# A link adaptation strategy for wireless multimedia transmission

Charly Poulliat, Inbar Fijalkow and David Declercq
ETIS laboratory
UMR 8051- ENSEA/University of Cergy Pontoise/CNRS
6, Avenue du ponceau
F-95014 Cergy-Pontoise Cedex, France
Telephone: 33 (0)1 30 73 66 10
Fax: 33 (0)1 30 73 66 27
E-mail:{poulliat,fijalkow,declercq}@ensea.fr

***Abstract*— In the context of multimedia wireless transmission, a link adaptation strategy is proposed, assuming that the source decoder may accept some remaining errors at the output of the channel decoder. Based on a mean bit error rate for erroneous frames criterion, a target bit energy-to-equivalent noise ratio is chosen. Under this constraint, a maximization of the minimum user information rate is applied through dynamic spreading gain and power control, allowing to guarantee a transmission for each and every user.**

## I. Introduction

With emerging "high rates" communication systems, like UMTS ([1], [2]), real time multimedia data packets wireless transmissions (like videos for example) become possible. Crucial points of this kind of transmissions are the lack of robustness of the source decoder when errors still occur after channel decoding and the need of continuous transmission for streaming like applications. Thus, the transmission has to ensure a required reliability of the data for a continuous transmission, introducing the concept of Quality of Service (*QoS*). In the different standards, fading channel parameters are estimated during a frame duration, during which the channel parameters are about constant. As the channel may evolves, frames contain some remaining errors, which rate (noted $\mathrm{CBER}$) varies. But a robust source decoder may accept some erroneous frames. So to guarantee a fixed *QoS* to the user of a multimedia service, we have to maintain a continuous transmission constraint to a given performance function of the CBER.

One way to achieve this goal is link adaptation [4]. In a wireless communication system, link adaptation allows to manage the radio parameters at the transmitter in order to achieve the required performance at the receiver when channel parameters evolves from frame to frame. After choosing a system performance criterion (here we use the *CBER*), in function of channels parameters, we adapt coding rates, spreading factors and powers at the transmitter in order to obtain the required *QoS*. Most of link adaption schemes proposed in the literature (see [6], [7] for example) consider the total throughput maximization in the cell constraint to Bit Error Rate (BER) or frame error rate (FER) at the output of channel decoder. This optimization is achieved by mean of dynamic spreading factor and power control. It results in the fact that some users may not be allowed to transmit. This solution is not well suited since we want to ensure a constant connection for each user (even for these facing severe fading). The *QoS* problem we want to address here is to ensure that each and every user can transmit at any time with the minimum user rate as high as possible. This can be stated as the maximization of the minimum of the user information rate within a cell. Thus, with this new link adaptation criterion, we should guarantee a minimum *QoS* for a given channel state. Moreover, most of the constraints used in the literature are based on BER or FER criteria (see [10], [6] for example). Here we will base our constraints on a CBER criterion which can take into account the fact that errors can be correlated at the output of the channel decoder. No retransmission is considered as we assume that a robust source decoder may accept some erroneous frames.

The paper is organized as follows. First, we present the channel model reminding that the global channel can be modelled efficiently as a gaussian channel whose bit-energy-to-equivalent-noise-spectral-density-ratio, $E_b/N_e$, depends on the channel and the transmitter parameters. We will also define the CBER as a function of $E_b/N_e$. Then we will present the proposed link adaptation scheme and the solution of the stated problem of the maximization of the minimum information rate. Last section will give some simulation results.

## II. System model

We consider the uplink of a Direct Sequence-Code Division Multiple Access (**DS-CDMA**) communication system composed of a transmitter (convolutional channel coder and spreader), a block Rayleigh fading channel, and a receiver (decorrelator + Viterbi decoder). We assume that there are $N_u$ users in the system. Let $S_k$ and $R_k$, respectively, be the spreading factor and the channel coding rate associated with user $k$. BPSK modulation with amplitudes $\{-1, +1\}$ is used for each user. At the transmitter the pulse shaping filter generates a rectangular pulse of a chip duration with unit energy. Let $P_k$ be the transmitted power and $\alpha_k$ be the channel

gain which is assumed known and constant during a frame for each user. The system is illustrated in figure 1.

