CHAPTER 8

CONCLUSIONS AND FUTURE RESEARCH

In this chapter a summary of the research work performed during this study is presented. Furthermore, we present future research areas of interest. Finally, the chapter is concluded with a discussion and dissertation conclusions.

First of all a brief summary of the research work carried out during this study, is presented.

The research covered in this dissertation was presented in three parts. In Chapter 1 the overall introduction and literature survey on specific topics related to four-dimensional modulation, demodulation, synchronisation and coding were presented. In the first part of this dissertation, Chapter 2, 3 and 4, the most important theories and general communication system concepts were given. More specifically, we have considered in Chapter 2 the principles of four-dimensional Q^2PSK signalling, as well as the advantages of multidimensional signal space utilisation. Furthermore, considerations of energy and bandwidth efficiency, and capacity have been given. In Chapter 3 we have presented detail concerning the mobile digital communication system, as well as the fading channel model adopted for evaluation purposes. In Chapters 4 the three main topics of modulation, demodulation and synchronisation of the digital Q^2PSK and CE-Q^2PSK communication system operation were treated and discussed in detail. The digital modulation and demodulation block diagrams were presented and analysed in detail. A novel frame synchronisation procedure for Q^2PSK was presented. Furthermore, investigations into the effects of carrier phase and frequency uncertainties were investigated. The final parts of Chapter 4 considered the problems concerning the design and implementation of carrier phase and frequency tracking loops for the Q^2PSK system.

In the second part the concepts of trellis coding have been considered, including classical, TCM and MTCM error correction techniques, for application into the Q^2PSK modem. In Chapter 5 specific designs of trellis codes for Q^2PSK for transmission over the AWGN channel have been considered.

The design and implementation of forward error correction codes, based on classical convolutional error correction were carried out, as possible solutions when complexity (low computational load) and cost are the primary design objectives. Furthermore, the state of the art TCM techniques were compared to the classical techniques with a view of achieving even better BEP performance. Appendix A presents the general theories of channel coding, with specific reference to the concepts of TCM. The Ungerboeck and analytical (Calderbank—Mazo) code descriptions, the decoding procedure and finally the very important issues of code performance evaluation are considered. The trellis codes designed and analysed were derived from the original unexpanded Q^2PSK signal set. Throughout this part of the dissertation, theoretical performance bounds on bit error probability were derived, when feasible, i.e. for codes of low complexity.

In Chapter 6 the designs of trellis codes (TCM and MTCM) have been carried out for Q^2PSK transmission over the mobile fading channel, again employing the original (unexpanded) Q^2PSK signal constellation. Therefore, the coding gains are obtained at the expense of the information data rate. We have concentrated on the design for Rician fading channels, with high Rician factors, i.e. $K \geq 5$ dB.

The final part of this dissertation was concerned with the extensive performance evaluation of the proposed modem, synchronisation and coding techniques presented in the foregoing chapters. Chapter 7 dealt with this performance evaluation by means of computer simulation. The coded and uncoded Q^2PSK signals have been evaluated on the AWGN, non-linear channel, and typical mobile fading channel conditions. For the non-linear channel, we have considered the effects of carrier phase and Doppler frequency effects in AWGN. Our system was evaluated under typical non-linear mobile conditions, where a maximum Doppler frequency $f_D = 100.0$ Hz and maximum phase offset $\theta_o = 0.2$ rad were simulated. The effects of phase fading on the received signal, typical of frequency selective multipath fading channels, have not been investigated in this dissertation, since the latter require the implementation of a multidimensional complex equaliser.

8.1 FUTURE RESEARCH

The work presented in this dissertation has brought about many new questions and possible areas of future research.

8.1.1 Design and implementation of a multidimensional equaliser

In this dissertation we have only considered the effects of amplitude fading on the received signal. In general, in a land mobile channel characterised by multipath effects, fading causes severe distortion of the transmitted waveform, i.e., random amplitude and phase variations and accordingly long, densely packed noise bursts. These effects cause phase and amplitude uncertainties, which result in Intersymbol Interference (ISI) and distortion of the signal space geometry. In order to maintain the signal space geometry as closely as possible to the original one, equalisation is required. As long as two orthogonal baseband signals are present in each of the in-phase and quadrature-phase signals, which is the case for four-dimensional Q^2PSK, a multidimensional complex equalisation procedure is required. At this point in time the design of such an equaliser, remains a subject for future research.

8.1.2 Application of a burst-error correcting Viterbi decoder

Interleaving random-error-correcting codes to combat burst noise is a standard technique that can be applied to any bursty channel. Interleaving randomises error clusters by spreading the erroneous bits in a burst so far apart that the bursty channel is effectively transformed into a random-error channel, i.e. a memoryless Additive White Noise (AWGN) channel. In general, the interleaving mechanism is robust in that changes in the channel statistics do not influence the system's performance appreciably [30, 92, 42].

