2 Mbit/sec M-FSK Higher-Speed PHY Proposal

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Introduction

The 1 Mbit/sec standard adopted by 802.11 is based on binary GFSK signaling at 1 Mbaud/sec. It is proposed to naturally extend this format into a 2 Mbit/sec standard by using 4-FSK with same baud rate and same pulse shape. The proposition enables to utilize the existent IF and baseband hardware and be compatible at the preamble and the end delimiter with the 1 Mbit/sec standard.

Proposed Implementation parameters

Data rate [Mbit/sec]	1.00 (regular)	2.00 (higher speed)
Baud Rate [Mbaud/sec]	1.00	1.00
Modulation format	2-FSK	4-FSK
Bits/Baud	1 bit	2 bits
Modulation index, h	0.34	0.15
Modulation index accuracy	+/-TBD %	
Tx pulse Shape	Gaussian BT=0.5 filter over NRZ data	
Preamble	ramp up followed by 80 symbols of 010101 followed by 16 bit pattern 0011011110000101 in 2-FSK format	
PHY Signaling Field	8/16 bits in 2-FSK format, includes the modulation type info for the rest of the packet	
End Delimiter	8 bit binary pattern 11000010 followed by ramp down at center frequency	

Modulation Index choice

The modulation index presented is chosen on a basis of equal RMS deviation, resulting in almost equal bandwidth. The 99% and 20 dB bandwidths are shown in the following table:

Modulation	2-GFSK	4-GFSK
Bit rate	1.0 Mb/s	2.0 Mb/s
Modulation Index	0.34	0.15
Frequency deviation, peak to peak	340 KHz	450 KHz
99% power BW	0.88 Fs	0.92 Fs
-20 dB BW	0.97 Fs	0.97 Fs

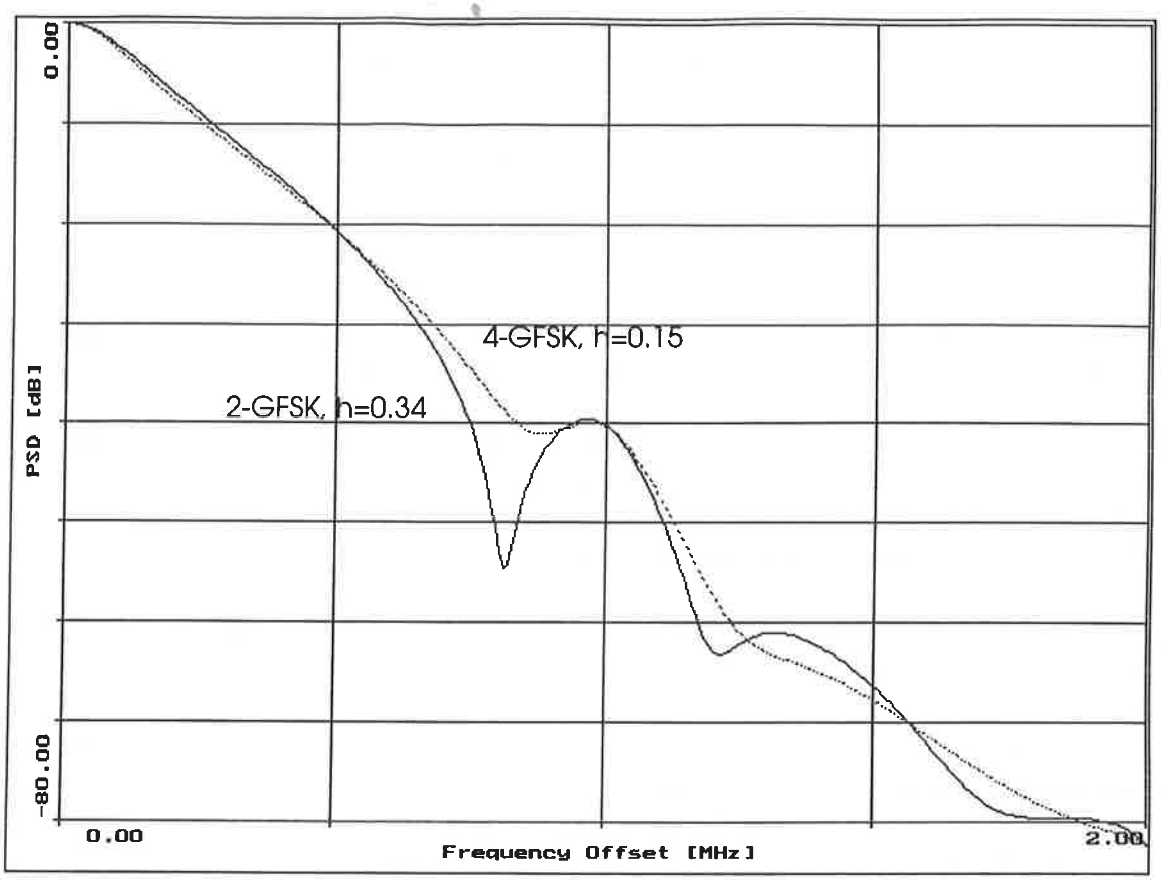

Figure 1: Spectra of 2-GFSK (solid) and 4-GFSK (dotted)