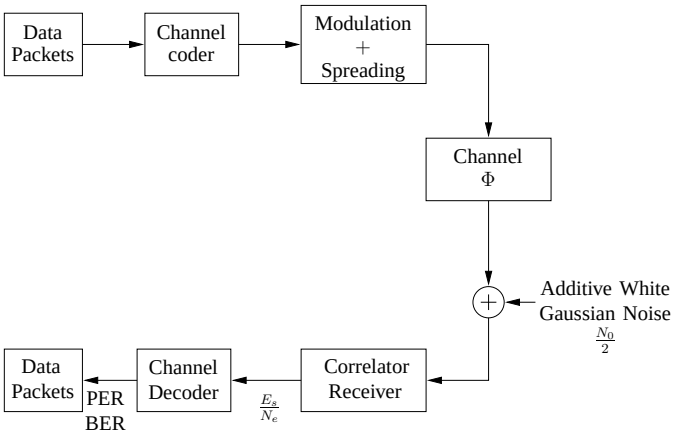


Fig. 1. Communication chain

At the receiver, the matched filter output for user $k'$ can be written as

$$r_{k'} = s_{k'} + n_u + n \tag{1}$$

where $s_{k'}$ is transmitted signal for user $k'$, $n_u$ denotes the multiuser interference and $n$ is Additive White Gaussian Noise (**AWGN**) with double sided spectral density $N_0/2$. Assuming the multiuser interference is gaussian and independence between $n_u$ and $n$, we can explicitly write ([9], [8]), within each frame, the bit-energy-to-equivalent-noise-spectral-density-ratio, $E_b/N_e$, at the input of the channel decoder as

$$\left(\frac{E_b(k')}{N_e}\right) = \frac{1}{R_{k'}} \frac{P_{k'}{\alpha_{k'}}^2 S_{k'}}{N_0 + \beta \sum_{k \neq k'} P_k {\alpha_k}^2} \tag{2}$$

where $E_b(k')$ is the mean bit energy at the receiver for user $k'$ and $\beta$ is a constant dependent on the choice of spreading sequences. We recall that $\alpha_k$ is the channel gain which is assumed constant during a frame.

Performance analysis of this system is equivalent to performance analysis of a convolutional code for an AWGN channel with mean signal-to-noise-ratio $E_b/N_e$. For a convolutional code over an AWGN channel, the Frame Error Rate (**FER**) can be expressed at the output of a Viterbi decoder for a terminated trellis as [3], [5]

$$\text{FER} = 1 - (1 - P_e)^{K-\nu} \tag{3}$$

where $K$ is the number of information bit within a frame, $\nu$ is the memory of the code and $P_e$ is error event probability. An error event of length $l$ and Hamming weight $d$ is a path diverging at a particular node from the reference path (here, the all-zero codeword) and merging again for the first time after $l$ trellis sections. $P_e$ can be expressed using the coefficients of the weight enumerator [11] as follows

$$P_e \simeq \sum_{d=d_{min}}^{+\infty} a_d P_d \tag{4}$$

where $a_d$ is the number of error events with Hamming weight $d$, $d_{min}$ is the minimum distance of the code and

$$P_d = Q\left(\sqrt{2dR\left(\frac{E_b}{N_e}\right)^{(i)}}\right) \tag{5}$$

where $Q(.)$ is the Gaussian tail probability function. In the same manner, the BER can be deduced from the weight enumerator [11] as

$$P_b \simeq \sum_{d=d_{min}}^{+\infty} c_d P_d \tag{6}$$

where $c_d$ is the number of erroneous information bits for all error events of hamming weight $d$.

