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Coded FSK and SFSK Performances Analysis under the Narrow-Band PLC Channel

Authors

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Motivation

- Several commercial PLC modems were based on SFSK for its robustness to difficult channel constraints.
- FSK and the mono carrier systems have low data rates, but have low complexity and are resistant to PLC channel noise.
- FSK modulation is a good candidate for home area network applications (HAN).
- Home automation applications require high reliability and low data rates.

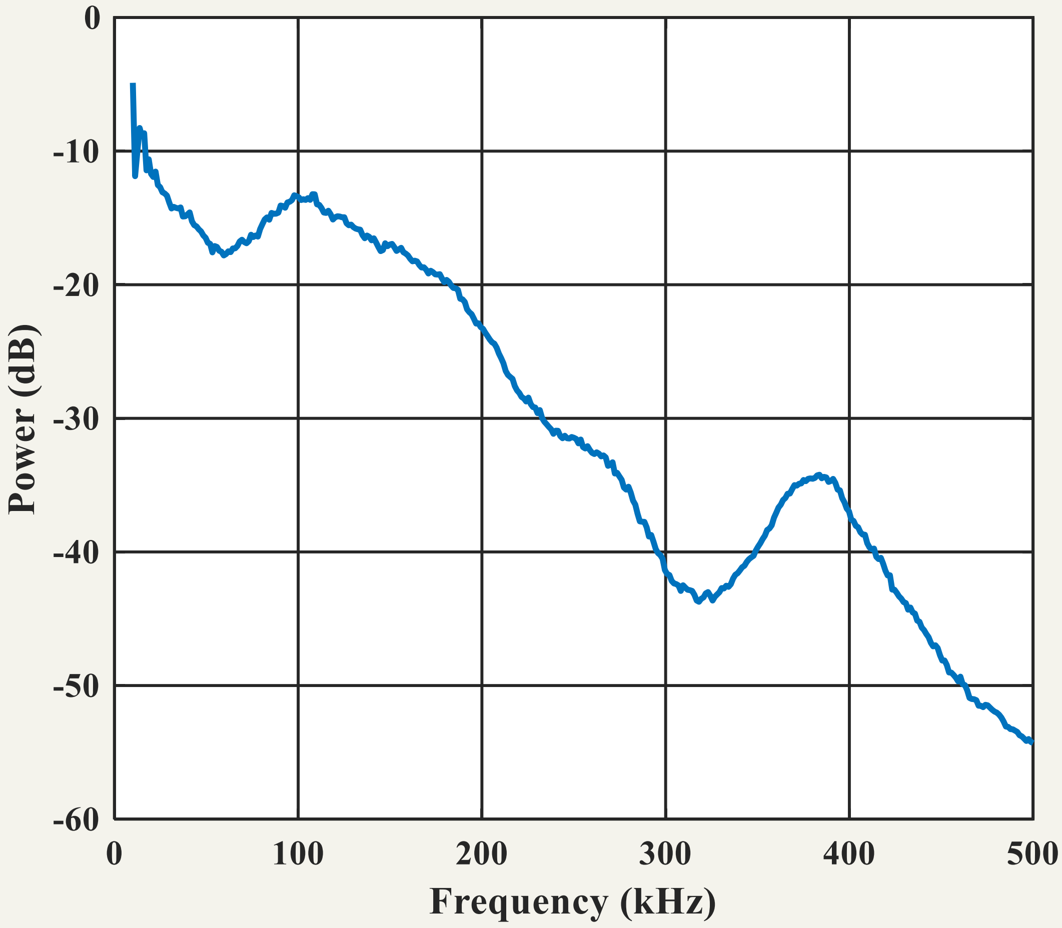
✓ **Study of the performances of FSK and SFSK under indoor narrowband PLC (NB PLC) channel constraints.**

✓ **Proposal of an improved coded FSK modulation scheme that can be used in the design of a low–cost NB PLC modem.**

Paper Outlines

- Narrowband PLC Channel Characteristics
- Improved Decision Techniques for Uncoded and Coded FSK
- Performance Results Analysis
- Conclusion

