CHAPTER SEVEN

FINAL SUMMARY AND CONCLUSIONS

Chapter seven concludes this dissertation, and contains the summaries and conclusions derived from all the previous chapters. The novel work attempted in this dissertation is clarified and its significance is discussed here. The first section describes significant discoveries and concepts with respect to the theoretical part of this dissertation. The second section summarizes practical simulation results and evaluations, and discusses the implications of these results. The final section proposes topics which may be considered for future work and research.

7.1 THEORETICAL SUMMARY AND CONCLUSIONS

In this dissertation the constant modulus type (LCCM and LCDCM) detectors are analyzed within the context of linear detectors. Linear detectors perform a linear vector operation on the received signal vector. The adaptive linear detector solves many of the complexity and assumed knowledge (Figure 7.1) issues associated with many of the other multiuser detector structures. Chapter four starts by characterizing the optimum linear multiuser detector in terms of multiuser efficiency. The optimum linear multiuser detector suffers from the same penalty as the decorrelating (or zero forcing) detector in the low SNR region, as it ignores the contribution of the noise. The MMSE and related blind (LCMV, LCCM, LCDCM) detectors allows some residual multiuser interference to remain in order to attain optimal performance with respect to AWGN and multiuser interference. In this dissertation, the real valued model in Verdu [31] is extended to encompass complex values. Differentiation with respect to a complex vector [57] is extended to differentiation with respect to a complex matrix in Appendix C. The complex gradient of the MMSE detector is consequently derived, and the MMSE detector is analyzed in the complex domain. Uniquely, in this dissertation, the model in [31] is also extended to model a multipath channel in a similar manner as in [47].

	Single-user Matched Filter	Decorrelator	MMSE	Adaptive MMSE	Blind MMSE (LCCMA, LCDCMA)	Decision Driven (SIC,PIC,etc)
Code of desired user	●	●	●		●	●
Timing of desired user	●	●	●	●	●	●
Received amplitudes			●			●
Noise level			●			
Code of interfering users		●	●			●
Timing of interfering users		●	●			●
Training seq. of desired user's data				●		

Figure 7.1: Knowledge needed for the different types of multiuser detection schemes.

Much novel mathematical analysis of the LCCM and LCDCM detectors is achieved in Chapter five. For the first time, a global condition is derived for the convexity of LCCM cost function. Some previous authors evaluated the LCCM cost function at the desired stationary point or vector solution, without considering any other possible solutions. This is an error, as any of the other stationary points may or may not be an undesired global minimum. On the other hand, the LCDCM cost function is shown to have a single stationary point, which is also a minimum. The convexity of the LCDCM cost function needs not even be considered, since the only stationary point is the global minimum. Using the same process as in Verdu [31], the stochastic gradient algorithms for the LCCM and LCDCM criteria are also derived. At the end of Chapter five, the effect of multipath on the LCCM and LCDCM detectors is qualitatively discussed. Under normal operation, the MMSE detector can combine multipaths, while the LCCM and LCDCM detectors merely attempt to cancel it out. If inverse channel plus noise estimation can be used within the linear constraint, the LCCM and LCDCM detectors can effectively combine the multiple paths, providing that the multipath channel plus noise inverse can be accurately modelled within the length of the detector. The multipath combination is achieved by convolving the estimated channel inverse plus noise with the desired user signature waveform. This is then used as the modified linear constraint in the LCCM and LCDCM detectors.

7.2 SIMULATION SUMMARY AND CONCLUSIONS

One can conclude from the simulation results that the basic LCCM and LCDCM detectors are effective in mitigating multiuser interference in AWGN and frequency flat fading channels. In all the simulation results, it is apparent that the performance of the LCCM[1] and LCDCM detectors approximate that of the MMSE detector. Even as the number of users increase, the LCCM and LCDCM detectors' performance match that of the MMSE detector. The SIR measurements in the case of $A_1^* A_1 < \alpha/4$ shows that while the LCCM detector fails, the LCDCM detector performs on par with the MMSE detector. This is consistent with the theoretical derivations done in Chapter five, where it is shown that the LCCM Hessian matrix becomes negative definite at the desired stationary point, indicating a local maximum. On the other hand, the LCDCM cost function has a global minimum, irrespective of desired user amplitude. Concerning BER performance, the LCCM, LCDCM and MMSE detectors show a massive improvement over the matched filter in the AWGN channel. There is still some small improvement to be gained when compared with the single user bound. This, however, is only about 1dB at an E_b/N_0 of 10dB. We can thus conclude that for the complexity of the adaptive MMSE type linear detector, the performance that is gained when compared with the optimum (non-linear) detector is excellent. The optimum non-linear detector for the same 6 user channel will require a trellis of 64 states, which is a complex detector for only 6 users. In a CDMA channel with 20 users the number of trellis states for the optimum detector will increase to over a million states, which is simply impossible to implement. If a linear detector were to be employed for the same channel, the complexity will only triple compared to the six user linear detector case.

In non fading frequency selective channels that are well behaved (mild ISI and minimum phase), the linear structure of the LCCM and LCDCM detectors exploits the multiple paths effectively, even if an accurate linear channel plus noise estimate is employed in the linear constraint. In this case, the performance of the LCCM and LCDCM detector approaches that of the best linear detector, viz. the MMSE detector. In multipath fading channels, all the linear detectors[2] are effective at cancelling out multiuser interference, but are insufficient at optimally combining the multiple paths. This is because the multipath mobile fading channel plus noise may assume a form that cannot be accurately inversed by using a finite linear structure. In this case, the use of a non-linear decision feedback structure may warrant further investigation.

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[1] Here it is assumed that $A_1^* A_1 \geq \alpha/4$.

[2] In this case the LCCM and LCDCM detectors are assumed to have for linear constraints, the best linear inverse channel plus noise estimation in a mean square error sense.

7.3 PROPOSALS FOR FURTHER RESEARCH

From the multipath fading channel results obtained from this dissertation, the question that is raised is if it's possible to do joint blind multiuser detection and fading multipath equalization in a single receiver structure. Previous authors [15, 60, 68] proposed the use of channel estimation in order to obtain the multipath linear constraint. These methods are cumbersome, and it means that two adaptive structures are needed for joint multiuser detection and multipath combination. Furthermore the channels have to be well behaved (minimum phase) for the inverse to be approximated by a finite linear filter. A second method for joint multiuser detection and multipath combination is the multichannel detector proposed by Mangalvedhe [47]. This structure has high complexity, especially where many multipaths are concerned. In obtaining a single simpler joint fading multipath combiner and multiuser detector, it is obvious that some sort of non-linear decision feedback detector should be employed to be able to equalize non-minimum phase channels. It would be informative and advantageous to pursue such an avenue in future research. In this context, fast adaptation algorithms and fractionally spaced structures can also be examined to be able to cope with fast fading multipath channels [57].

Implementation concerns in DSP or FPGA, are of paramount importance when considering multiuser detectors. It should be informative to evaluate the behavior of fixed point implementations of blind adaptive multiuser detector structures, as well as any limitations revealed in this regard.

Application of the blind constant modulus algorithms to specific existing DS-CDMA systems employing constant envelope complex spreading sequences, warrants further investigation [5, 69]. These systems offer good fading channel performance along with excellent non-linear amplification performance figures.