A SUITABLE CHANNEL EQUALIZATION SCHEME FOR IEEE 802.11B

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ABSTRACT

This paper discusses suitable methods for channel equalization for the IEEE 802.11b wireless LAN standard and the complexity of implementation of channel equalization in a programmable DSP processor. Because of the complementary code keying used for data rates of 5.5 and 11 Mbit/s, a rake receiver is not suitable for this standard, instead the use of a sparse FIR filter is recommended. The RAKE receiver and FIR filter are in fact equivalent for direct sequence spread spectrum (DSSS) modulation, which is the technique used in 802.11b at 1 and 2 Mbit/s.

Two schemes for channel estimation are also investigated: LMS adaptive filtering and correlation with the spreading sequence. In both cases the 128 symbol preamble of the 802.11b frame is used for channel estimation. The correlation method has been found more suitable for implementation in a DSP processor.

1. INTRODUCTION

This paper gives a short survey of methods for channel estimation and channel equalization for the wireless LAN standard IEEE 802.11b. The complexity of the algorithms are investigated focusing on implementation in a programmable DSP processor.

The 802.11b standard is a direct sequence spread spectrum (DSSS) system which provides transmission rates between 1 and 11 Mbit/s. For transmission at 1 Mbit/s and 2 Mbit/s DBPSK and DQPSK is used and the symbols are spread by the eleven chip Barker sequence [1,-1,1,1,-1,1,1,1,-1,-1,-1]. For transmission at 5.5 or 11 Mbit/s complementary code keying (CCK) is used.

The 802.11b frame consist of a preamble of 128 bits used for synchronization and channel estimation, followed by a 16 bit start frame delimiter, a 48 bit header and finally a data unit of variable size. Preamble and header are always transmitted at 1 Mbit/s regardless of the rate chosen for data. (There exist an optional “short preamble mode” where the synchronization field is only 56 bits and the header is sent at 2 Mbit/s).

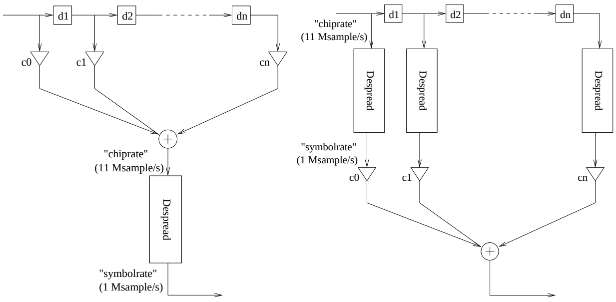
Two common methods for channel equalization are the LMS adaptive FIR filter and the RAKE receiver. The two methods both include a way of estimating the channel and a way of compensating for the channel distortion (equalizing) using the channel estimate.

However, it turns out that the method used for equalization really does not depend on how channel estimation is carried out. In other words nothing stops us from using the estimation method of the RAKE receiver but a FIR filter for equalization, especially not in a processor where the FIR filter or RAKE structure is not hardwired. In fact this paper will show that this combination is a very suitable solution for 802.11b.

2. EQUALIZATION

The two main structures used for equalization in DSSS systems are the FIR filter and the RAKE structure. These are depicted in figure 2. Closer study reveals that the two structures are equivalent. In the RAKE structure the despread is just placed “inside” the FIR filter instead of after it. If the delay elements and coefficients are the same the output will be the same.

Note that in a FIR filter the delays (d1, d2,...) are usually all equal, but in a RAKE receiver they are usually not. In a RAKE receiver often only the strongest paths are kept and the rest of the coefficients are replaced by zeros. There is no apparent reason why this should not work for the FIR filter too.



(a) FIR filter (b) RAKE receiver

Fig. 1. Channel Equalizer architectures

The complexity differs slightly between the two approaches. The FIR needs more MAC (multiply and accumulate) instructions, but the RAKE needs more despread operations. In a ordinary DSSS system the complexity of implementation in a dsp processor is quite similar, with a small advantage for the RAKE.

This is however not the case for 802.11b at 5.5 and 11 MHz. Here CCK modulation is used which means that the despread is replaced by the much more complex modified Walsh transform followed by finding the absolute maximum value of a size 4 or 64 (5.5 or 11 Mbit/s) complex vector. In other words the RAKE is not suitable for equalization in a 802.11b system.

	FIR	RAKE
MAC operations	nt	t
Despread operations	1	t

Table 1. Operations per symbol using FIR-filter and RAKE-receiver, t is the number of taps or fingers, n is the number of chips in a symbol

The conclusion is that a FIR filter will be used for equalization in 802.11b. The FIR filter may be complemented with a decision feedback equalization (DFE) filter, that will however not be discussed in this paper.

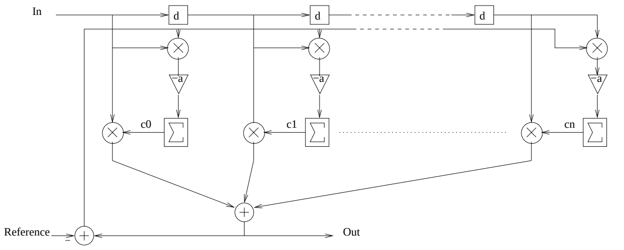
3. CHANNEL ESTIMATION

We have now established that a FIR filter will be used for channel estimation. Our next concern is how to find the coefficients Again two main strategies are studied namely the LMS adaptive filter and correlation with the spreading sequence (despreading), which is what RAKE-receivers are based on. The two methods are illustrated in figure 3.