Narrowband PLC Channel Characteristics
Channel transfer function



High attenuation varying from -5 dB to -54 dB

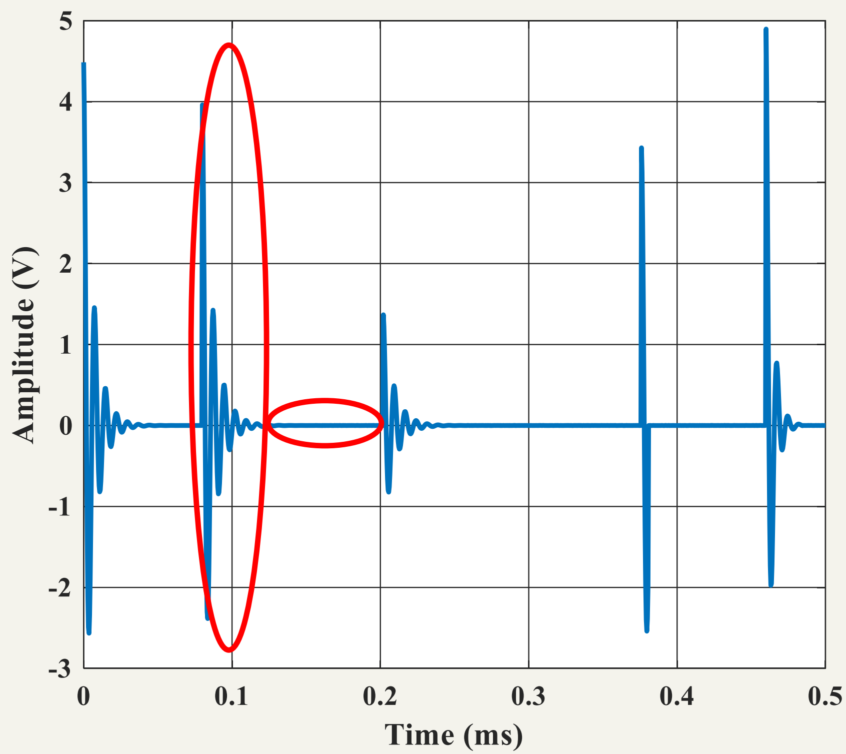
Narrowband PLC Channel Characteristics
Narrow Band PLC impulse noise model

- Model of the single pulse

$$b(t) = A_{IN} \sin(2\pi f t)\exp(-t/\tau); t \in [0, T_d]$$

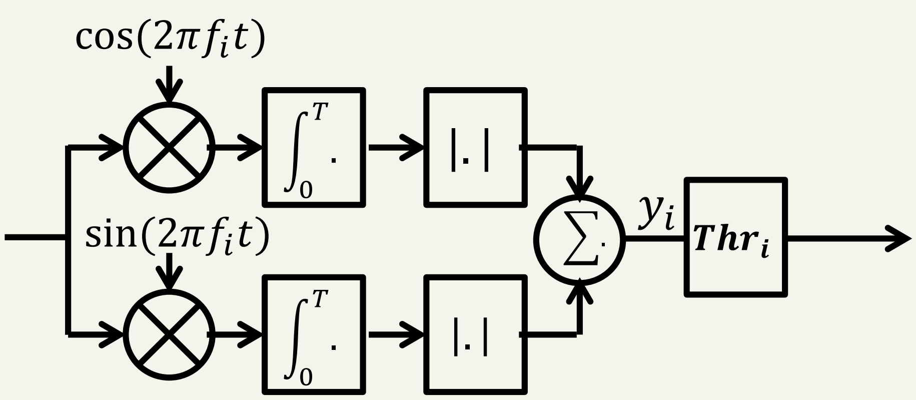
- The pulse is completed by an AWGN of duration T_{it}

Parameter	Min value	Max Value
Amplitude A_{IN}	0.01 V	5 V
Pseudo-frequency f	135 kHz	
Duration T_d	2 µs	82 µs
Inter-arrival Time T_{it}	14 µs	270 µs



Improved Decision Techniques for Uncoded and Coded FSK
Coded modulation description

- A permutation code C consists of |C| code words of length M, where every code word contains M different symbols (1, …, M).
- Every symbol corresponds to a unique transmitted frequency from the M-FSK modulator.
- In the classical decoding method, a threshold is introduced at the output of the envelope detector to construct the received code word.