Preamble, PSF and End Delimiter

The demodulation of the proposed format essentially involves the same steps with switching to 4 level slicer instead of 2 level slicer. This switching can be performed on a per-symbol basis. As a result, the preambles can be entirely compatible with the 1 Mb/sec standard. The only provision required is to know the format of the packet before the data body. To satisfy this need there is a field in the PSF (PHY Signaling Field) which indicates the modulation format for the rest of the packet. We propose to reserve 3-4 bits in the PSF to accommodate future options of trellis coding and additional (slower?) rates.

The preamble format proposed coincides with the proposal in P802.11-93/209, with a different Unique Word. The merits of the proposed UW are better correlation properties and structure suitable for equalizer training. This merits are discussed in some detail in P802.11-94/49.

The purpose of the End Delimiter is to provide an accurate the end-of-data position. The End Delimiter proposed is a Barker-like sequence which is detected in conjunction with the fall of RSSI. The 2-level ED is detected by using sign-only information, resulting in an independence of the number of levels(2/4) and in conformance to the regular standard.

Sensitivity - Nonfading Gaussian Channel

The simulated results presented in the table assume a receiver based on an IF filter, discriminator, equalizer to suppress ISI and M-level slicer. The comparison is based on idealized IF and postdetection filters, with some implementation penalty expected.

Modulation	2-GFSK	4-GFSK
Modulation Index	0.34	0.15
Bit rate	1.0 Mb/s	2.0 Mb/s
Eb/No @ 1e-5	19 dB	22 dB
Es/No @ 1e-5, =C/N@1 MHz	19 dB	25 dB

Fading Channel Performance

Case I - Selective fading, no noise

The multipath propagation causes two main types of disturbance: flat fading (power fluctuations) and frequency selective fading (distortion). Significant distortion usually manifests itself as a notch within the signal band, and it causes loss of a packet, even when there is no noise. Mild distortion can be equalized after the discriminator. Even smaller distortion can be received without adaptive equalization.

The probability of packet loss without noise depends primarily on the modulation/demodulation method, the RMS delay spread and the diversity. The dependence on packet length is weak, as in the case of large distortion a large fraction of the packet gets corrupted. Without antenna diversity the probability of packet loss behaves approximately quadratically with the RMS delay spread. With two antenna diversity the failure probability is squared, so it behaves as a fourth power of RMS delay spread.

The following table summarizes the simulated probability of failure without diversity for a 256 symbol packet with 150 nsec RMS delay spread. The simulation includes an adaptive equalizer trained on a preamble, as proposed in the begining. The average throughput is computed as Rate*(1-P_{loss}), and the comparison does not include the protocol overhead.

Modulation format, Demodulation Method	Rate (Mbit/s)	P_{loss}, 256 sym	Average Throughput
HS M=4, Adaptive Equalizer	2.00	0.045	1.91
Regular M=2, Adaptive Equalizer	1.00	0.0035	0.997

The next table describes the same situation, but with RSSI-based two antenna selection diversity. Independent fading in the antennas is assumed. Actually, there is some penalty with respect to "probability squared" law, attributed to nonideal selection of antenna by RSSI.

Modulation format, Demodulation Method	Rate (Mbit/s)	P_{loss}, 256 sym	Average Throughput
HS M=4, Adaptive Equalizer	2.00	0.005	1.99
Regular M=2, Adaptive Equalizer	1.00	0.00003	1.00

Case II - Flat fading, Gaussian noise

The FSK modulation in a nonfading channel has an Q(sqrt(k*E_b/N_0)) type dependence of BER versus E_b/N_0. It is shown in Appendix A, that in Rayleigh fading channel, a margin required to obtain 1% packet loss probability is, respectively, 15.5-19 dB without diversity and 5.5-9 dB with two antenna selective diversity, when referenced to the E_b/N_0 required for 10^{-5} bit error rate. The following table shows the E_b/N_0 required for 1% packet loss probability obtained by applying the discussed result to M-FSK with two antenna diversity:

Block length	2-FSK	4-FSK
BER=1e-5, nonfading	19.0 dB	22.0 dB
N=100	24.5 dB	27.5 dB
N=1000	26.5 dB	29.5 dB
N=10000	28.0 dB	31.0 dB

The packet loss probability is inversely related to E_b/N_0 without diversity and inversely in square root of E_b/N_0 with two antenna diversity. This means that obtaining 0.1% packet loss probability requires additional 10 dB without diversity and additional 5 dB with diversity.