We can also define the conditional bit error rate

$$\text{CBER} = \text{BER}/\text{FER}$$

as the bit error rate for an erroneous frame. The CBER allows us to take into account the fact that an erroneous frame has a residual bit error rate that is higher than the average BER.

Figure 2 shows simulation results and theoretical bounds for various frame lengths for the rate 1/2 convolutional code with polynomial representation in octal (561,753), used in the UMTS norm [2]. Analysis of these curves show that for high signal-to-noise-ratios, the CBER remains almost constant. This is used in the sequel.

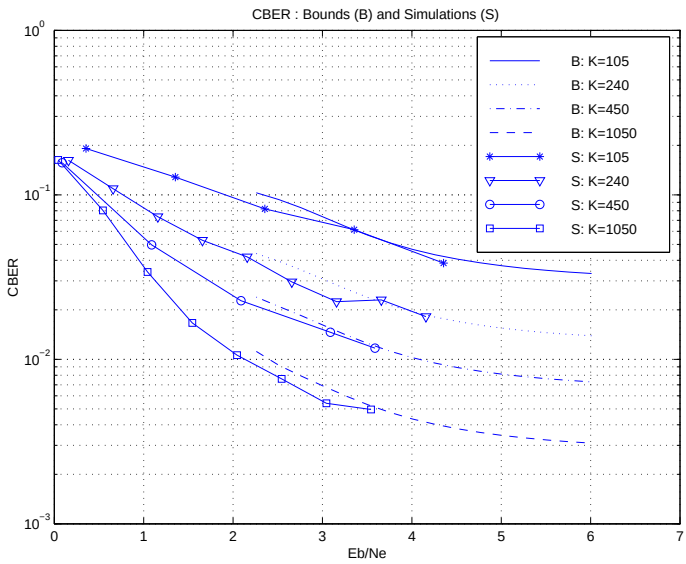


Fig. 2. CBER for AWGN channel with different frame lengths. (B) bounds for high signal-to-noise-ratios, (S) Simulations.

## III. A LINK ADAPTATION STRATEGY

We consider the case where all users have the same priority and importance in the cell, *i.e.* the same *QoS* is required for each user. We assume that there is no retransmission of erroneous frames and that the source decoder can tolerate some errors. For each frame, each and every user is transmitting. The observations made about the CBER allow to fix a target

$(E_b/N_e)_t$: we consider the signal-to-noise-ratio range for which the CBER is slightly decreasing, ensuring for each frame length a CBER "quasi" minimal. As we allow each and every users to transmit simultaneously, a link adaptation based on maximization of the total throughput (see [7], [6] for example) is not well suited, because , as a result of the optimization, some users may be not allowed to transmit during a frame duration. Moreover, we want to be able to guarantee a minimum $QoS$ for each user. Thus we propose a link adaptation based on the maximization of the minimum information rate for each user with a constraint on $(E_b/N_e)_t$. Also, transmission with a given reliability (parameterized by $(E_b/N_e)_t$ and a minimum information rate will be provided for each user.

### A. Problem statement

Considering (2), we can write for each user $k'$

$$r_{k'} = (E_b/N_e)_t^{-1} \frac{P_{k'} {\alpha_{k'}}^2}{N_0 + \beta \sum_{k \neq k'} P_k {\alpha_k}^2} \tag{7}$$

where $r_{k'} = R_{k'}/S_{k'}$ is the information rate of user $k'$.

The maximization of the minimum of the information rates can be expressed using (7) as follows

$$\max_{\{P_{k'}\}} \min_{k'} r_{k'} \tag{8}$$

The solution of (8) is given in the following proposition (see the appendix for proof). We assume that each and every user is allowed the same maximum power $P_{\max}$ due to mobile power limitation.