Improved Decision Techniques for Uncoded and Coded FSK
Select-Largest principle

- **For uncoded FSK** : comparison of the outputs of the demodulator
- **For the coded FSK** : choice of the code word that has the maximum magnitude :
- For the received code word *Y*, calculate :

$$P(Y \mid c_k) = \sum_{i,j=1}^{2} \Pr(y_{ij} \mid c_{kij} = 1), k = 0,1$$

- In our case, $c_0 = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$ and $c_1 = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$
- For a received word $Y_C = \begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix}$

$$d(Y_c, c_0) = y_{11} + y_{22} \text{ and } d(Y_c, c_1) = y_{12} + y_{21}$$

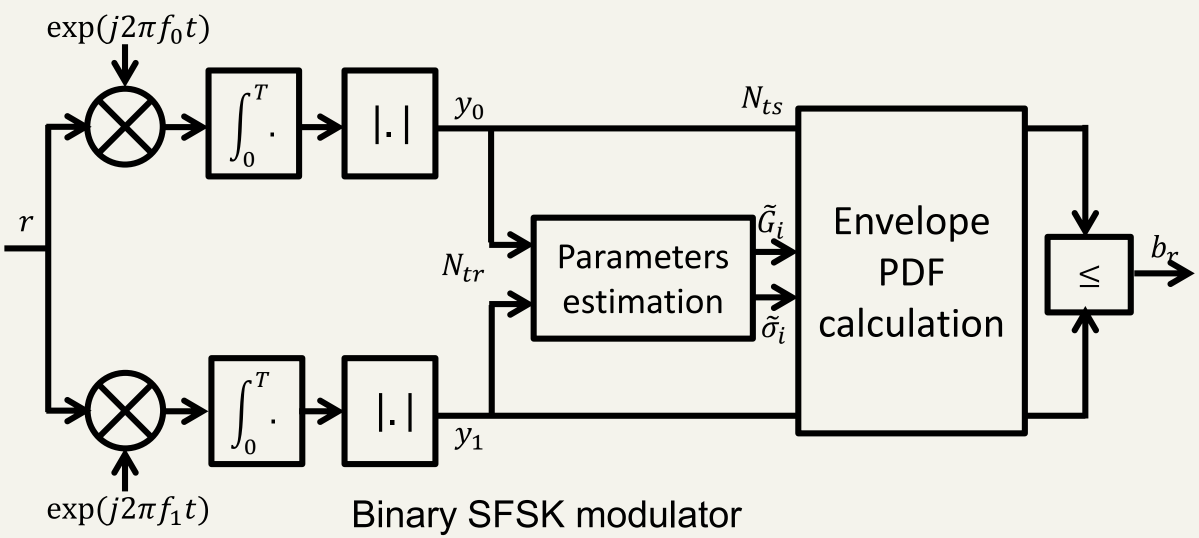
- The code word giving the maximum value is selected

Improved Decision Techniques for Uncoded and Coded FSK
The Spread FSK system

- **For uncoded SFSK :** direct comparison of the outputs of the specific decision unit

- **For coded SFSK :** calculate and choose the largest :