Combined selective fading and noise

The following graph summarizes a simulation of packet loss probability versus average E_b/N_0 at 150 nsec RMS delay spread, with 4-GFSK and two antenna diversity, at 256 symbol packet length. At low SNR a behaviour typical of flat Rayleigh fading is observed, which at high SNR reaches a floor caused by the selective fading.

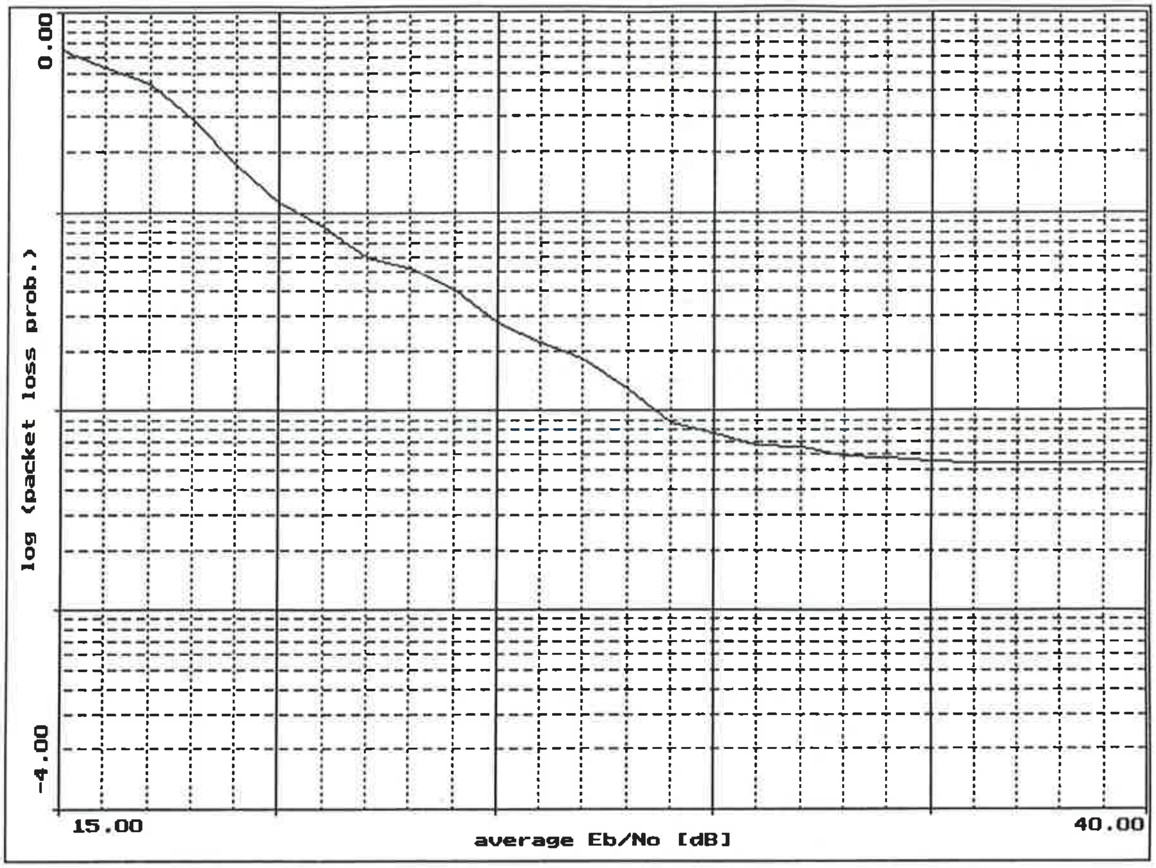

Figure 2: Simulated Packet loss probability, 4-GFSK, 150 nsec delay spread.