*Proposition 1:* Assuming that, for each and every user $k$, we have $0 \leq P_k \leq P_{\max}$, and that the user indices $\{1 \ldots N_u\}$ are in increasing channel gain order ($\alpha_1^2 \leq \cdots \leq \alpha_{N_u}^2$), the solution of (8) is given by

$$P_k \alpha_k^2 \quad = \quad P_{\max} \alpha_1^2 \ , \ k = 1, \cdots, N_u \tag{9}$$

where $\alpha_1$ is the weakest channel gain.

*Corollary 1:* When the maximization of the minimum rate is achieved, each and every user has the same information rate given by

$$r_{\max-\min} = (E_b/N_e)_t^{-1} \frac{P_{\max} \alpha_1^2}{N_0 + \beta (N_u - 1) P_{\max} \alpha_1^2} \tag{10}$$

### B. Link adaptation scheme

Based on the above section, we describe here a link adaptation scheme which consists on the maximization of the minimum rate, constrained by a required $E_b/N_e$ at the input of the channel decoder based on the CBER.

We now describe the different steps of the link adaptation we propose:

1) Select the required target $E_b/N_e$. This constraint is based on the CBER ensuring that CBER is minimal for each frame length.
2) Knowing the channel gain amplitudes $\alpha_k$ and the number of users $N_u$ in the cell, select the weakest user (associated with the minimum channel gain).
3) Compute powers at the transmitter according to Proposition 1.
4) Knowing the set of available $R_k$ and $S_k$ for user $k$, select the best suited set $\{R_k, S_k\}$ such as

$$r_k = \frac{R_k}{S_k} <= r_{\max-\min} \tag{11}$$

## IV. Simulation results

In this section, we present some simulation results for the above proposed link adaptation. In order to analyze the performance of this link adaptation scheme, we have to track the constants and the variables of the system. The main constant is the channel statistics, composed by the channel gains distribution (assumed to be the same for each user) and the gaussian noise distribution. The number of users $N_u$ is also assumed to be known and constant. Let $\overline{r}_k$ be the average information rate achieved for user $k$ during the transmission for a given link adaptation scheme. It is defined as the mean of the information rates of user $k$ over the number of transmitted frames where the rate for a given frame is solution of the adaptation link optimization. Let $\overline{E}_b(k)$ be the average energy per bit required during the entire transmission, defined as the mean of the energy per bit over the number of transmitted frames. For a given frame, the received energy per bit is defined as $E_b(k) = P_k \alpha_k^2 S_k / R_k$, where $\{P_k, \alpha_k, S_k, R_k\}$ are the solutions of (9). Also, it is clear that $\overline{E}_b(k)$ and $\overline{r}_k$ are functions of the system parameterized by the channel evolution and the link adaptation strategy. Hence, we will give performance parameterized by the channel distribution and the number of users versus the gaussian noise power.

In this paper, we restrict our analysis to the case where each and every user has just one channel coding rate available. Let $R$ be this channel coding rate. We assume that all user's channel gains are independent and follow the same Rayleigh distribution. The convolutional code we use is the rate $1/2$ with polynomial representation (561,753). If steps 1 to 3 are strictly unchanged, step 4 is reduced to the selection of the best suited spreading factor given according to (11) by

$$\frac{1}{S_k} <= R_{opt}/R \tag{12}$$

Moreover, as all user have the same coding rate, they have the same spreading factor. From the above definitions, we have $\overline{r}_k = \overline{r}$ and $E_b(k) = E_b = P_{\max} \alpha_1^2 S_f / R$ for all $k$, where $\alpha_1$ is the channel gain of the weakest user and $S_f$ is the solution of problem (8) for a given frame. In the sequel $P_{\max}$ is set to 1 and the Rayleigh distribution for each user is parameterized such as $\mathrm{E}(\alpha^2) = 1$. The required $(E_b/N_e)_t$ is set to 3 dB. In figures (3) and (4), we display $\overline{r}$ and the average transmitted $\overline{E}_b$ versus the gaussian noise power for the above given Rayleigh distribution. Each data packet contains $4000$ bits that are send over several frames, depending on the the

