Waveform Comparison based on Multipath and Doppler Spread Capability

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Presentation Overview

- Motivation
- Multipath (MP) and Doppler Spread (DS) Capability
- Fair comparison between waveforms
- Summary

Motivation

- The HF channel is characterized as a multipath time-varying environment that produces both time and frequency dispersion
  - The sources of multipath for long-haul communications
    - Reflections of radio signals from different layers in the ionosphere
    - Multiple reflections between the earth's surface and the ionosphere, giving rise to multi-hop propagation
    - The received signal can contain several "echoes" or modes, separated in time by a matter of milliseconds (i.e. time dispersion)
  - Frequency dispersion occurs because each mode is itself fading due to the specular nature of the ionospheric reflection

Motivation

- Mid-latitude HF circuits
  - Amount of multipath (often called delay spread) can range up to 6 ms
  - Fade rate (often called Doppler spread) can be as high as 5 Hz
  - More typical values are 2 ms and 1 Hz, respectively, which are the basic parameters of the standardized ITU Mid-Latitude Disturbed Channel
  - It should be noted that higher values are possible on other HF circuits such as certain transauroral paths where up to 10 ms of delay spread and 50 Hz of Doppler spread have been measured
- With such a wide range of values for multipath and Doppler spread, designing waveforms for HF requires tradeoffs between data rate and robustness to multipath/fading conditions
  - Lower data rates tend to work better for large multipath and fading values
  - Higher data rates work in more benign HF channel conditions

Motivation

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- When different waveforms that provide the same data rate differ in either multipath and Doppler spread capability or both, how can one compare them in a fair way ?
  - US MIL-STD-188-110C Appendix A 39-tone 300 bps waveform can handle about 4.7 msec of multipath
  - US MIL-STD-188-110C Main body 300 bps waveforms can handle about 8.3 msec of multipath
  - Testing both waveforms on a channel with only 2 msec of multipath does not reveal the benefits of the waveform that provides more multipath capability

MP and DS Capability

- MP and DS capability of a waveform
  - Orthogonal Frequency Division Multiplexing (OFDM)
    - Cyclic prefix used to avoid inter-symbol interference (ISI or MP) from adjacent OFDM frames
    - Spacing between OFDM tones and length of OFDM frame determine DS capability
  - Single-carrier waveforms
    - Symbol stream contains known symbols
      - Number of adjacent known symbols controls MP capability
      - How often the group of known symbols is inserted into symbol stream controls the DS capability of waveform

Fair comparison between waveforms

- For discussion purposes, let’s compare two single-carrier 2400 bps waveforms found in US MIL-STD-188-110C
  - Main Body Waveform (110A)
    - Symbol rate = 2400 symbols per second
    - Modulation = 8-PSK
    - Rate 1/2 convolutional error correcting code
    - Length of adjacent known symbols (K) = 16
    - Length of data symbols (U) = 32
    - Interleaver size is 0.0, 0.6, 4.8 seconds
    - MP capability = 6.67 msec
      - Tested > 6 msec
    - Theoretical DS capability = 25 Hz
      - Tested = 10 Hz

Fair comparison between waveforms

- For discussion purposes, let's compare two single-carrier 2400 bps waveforms found in US MIL-STD-188-110C (continued)
  - 110C Appendix D Waveform (110CD)
    - Symbol rate = 2400 symbols per second
    - Modulation = 4-PSK
    - Rate 9/16 convolutional error correcting code
    - Length of K symbols = 32
    - Length of U symbols = 256
    - Interleaver size is 0.120, 0.48, 1.92, 7.68 seconds
    - MP capability = 6.67 msec
      - Tested > 6 msec
      - May be possible to extend multipath capability ?
    - Theoretical DS capability = 4.167 Hz
      - Tested = 2.5 Hz
  - Note the different interleaver lengths

Fair comparison between waveforms

- 110A Waveform chose 8-PSK in order to handle higher DS rates
  - K = 16, U = 32
- 110CD chose 4-PSK for better power efficiency
  - K = 32, U = 256

Fair comparison between waveforms

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- A cursory look [1] at the 2400 bps options of 110A and 110CD would tend to suggest that:
  - 110CD was better than 110A by about 5 dB on AWGN and Mid-Latitude Disturbed channel
- Was this a fair characterization of both waveforms performance ?
  - No mention of additional capability of 110A to handle much higher DS than 110CD waveform ?
- Performance of 110A was an average of 3 modems
  - Why not the best performance out of the 3
  - Should comparisons be based on theoretical performance achievable versus particular implementations ?