Remarks

- **Modulation Index:** The proposed modulation index is based on preserving the R.M.S. modulation, i.e. $\mathbf{h_M=h_2sqrt(3/(M^2-1))}$. The motivation is to have the same bandwidth after FSK modulation. For h_2=0.34 we get h_4=0.15. A simpler relation $h_M=h_0/M$ can be used, facilitating 3 bit D/A implementation, but then the 2-FSK modulation index has to be decreased in order to accommodate the increased bandwidth of 4-FSK.
- **Trellis Code Option:** There is an option to introduce a trellis code, which will reduce the required C/N and improve the robustness of the system. A simple 4 state Ungerbeck code for a baseband channel is suggested, but further study of a code suited for the GFSK channel is required. The information on the existence of a trellis code should be passed in the PSF in order to initialize the proper decoding mode for the rest of the packet. It is advised to leave 3-4 bits in the PSF for the rate/trellis information

Appendix A: Fading margin for packet loss with diversity

The following analysis assumes that a flat Rayleigh fading channel is fixed along the whole packet. Independent symbol errors and independently fading Rayleigh channel for each antenna are assumed. The modulation is assumed to have a Q(sqrt(k*E_b/N_0)) type dependence of BER versus instantaneous E_b/N_0. The packet loss probability of a packet of N symbols received with K-antenna selection diversity is given for by:

P_{loss}= integr(d/dt((1-exp(x))^K)*(1-(1-Q(sqrt(x*k*EbNo))^N) dx

The following graph shows the packet loss probability vs. average E_b/N_0 for block lengths N of 100,1000 and 10000, and for diversity K=1 (none) and K=2, for BPSK (BER=1e-5 @ E_b/N_0=9.6 dB in nonfading channel).

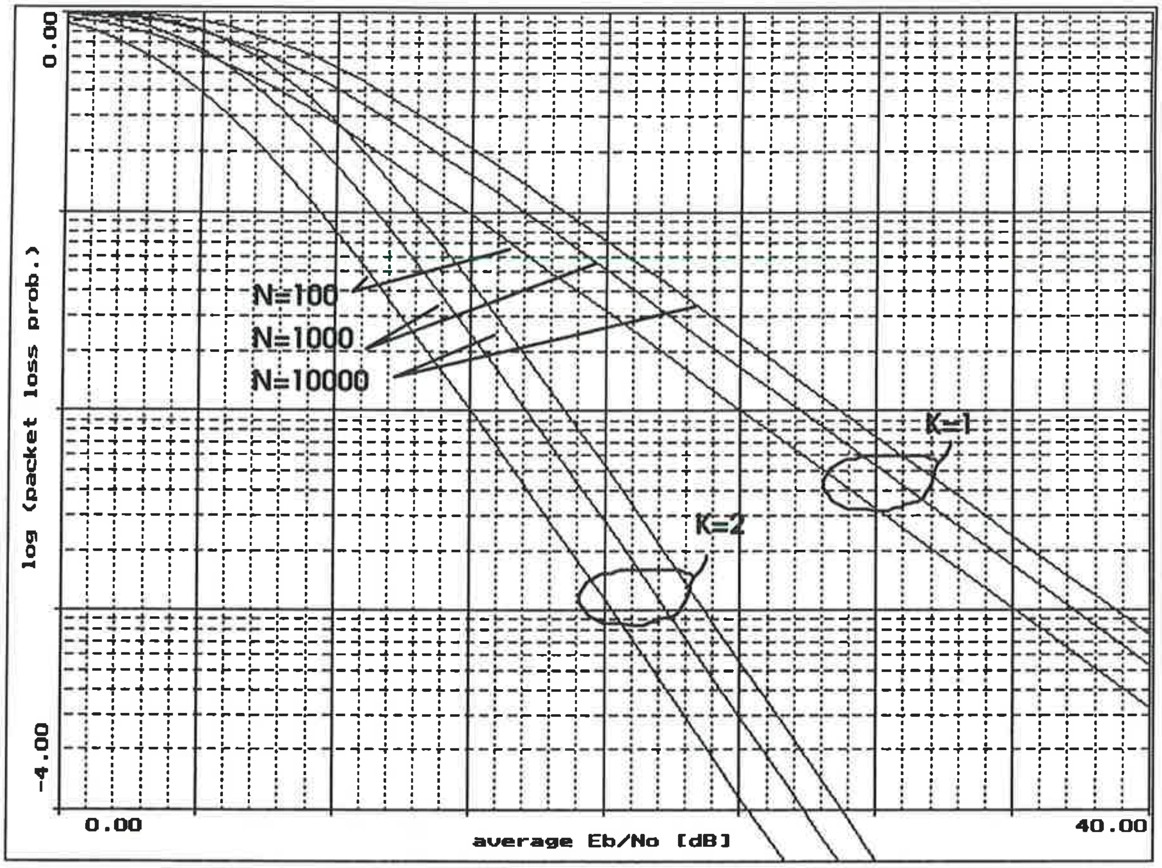

Figure 3: Packet loss probability in Rayleigh fading, vs. diversity and length

It can be seen that when referenced to the E_b/N_0 required for 10^{-5} bit error rate, the margin required to achieve 1% packet loss probability is, respectively, 15.5-19 dB without diversity and 5.5-9 dB with two antenna selective diversity.