$$P(Y \mid c_k) = \prod_{i,j=1}^{2} \Pr_i(y_i, y_j), k = 0,1$$



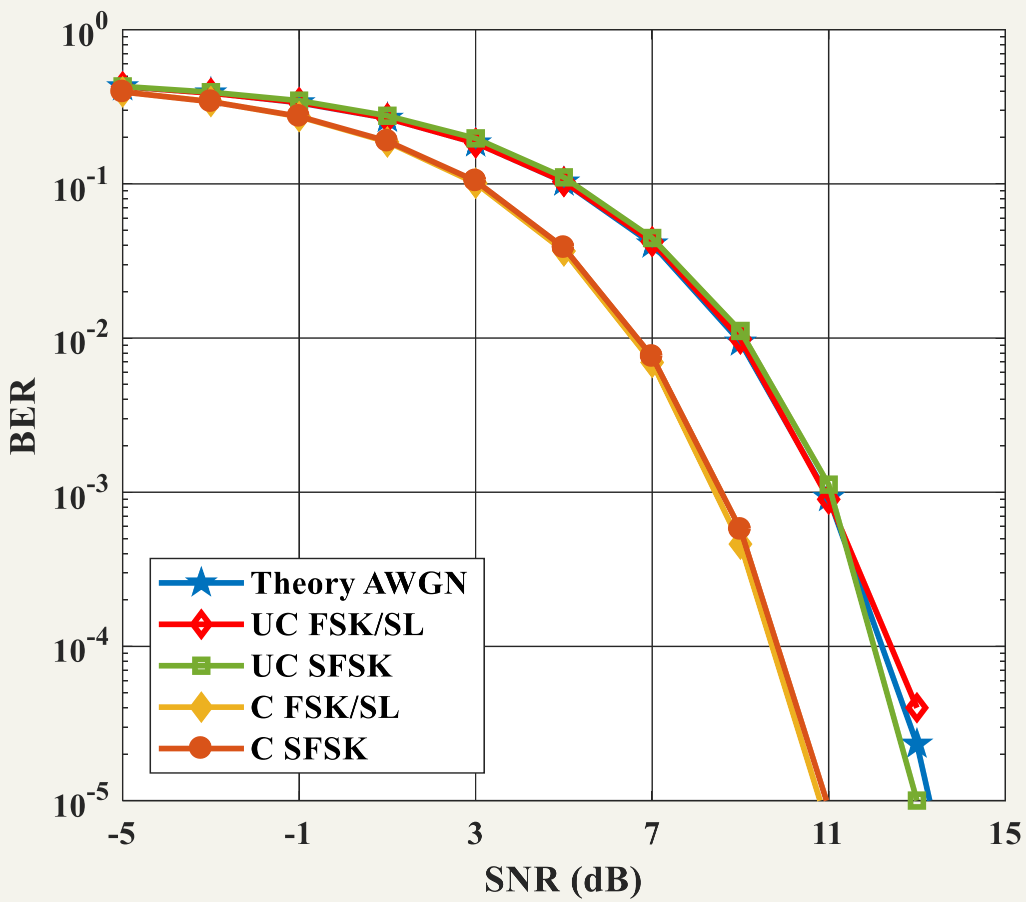
Binary SFSK modulator

Performance results analysis
Simulation parameters

Transmitted signal Peak amplitude	$A = 1$ V
Data Bit Rate	$D = 9600\ bps$
Number of used bits	Up to 10^9
Carrier frequencies	$f_0 = 100\ kHz$ $f_1 = 119.2\ kHz$
Sampling frequency	1 MHz

Performance results analysis

Performance Results in the Gaussian Channel



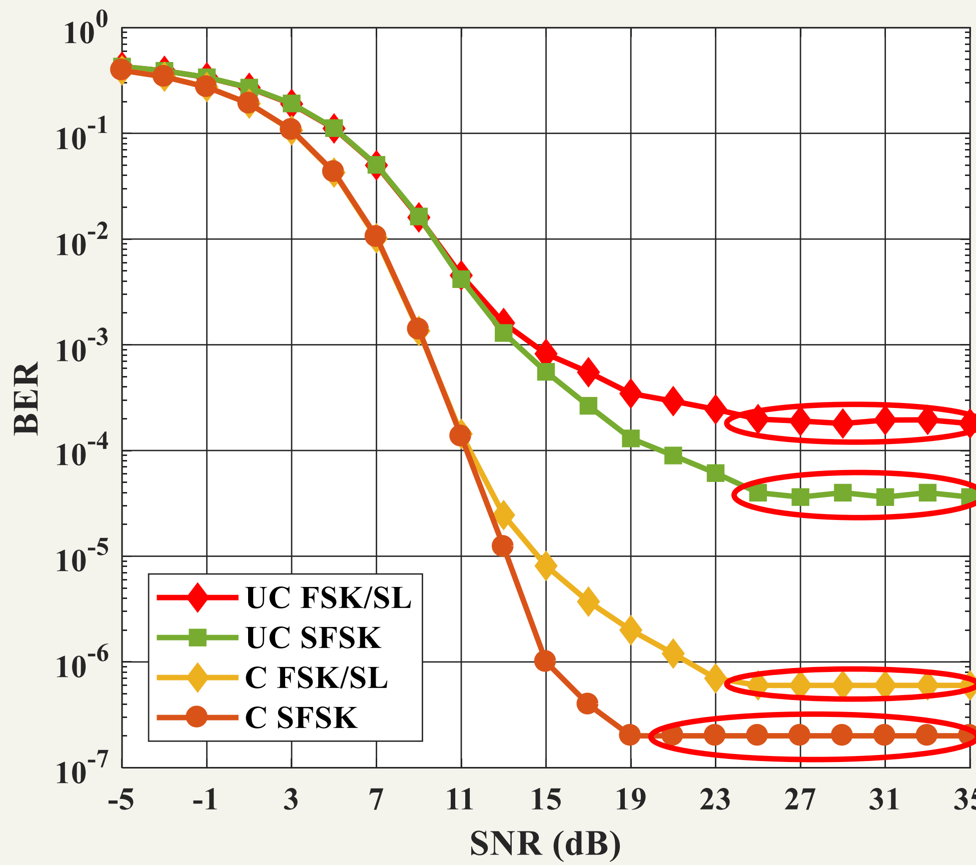
Performance results analysis
Performance Results under the Effect of the Impulse Noise

