Performance Evaluation and Parameters Sensitivity of the OFDM Modulation in HF Transmission

Rafael B. Dutra André C. Mendes Mariane R. Petráglia

http://www.pee.ufrj.br http://www.ipqm.mar.mil.br

December 2010

Introduction

- Electromagnetic Spectrum
  - Scarce natural resource
  - Efficient use
  - Secondary users
  - Cognitive Radios (CR)
- CR Physical layer must be highly flexible and adaptable
- OFDM - potential of fulfilling such requirements
  - Simple channel estimation and equalization techniques
  - Channel estimation by inserting pilot subcarriers

OFDM and HF

- OFDM is mostly employed in the VHF, UHF and SHF bands (WiMAX, DVB, IEEE 802.11-b/g/n)
- HF band the OFDM modulation is not very effective.
- HF provides a communications beyond horizon.
- Ionospheric layers suffer several disturbs (multipath, time dispersion, dispersion, non-gaussian noise and co-channel interference)

Proposal

Performance evaluation and sensitivity to the OFDM modulation parameters in HF channels.

Aiming...

The cognitive radios can select the adequate parameters for each channel condition, in order to improve the performance for the OFDM modulation in the HF band.

System Description

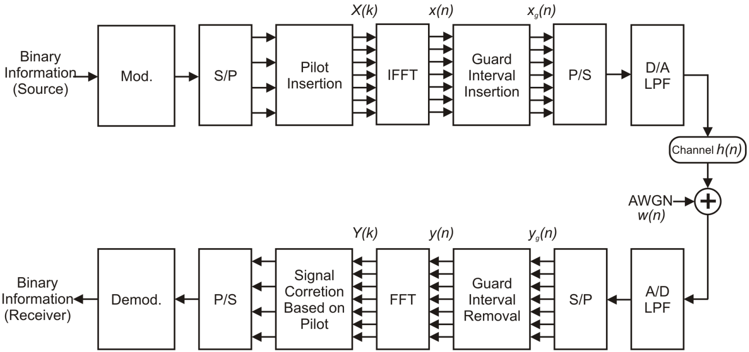


Figure: Block diagram of an OFDM with pilot subcarriers

System Description

- $Y(k) = X(k)H(k) + I(k) + W(k), \quad k = 0, 1, \cdots, N-1$
  - $H(k) = DFT\{h(n)\}$
  - $W(k) = DFT\{w(n)\}$
  - $I(k)$ denotes the subcarrier interferences.

- The pilot subcarriers $Y_p(k)$ are extracted from $Y(k)$.

- The channel frequency response $H(k)$ can then be estimated by interpolation from $H_p(k)$.

- Knowing $H(k)$, one can recover the transmitted data $X(k)$ by:
  - $\hat{X}(k) = \frac{Y(k)}{\hat{H}(k)}, \quad k = 0, 1, \cdots, N-1$
  - $\hat{H}(k)$ is an estimation of the channel response $H(k)$.

Estimation of the Pilot Signals

- N_p pilot signals $X_p(m)$, $m = 0, 1, \cdots, N_p - 1$, are inserted uniformly-spaced in $X(k)$.
- The N carriers are subdivided in N_p groups, each one with $L = N/N_p$ adjacent subcarriers. In each group, the first subcarrier is used to send the pilot signal.
- The OFDM modulated signal in the k-th subcarrier can be expressed as

$$X(k) = X(mL + l) = \begin{cases} X_p(m), & l = 0 \\ data, & l = 1, 2, \cdots, L - 1 \end{cases} \tag{1}$$

  - The pilot subcarriers $X_p(k)$ might have the same complex value c in order to reduce the computational complexity.

Estimation of the Pilot Signals

- $\mathbf{Y_p} = \mathbf{X_p}\mathbf{H_p} + \mathbf{I_p} + \mathbf{W_p}$
  - $\mathbf{I_p}$ contains the subcarriers interferences
  - $\mathbf{W_p}$ contains the added gaussian noise

- The pilot subcarriers are estimated by the Least Squares (LS) method:
  - $\hat{\mathbf{H}}_{\mathbf{p,ls}} = \mathbf{X_p}^{-1}\mathbf{Y_p}$

Estimation of the Pilot Signals

- For general result, the frequency coherence of the channel $(\Delta f)_c$ is related to the spacing between pilot subcarriers $(\Delta f)_p$ through the parameter:
  - $\mu = \frac{(\Delta f)_p}{(\Delta f)_c}$
  - $(\Delta f)_c$ is inversely proportional to the time spread of the channel

- For appropriate channel estimate, the spacing between pilot subcarriers should be considerably smaller than the frequency coherence of the channel.
  - $0 < \mu << 1$
  - Values of μ between 0.01 and 0.1 are usual.

