Performance Analysis of Direct Sequence CDMA in Impulse Noise Channel

V. Tamgnoue, V. Moeyaert, S. Bette, P. Mégret

Faculty of Engineering, Mons (FPMs), Department of Electromagnetism and Telecommunications,
Boulevard Dolez 31, 7000 Mons, BELGIUM
Valery.tamgnoue@fpms.ac.be

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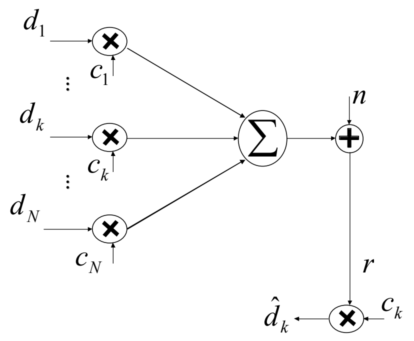
We analyse performances of DS-CDMA-QAM (Direct Sequence-Code Division Multiple Access-Quadrature Amplitude Modulation) in presence of impulse noise. This analysis is carried out theoretically and confirmed by simulation. It allows to precisely determine the reduction of the penalty induced by impulse noise on the SEP (Symbol Error Probability) of DS-CDMA-QAM transmission.

Introduction

The DS-CDMA signal



d_k is the baseband symbol with $k = 1,2,\ldots,N$
c_k is the spreading codes with N chips
T is the symbol's period
T_c is the chips period with $T = NT_c$
n is the channel noise

- The discrete baseband signal is given by

$$r_i = \frac{1}{\sqrt{N}}\sum_{k=0}^{N-1} d_k c_k(i) + n_i \,,\; 0 \le i \le N-1$$

where n_i is the channel noise and $c(i) = \{-1,+1\}$

- In the assumption of perfect synchronisation, the estimated received symbol is given by

$$\hat{d}_k = \frac{1}{\sqrt{N}}\sum_{k=0}^{N-1} r_i c_k(i) = d_k + \frac{1}{\sqrt{N}}\sum_{k=0}^{N-1} n_i c_k(i)$$

- The additive noise term denoted z_k is defined as

$$z_k = \frac{1}{\sqrt{N}}\sum_{k=0}^{N-1} n_i c_k(i)$$

Impulse noise model

- Complete and canonical statistical Middleton class-*A*
- The I and Q pdf is given by

$$f_n(x,y) = e^{-A}\sum_{q=0}^{\infty}\frac{A^q}{q!\,2\pi\sigma_q^2}\exp\left(\frac{x^2+y^2}{2\sigma_q^2}\right)$$

where $\sigma_q^2 = \frac{(q/A)+\Gamma}{1+\Gamma}$, $\Gamma = \frac{\sigma_g^2}{A\sigma_i^2}$

A is the impulsive index and Γ the mean power ratio

σ_g^2 and σ_i^2 are the variance of Gaussian and Impulse component of noise

✓ $A\searrow$ and $\Gamma\searrow$ $\Rightarrow$ predominance of impulse type of noise
✓ $A\nearrow$ and $\Gamma\nearrow$ $\Rightarrow$ predominance to Gaussian noise

Symbol Error Probability (SEP) of DS-CDMA

PDF of additive noise

- CDMA process $\Rightarrow$ Spreading Effect
  - ✓ Gaussian part of noise, which is a white noise, will appears with the same power at all frequencies
  - ✓ A typical impulse of duration N_i (expressed here in term of symbol duration) will be spread out on the signals transmitted at that time

⚠ Therefore, in DS-CDMA system, the new duration of the impulse will be N, The impulsive index will change by a factor N/N_i , however the mean power ratio, Γ, remains constant.

- The PDF of random variable z_k is obtained by

$$f_z(x,y) = e^{-A\alpha}\sum_{q=0}^{\infty}\frac{(A\alpha)^q}{q!\,2\pi\kappa_q^2}\exp\left(\frac{x^2+y^2}{2\kappa_q^2}\right)$$

where $\kappa_q^2 = \frac{(q/(A\alpha)+\Gamma')}{1+\Gamma'}$, $\Gamma' = \frac{\sigma_g^2}{(A\alpha)(\sigma_i^2 N_i/N)} = \Gamma$ and $\alpha = N/N_i$

SEP calculation

- The SEP of DS-CDMA-QAM is compactly given by

$$SEP = 4e^{-A\alpha}\sum_{q=0}^{\infty}\frac{(A\alpha)^q}{q!}p_q\left(1-\frac{1}{\sqrt{M}}\right)\left(1-\left(1-\frac{1}{\sqrt{M}}\right)p_q\right)$$

Where $p_q = \frac{1}{2}erfc\left(\sqrt{\frac{3}{2(M-1)}\frac{E_s}{\kappa_q}}\right)$, $M = 2^{2m}$ (square constellation)

and E_S is the mean energy of M-QAM complex symbol

⚠ The depth of plateau, which is the asymptotic penalty induced by the joint presence Gaussian and of impulsive components of noise compared to the case where only the Gaussian noise is present, is given by

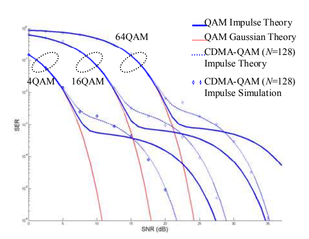
$$d_{snr} = 10\log\left(\frac{1/(A\,N/N_i)+\Gamma}{\Gamma}\right)$$

Simulation and results analysis

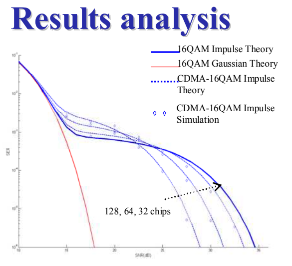
Noise Generation

- Three parameters for impulse noise: the impulse duration, the impulse inter-arrival times and the impulse maximum amplitude
- Gated Additive White Gaussian Noise (GAWGN)
  - The mean value of the duration and the inter-arrival time are linked with the constraint that the ratio of the mean duration and the mean inter-arrival time must be equal to the impulsive index.
- AWGN (Additive White Gaussian Noise) is added on the top of this GAWGN to simulate the Gaussian contribution.

Results analysis



Simulation of SEP of DS-CDMA with many QAM in impulsive channel (A=10^{-3}, Γ=10, N_i=26=>5 µs)



Simulation of SEP of DS-CDMA with many chips numbers in impulsive channel (A=10^{-3}, Γ=10, N_i=26=>5 µs)

In presence of impulse noise

✓ SNR $\nearrow$ $\Rightarrow$ DS-CDMA-QAM becomes better than pure QAM

✓ $N\nearrow$ $\Rightarrow$ ameliorate de SEP of DS-CDMA-QAM

We have analysed the symbol error probability of DS-CDMA-QAM in presence of impulse noise. We have proved that the curve of error probability depends on the QAM order, the chips number, and all the noise properties.
Based on that, we provided to a scientific literature a formula that allows to determined the penalty induced by impulse noise in DS-CDMA-QAM.
Our analytical formula could be used when installing a new CDMA communication. By this way, according to the desired SEP and the impulse noise properties, the number of chips and the modulation can be obtained efficiently.

Thirteenth Annual Symposium of the IEEE/CVT Benelux Chapter

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