The Binary Jitter Channel: A New Model for Magnetic Recording

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Abstract — **The capacity of future high-density magnetic recording systems is expected to be limited primarily by "jitter". For such systems, a new simple channel model is proposed. A factor graph representation as well as upper and lower bounds on the capacity of this channel model are given.**

As mechanical and electronic components of magnetic recording systems are being improved, the "noise" of the magnetic medium itself will begin to dominate other noise sources [1]. This "medium noise" is highly signal-dependent [2] and comes in two different forms. First, *isolated transitions* (i.e., changes of magnetic polarization) are affected by *jitter* [3]: the transition is read at a different position than where it was written. Second, very short polarization regions tend to be *unstable*: the two transitions move towards, and may actually cancel, each other.

The present paper addresses the problem of modeling these effects in a way that is suitable for signal processing. To this end, the magnetic recording channel is first decomposed into three parts: a "binary jitter channel" (BJC) that captures the mentioned medium noise, a linear intersymbol interference channel that is defined by the impulse response of the read head, and additive white Gaussian noise due to the amplifier. The BJC is then further decomposed as follows.

Let $X_k \in \{0,1\}$ and $Y_k \in \{0,1\}$ be the time-k input and output, respectively, of the BJC, where $X_k = 1$ ($Y_k = 1$) means that a transition is written into (read from) the time-k slot. The BJC $X_k \to Y_k$ is decomposed into a memoryless probabilistic channel $X_k \to J_k$ and a deterministic channel $J_k \to Y_k$ with memory. The auxiliary variable J_k takes values in the set $\{0\} \cup \{D^i : i = -m, -m+1, \ldots, m\}$ for some positive integer m; $J_k = D^j$ means that a transition was written into the time-k slot and moved into slot $k+j$. We mainly consider the simplest case with $m = 1$, $p_{J|X}(D^{\pm 1}|1) = p$, and $p_{J|X}(1|1) = 1 - 2p$. We always have $p_{J|X}(0|0) = 1$.

The deterministic channel $J_k \to Y_k$ —which takes into account the cancellation of transitions that fall into the same slot or cross—can be described by a trellis. For $m = 1$, this trellis has 4 states and 16 branches.

The factor graph [4] that corresponds to this BJC model is shown in Fig. 1. This factor graph can be plugged into a block factor graph (as in Fig. 2) of the whole system. The sum-product algorithm ("probability propagation") [4] can then be applied to "turbo" decoding of such a system.

The mentioned cancellation of crossing transitions makes it difficult to compute the capacity of the BJC. However, methods similar to those of [5] (where cancellations were not considered) can be used to obtain tight upper and lower bounds by optimization of $\overline{C}_L^M \triangleq \max_{P_X}\left[H(Y_L|\mathbf{Y}_{-L}^{L-1}) - H(Y_L|\mathbf{X}_{-L+1}^{+L+1}\mathbf{Y}_{-L}^{L-1}S'_{-L})\right]$ and $\underline{C}_L^M \triangleq \max_{P_X}\left[H(Y_L|\mathbf{Y}_{-L}^{L-1}S'_{-L}) - H(Y_L|\mathbf{X}_{-L-1}^{+L+1}\mathbf{Y}_{-L}^{L-1})\right]$ respectively, where S'_{-L} is the state of the BJC composed of the time-$(-L)$ state and M prior inputs. The input is assumed to be stationary and generated by a Markov-Chain of order M. Then $\underline{C}_L^M \le C^M \le \overline{C}_L^M$, and C^M approaches capacity for $M \to \infty$. Fig. 3 shows upper and lower bounds on the capacity of the BJC for $(1,\infty)$-constrained input sequences, i.e., there is at least one zero between two ones.

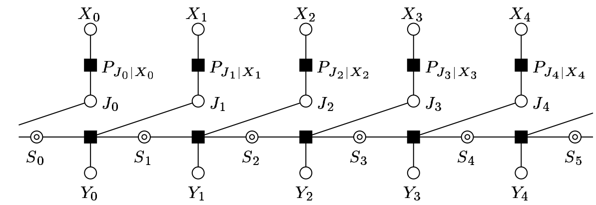

Fig. 1: Factor graph representation of the BJC.

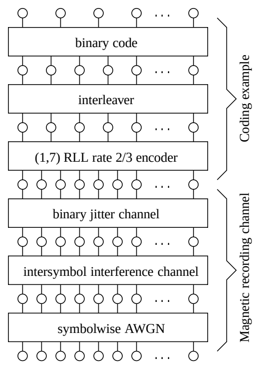

Fig. 2: Block factor graph.

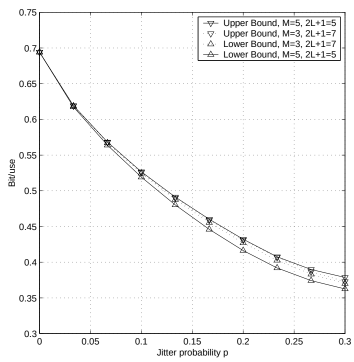

Fig. 3: Bounds of the BJC for $(1,\infty)$-constrained inputs.

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