Simulation

- HF channel specifications given in the MIL-STD-110/B norm were adopted.

- Two HF channels:
  - ITU-R F.1487 Mid Latitude Disturbed Conditions (ITU-R Poor)
  - ITU-R F.1487 Mid Latitude Disturbed Conditions with Doppler frequency of 2 Hz (ITU-R Poor with Doppler of 2 Hz)

- Frequencies above 3.4kHz are to be attenuated by at least 40dB

- The channel frequency response $H(k)$ can then be estimated by interpolation from $H_p(k)$.

- The HF channel is simulated using the Watterson model

Simulations Parameters

Parameter	Description	Values
N	Number of OFDM subcarriers	128, 256, 512 and 1024
M	Modulation	B/Q/8-PSK and 16-QAM
L	Distance between Pilot subcarriers	2, 4, 8 and 16
GI	Guard interval	N/8
R	Coder effective rate	1/2
Fs	Symbol rate	4800 baud

Table: Parameters values employed in the simulations

Simulations Parameters

M	L	Rate bits/s	M	L	Rate bits/s
2(BPSK)	2	1067	4(QPSK)	8	3733
2(BPSK)	4	1600	8(8PSK)	2	3200
2(BPSK)	8	1867	8(8PSK)	4	4800
4(QPSK)	2	2133	16(16-QAM)	2	4267
4(QPSK)	4	3200			

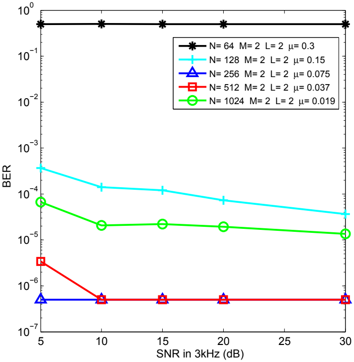
Table: Effective rates for the simulations

Simulations Parameters

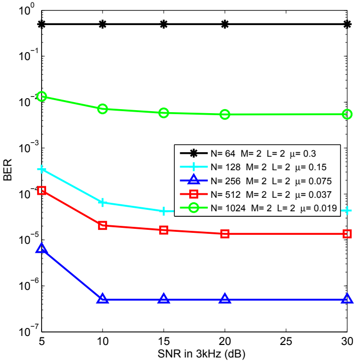
N	L	μ	L	μ	L	μ
64	2	0.300	4	0.600	8	1.2
128	2	0.150	4	0.300	8	0.600
256	2	0.075	4	0.150	8	0.300
512	2	0.0375	4	0.075	8	0.150
1024	2	0.01875	4	0.0375	8	0.075

Table: Spacing between the pilot subcarriers for the simulations

Performance comparisons for rate 1067 bps



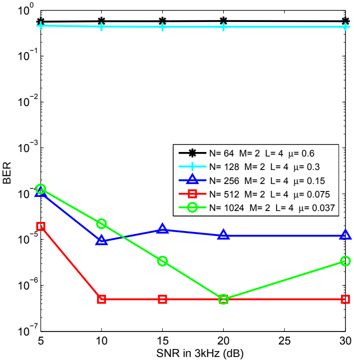
(a) ITU-R Poor



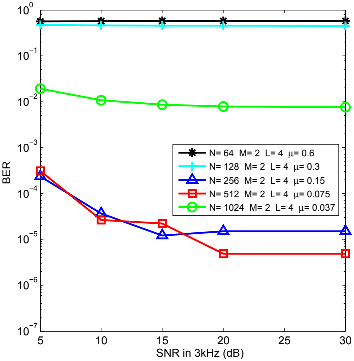
(b) ITU-R Poor with Doppler of 2Hz

- $\mu > 0.25 \rightarrow$ the channel was not correctly estimated.
- L $= 2$ e $\mu = 0.075$(N=256) $\rightarrow$ The best performance.

