IEEE P802.15
Wireless Personal Area Networks

Project	IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)
Title	**Tutorial: Effects of Pulsed Interference**
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Re:	Potential effects of pulsed waveforms in overlay spectral reuse scenario
Abstract	A simple model of pulsed interference and its effect on (uncoded) bit error rate is shown, parametric in duty cycle and average interference power. For pulses whose ON/OFF periods respectively cover multiple receiver bits, a duty cycle of 25% is about 5 dB more damaging than a continuous interferer with the same average power, when the receiver performance is interference-limited.
Purpose	Theoretical explanation of test results
Notice	
Release	

Potential Effects of Pulsed Interference

It is well known that an intentional interferer (jammer) that is targeting a frequency-hopping system will achieve maximum effect (highest average probability of error) by concentrating its limited power so as to "hit" a fraction of the hops, unless the jammer's power is so large that it can cause errors for all hops by spreading its power across the whole band.

When the targeted system is not hopping, the same principle applies: depending on the power of the jammer that is projected to the receiver location, it is more effective for the jammer with a limited average power to employ a non-unity duty cycle in order to cause near-certain errors during the times that the jammer is on. In what follows, this principle is illustrated mathematically for a simple system model, after which the application of the principle to overlay reuse of the "UWB band" will be discussed.

MODEL

Let the average power spectral density of the noise and interference be denoted by N_0 by N_I, and let its duty cycle be denoted by γ. Then the receiver's effective energy-to-noise density ratio equals

$$\frac{E_b}{N_{eff}} = \begin{cases} \dfrac{E_b}{N_0} & \text{with probability } 1-\gamma \\[2ex] \dfrac{E_b}{N_0 + N_I/\gamma} = \dfrac{\gamma \dfrac{E_b}{N_0} \cdot \dfrac{E_b}{N_I}}{\dfrac{E_b}{N_0} + \gamma \dfrac{E_b}{N_I}} & \text{with probability } \gamma \end{cases} \tag{1}$$

Among other factors, the effect of the interference on the receiver depends on the length of the interference ON/OFF cycle in time, denoted T_I, relative to the receiver's bit duration, denoted T_b. If T_I is relatively large compared to T_b, then the fraction γ of the bits are jammed and the average (uncoded) probability of error is reasonably modeled by

$$P_e\left(\frac{E_b}{N_0};\frac{E_b}{N_I},\gamma\right) = (1-\gamma)\,Q\left(\sqrt{\frac{2E_b}{N_0}}\right) + \gamma Q\left(\sqrt{\frac{2E_b}{N_0 + N_I/\gamma}}\right) \tag{2}$$

For definiteness, in (2) we use the BPSK error probability involving the Gaussian Q-function. If T_I is relatively short compared to T_b, then it may be reasonable (depending on receiver processing) to model the error probability as a function of the average interference power, which is given by (2) when $\gamma = 1$.

Plots of (2) are shown in the figures below for fixed values of E_b/N_0 and γ, and for E_b/N_I varied. The figure shows that, as E_b/N_I increases (the interference decreases), the error probability is

