Winter School on Coding and Information Theory, Monte Verità, Switzerland, Feb. 24 – 27, 2003

On Achievable Rates and Coding for UWB Systems

Younes Souilmi and Raymond Knopp[1]
Mobile Communications Department, Institut Eurécom
2229, route des Crêtes, 06904 Sophia Antipolis Cedex, France
{souilmi,knopp}@eurecom.fr

Abstract — **In this work we study the achievable rates of Ultra-wideband (UWB) systems using M-ary pulse position modulation (PPM) in multipath fading environments. We focus on strategies which do not have explicit knowledge of the instanteneous channel realization, but may have knowledge of the channel statistics. We derive random coding bounds on the achievable information rates in both single and multiuser settings and draw some conclusions on appropriate coding strategies .**

I. System Models

We consider a baseband PPM Ultra-WideBand system in additive white Gaussian noise multipath fading environment. Each PPM symbol corresponds to choosing one out of m symbol times in which to emit the transmit pulse $p(t)$. The transmitted pulse, of duration T_p, is passed through a linear channel $h(t,u)$. We assume that the impulse response of the channel is of duration $T_d \gg T_p$. The large bandwidths considered here (>1GHz) provide a high temporal resolution and enable the receiver to resolve a large number of paths of the impinging wavefront. Providing that the channel has a high diversity order (i.e. in rich multipath environments), the total channel gain is slowly varying compared to its constituent components. We may assume, therefore, that for all practical purposes, the total received energy should remain constant at its average path strength, irrespective of the particular channel realization.

II. Results

The data is encoded using a randomly generated codebook $\mathcal{C} = \{C_1, C_2, \ldots, C_M\}$ of cardinality M and codeword length N. Each codeword C_l is a sequence $C_l = (c_{1,l}, c_{2,l}, \ldots, c_{N,l})$ corresponding to the emission timeslot indexes within each of the N symbol-times used for its transmission. With $c_{i,j} \in \{0, m-1\}$ and T_c is the spacing between two consecutive emission time slots. A guard interval of length T_d is left at the end of each symbol so that the channel can be considered to be memoryless. Let C_w be the transmitted codeword, the transmitted signal is written as $x(t) = \sum_{k=0}^{N} \sqrt{E_s} p(t - kT_s - c_{k,w}T_c)$ where $T_s = mT_c$ is the frame duration and $E_s = PT_s$ the transmitted symbol energy. We use the same threshold decoding rule as in [1] and derive achievable rate expressions for both the optimal estimator-correlator and a suboptimal version that can be easily implemented with analog technology. Similar bounds are also derived for the coherent detector in the case where only a noisy channel estimate is available in the receiver. Numerical calculation of achievable rates as a function of various system parameters (T_p, T_d, SNR) has been carried out and are compared to generic non-coherent flash signaling [2] performance.

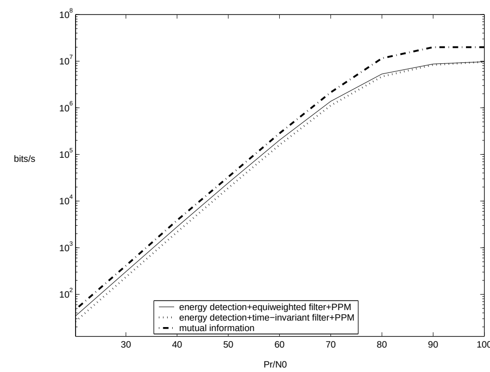

Fig. 1: Achievable rates of energy detection based receivers: Td=50 ns, W=1GHz

The PPM based energy detector is shown to perform as well as the quasi-coherent detector and achieve information data rates close to the 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 repetition coding concatenated with M-PPM (as proposed in [3]) suffers a severe loss in transmission capacity with respect to the proposed coding scheme. Derivation details and proofs can be found in [4]. The results are then generalized to the multiple access case through the use of a single user erasure based energy detector and similar random coding bounds are derived. The theoretical high processing gain of UWB systems is shown to be effective against multiuser interference and and results in information rates close to those of multiuser receivers in the case of strong interference.

References

[1] Telatar, I. E.; Tse, D. N. C. ,"Capacity and mutual information of wideband multipath fading channels" *IEEE Transactions on Information Theory*, Vol. 46, Issue:4, pp. 1384-1400, 2000.

[2] Verdu, S. ," Spectral efficiency in the wideband regime " *IEEE Transactions on Information Theory*, Vol. 48 Issue: 6 , June 2002 pp. 1319 -1343.

[3] Win, M. Z. , Scholtz, R. A. , " Ultra-wide bandwidth time-hopping spread-spectrum impulse radio for wireless multiple-access communications " *IEEE Transactions on Information Theory* Volume: 48 Issue:4, Pages: 679 -689, April 2000.

[4] Souilmi, Y, Knopp, R, "Challenges in UWB Signalling for Ad-hoc Networking" DIMACS Workshop on Signal Processing for Wireless Transmission, 2002.

[1]Eurecom's research is partially supported by its industrial partners: Ascom, Swisscom, France Telecom, La Fondation Cegetel, Bouygues Telecom, Thales, ST Microelectronics, Motorola, Hitachi Europe and Texas Instruments. The work reported here was also partially supported by the French RNRT project ERABLE.