Performance comparisons for rate 1600 bps



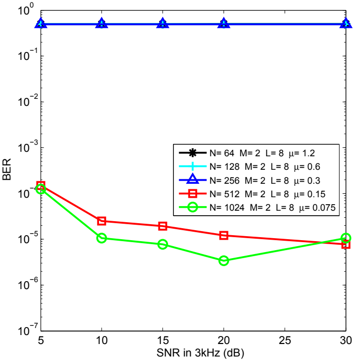
(c) ITU-R Poor



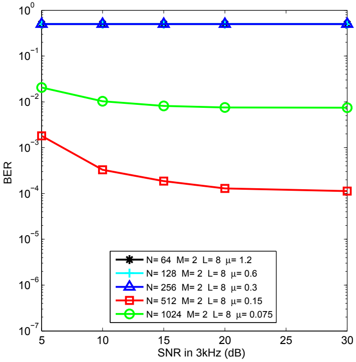
(d) ITU-R Poor with Doppler of 2Hz

- $\mu > 0.25 \rightarrow$ the channel was not correctly estimated.
- L $= 4$ e $\mu = 0.075$(N=512) $\rightarrow$ The best performance.

Performance comparisons for rate 1867 bps



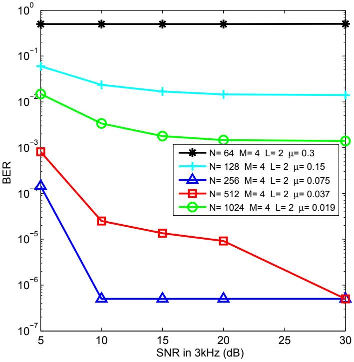
(e) ITU-R Poor



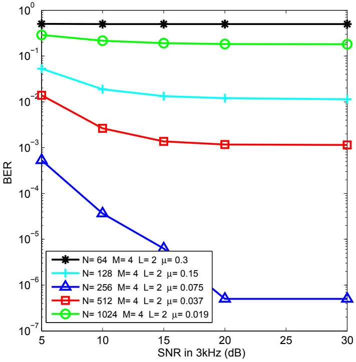
(f) ITU-R Poor with Doppler of 2Hz

- $\mu > 0.25 \rightarrow$ the channel was not correctly estimated.
- L $= 8$ e $\mu = 0.15$(N=512) $\rightarrow$ The best performance.

Performance comparisons for rate 2133 bps



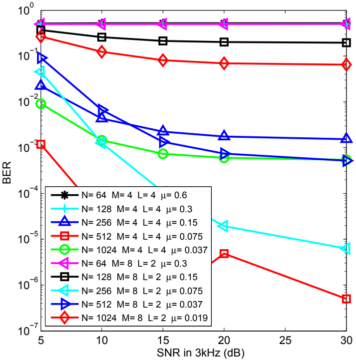
(g) ITU-R Poor



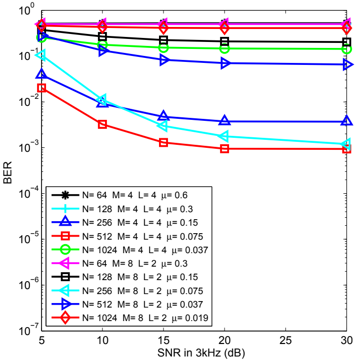
(h) ITU-R Poor with Doppler of 2Hz

- $\mu > 0.25 \rightarrow$ the channel was not correctly estimated.
- L $= 2$ e $\mu = 0.075$(N=256) $\rightarrow$ The best performance.

Performance comparisons for rate 3200 bps



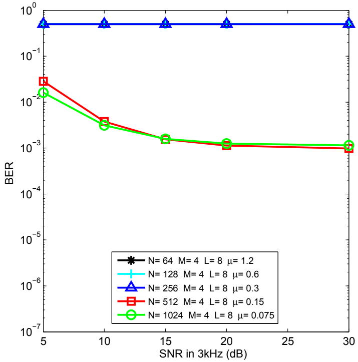
(i) ITU-R Poor



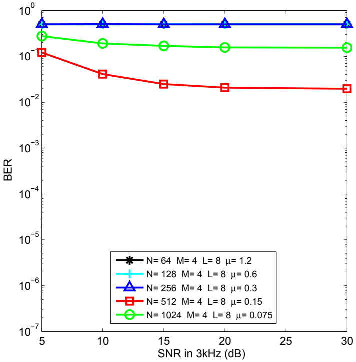
(j) ITU-R Poor with Doppler of 2Hz

- $\mu > 0.25 \rightarrow$ the channel was not correctly estimated.
- M $=$ 4, L $=$ 4 e $\mu = 0.075$(N=512) $\rightarrow$ The best performance.