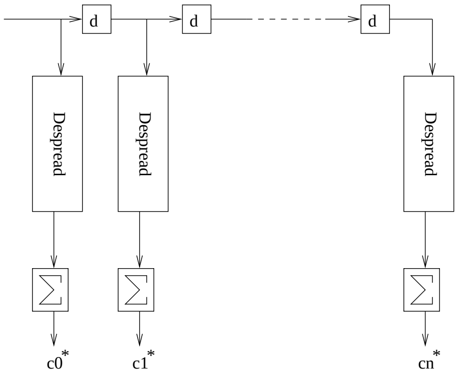
In 802.11b the reference signal used for LMS is not directly available, but has to be regenerated after the despreading and demodulation of the input signal as illustrated in figure 3.

The delay in the feedback loop may cause stability problems in an implementation like the one in figure 3, but in a processor implementation the flow is probably more like the one illustrated in figure 3. Then stability problems are smaller since all coefficient updating regarding one symbol is completed before the filtering for the next symbol is started. However the convergence is a bit slower than for systems with a known reference/pilot symbol.

Table 3 shows the number of operations needed per frame for the two methods. When the to-



(a) LMS adaptive filter



(b) Correlation based

Fig. 2. Channel estimation schemes

tal number of operations was calculated, despread was counted as 11 operations (it can be computed as 11 MAC operations in 11b) and all other operations as one each. It should be noted that the values of n (the number of preamble symbols that are used for channel estimation) and possibly also for t (the number of taps) are different for the two methods. Simulations have shown that for correlation n=8 is enough while for LMS n should be at least about 50. Assuming t is somewhere between 10 and 20, clearly the correlation method has an advantage when it comes to the total number of operations.

The LMS method however, does have fewer operations per symbol during the part of the frame where channel estimation is performed. This means that the correlation method may need a higher peak MIPS count *or* a larger data buffer

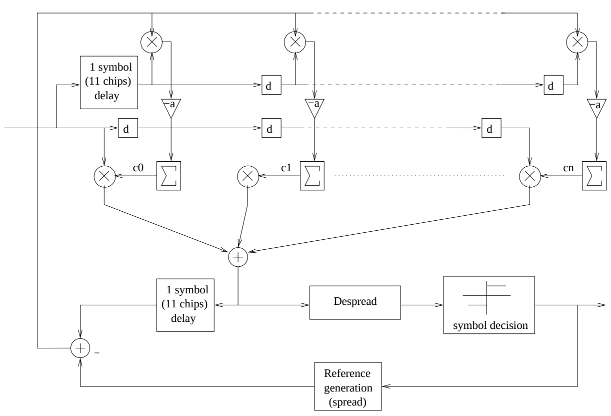


Fig. 3. Possible LMS realization in 802.11b

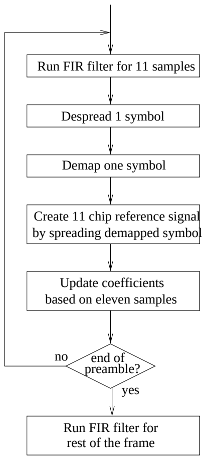


Fig. 4. Processing flow for DSP implementation of LMS adaptive filter

When implementation in a programmable DSP processor is considered, the need for a slightly larger data buffer is not a problem, and so correlation would be the preferred method.

The resulting filter of the correlation method is an estimation of a channel matched filter, which is optimal. Simulations also indicate that this channel matched filter approximation gives better results than the filter resulting from LMS adaptation.

4. PRELIMINARY RESULTS

Simulations have been carried out on a channel matched filter equalizer using correlation for channel estimation. The channel models used was the

Correlation:	**exact**	**approx.**
Accumulate	nt	160
Despread	nt	160
TOTAL OPERATIONS	12nt	1920
OP. PER SYMBOL	12t	240
LMS:		
MAC	2nt	2000
Despread	n	50
Subtract	n	50
multiplication	nt	1000
TOTAL OPERATIONS	3nt+2n	3100
OP. PER SYMBOL	3t+2	62

Table 2. Operations per frame for channel estimation. t is the number of taps, n is the number of frames used for channel estimation. The approximation uses t=20, n=8 for the correlation method and t=20, n=50 for LMS.

JTC office models A, B and C [2], which are multipath channels with between 3 and 8 paths and RMS delay spread between 35 and 450 ns, and with AWGN on each path.

It was found that by replacing all but the largest coefficients with zeros (resulting in a sparse FIR filter), the complexity of the filter can be significantly reduced with a minimal reduction in quality. Basically there never seems to be any need for more than 5 non-zero coefficients (corresponding to a 5 finger RAKE receiver).

A receiver with two times oversampling, four non-zero coefficients and using 8 symbols for channel estimation, handles the Office A (3 paths, 35 ns RMS delay spread) and Office B (6 paths, RMS delay spread 100 ns) reasonably well (frame error rate $<1\%$ and $<15\%$ respectively, with 1024 byte frames at 11Mbit/s and SNR=10).

5. CONCLUSIONS

It was found that a channel matched FIR filter is a suitable channel equalizer for a 802.11b receiver. It was also found that the “correlation method” is a more suitable channel estimation method for implementation in a DSP processor than the LMS adaptive filter.

Simulations has shown that a sparse FIR filter, using only four MAC operations per chip can provide good enough equalization for 11 Mbit/s traffic in moderately difficult multipath channels (RMS delay spread up to 100 ns).

6. REFERENCES

[1] IEEE Std 802.11b. *Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications: Higher-Speed Physical Layer Extension in the 2.4 GHz Band*, IEEE, 1999.

[2] Emmanuel Dal, Valerio Raimondi, *Simulation of a DSSS receiver based on the IEEE 802.11b standard,* Master’s thesis, Linköping University, 2002.