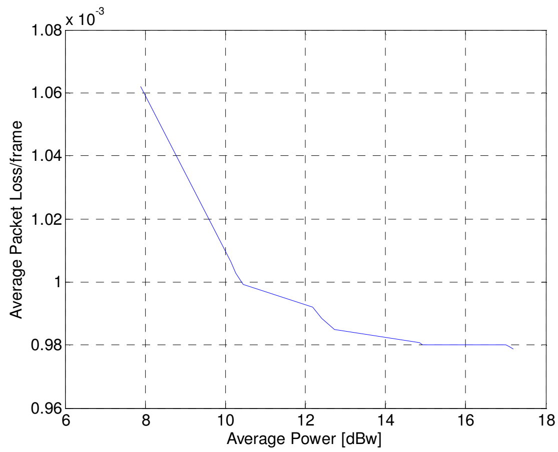
Fig. 3. The structure of the optimal transmission policy for a) i.i.d. channel and b) time correlated Rayleigh slow fading channel obtained by proposed optimization MDP algorithm.

For the case of i.i.d. fading, all elements of transition matrix of probabilities (11) have an equal value 1/8. Based on the MDP, solution vector U_i, the number of rejected packets L_o and the value of transmission power P_i are determined. By averaging the obtained values for the transmission power (P_i), the number of rejected packets (L_o) for all frames i, Pareto-optimal values have been obtained. In Fig. 3 there is the structure of the obtained optimal transmission policy for the case a) channel with i.i.d. fading and b) channel with correlated Rayleigh fading for same $\overline{P}$. The composite state of the communication system $S_i=(B_i,G_i)$ is presented by the quadrate surface in the plane *Channel State – Buffer State* (Fig. 3).

Optimal number of packets by which the network node should be emptied is presented as a parallelepiped of certain height – *Packets/frame* whose base is the surface determined by the state of the communication system. In the graphic 3a related to i.i.d. fading channel it can be noticed that the optimal policies correspond to the “water-filling” structure. In the “water-filling” structure it is necessary to send great number of packets with better quality of the channel. On the other hand, if the buffer occupancy increases, the transmission rate also increases. It is evidently (Fig. 3b) that the structure of the optimal policies in the correlated fading channel does not correspond to the “water-filling” structure. In channels with time correlated fading with the increase of the communication channel quality does not necessarily come to the increase of the rate of sending the packets out of the buffer. The structure of the optimal policies depends on the model of the communication channel, i.e. transition matrix of the communication channel (11). Fig. 4 presents graphics average rejected packets in function of average transmission power level $\overline{P}$. If transmission power increases, the number of rejected packets decreases both for the case of communication channel with i.i.d. (Fig. 4a) and for the case of the communication channel with correlated fading (Fig. 4b). Looking at the graphics in Fig. 4a and 4b can be observed that in areas of smaller transmitting power, the number of packets dropped by the channel fading significantly higher than in the uncorrelated fading channel.



a)



b)

Fig. 4. Average transmission power versus average packets loss for a) i.i.d. channel b) time correlated Rayliegh fading channel.

Depending on the applied transmission policy, various values of optimization parameters can be reached, which provides adaptation of parameters to the desired value. This means that the demand for quality of services of various users can be satisfied.

VIII. CONCLUSIONS

The cross-layer design provides joint optimization of network parameters with many ISO/OSI layers from the protocol stack, which improves performances of the wireless communication system. When wireless communication system can be modeled in the form of long-term average cost MDP problem, it is possible to find an optimal transmission policy. In this paper it was shown that simultaneous optimization of network parameters with PHY and MAC layers allows the throughput maximization in slow fading channel. The performances of the optimal transmission policy are: 1) The channel with i.i.d. fading demands considerably less transmission power in relation to the wireless communication channel with Rayliegh correlated fading; 2) If transmission power increases, the number of rejected packets decreases both for the case of communication channel with i.i.d. and Rayliegh fading. Simulation results confirm that the proposed cross-layer algorithm provides trade-off between network parameters and makes it possible for satisfying wide range of QoS.

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