Fair comparison between waveforms

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- Same presentation also compared 1200 and 600 bps
  - Both 110A waveforms can handle
    - MP close to 8.333 msec
    - DS Theoretical about 30 Hz
  - Both 110CD waveforms can handle
    - MP close to 6.67 msec
    - DS Theoretical about 9.375 Hz
  - A significant difference in MP and DS capability
    - This additional capability was achieved at a cost of worse performance in more benign channels

Fair comparison between waveforms

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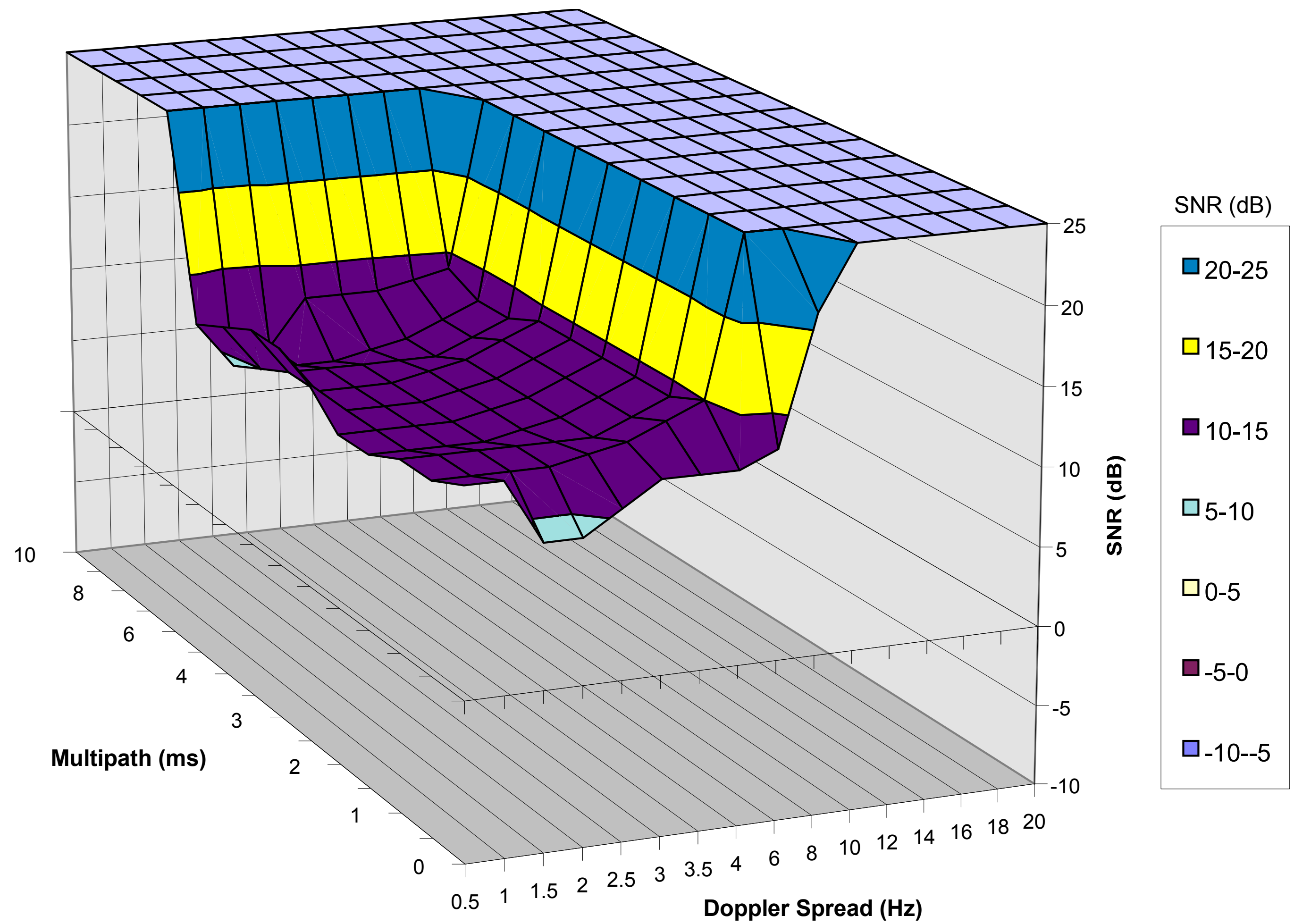
- HF waveform standards include a very small subset of performance tests which are used to validate the quality of the modem implementation
  - AWGN and Mid-Latitude Disturbed channels tested
  - Sometimes a Rician channel (STANAG 4539)
- During the STANAG 4539 waveform run-off, QINETIC (then DERA) suggested a more comprehensive way to exemplify waveform performance
  - Known as “Characterization” plots

Fair comparison between waveforms

Characterization plot: 10^{-3} BER, 2400bps, Long interleaver
Figure from STANAG 4539 Annex D Figure 3-11



Summary

- When comparing waveforms that provide different MP and DS capabilities, it is important to highlight each waveform's capabilities in addition to the specific channel conditions tested, so users understand the benefits and limitations of each waveform
- Characterizing a waveform's performance over the full range of MP and DS is the only fair way to understand and compare the true capabilities of each waveform
  - Usually robustness to larger MP and DS comes at a cost in performance in more benign channels

Summary

- Perhaps a simple robustness score can be defined which scores how well the waveforms perform relative to a maximum MP and DS capability
  - For example
    - Max MP = 10 msec, Max DS = 50 Hz
    - 110A 2400 bps
      - MP score = 6.0/10.0
      - DS score = 10.0/50.0
    - 110CD 2400 bps
      - MP score = 6.0/10.0
      - DS score = 2.5/50.0
    - 110A 75 bps
      - MP score = 10.0/10.0
      - DS score = 50.0/50.0

References

[1] "MIL-STD-188-110C Appendix D Digital Voice Data Rate Performance", Jim Gregory Rockwell Collins, January 27, 2011 HFIA Meeting in San Diego, CA.