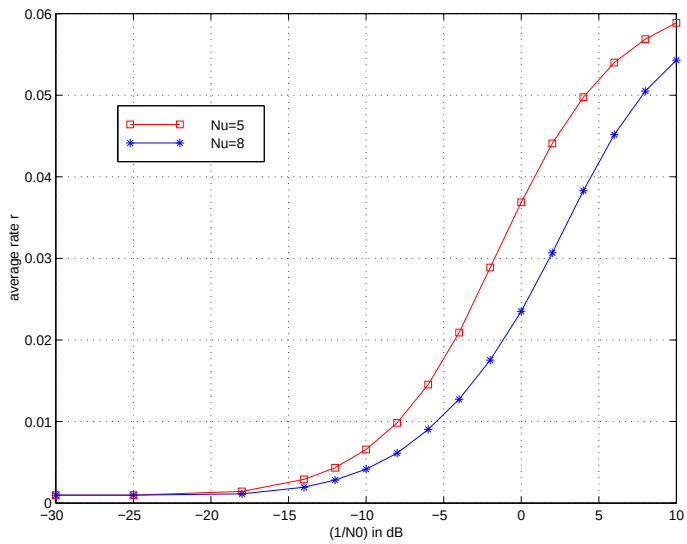


Fig. 3. Average information rate versus Gaussian Noise power

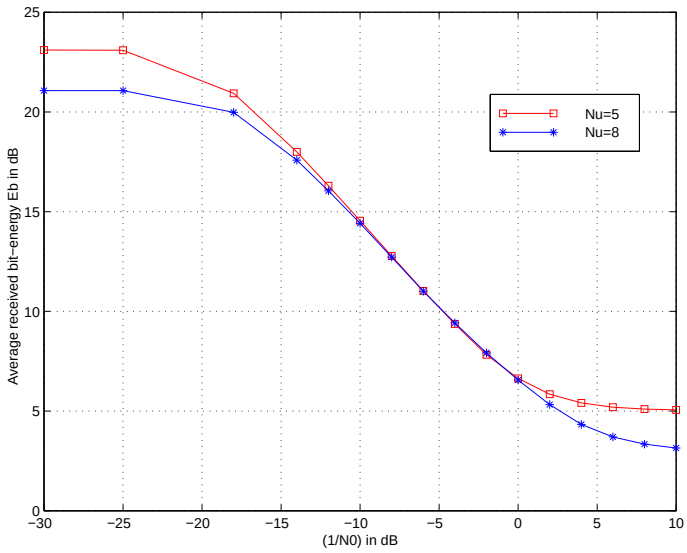


Fig. 4. Average received bit energy versus Gaussian Noise power

spreading factor (between 8 and 512). Results are given for $N_u = 5$ and $N_u = 8$ users.

Figure 3 shows that when the number of users increases, the minimum rate decreases, as expected, as it is directly connected to the multiuser interference term. The curves can be separated into three regions: the two boundaries regions and a linear one for medium gaussian noise power. The boundaries behaviors are due to the finite set of available spreading factors for the transmission. For the low noise power region (right end of the figure), the information rate is bounded by $r_{\min} = R/S_{f\,\max}$, where $S_{f\,\max}$ is the highest spreading factor available. The saturation is also due to the inability of the system to provide lower information rates than $r_{\min}$. The high noise power region is bounded by $r_{\max} = R/S_{f\,\min}$, here $S_{f\,\min}$ is the lowest spreading factor available. Typically, $S_{f\,\min}$ is the lowest spreading factor that satisfies $N_u/S_{f\,\min} \leq 1$. In our example, $S_{f\,\min} = 8$. Figure 4 shows the results for the average received bit-energy $\overline{E}_b$. The same 3 regions can differentiated. We notice that the linear region is about the same for the two cases. The interpretations at the boundaries are the same. For low noise powers, $\overline{E}_b$ is bounded by $\overline{E}_{b\,\max}$ for a constant information rate given by $r_{\min} = R/S_{f\,\max}$. For high noise powers, it is bounded by $\overline{E}_{b\,\min}$ for a constant information rate $r_{\max} = R/S_{f\,\min}$.