For SNR up to 11 dB, the coded and uncoded systems have the same BER performances

A gain up to 3 dB for the coded systems

As the SNR value increases, appearance of an error floor due to the impulse noise

The error floors of the coded systems are in the order of is 10^{-7}



- ✓ Coding gain in low SNRs
- ✓ Improved error floors

Performance results analysis

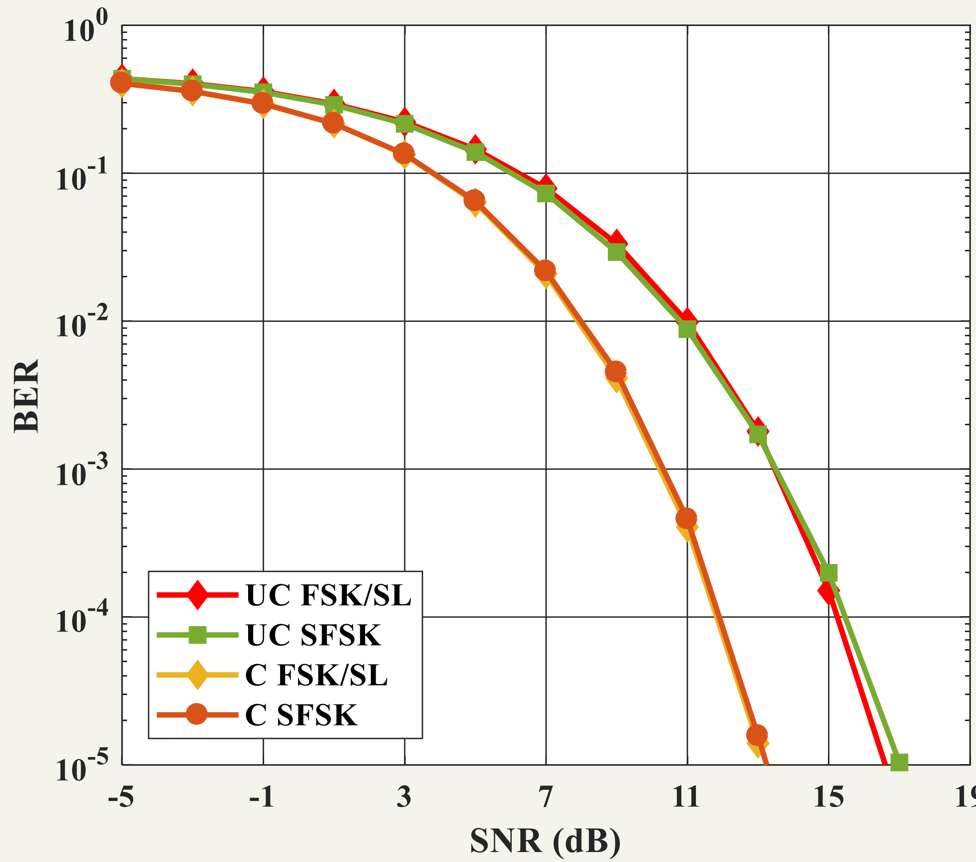
Performance Results under the Effect of the PLC Channel Transfer Function

UC FSK/SL and UC SFSK have the same performances

Channel attenuation around -13 dB

For higher attenuation values, UC FSK/SL has worse BER than and UC SFSK.