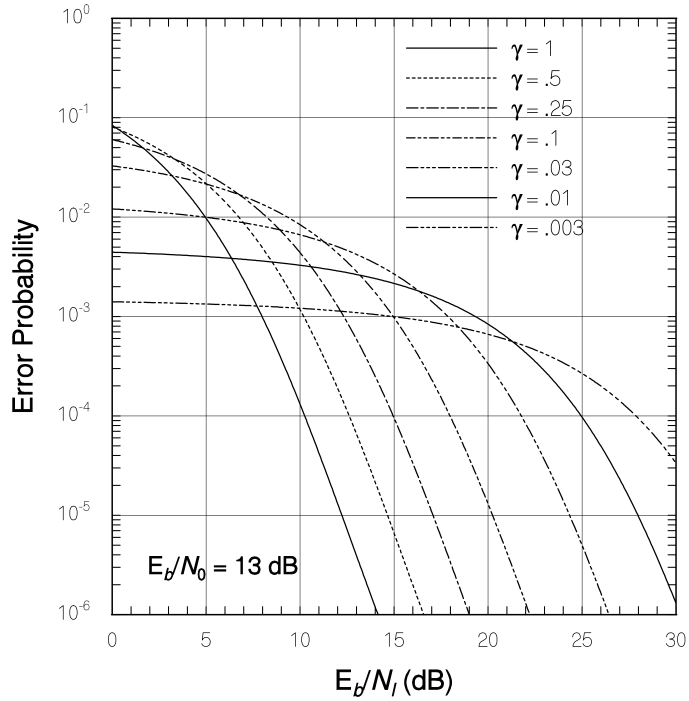

Figure 1. Plot of (2) vs. E_b/N_I, parametric in γ, for E_b/N_0 = 13 dB.

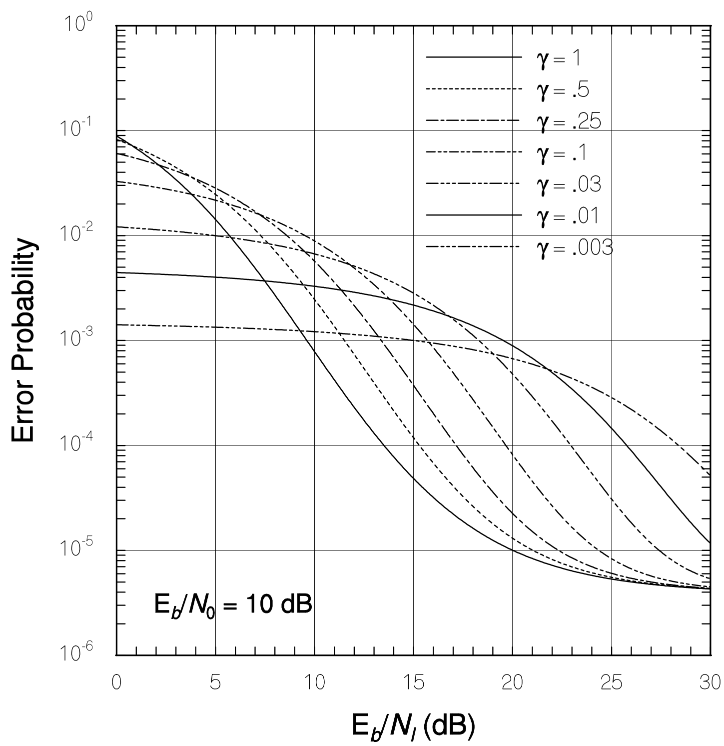

Figure 2. Plot of (2) vs. E_b/N_I, parametric in γ, for E_b/N_0 = 10 dB.

higher for a smaller value of the duty cycle. That is, the worst-case value of the duty cycle is inversely proportional to E_b/N_I and is also a function of E_b/N_0.

For fixed duty cycle, note that a 25% duty cycle with the same average power as for a 100% duty cycle, the error curve is approximately 5 dB to the right of the 100% duty cycle curve, indicating that the pulsing of the interference is 5 dB worse than interference with the same average power and full duty cycle. These results occur when the average interference power relative to the received signal power is sufficient to give a value of E_b/N_I in the range of about 5 to 20 dB. If E_b/N_I is significantly lower than 5 dB (very strong interference), the error probability is bad but "less bad" for less than full duty cycle. If E_b/N_I is significantly greater than 20 dB, the interference is having little effect because the receiver performance is noise-limited.

DISCUSSION

The model for interference shown here applies to potential interference from hopping (agile multiband) systems to fixed receivers in an overlay system of frequency reuse. The particular effects are conditioned on the parameter values shown—particularly received interference power—which may or may not pertain to a realistic scenario in terms of the proximity and emitted power levels of the various devices, as well as the receiver noise level.

The application of (2) is generally apt for situations in which the pulse ON/OFF periods correspond to multiple receiver bits—the receiver bandwidth (baud rate) is relatively large compared to the interference pulse rate. If the receiver bandwidth is small relative to the pulse rate, then the effective spectral density for the receiver bits tends toward its average value.

This analysis does not predict the success or failure of forward error correction coding to combat noise and interference. Since pulsed interference is at least conceptually related to the burst-error channel, interleaving parameters will strongly affect the coded performance of the receiver, in addition to the parameters in (2).