On the Achievable Rates of Ultra-Wideband Systems in Multipath Fading Environments

Younes Souilmi, Raymond Knopp[1]
Institut Eurécom, France
{souilmi, knopp}@eurecom.fr

I. Introduction

In this work, we consider achievable rates for transmission strategies suited to *Ultra-wideband (UWB)* systems and focus non-coherent receivers (i.e. those which do not perform channel estimation, but may have prior knowledge of the second-order channel statistics). Here we take a UWB system to be loosely defined as any wireless transmission scheme that occupies a bandwidth between 1 and 10 GHz and more than 25% of it's carrier frequency in the case of a passband system.

The most common UWB transmission scheme is based on transmitting information through the use of short-term impulses, whose positions are modulated by a binary information source [3]. This can be seen as a special case of *flash signaling* coined by Verdu in [2]. We focus on the case of non-coherent detection since it is well known [1] that coherent detection is not required to achieve the *wideband* AWGN channel capacity C_∞. In [2] Verdu addresses the spectral efficiency of signaling strategies in the wideband regime under different assumptions regarding channel knowledge at the transmitter and receiver. He shows that approaching C_∞ with non-coherent detection is impossible for practical data rates (>100 kbit/s) even for the vanishing spectral efficiency of UWB systems. This is due to the fact that the slope $\mathcal{S}_0$ of the curve representing $(E_b/N_0)_{\min}$ versus spectral efficiency, is zero at the origin for non-coherent detection.

We restrict our study to strictly time-limited memoryless real-valued signals, both at the transmitter and receiver. The transmitted pulse, of duration T_p, is passed through a linear channel, $h(t,u)$ of duration T_d and corrupted by additive white Gaussian noise with power spectral density $N_0/2$. The transmitted signal is written as $x(t) = \sum_{k=0}^{N} s(u_k)\sqrt{E_s}p(t-kT_s)$ where k is the symbol index, T_s the symbol duration, $E_s = PT_s$ the transmitted symbol energy, $u_k \in \{1,\ldots,m\}$ is the transmitted symbol at time k, $p(t)$ and $s(u_k)$ are the assigned pulse and amplitude for symbol u_k. For all k, $p(t)$ is a unit-energy pulse of duration T_p. The considered model encompasses modulation schemes such as flash signaling, m-ary PPM, amplitude, and differential modulations. A guard interval of length T_d is left at the end of each symbol (from our memoryless assumption) so that $T_s \geq T_p + T_d$. We characterize UWB propagation channel in terms of statistical eigenvalue distributions and optimal transmit pulse shapes, and highlight the "no-fading", or constant received energy, behavior these channels.

II. Achievable Rates of flash signaling and m-PPM

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Assuming that no side information about the channel is available to the transmitter, we numerically compute the average mutual information for flash-signaling with non-coherent detection. Then we derive lower random coding bounds on the achievable data rates for m-PPM (system shown in figure 1)with both the optimal non-coherent detector for known second order channel statistics (estimator correlator) and a suboptimal mismatched detector(energy detector, typical of UWB radar applications).

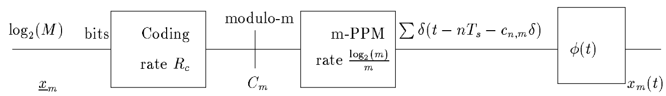

Figure 1: Transmitter block diagram.

Optimal and suboptimal PPM based energy detection is shown to achieve data rates close to average mutual information for flash-signaling with non-coherent detection. The optimization of the modulation size, as a function of the system operating SNR, leads to a constant received peak SNR (and outer code rate on the order of 1/2 irrespective of average received SNR. It is also shown that increasing the system bandwidth W degrades the performance in the low SNR region and that in practice system bandwidths should be on the order of 1, 2 GHz.

III. Multiuser setting

The networks which will likely employ UWB signaling, for example *Wireless Personal Area Networks*(WPAN), are characterized by requirements for adhoc and peer-to-peer communications and thus need to use signaling schemes robust to strong impulsive interference (from nerby interferers). We extend the results presented above to the multiple access case through the use of a single user erasure based energy detector and derive similar random coding bounds. The theoretical high processing gain of UWB systems is shown to be effective against multiuser interference and results in information rates close to those of *genie aided* (i.e. known interfering codewords) multiuser receivers in the case of strong interference.

References

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