The coded systems reach a gain of 4 dB



Performance results analysis

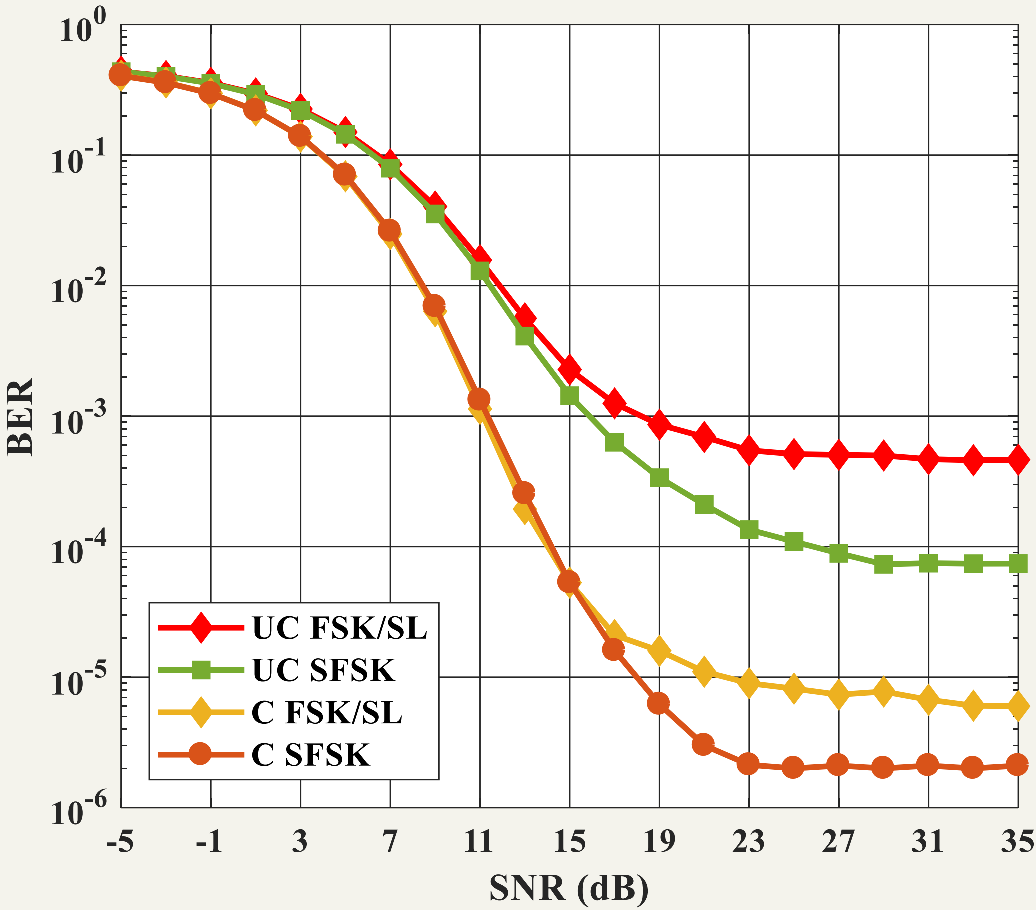
Performance Results under the Effect of the PLC Channel and Noise

The coded systems have the same BER performance for SNR values up to 15 dB

SFSK systems have the best error floor performances for both coded and uncoded cases.

The error floors of both coded systems are in the order of 10^{-6}.

C FSK/SL achieves an excellent performance with low complexity.



Conclusion

- Two decision methods for the coded FSK modulation techniques were exposed and their performances were compared under the indoor NB PLC channel attenuation and noise
- The decision schemes are SFSK and “Select Largest”
- SFSK proved to have the best performances and to be efficient in combating the PLC channel impairments
- For the coded systems, the error floors of both methods are in the order of 10^{-6} under the NB PLC channel conditions
- Coded FSK/SL proved efficient in combating the harsh PLC channel impairments since it achieves the same performance as the coded SFSK for the SNR values up to 15 dB
- Future works will explore the effect of using M-ary FSK coded modulations for more robustness and investigate low complexity impulse noise mitigation methods.

Thank you !

