IEEE P802.11
Wireless LANs

REED SOLOMON FEC FOR OFDM TRANSCEIVER

Date: November 11, 1998

Author: Hatim Zaghloul, Steven Knudsen, Michel Fattouche
Wi-LAN Inc.
300 – 801 Manning Road N.E.
Calgary, Alberta, Canada T2E 8J5
Phone: (403) 273 9133
Fax: (403) 273 5100
e-Mail: zaghloul@wi-lan.com

Abstract

This submission recommends introducing a forward error correction code that becomes an option to the convolutional coding recommended in the IEEE802.11a Draft Standard [1]. The FEC method recommended in this submission is Reed Solomon (RS) coding. The submission compares RS coding to the currently proposed convolutional coding with a Viterbi decoder using soft decisions in the receiver and shows that RS coding has the potential to be clearly superior.

Introduction

Wireless transmission systems based on orthogonal frequency division multiplexing (OFDM) modulation are attractive due to their high spectral efficiency and resistance to noise and multipath effects [2]. Though resistant to the data errors introduced by noise, multipath, and other effects, OFDM-based data transceiver systems still require extra signal processing steps compared to their spread spectrum counterparts to achieve comparable bit error rates[1]-[6].

The incorporation of pilot subcarrier symbols in the transmitted OFDM symbol stream [1][3]-[6], either in addition to or as part of the OFDM symbols themselves, allows for the correction of such effects as transmitter/receiver carrier frequency and sampling frequency offsets, and fading due to multipath transmission. The pilot subcarrier symbols are known to the receiver; hence the received symbols can be compared against the reference symbols and the result used to characterize the impulse response of the transmission channel. The impulse response can be used to provide channel equalization information at the receiver and sent back to the transmitter to pre-distort data prior to transmission.

FEC

Wireless OFDM systems on their own do not yield extremely low bit error rates (BERs); consequently, some form of forward error correction (FEC) must be used for obtaining the extremely low bit error rates. The IEEE 802.11a draft standard [1] recommends the use of convolutional coding and Viterbi decoding. In general, this FEC scheme has been shown to yield very low overall BERs in wireless data transmission applications. However, when information about the transmission channel is available, as described above, convolutional coding may not offer the best solution.

Instead, block coding may be more appropriate. Reed Solomon coding is known to deliver good results for systems in which errors are generated in bursts [7]. Consider OFDM transmission in a multipath channel environment. A deep null in the frequency response results in bit errors in one or more consecutive data subsymbols. The errors are generated in the same subsymbols in one or more OFDM symbols for the duration of the null. The positions of the subcarriers (subsymbols) affected by the null are estimated from the estimated channel response. A simple threshold is applied in to determine the subcarrier frequency indices in which data is suspected to be corrupt. These indices are matched to the corresponding locations in the Reed Solomon codeword to indicate words that are to be erased. By erasing data known (or suspected) to be in error, the error correcting power of the Reed Solomon code is doubled. Although a simple threshold works, more complicated ways of determining corrupt data may be employed to determine the subcarrier erasure locations. For example, the data may be fitted to a curve to assess whether the low amplitude is due to fading or to noise. If the low amplitude is due to noise, a decision may be made that subsequent data subsymbols are not corrupt and may be kept.

An exemplary receiver architecture employing this approach is illustrated in Figure 1. The receiver includes a conventional amplifier, a conventional I and Q demodulator connected to receive signals from the amplifier section, a conventional guard interval remover connected to receive demodulated signals from the demodulator and remove guard intervals, a conventional Fast Fourier transformer connected to receive signals from the guard interval remover, a channel estimator connected to receive output symbols from the Fast Fourier transformer and having as output an estimate of the channel response of channels over which the OFDM receiver receives signals, an equalizer following the Fast Fourier transformer, and a decoder section, which includes a deinterleaver (if required), a subsymbol demodulator (if required), and a Reed Solomon decoder. The subcarrier correction (erasure) location is determined from the estimate of the channel response from the channel estimator and is provided either to the equalizer or to a decoder, or both, to instruct the equalizer or decoder (or both) to discard symbols for which the channel response indicates the symbol may be a suspect symbol. The channel estimator may also output an estimate of the channel directly to the equalizer.

