6.440 Essential Coding Theory	MIT, Fall 2011
Problem Set 2	
Instructor: Dana Moshkovitz	October 4, 2011

Due: October 18, 2011.

Question 1 - Useful Approximations

Formalize and prove:

1. For a small $\delta > 0$, $H(\delta) \approx \delta \log \frac{1}{\delta}$.
2. For a small $\epsilon > 0$, $H(\frac{1}{2} - \epsilon) \approx 1 - \Theta(\epsilon^2)$.
3. For a large $q > 1$, $H_q(\delta) \approx \delta + O(\frac{1}{\log q})$, where $H_q(\delta) = \delta \log_q \frac{q-1}{\delta} + (1-\delta) \log_q \frac{1}{1-\delta}$.

Question 2 - Random Codes

Let $0 < p < 1/2$.

1. Show that the expected distance of a random code $C \subseteq \{0,1\}^n$ of rate $1 - H(p)$ is $\ll pn$.
2. Show that by deleting a small fraction of the codewords in a random code $C \subseteq \{0,1\}^n$ of rate $1 - H(p)$ one can obtain a code of distance $\approx pn$ with high probability.
3. Show that a random binary generator matrix whose dimensions are $n \times (1 - H(p))n$ yields a linear code $C \subseteq \{0,1\}^n$ of distance $\approx pn$ with high probability.

Question 3 - q-ary Plotkin Bound

Prove that for any code of rate R and relative distance δ over an alphabet of size q,

$$R + \frac{q}{q-1}\delta \leq 1.$$

Question 4 - k-wise Independence

Let $m = 2^r - 1$ and $k = 2t + 1$ such that $k \leq m$. Define $N \doteq 2(m+1)^t$. Describe an explicit construction of a 0-1 matrix A with columns $a^{(1)}, \ldots, a^{(m)} \in \{0,1\}^N$ such that:

- For every $1 \leq i \leq m$, the column $a^{(i)}$ has the same number of 0's and 1's.
- For every $1 \leq i_1 < \ldots < i_k \leq m$, the k columns $a^{(i_1)}, \ldots, a^{(i_k)}$ contain every binary string of length k in $N/2^k = 2^{rt-k+1}$ rows.

(Such a matrix is very useful for construction of hash families and for derandomization of certain algorithms; see, for example, Luby and Wigderson's survey "Pairwise independence and Derandomization").

Hint: BCH codes.

Question 5 - ε-Biased Sets/Balanced Codes

We say that $S \subseteq \{0,1\}^n$ is ε-biased if for every $c \neq \vec{0} \in S$, the weight of c (i.e., the number of non-zeros) satisfies:

$$\frac{1-\varepsilon}{2}n \leq wt(c) \leq \frac{1+\varepsilon}{2}n.$$

Show how to convert an $(n,k,d)_q$ code C with distance $d = (1-\frac{1}{q}-\varepsilon)n$ into a $(\varepsilon+1/q)$-biased set $S \subseteq \{0,1\}^{nq}$ of the same size.

Hint: Concatenation with Hadamard.

Question 6 - Finite Fields Drill

Show the following:

1. For every $\gamma \neq 0 \in \mathbb{F}_q$, there are $q+1$ elements $\alpha \in \mathbb{F}_{q^2}$ such that $N(\alpha) = \gamma$.
2. For every $\gamma \in \mathbb{F}_q$, there are q elements $\alpha \in \mathbb{F}_{q^2}$ such that $Tr(\alpha) = \gamma$.