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SFSK versus OFDM Performances under the Narrowband PLC Channel Impairments

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The Spread FSK system (1)

- SFSK decision is based on the calculation of the conditional PDF of the received signal at the output of the demodulator for the symbols *i* and *j*, respectively, while assuming the symbol *i* was transmitted :

$$f_{i|i}(y_i) = \frac{2y_i}{\sigma_i^{\ 2}} I_0\left(\frac{y_i A G_i \sqrt{2}}{\sigma_i^{\ 2}}\right) \exp\left(-\frac{y_i^{\ 2} + (AG_i)^2/2}{\sigma_i^{\ 2}}\right), i = 2$$

$$f_{j|i}(y_j) = \frac{2y_j}{\sigma_j^{\ 2}} \exp\left(-\frac{y_j^{\ 2}}{\sigma_j^{\ 2}}\right), i, j = 2; i \neq j$$

Where σ_i is the noise variance, G_i the channel gain, y_i the value of the demodulated signal and I_0 is the modified Bessel function of the first kind of order 0.

- The decision is then taken by choosing the largest value among:

$$\Pi_0(y_0, y_1) = f_{0/0}(y_0).f_{1/0}(y_1)$$

$$\Pi_1(y_0, y_1) = f_{0/1}(y_0).f_{1/1}(y_1)$$

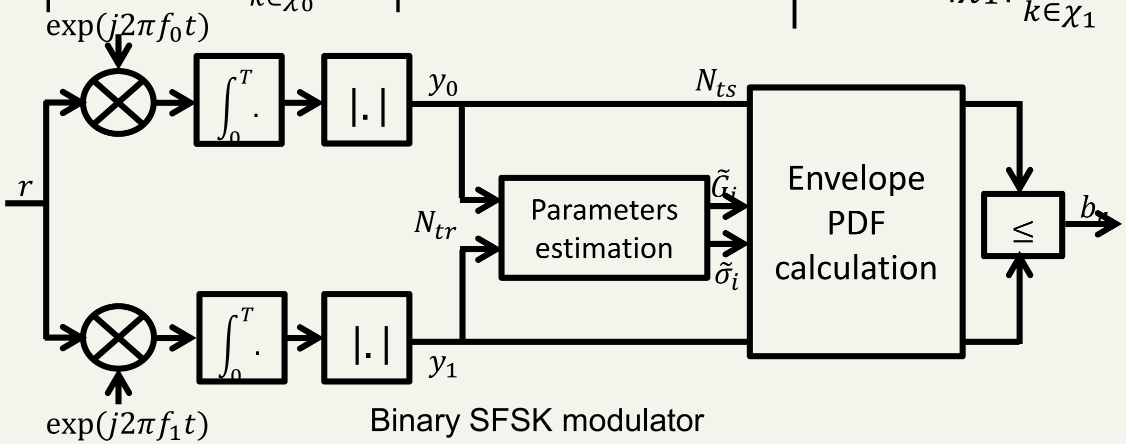
D. Veronesi & al. “Improved spread frequency shift keying receiver,” IEEE I- ISPLC, 2010

The Spread FSK system (2)

- To determine the values of noise and channel parameters, a pilot sequence is transmitted as a preamble, composed of 16 zeros followed by 16 ones.
- The noise variances and the channel gains are estimated as follows:
  - χ_0 is the set of the indices of zeros in the preamble
  - χ_1 is the set of the indices of ones in the preamble

$$\tilde{\sigma}_0{}^2 = \frac{1}{|\chi_1|} \sum_{k \in \chi_1} r_{0,k}{}^2 \qquad \tilde{\sigma}_1{}^2 = \frac{1}{|\chi_0|} \sum_{k \in \chi_0} r_{1,k}{}^2$$

$$\tilde{G}_0{}^2 = \left| -\tilde{\sigma}_0{}^2 + \frac{1}{|\chi_0|} \sum_{k \in \chi_0} r_{0,k}{}^2 \right| \cdot \frac{1}{A^2} \qquad \tilde{G}_1{}^2 = \left| -\tilde{\sigma}_1{}^2 + \frac{1}{|\chi_1|} \sum_{k \in \chi_1} r_{1,k}{}^2 \right| \cdot \frac{1}{A^2}$$



Binary SFSK modulator

y_0 and y_1 : the output of the envelope detector
N_{ts} : number of random test bits
N_{tr} : number of bits in the preamble

$\tilde{G}_i$: estimated channel gain over the symbol/bit i in the preamble
$\tilde{\sigma}_i$: estimated noise variance on the symbol/bit i in the preamble