The decoder, which follows the equalizer, is a Reed Solomon decoder for decoding equalized symbols output from the equalizer, and is modified to receive a list of locations where data is to be discarded and to discard data at those locations. By carrying out data discarding at the equalizer, some unnecessary computations may be avoided. Whether a symbol is suspect may be determined by comparing the amplitude of the signal with a threshold. For example, all symbols whose amplitude is more than, say, 10 dB below the running mean of the magnitude frequency response of the channel, may be considered to be within a null and labelled for erasure. The threshold may be set so that suspect data is considered corrupt

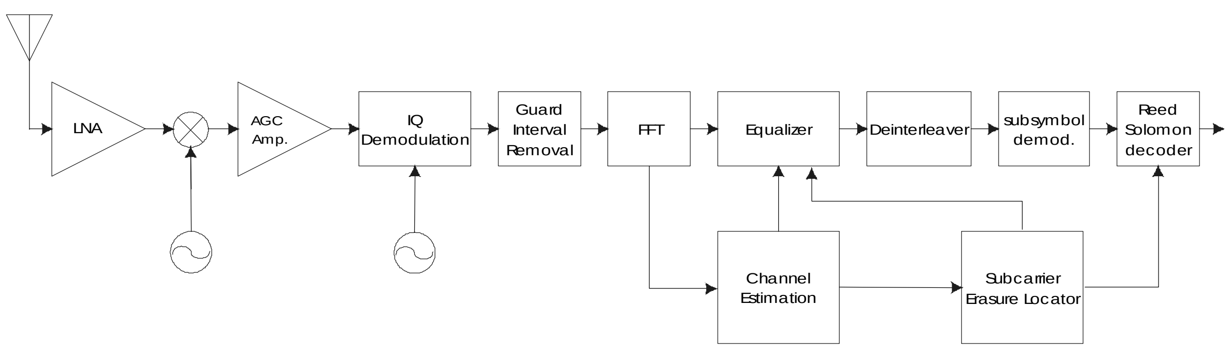

Figure 1 A simple receiver architecture. Pilot subsymbols are extracted after OFDM demodulation (fast Fourier transform, FFT, operation) and used for channel response estimation. The estimated channel response is used to equalize demodulated OFDM data symbols and to provide information for subcarrier erasure location determination. The locations of the erasures are fed to the Reed Solomon decoder to augment error detection and correction.

The distortion due to the transmission channel is corrected for each received OFDM symbol in the equalizer. Distortion removal may be carried out in conventional fashion, and the equalizer may be a conventional device to this extent. However, subsymbols too severely distorted to be equalized are erased and the erasure location is passed to the Reed Solomon decoder.

The bit error rate curve from a simulation of the transmission system that shows the improvement in error performance with various Reed Solomon erasure schemes is shown in Figure 2.

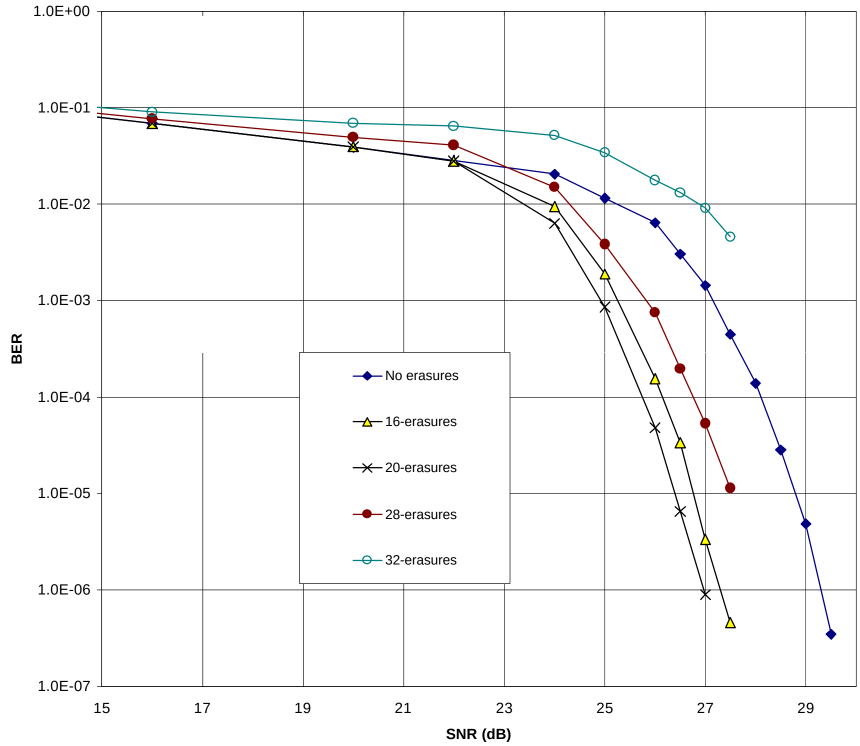

Figure 2 Bit error rate versus signal to noise ratio. The best performance is achieved by employing Reed Solomon coding with 20 erasures. The simulation parameters are N=256, FEC RS(255,223), the channel delay is 1000 nanoseconds with a reflection coefficient of 0.9, the carrier frequency is 2.410 GHz, the symbol duration is 50 nanoseconds, the guard time is 1 microsecond (20 subsymbols), and the subsymbol modulation is 16 QAM.

Clearly, without FEC, the bit error performance of the system is the worst. With Reed Solomon coding, the performance is improved, but the addition of coding with erasures yields the best BERs of all.

