Decision feedback demodulation-based adaptive linear equalisers for differentially coherent DPSK systems

Dhong-Woon Jang, Sang-Kyun Oh and
Yong-Hoon Lee

Indexing terms: Decision feedback equalisers, Phase shift keying

The authors propose to combine linear feedback equalisation and decision feedback demodulation for the equalisation of differentially coherent PSK signalling. By modifying the equaliser output based on the decision feedback demodulation before feeding back, the proposed equaliser can be made to behave like one with a decision feedback structure. Indeed, computer simulation results demonstrate that this equaliser performs much better than existing equalisers, such as linear equalisers for differentially coherent detection. Furthermore its performance is even comparable to that of a decision feedback equaliser with coherent detection.

Introduction: To compensate for the unknown, time-varying channel distortion in differentially coherent receivers, linear [1, 2] and nonlinear equalisers [3] have been proposed. The linear equaliser in [2] is designed to reduce the intersymbol interference (ISI) caused by a linear channel, and is located before the nonlinear differential detector of the receiver. In this case, unlike conventional linear equalisers used for coherent demodulation, conversion of the linear structure into a decision feedback structure is not straightforward. This is due to the existence of the differential detector between the equaliser and the decision device. A decision feedback structure can be used if an equaliser is located after the differential detector. When this happens however, the equaliser should compensate for the nonlinear effect caused by the differential detection. This observation leads to a nonlinear Volterra-type decision feedback equaliser (VDFE) [3]. This VDFE can outperform linear equalisers for some channels with severe ISI, but compensating for the nonlinearity of the differential detection seems wasteful. It is desirable to have an equaliser that is located before the differential detector and, at the same time, uses a decision feedback structure.

In this Letter, we show that such an equaliser can be developed by exploiting the decision feedback DPSK demodulation schemes in [4–7]. The proposed equaliser has a linear feedback structure, but its outputs are processed following the decision feedback DPSK demodulation, before feeding back into (the feedback part of) the equaliser. It will be seen that this equaliser, called the modified linear feedback equaliser (MLFE), can outperform existing equalisers for differentially coherent DPSK, and that its performance is even comparable to that of the DFE for coherent demodulation of DPSK.

Modified linear feedback equaliser (MLFE): Before introducing the MLFE, we will briefly review the linear equaliser for DPSK, introducing our notation. In addition, the combination of a linear equaliser with decision feedback DPSK demodulation will be discussed.

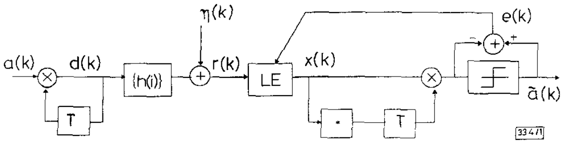

Fig. 1 *Baseband model of linear equaliser (LE) for DPSK*

T denotes delay equivalent to one symbol period, the complex conjugate

Fig. 1 illustrates the differentially coherent DPSK with a linear equaliser. At the transmitter, the information symbols $a(k)$ are differentially encoded into the symbols

$$d(k) = a(k)d(k-1) = d(0)\prod_{i=1}^{k} a(i) \qquad (1)$$

The input to the equaliser in the receiver is represented as

$$r(k) = e^{j\theta}\sum_{i=-\infty}^{\infty} h(i)d(k-i) + \eta(k) \qquad (2)$$

where θ is the unknown carrier phase; $\{h(i)\}$ is the overall channel impulse response that includes the transmitter filter, the channel, and the receiver filter and $\eta(k)$ represents additive white Gaussian noise. The equaliser output $x(k)$ is differentially detected and quantised to produce the decision $\tilde{a}(k)$; the error signal $e(k)$ is obtained for equaliser tap adaptation.

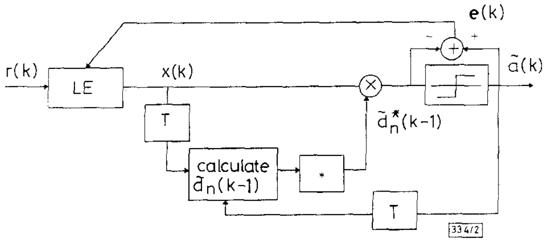

Fig. 2 *Linear equaliser followed by decision feedback DPSK demodulator: the modified linear equaliser*

In an attempt to improve the performance of the above DPSK system, we may consider using decision feedback DPSK demodulation [4–7], along with the linear equaliser, as shown in Fig. 2. In decision feedback demodulation, the phase reference at k is given by $\arg[\tilde{d}_n(k-1)]$ where $\tilde{d}_n(k-1) = \tilde{d}(k-1)/|\tilde{d}(k-1)|$ and

$$\tilde{d}(k) = x(k) + \sum_{i=1}^{M}\left\{\prod_{j=0}^{i-1}\tilde{a}(k-j)\right\}x(k-i) \qquad (3)$$

This direct combination of the linear equaliser with the decision feedback demodulation, which will be referred to as the modified linear equaliser (MLE), would not perform much better than the linear equaliser in Fig. 1, because eqn. 3 results in an unreliable phase reference whenever the linear equaliser fails to compensate for ISI.

