Performance Analysis of Fractionally Spaced Equalization in Non-linear Multicarrier Satellite Channels


32th AIAA International Communications Satellite System Conference (ICSSC), San Diego
August 5th, 2014
Presentation Overview

1. Scenario
2. Channel impairments and System Constraints
3. System Architecture
4. Fractionally Spaced Equalization
5. Optimized Receiver De-mapping
6. Simulations
7. Conclusions
8. Acknowledgments
Outline

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Scenario

- Multicarrier gateway uplink
- Multicarrier transponder
  - Joint input/output filtering
  - Joint power amplification

- Advantages:
  - HW saving
  - Weight saving
  - Flexibility
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Channel Impairments and System Constraints

- **Power & Spectral Efficiency Trade off**

- **System Constraints:**
  - No On-board Signal Processing
  - Low complexity User Terminals

INTERMODULATION PRODUCTS
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Countermeasures Techniques:
1. Multicarrier Predistortion at the gateway
2. Advanced Receiver Processing:
   1. Fractionally Spaced Equalization
   2. Optimized de-mapping at the user terminals (UT)

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Fractionally Spaced Equalization

- Receiver equalization that exploits higher sampling rate $^2$:
  - $K>1$ samples per symbol
- It aims to compensate for:
  - Non-constant group delay of the channel
  - Residual Linear and non-linear distortions
  - Non-optimal receiver sampling

FSE Architecture

• FSE as Linear Filtering:
  
  \[- r_m(n) = \sum_{k_1} b_m(k_1) v_m(n - k_1) = b_m v_m(n) \]

• Parameters Estimation:
  
  \[- b_m = \arg\min_{b_m} \{ \sum_{n=1}^{N} E[ r_m(n) - u_m(n)]^2 \} \]
  
  – Standard Least Squares Solution
  
  – Adaptive and based on pilots
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Non-linear Bias in the RX symbols

- Equalized symbols shows some residual non-linear bias w.r.t. to the reference constellation

- This bias degrades the bit error rate (BER) performance
  - Need to determine more accurate reference constellation for decoding
Average and Centroids based De-mapping

• For linear systems average constellation de-mapping (ACD) suffices:
  – One scaling factor: \( \beta = \arg\min_c \sum_{k=1}^M \sum_{x \in F_k} |x - c|^2 \frac{\sum_{k=1}^M |a_k|^2}{\sum_{k=1}^M |a_k|^2} \)

• For a general non-linear system we need one-to-one re-mapping (CBD):
  – For each constellation point \( k \):
    \( \text{Centroid } c_k = \arg\min_c \sum_{x \in F_k} |x - c|^2, \quad k \in [1, M] \)
  – Centroids estimation based on pilots
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Figure Of Merit

- Total Degradation:
  - Evaluated at a Target Packet Error Rate
  - Spectral Efficiency & HPA Power efficiency

\[ TD = \left( \frac{E_b}{N_0} \right)_{NL} - \left( \frac{E_b}{N_0} \right)_{Ideal} + OBO. \]

where \[ OBO = \left| \frac{P_{out}}{P_{sat}} \right|_{dB} \]
TD Performance Two Carriers
Satellite Channel (1)

- Setting: 16.36 Mbaud, 16 APSK, Roll-off=0.2, LDPC with Code Rate=3/4, Transp. BW=36MHz

- EQ: Baseline symbols spaced equalization
- FSE with Average Const. Decoding provides 0.2 dB over EQ
- Centroids decoding provides additional 0.15 dB
- Total of 0.3-0.4 dB of gain
• Setting: 18 Mbaud, 16 APSK, Roll-off=0.2, LDPC with Code Rate=3/4, Transp. BW=36MHz

- Higher baud-rate leads to higher degradation
- FSE with Average Const. Decoding provides 0.15dB over EQ
- Centroids decoding provides additional 0.25 dB
- Total of ~0.4 dB of gain
TD Performance Triple Carriers
Satellite Channel (1)

• Setting: 10 Mbaud, 16 APSK, Roll-off=0.2, LDPC with Code Rate=3/4, Transp. BW=36MHz

- External carrier degraded by the MUX filters edge
- FSE with Average Const. Decoding provides up to 0.1dB over EQ
- Centroids decoding provides additional~ 0.15 dB
- Total ~0.2 dB of gain
TD Performance Triple Carriers
Satellite Channel (2)

- Setting: 10 Mbaud, 32 APSK, Roll-off=0.2, LDPC with Code Rate=4/5, Transp. BW=36MHz

- Higher Spectral efficiency leads to higher degradation
- FSE with Average Const. Decoding provides up to 0.25 dB to over EQ
- Centroids decoding provides additional ~0.25 dB
- Total ~0.5 dB of gain
Robustness to Sampling Error: Central carrier of a Three Carrier Channel

- Setting: 16 APSK, Roll Off=0.2, IBO=4 dB, LDPC with Code Rate=3/4, Transp. BW=36 MHz

- Standard EQ is very sensitive to sampling
- FSE compensates substantially for the sampling error
  - 22%: perfect recovery
  - 35%: only 0.5 dB of loss
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Conclusion

• UT FSE equalization evaluated for multicarrier satellite channels:
  – Provides about ~0.1/0.2 dB of gain when multicarrier predistortion is applied at the GW
  – Is shown to be robust with respect to sampling accuracy

• Optimized Symbols de-mapping:
  – Provides additional ~0.1-0.3 dB of gain
  – Low complexity
The authors would like to thank the European Space Agency (ESA) for their support through the ARTES 5.1 project “On Ground Multicarrier Digital Equalization/Predistortion Techniques for Single or Multi Gateway Applications” (APEXX) – ESA Contract No.: 4000105192/12/NL/AD.

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