The burst-error-correction Viterbi decoder, proposed by Schlegel and Herro [93], combines maximum-likelihood decoding with a burst error detection scheme and can be considered as an alternative coding method for bursty channels. As proposed by Schlegel and Herro, the burst-error-correction strategy combines maximum-likelihood decoding with a burst error Viterbi detection scheme. The decoder nominally operates as a Viterbi decoder and switches to a burst-error-correcting mode when the receiver detects incoming error patterns the Viterbi decoder is unable to correct, i.e., the dual-mode decoder automatically switches modes according to the state of the channel.

The strength of using the Viterbi decoder in this dual-mode configuration lies in its undiminished error-correcting power when the channel is in the random-error state. Most known burst correction schemes sacrifice error-correcting power in order to detect bursts, which makes them unsuitable for use on random-error channels plagued by occasional deep fades and associated error bursts. The proposed burst-error-correcting algorithm could therefore be investigated as an alternative to the standard interleaving strategies usually employed on digital communication systems utilising the Viterbi algorithm.

8.2 Design of Ungerboeck-type codes for fading channels

Under certain conditions it is possible to reduce a multiple trellis code with parallel paths, to an Ungerboeck-type code (multiplicity $k = 1$) with no parallel paths, but an increased number of states. We first note that in order for an Ungerboeck-type code with rate $b/(b+1)$ and no parallel paths to achieve diversity L, the smallest number of states required is

$$2^{v} = 2^{b(L-1)} \tag{8.1}$$

For example, for $b = 3$, the minimum number of states required to achieve $L = 4$ would be $N_s = 2^{3(4-1)} = 2^{512}$. The application of these codes to the Q^{2}PSK modem operating on fading channels needs to be investigated on merits, with considerations on application, bandwidth constraints, cost and complexity.

8.3 CONCLUDING REMARKS: CHAPTER 8

In this dissertation the problem of modulation, demodulation, synchronisation and coding of a four-dimensional signalling digital modem have been addressed for the mobile digital communication environment. Evaluation of the Q^2PSK communication system was carried out by means of extensive computer simulations under typical mobile communication channel conditions. Two different cases were considered, namely the conventional Q^2PSK and the constant envelope version. In most cases the CE-Q^2PSK system achieved superior performance to that of the non-constant envelope system.

Concerning, the synchronisation aspects of the Q^2PSK system, it was found that the novel frame synchronisation procedure yielded good performance under AWGN channels, as well as under fading channel conditions. The complex correlation-magnitude information obtained during frame synchronisation can furthermore be used to provide a means of Channel State Information (CSI). It was shown by means of simulation that this channel reliability information can lead to improved bit error performance under fading channel conditions when a coded system is utilised. It is should, however, be mentioned that for the uncoded systems, the presence of CSI provide no improvement in performance. The designed carrier phase and frequency tracking loops performed well under specific non-ideal channel conditions in AWGN. It was found however, that the Dual Phase and Frequency Kalman Estimator (DPFKE) is not well suited for typical mobile fading conditions. This can be mainly attributed by the fact that the phase tracking loop in this DPFKE is unable to track the effects of phase non-linearities due to fading. It should, however be mentioned that the application of a complex equaliser may prove advantageous in estimating these carrier phase and frequency uncertainties.

For the uncoded Q^2PSK system operating over the fading channel, it was found that the system performed poorly in the Rayleigh and Rician mobile fading channels, with all of the performance curves saturating at a BEP above 10^{-5}, except for the cases of high Rician channel factors, i.e. $K \geq 5.0\ dB$.

Several design criteria in the design of optimum trellis coded system on the fading channel have been derived. Design criteria revealed that the design of trellis coded Q^2PSK systems aimed to achieve optimum performance on the Rician fading channel is guided by a factor that differs from the optimum trellis code design on the AWGN channel. In particular, the primary objective to minimise the bit error probability of the code, requires the maximisation of the number of symbols at non-zero Euclidean distance to the shortest error event path. The secondary objective is to maximise the product of the branch distances along the shortest error event path normalised by the Euclidean distance. Following the criteria derived, different multiple trellis codes were designed, aided by computer searches to find the optimum Q^2PSK/MTCM codes. The 4-state rate-5/8 and 6/8 trellis codes were evaluated on Rician fading channels with $K = 5$ and $K = 10\ dB$. Results on the Rician fading channel with $K = 5\ dB$ have shown the importance of the multiplicity or diversity factor of the trellis coded system under these channel conditions. On the contrary, the results obtained for Rician fading channels with $K = 10\ dB$, demonstrate that for these channel situations, the diversity of the code does not constitute the primary objective for optimum performance. This is true since the free Euclidean distance of the code dominated the performance of the trellis coded system.

In conclusion, it should be kept in mind that the best error correction strategies discussed in this dissertation are probably good in overall terms, but that better schemes do exist if unlimited complexity is allowed. The existence of possibly better schemes of similar complexity cannot be proved or denied. The problem is that there is no unified theory for the design of error correction codes — the design of new codes should be the result of long term research and the application of the experienced gained in the field over time. Evaluation of the coded and uncoded Q^2PSK mobile digital communication system was accomplished on the AWGN and typical mobile fading conditions. It was shown that this four-dimensional modulation scheme may be advantageously utilised for digital communications over these mobile channels at data rates exceeding that of for instance the American adopted $\pi/4$-QPSK modulation scheme under identical channel bandwidth and propagation conditions.