Low SNR FreeDV Mode

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1 Glossary

Acronym	Explanation
AWGN	Additive White Gaussian Noise - a communications channel with flat frequency response and additive noise
FEC	Forward Error Correction
PTT	Push To Talk - voice communications where only one person is transmitting at any one time. Common in two way radio but not mobile telephones
MPP	Multipath Poor channel, 1 Hz Doppler, 2ms delay spread, typical for US and Australian interstate propogation
MPD	Multipath Disturbed channel, 2 Hz Doppler, 4ms delay spread, typical for UK Winter NVIS propogation

Table 1: Glossary of Acronyms

Symbol	Explanation	Units
B	Noise bandwidth	Hz
E_b/N_0	Energy per bit on spectral noise density	dimensionless, dB[1]
N_p	Pilot symbol insertion rate	-
R_b	Bit rate	Bits/second
R_s	Symbol rate	symbols/second
T_s	Symbol period	seconds
SNR	Signal to Noise Ratio	dB
S	Signal Power	Watts
N	Noise Power	Watts

Table 2: Glossary of Symbols

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[1]Can be expressed as a linear ratio E_b/N_0 or $10log_{10}(E_b/N_0)$ dB

2   Introduction

After 10 years development and on air experience with various FreeDV waveforms, we would like to develop a new waveform that outperforms and replaces a variety of existing modes such as 700C/D/E and 1600. Requirements include [1]:

1. Better performance than SSB at 0dB SNR on MPP and MPD channels.

2. A single mode that can handle MPP and MPD, and replace several existing FreeDV modes, simplifying the end user experience.

3. For compliance with Export Control regulations, the minimum speech codec bit rate is 700 bit/s.

3   Theory

In this section we will develop a theoretical model to help us explore performance limits. For practical PTT voice systems algorithmic delay is limited to a few 100ms, which limits the FEC codeword size and hence the performance of the code. For PSK channels a threshold $E_b/N_0 = 2$ dB and a code rate $R = 0.5$ is typical, where E_b/N_0 is the energy per payload data bit (coded E_b/N_0). The lowest (threshold) SNR for a viable voice link is given by:

$$\frac{S}{N} = \frac{E_b R_b}{N_0 B}$$
$$SNR = 10log_{10}\left(\frac{E_b}{N_0}\right) + 10log_{10}\left(\frac{R_b}{B}\right) \quad [\text{dB}]$$

(1)

where R_b is the payload data bit rate, and B is the bandwidth in which we measure SNR. Given $Rb = 700$ and $B = 3000$ we have:

$$SNR = 2 + 10log_{10}(700/3000)$$
$$= -4.3\,\text{dB}$$

(2)

This is ideal performance for an AWGN channel. In practice we must allocate some power to symbols used for synchronisation, such as pilot symbols used for frequency and phase estimation, or unique word bits used for frame synchronisation. Synchronisation algorithms often struggle at low SNRs, introducing additional "implementation" losses.

Performance on multipath channels is significantly worse, in our use cases typically 5 dB. On these channels, we may allocate some carrier power to deal with intersymbol interference (for example a cyclic prefix in OFDM modems).

A more complete model is:

$$SNR = 10log_{10}\left(\frac{E_b}{N_0}\right) + 10log_{10}\left(\frac{R_b}{B}\right) + L_s + L_{il} + L_{cp}$$

(3)

where L_s is the loss from power allocated to synchronisation symbols, L_{il} is the real world implementation loss, and L_{cp} is the loss in SNR due to the power allocated to the cyclic prefix.

3.1 Pilot symbol overhead

In this section we explore the effect of inserting pilot symbols on the threshold SNR (1). Consider a sequence of $N_p - 1$ PSK data symbols that carry the modulated FEC codeword bits (e.g. data and parity bits) over the channel. We denote this sequence a *frame*. The frame of $N_p - 1$ has a period of $T_f = (N_p - 1)T_s$ seconds, where T_s is the period of each symbol. We wish to insert a single pilot symbol after the data symbols, creating a new frame N_p symbols long, with period $T'_f = N_p T_s$. To maintain the same payload data rate:

$$
\begin{aligned}
T_f &= T'_f \\
(N_p - 1)T_s &= N_p T_s \\
R'_s &= R_s \frac{N_p}{N_p - 1}
\end{aligned}
\tag{4}
$$

where the symbol rate $R_s = 1/T_s$. Expressing S/N in terms of E_s and R_s:

$$
\begin{aligned}
\frac{S}{N} &= \frac{E_s R_s}{N_0 B} \\
\frac{S'}{N} &= \frac{E_s R'_s}{N_0 B} \\
&= \frac{E_b R_s N_p}{N_0 B (N_p - 1)} \\
\frac{S'/N}{S/N} &= \frac{N_p}{N_p - 1}
\end{aligned}
\tag{5}
$$

Thus when we insert pilots, the threshold S/N increases by a factor of $N_p/(N_p - 1)$. Expressed in dB:

$$
\begin{aligned}
10log_{10}\left(\frac{S'}{N}\right) &= 10log_{10}\left(\frac{S}{N}\right) + 10log_{10}\left(\frac{N_p}{N_p - 1}\right) \\
SNR' &= SNR + 10log_{10}\left(\frac{N_p}{N_p - 1}\right) \\
SNR' &= SNR + L_p \quad [\text{dB}]
\end{aligned}
\tag{6}
$$

where L_p can be considered the pilot symbol *loss* - the SNR degradation from the ideal performance (1) due to the insertion of pilot symbols. For example a pilot insertion rate of $N_p = 8$ results in $L_p = 10log_{10}(8/7) = 0.58\,\text{dB}$, thus we need 0.58 dB more SNR to acheive the threshold SNR for the voice link. If there is no other synchronisation overhead, then $L_s = L_p$ in Equation 3.

4   Unorganised Notes

TODO could have expression for Fading channels, block error rate

and we may need an increased pilot symbol rate, and a

TODO check performance of a few codes

Table explaining MPP MPD

TODO: set up model, then discuss various algorithms and how they affect model

Where we can gain, diversity, PAPR reduction, reduced overheads for fast fading and ISI (discuss)

Challenges, fast fading, ISI

Initial goal, single waveform that handles MPP and MPD at low SNR, better than 700D performance

Joint low latency/high latency on two carriers ()diveristy

Wades techniques (ref)

References

[1] David Rowe. FreeDV-020 WP4000 Low SNR Mode.