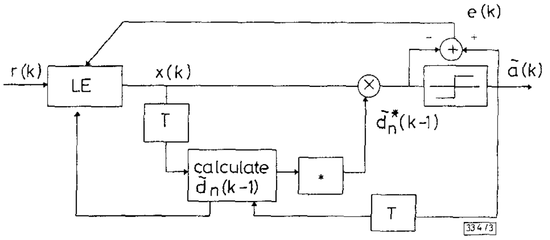

Fig. 3 *Modified linear feedback equaliser*

The MLFE proposed in this work is derived by replacing the linear equaliser with a linear feedback equaliser, and by feeding $\tilde{d}(k-1)$ into its feedback part. It is illustrated in Fig. 3. If we use the least mean square (LMS) algorithm for tap adaptation, the system is specified by the following equations:

$$x(k) = W_k^t Q_k \qquad (4a)$$

$$e(k) = \tilde{a}(k) - x(k)\tilde{d}_n^*(k-1) \qquad (4b)$$

$$W_{k+1} = W_k + \mu e(k)\tilde{d}_n(k-1)Q_k^* \qquad (4c)$$

where t means the transpose, $Q_k^t = \{r(k+N_f), \ldots, r(k), \tilde{d}_n(k-1), \ldots, \tilde{d}_n(k-N_b)\}$ with N_f and N_b the number of feedforward and feedback taps, respectively. W_k is the (N_f+N_b+1) dimensional tap coefficient vector at k. This system reduces to the linear equaliser in Fig. 2 if we replace $\tilde{d}_n(k-1)$ and Q_k with $x(k-1)$ and $R_k^t = \{r(k+N_f), \ldots, r(k), \ldots, r(k-N_b)\}$, respectively. If only Q_k is replaced with R_k, then it reduces to the MLE.

Simulation results: To evaluate the performance of the proposed MLFE and compare it with the LE, MLE and VDFE, simulations have been carried out using two linear phase, finite impulse response (FIR) channels considered in [3]. They are channels A and B, specified by $\{h_0, h_1, h_2\}$ = {0.304, 0.903, 0.304} and {0.407, 0.815, 0.407}, respectively. Channel B has a spectral null in its frequency response and causes more severe ISI. Each equaliser, with the exception of VDFE, has 15 taps: for MLFE, $N_f = 9$ and $N_b = 5$. The VDFE inherently has 8 taps. The value of M in eqn. 3 is set at 3 for MLE and MLFE. (Simulations with $M = 10$ were also performed; but the results are not shown here because they are almost identical to those with $M = 3$.) The carrier phase offset $\theta = 1.5\pi$, and the step size μ for the adaptation is 5×10^{-3}. Assuming binary DPSK, the tap coefficients were initially obtained by using 10^4 training data. The bit error rate (BER) values were empirically estimated by processing 10^7 binary input data.

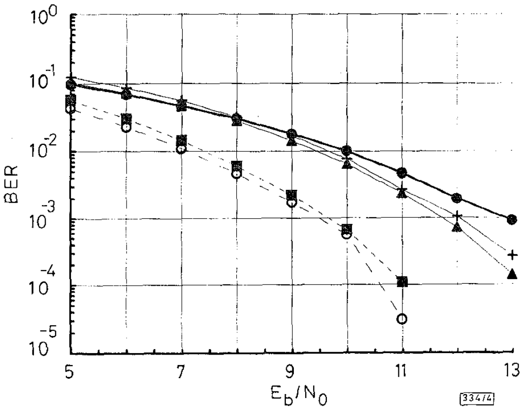

Fig. 4 *Bit error probability against E_b/N_0 for channel A*

■ MLFE
▲ MLE
+ LE
○ DFE
● VDFE

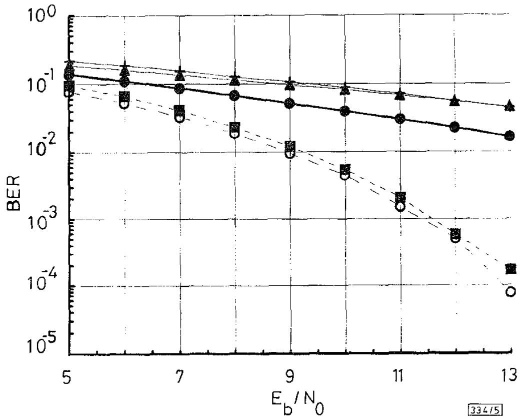

Fig. 5 *Bit error probability against E_b/N_0 for channel B*

■ MLFE
▲ MLE
+ LE
○ DFE
● VDFE

Figs. 4 and 5 show the BER values for channels A and B, respectively. For comparison, the BER associated with coherently detected DFE (DFE/coherent) is also shown. As was expected, the performance of the MLE is close to that of the LE. The VDFE performed better than the LE and the MLE for channel B, but somewhat worse than for channel A. The MLFE outperformed all the other noncoherently detected schemes; furthermore, it is almost comparable to DFE/coherent.