In Figure 3, the theoretical bit error rate performance is shown for no coding, Reed Solomon coding, Reed Solomon coding with erasures employed in decoding, and convolutional coding with a Viterbi decoder using soft decisions. It is obvious from the curves that coding is needed to achieve practical error rates. AViterbi decoder using soft decisions is good for signal to noise ratios (SNRs) below 14.5 dB. If Reed Solomon coding is employed in conjunction with a decoder employing erasures, then the Viterbi decoder is only better for SNRs below 8 dB. However, at such low SNRs, the bit error rate will be unacceptable, so the advantage is moot.

Conclusion

We recommend introducing Reed Solomon as an option in the standard.

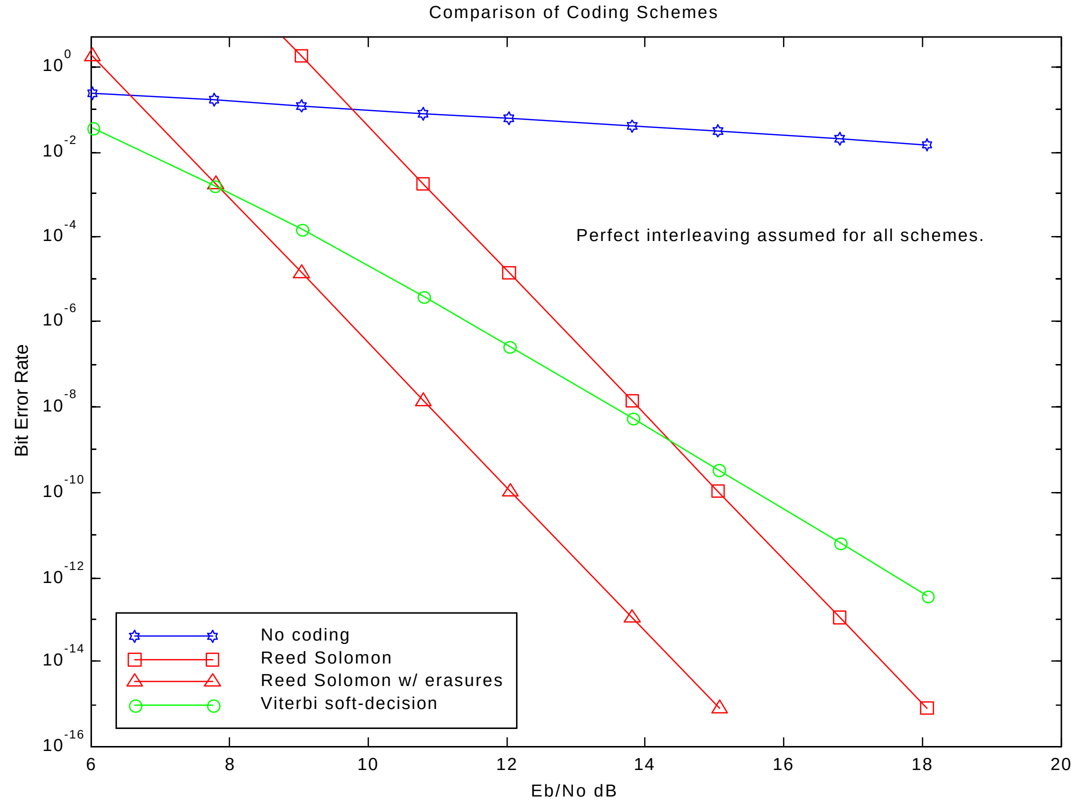

Figure 3 A theoretical comparison between the error rates generated with no coding, Reed Solomon, Reed Solomon with erasures, and convolutional coding using a Viterbi decoder with soft decisions.

References

[1] Hitoshi Takanashi, Masahiro Morikura and Richard Van Nee, “OFDM Physical Layer Specification for the 5 GHz Band” Doc. IEEE P802.11-98/72-r5, Submission to the IEEE802.11 committee

[2] L.J. Cimini, Jr., “Analysis and simulation of a digital mobile channel using orthogonal frequency division multiplexing,” IEEE Trans. Commun., vol. COM-33, pp. 665-675, July 1985.

[3] M. Fattouche and H. Zaghloul, “Method and apparatus for multiple access between transceivers in wireless communications using OFDM spread spectrum,” U.S. Patent 5,282,222, January 25, 1994.

[4] European Telecommunications Standards Institute (ETSI) ETS 300 744: Digital Video Broadcasting; Framing structure, channel coding and modulation for digital Terrestrial television (DVB-T). Sophia Antipolis, France, 1997.

[5] P.H. Moose, “A technique for orthogonal frequency division multiplexing frequency offset correction,” IEEE Trans. Comm., vol. COM-42, pp. 2908-2914, October 1994.

[6] S. Kapoor, D.J. Marchok and Y. Huang, “Pilot assisted synchronization for wireless OFDM systems over fast time varying fading channels,” Proc. VTC’98, pp. 2077-2080, Ottawa, May 1998.

[7] J.D. Gibson, ed., *The Mobile Communications Handbook*. Boca Raton, Florida: CRC Press, 1996.