model for the AWGN channel. The received signal over a block of n symbols can be described by

$$Y_i = X_i + N_i \tag{1}$$

where $i = 1, \dots, n$, X_i denotes the transmitted symbol at time i and $N_1, \dots, N_n$ are independent standard Gaussian random variables. For simplicity, we assume no inter-symbol interference is at receiver. Each symbol modulates a continuous-time pulse waveform for transmission. If the width of all pulses were exactly of one symbol interval, which is denoted by T, the duty cycle is equal to the fraction of nonzero symbols in a codeword. In practice, however, the pulse is usually wider than T, so that the support of the transmitted waveform is greater than the sum of the intervals corresponding to nonzero symbols due to leakage into intervals of adjacent zero symbols. To be specific, suppose the width of a pulse is $(1+2c)T$, then each transition between zero and nonzero symbols incurs an additional cost of up to cT in terms of actual transmission time.

Let $1-q$ denote the maximum duty cycle allowed. In this paper, we require every codeword $(x_1, x_2, \cdots, x_n)$ to satisfy

$$\frac{1}{n}\sum_{i=1}^{n} 1_{\{x_i \neq 0\}} + \frac{1}{n}2c\left(\sum_{i=1}^{n-1} 1_{\{x_i=0, x_{i+1}\neq 0\}} + 1_{\{x_n=0, x_1\neq 0\}}\right) \leq 1-q \tag{2}$$

where $1_{\{\cdot\}}$ is the indicator function, and the transition cost is twice that of zero-to-nonzero transitions, because the number of nonzero-to-zero transitions and the number of zero-to-nonzero transitions is equal under the cyclic transition cost configuration. From now on, we refer to (2) as *duty cycle constraint* (q, c). Note that the idealized duty cycle constraint is the special case $(q, 0)$. If $c \in [0, \frac{1}{2}]$, then the left hand side of (2) is equal to the actual duty cycle. If $c > \frac{1}{2}$, the left hand side of (2) is an overestimate of the duty cycle. Nonetheless, we use constraint (2) for its simplicity. In addition, we consider the usual average input power constraint,

$$\frac{1}{n}\sum_{i=1}^{n} x_i^2 \leq \gamma. \tag{3}$$

In many wireless systems, the transmitter's activity is constrained in the frequency domain as well as in the time domain. In principle, the results in this paper also apply to the more general model where the duty cycle constraint is on the time-frequency plane.