Conclusions: A decision feedback demodulation-based equaliser compatible with differentially coherent PSK has been proposed. This equaliser, called the MLFE, has a linear feedback structure, but the equaliser output is modified by using the decision feedback demodulation algorithm before feedback. Through computer simulations, it was observed that the MLFE can perform much better than other existing equalisers, and that its performance is even comparable to that of a DFE with coherent detection.

© IEE 1996 7 August 1996
Electronics Letters Online No: 19961261

Dhong-Woon Jang and Sang-Kyun Oh (*Agency for Defence Development, Yusong PO Box 35-5, Taejon 305-600, Korea*)

Yong-Hoon Lee (*Department of Electrical Engineering, Korea Advanced Institute of Science and Technology, 373-1 Kusong-dong, Yusong-gu, Taejon 305-701, Korea*)

References

1 GITLIN, R.D., and MULLER, K.H.: 'Optimization of digital post detection filters for PSK differential detectors', *IEEE Trans. Commun.*, 1976, **COM-24**, (9), pp. 936–970
2 SEHIER, P., and KAWAS-KALEH, G.: 'Adaptive equalizer for differentially coherent receiver', *IEE Proc. I*, 1990, **137**, (1), pp. 9–12
3 MASOOMZADEH-FARD, A., and PASUPATHY, S.: 'Nonlinear equalization of multipath fading channels with non-coherent demodulation', *IEEE J. Sel. Areas Commun.*, 1996, **14**, (3), pp. 512–520
4 LEIB, H.: 'Data-aided non-coherent demodulation of DPSK', *IEEE Trans. Commun.*, 1995, **43**, (2–4), pp. 722–725
5 EDBAUER, F.: 'Bit error rate of binary and quaternary DPSK signals with multiple differential feedback detection', *IEEE Trans. Commun.*, 1992, **40**, (3), pp. 457–460
6 LIU, J., KWATRA, S.C., and KIM, J.: 'An analysis of decision feedback detection of differentially encoded MPSK signals', *IEEE Trans. Veh. Tech.*, 1995, **44**, (2), pp. 261–267
7 ADACHI, F., and SAWAHASHI, M.: 'Decision feedback differential phase detection of M-ary DPSK signals', *IEEE Trans. Veh. Tech.*, 1995, **44**, (2), pp. 203–210

Dual FH/MFSK system over a Rayleigh fading channel

Chanbum Park and Jae Hong Lee

Indexing terms: Frequency agility, Frequency hop communication, Frequency shift keying

A dual frequency-hopped/multilevel frequency shift keying (FH/MFSK) system is proposed for a Rayleigh fading channel. The dual FH/MFSK system is achieved by frequency-hopping a carrier frequency of the FH/MFSK system proposed by Goodman *et al.*. The numerical results show that the proposed system allows more users than does the conventional system.

Introduction: Frequency-hopped/multilevel frequency shift keying (FH/MFSK) system was proposed for wireless communications to increase the number of users [1]. It was shown that an FH/MFSK

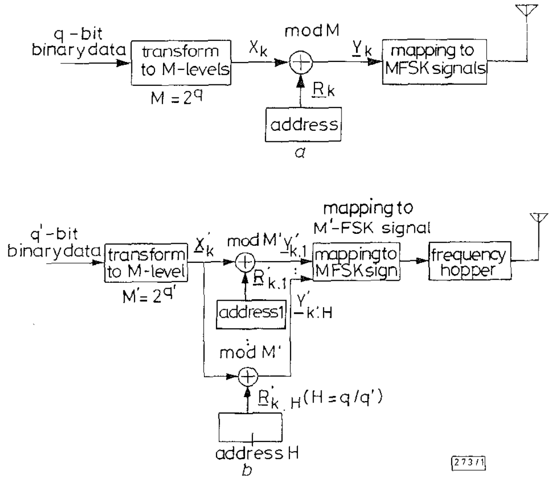

Fig. 1 *Block diagram of transmitter*

a Conventional FH/MFSK system
b Dual FH/MFSK system with multiple addresses