Exploiting Protocol Information for Transmission over Unknown Fading Channels

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Abstract — **We consider the transmission of two independent sources with different priorities over unknown fading channels. One source (protocol information) has a low information rate and a delay constraint. The other source has a high information rate and no delay constraints. We study a receiver structure in which the protocol information is first decoded incoherently and then fed back to facilitate coherent decoding for the high-rate information.**

We derive lower bounds on the achievable rate for the high-rate source by this decision directed structure. These bounds are given as functions of the low-rate message error probability γ, which characterizes the impact of γ on the performance of the system. It is shown that, in terms of the achievable rate for the high-rate information, the decision directed scheme achieves the performance of the known-training scheme as γ goes to zero.

I. SUMMARY

Consider the transmission of two independent sources over an unknown ISI channel (Fig. 1). The low-rate source has rate R_l and delay constraint N. The high-rate source has rate R_h and no delay constraints. In practice, the low-rate sources may contain delay sensitive protocol information.

We use OFDM as the modulation scheme. Since the protocol information has to be decoded after N channel uses, a joint encoding/decoding scheme is difficult to design. In this work, we assume that the two sources are encoded independently and transmitted over dedicated tones (Fig. 1). We assume that the tones for the low-rate transmission are periodically placed since this is the optimal placement for training-based scheme [1]. The channel law is given by

$$\mathbf{y}_l = \mathbf{D}_l\mathbf{x}_l + \mathbf{w}_l \qquad \mathbf{y}_h = \mathbf{D}_h\mathbf{x}_h + \mathbf{w}_h \tag{1}$$

where $\mathbf{x}_l$, $\mathbf{y}_l$ and $\mathbf{w}_l$ are the low-rate channel input, output and noise respectively ($\mathbf{x}_h$, $\mathbf{y}_h$ and $\mathbf{w}_h$ are for the high-rate channel). The diagonalized channel matrices $\mathbf{D}_l = \text{diag}(\mathbf{F}_l\mathbf{h})$ and $\mathbf{D}_h = \text{diag}(\mathbf{F}_h\mathbf{h})$ where $\mathbf{F}_l$ and $\mathbf{F}_h$ are two matrices defined by the tone allocation. The taps of the channel $\mathbf{h}$ are i.i.d. circularly symmetric complex Gasussian with zero mean and variance $\frac{1}{m}$ where m is the channel length. The realization of $\mathbf{h}$, unknown at the transmitter and the receiver, remains constant during one OFDM block and changes to an independent value in the next OFDM block.

Because of the delay constraint, the receiver decodes the low-rate information first, and then decodes the high-rate information with the aid of the decoded low-rate information. We assume that the low-rate channel input $\mathbf{x}_l$ belongs to a set of vectors with constant energy elements, i.e., $|x_{l,k}|^2$ is a constant. The size of the set is A. The receiver first incoherently detects the low-rate input $\mathbf{x}_l$, and then decodes the low-rate message. The receiver re-encodes the decoded low-rate message and obtains $\hat{\mathbf{x}}_l$ as the training input to the high-rate decoder. Denote the low-rate message error probability as γ. We assume the high-rate transmitter has an average energy constraint P_h.

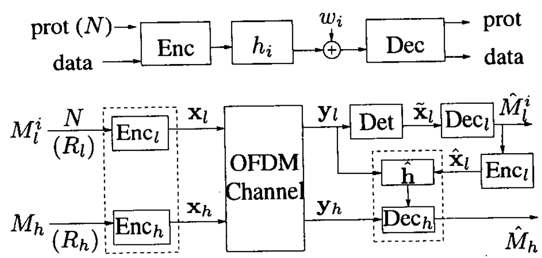

Figure 1: Problem setup and system structure.

When a channel estimate $\hat{\mathbf{h}}$ is obtained using $\hat{\mathbf{x}}_l$ and $\mathbf{y}_l$, we obtain the following lower bound

$$\max_{p(x_h):E(|x_h|^2)=P_h} I(\mathbf{x}_h;\mathbf{y}_h|\,\hat{\mathbf{h}}) \geq \sum_{k=1}^{T_h} E_{\hat{\mathbf{h}}}\log\left(1+\frac{P_h|E(d_{h,k}|\,\hat{\mathbf{h}})|^2}{1+P_h(E(|d_{h,k}|^2|\,\hat{\mathbf{h}})-|E(d_{h,k}|\,\hat{\mathbf{h}})|^2)}\right) \tag{2}$$

where $d_{h,k}$ is the k-th diagonal element of D_h and T_h is the number of tones allocated to the high-rate transmission. A lower bound similar to (2) can also be found in [3]. The joint p.d.f. $p(\mathbf{h}, \hat{\mathbf{h}})$ is needed to evaluate (2). We consider the channel estimator that is the MMSE estimator when $\gamma = 0$. We derive an upper and a lower bound on $p(\mathbf{h}, \hat{\mathbf{h}})$ as functions of γ, which, together with (2), gives a lower bound, as a function of γ, on the maximum achievable rate. This bound converges to a tight lower bound on the training-based capacity in [2] as $\gamma \to 0$.

For a decoder structure without explicit channel estimation, $I(\mathbf{x}_h;\mathbf{y}_h|\,\mathbf{y}_l\hat{\mathbf{x}}_l)$ is achievable and we derive

$$I(\mathbf{x}_h;\mathbf{y}_h|\,\mathbf{y}_l,\hat{\mathbf{x}}_l) \geq I(\mathbf{x}_h;\mathbf{y}_h|\,\mathbf{y}_l,\mathbf{x}_l) - H(\gamma) - \gamma\log(A-1)$$

where $H(x) = -x\log x - (1-x)\log(1-x)$ and $I(\mathbf{x}_h;\mathbf{y}_h|\,\mathbf{y}_l,\mathbf{x}_l)$ is achievable by the training based scheme.

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