Joint Power and Rate Control for Packet Coding over Fading Channels

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We use random linear packet coding for fading channels with long propagation delays such as the underwater acoustic channel. We propose a scheme where the number of coded packets to transmit is determined so as to maintain a pre-specified outage/reliability criterion. We also perform joint power and rate control with constrained resources.

We consider a system in which the transmitter wants to send a block of M packets to a receiver at a transmit power P_T over a channel with large-scale channel gain G. The signal power at the receiver is $P_R = GP_T$. The signal-to-noise ratio at the receiver is given by $\gamma = P_R/P_N = GP_T/P_N$, where P_N is the noise power. For this analysis, we assume a block fading channel, where the channel gain remains constant over a block of packets and changes from one block to another. The duration for which the channel remains constant is called the coherence time of the channel, and is represented by T_C. Since the large-scale channel gain is varying slowly over time, it can be fed back to the transmitter for adapting the transmit power and rate. We model the large scale channel gain as log-normally distributed, i.e., $10\log_{10} G \sim \mathcal{N}(\bar{g}, \sigma_g^2)$.

In each cycle, the transmitter buffers a block of M packets and encodes them into $N \geq M$ packets for transmission over the channel. Each coded packet contains N_b bits, K_b of which are the information bits and $N_b - K_b$ are the overhead bits. The duration of each packet is $T_p = N_b/R_b$, where R_b is the bit rate in the channel and the effective information rate is K_b/T_p. After every block of packets, the transmitter waits for a feedback from the receiver which contains the channel gain G.

The overall system model is shown in Fig.1.

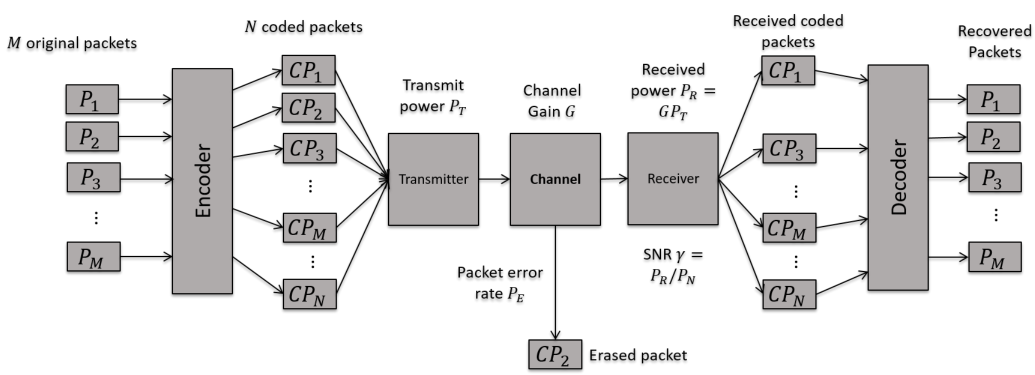

Figure 1: System model.

The probability of bit error (BER) is a function of the signal-to-noise ratio and is represented by $P_e(\gamma)$. The corresponding packet error rate is given as $P_E(\gamma) = 1 - (1 - P_e(\gamma))^{K_b}$. Since the channel gain G is randomly varying, so is the packet error rate $P_E(\gamma)$.

We define the probability of successful decoding P_s as the probability that at least M out of the N transmitted packets are received without errors. It is given by

$$P_s(\gamma) = \sum_{m=M}^{N} \binom{N}{m} (1 - P_E(\gamma))^m P_E^{N-m}(\gamma) \tag{1}$$

We wish to maintain a pre-defined success rate at the receiver and this value is denoted by P_s^*. We can now define the outage probability as the probability that $P_s(\gamma)$ falls below a pre-defined value P_s^*, i.e., $P_{out} = \{P_s(\gamma) < P_s^*\}$.

In practical applications, power is limited, and hence the minimizing the average energy per bit aims at increasing the duration of each deployment. The average energy per bit is given by

$$\bar{E}_b = \frac{1}{R_b} \frac{E\{NP_T\}}{P_s^* M} \tag{2}$$

In the interest of energy conservation, we have chosen the average energy per bit as the figure of merit to determine the optimal transmit power and number of coded packets. The average energy per bit is influenced by both the number of coded packets and the transmit power. On the one hand, increasing the transmit power leads to higher signal-to-noise ratio, and hence fewer coded packets would be necessary. On the other hand, increasing the transmit power also directly increases the average energy per bit. It is this trade-off we wish to exploit and find the optimal values for the transmit power and the number of coded packets.

In a practical system, we do not have the liberty of unlimited resources. Keeping this in mind, we impose two constraints:

1. The transmit power cannot exceed a maximal level $P_{T,max.}$ This level is dictated by hardware system constraints or by the total budget.

2. The number of coded packets cannot exceed a maximal value N_{max}. N_{max} is determined so as to satisfy all of the following requirements: (i) a batch must not last longer than a value dictated by the coherence of the channel gain T_C; (ii) decoding delay T_d must not exceed a maximum tolerable value, and (iii) average bit rate must not fall below a tolerable minimum $R_{b,min}$.

The source code available for download at http://millitsa.coe.neu.edu/?q=projects contains functions to determine the optimal transmit power P_T and number of coded packets N such that the average energy per bit is minimized. Executing RunMe.m in MATLAB will determine the optimal number of coded packets N_{opt} and N_{max}, followed by P_T and N. This is followed by generation of information bearing packets, generating N coded packets and demonstration of the decoding procedure. Finally, the joint power and rate control procedure is demonstrated with a plot of P_T and N as a function of the channel gain G. The package provides the features described in [1], but omissions have been made to simplify the exercise. Any of the functions in the package may be used for non-commercial purposes. For questions about the implementation, please contact Rameez, rarameez@gmail.com.

References

[1] R.Ahmed and M.Stojanovic, "Joint Power and Rate Control for Packet Coding Over Fading Channels", *IEEE J. Oceanic Eng.,* August *2016.*