Finally, in figure 5, we display the CBER versus the average received $\overline{E}_b/N_0$ for $N_u = 8$ to illustrate the performance of the proposed link adaptation. We observe two regions. For $\overline{E}_b/N_0$ greater than a threshold (between 3 and 5 dB), the CBER is set to a fixed value, as desired. We notice that the threshold in $\overline{E}_b/N_0$ corresponds to the target $(E_b/N_e)_t$.

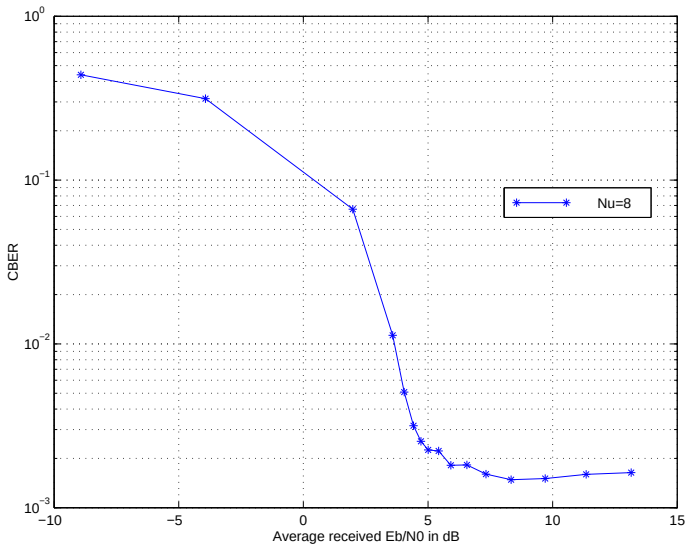


Fig. 5. Conditional bit error rate

## V. CONCLUSION

In this paper, we consider the optimization of the transmitter resources in a time-varying fading environment while guaranteeing a target *QoS* (CBER) and a connection to any user through the network. We proposed a new link adaptation strategy based on the maximization of the minimum user information rate under the constraint of a required bit energy-to-equivalent noise ratio based on a mean bit error rate for erroneous frames criterion. This is performed through dynamic spreading gain and power control and an easy computational solution to this problem is provided. Through simulations, we analyze the influence of finite spreading factor set on the performance of the link adaptation.

Future works are related to the determination of theoretical bounds to predict asymptotic behaviors and the study of a possible extension of this method to systems with different *QoS* classes.

ACKNOWLEDGEMENTS

The authors would like to thank Dr. Haley Jones for her interesting remarks on the paper.

Part of this work is supported by the French RNRT project **V**isiophony on **I.P.** (VIP).

## APPENDIX

When

$$P_k\alpha_k^2 \quad = \quad P_{\max}\alpha_1^2 \ , \forall k \tag{13}$$

,

$$r_k = C\frac{P_{\max}\alpha_1^2}{N_0+\beta(N_u-1)P_{\max}\alpha_1^2} = r_0 \ \forall k \tag{14}$$

where $C = (E_b/N_e)_t^{-1}$ is the inverse of the desired $E_b/N_e$. Therefore $r_{\max-\min}$ satisfying (8) verifies

$$r_{\max-\min} \geq r_0 \tag{15}$$

We want to prove that $r_{\max-\min}$ is equal to $r_0$. We will use a *reductio ad absurdum*. We assume that $r_{\max-\min} > r_0$, therefore all users satisfy $r_k > r_0$, otherwise there exists one user so that $r_k \leq r_0$. $\forall k \neq 1$, let $\lambda_k$ be defined as

$$P_k\alpha_k^2 = \frac{P_{\max}\alpha_1^2}{\lambda_k}$$

Considering (7), we can also rewrite for all $k' \neq 1$

$$r_{k'} = \frac{CP_{\max}\alpha_1^2/\lambda_{k'}}{N_0+\beta P_{\max}\alpha_1^2\sum_{k=1,k'}1/\lambda_k+\beta P_1\alpha_1^2} \tag{16}$$