Performance comparisons for rate 3733 bps



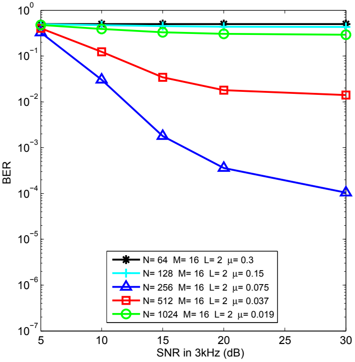
(k) ITU-R Poor



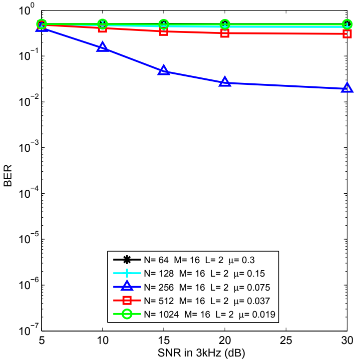
(l) ITU-R Poor with Doppler of 2Hz

- $\mu > 0.25 \rightarrow$ the channel was not correctly estimated.
- L $=$ 8 e $\mu = 0.15$(N=512) $\rightarrow$ The best performance.

Performance comparisons for rate 4267 bps



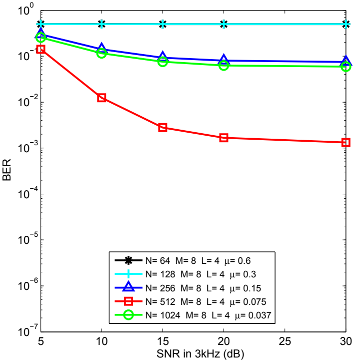
(m) ITU-R Poor



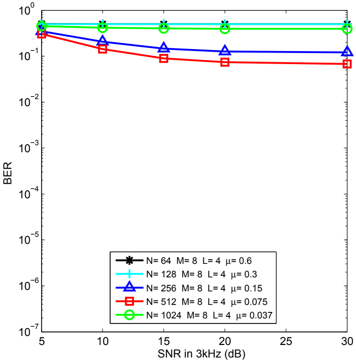
(n) ITU-R Poor with Doppler of 2Hz

- $\mu > 0.25 \rightarrow$ the channel was not correctly estimated.
- L $= 2$ e $\mu = 0.075$(N=256) $\rightarrow$ The best performance.

Performance comparisons for rate 4800 bps



(o) ITU-R Poor



(p) ITU-R Poor with Doppler of 2Hz

- $\mu > 0.25 \rightarrow$ the channel was not correctly estimated.
- L $= 4$ e $\mu = 0.075$(N=512) $\rightarrow$ The best performance.

Discussion

- In all simulations $\mu \geq 0.3$ the channel was not correctly estimated.
- The best performance for the majority of the simulated bit rates and for $L = 2$ and $L = 4$ was obtained with $\mu = 0.075$.
- For rates of 1867 bps and 3733 bps, where $L = 8$, the value $\mu = 0.15$ yielded the smallest error rates.

Analysis

These results suggest that for a determined quantity of data subcarriers between pilot subcarriers (L) there is an optimal value for μ that defines the total number of subcarriers (N).

Discussion

- The 3200 bps rate was simulated with parameters ($M = 4$, $L = 4$) and ($M = 8$, $L = 2$). The best performance was obtained with ($M = 4$, $L = 4$).

Analysis

Such analysis suggests that for a given amount of transmitted information, a reduced modulation scheme with larger space between subcarriers is more efficient than a modulation scheme with a larger number of symbols in its constellation and a smaller number of pilot subcarriers.

Conclusion

The HF channel estimation with the use of pilot subcarriers in OFDM modulation proved very efficient when adequate parameter values for a given channel condition are employed. In its learning period, cognitive radios might analyze the channel conditions in order to select the optimal parameters in each circumstance.