Let us focus on the sub-system composed by the $N_u-1$ inequalities defined such that $r_{k'} > r_0$, this is equivalent to

$$\begin{aligned}\frac{CP_{\max}\alpha_1^2/\lambda_{k'}}{N_0+\beta P_{\max}\alpha_1^2\sum_{k=1,k'}1/\lambda_k+\beta P_1\alpha_1^2} \\ > \frac{CP_{\max}\alpha_1^2}{N_0+\beta(N_u-1)P_{\max}\alpha_1^2} \\ N_0(1-\lambda_{k'})+\beta P_{\max}\alpha_1^2((N_u-1)-\sum_{k\neq k',1}\frac{\lambda_{k'}}{\lambda_k}) \quad > \quad \beta\lambda_{k'}P_1\alpha_1^2\end{aligned} \tag{17}$$

As for each inequality, the second member is strictly positive, we have also a second sub-system with $N_u-1$ inequalities by considering the first member strictly positive. We are looking for a solution set $\{\lambda_2,\cdots,\lambda_{N_u}\}$ for these inequalities. If a solution set doesn't exist, $\exists i_0$, $r_{i_0} \leq r_0$ and so $r_{\max-\min} \leq r_0$. As $r_{\max-\min} \geq r_0$, this implies that $r_{\max-\min} = r_0$.

If there exists a solution set to this sub-system, let $i_0$ be the user index such that, for all user $k \neq 1, k \neq i_0$, $\lambda_{i_0} \geq \lambda_k$. We can consider the following two cases : $(1)\lambda_{i_0} < 1$ and $(2)\lambda_{i_0} \geq 1$. For case $(1)$, $\forall k \neq 1$, $\lambda_k < 1$. Thus,

$$r_1 < \frac{CP_1\alpha_1^2}{N_0+\beta(N_u-1)P_{max}\alpha_1^2} \leq r_0 \tag{18}$$

since $P_1 \leq P_{\max}$. This is in contradiction with the hypothesis that for all $k$, $r_k > r_0$. For case $(2)$, considering the inequality associated with rate $r_{i_0}$, we have

$$N_0(1-\lambda_{i_0})+\beta P_{\max}\alpha_1^2((N_u-1)-\sum_{k\neq i_0,1}\frac{\lambda_{i_0}}{\lambda_k}) > \beta\lambda_{i_0}P_1\alpha_1^2 \tag{19}$$

As $\lambda_{i_0} \geq \lambda_k$,

$$N_0(1-\lambda_{i_0})+\beta P_{\max}\alpha_1^2 \quad > \quad \beta\lambda_{i_0}P_1\alpha_1^2 \tag{20}$$

$$\Rightarrow P_{\max}\alpha_1^2 > \lambda_{i_0}P_1\alpha_1^2 \tag{21}$$

Finally, we have $P_1 < P_{\max}/\lambda_{i_0}$, which gives us

$$\begin{aligned} r_1 \quad &= \quad \frac{CP_1\alpha_1^2}{N_0+\beta P_{max}\alpha_1^2\sum_{k\neq 1}1/\lambda_k} \\ &< \quad \frac{CP_{\max}\alpha_1^2/\lambda_{i_0}}{N_0+\beta(Nu-1)P_{\max}\alpha_1^2/\lambda_{i_0}} \leq r_0 \end{aligned} \tag{22}$$

which is in contradiction with the hypothesis that for all $k$, $r_k > r_0$.

Finally, we can conclude that $r_{max-min} = r_0$.

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