CHAPTER I

INTRODUCTION

1.0 CODING AND RELIABILITY IN COMMUNICATION

Application of forward error correction (FEC) techniques is found to take care of different kinds of channel errors in the digital communication systems.For this purpose both block and convolutional codes have been employed to combat random as well as burst kind of errors. While the random errors are due to Additive White Gaussian Noise, burst errors are introduced due to the impulse noise and/or fading. Channels such as HF-ionosphere, troposcatter, LOS-microwave, under-water acoustic and satellite channels suffer from the problem of signal fading. Studies on these channels have resulted in different kinds of coded and uncoded communication techniques to improve the reliability of communication.

Among the FEC schemes the block codes have inherent advantage in situations such as automatic repeat request (ARQ) and computer main and/or control memories. On the other hand convolutionally coded FEC schemes in general require slightly lesser storage and are easier to implement. The decoding of these codes can be done by Viterbi, sequential and feedback decoding techniques. Out of these three methods of decoding of convolutional codes, feedback decoding, though simple, is applicable to a class of convolutional codes and hence cannot be used to decode any type of convolutional code. Viterbi decoding on the other hand is attractive to codes having small constraint lengths say, upto about seven. It is a maximum likelihood decoding technique and has found application in situations involving high data rates without large decoding delays [1]. Therefore the sequential decoding finds application in situations involving high performance employing codes of larger constraint lengths and/or lower storage requirements.

1.1 PROBLEMS IN SEQUENTIAL DECODING

Viterbi decoding and sequential decoding methods, are probabilistic methods and both employ tree searching operations for decoding the received sequence. Viterbi decoding involves an exhaustive search approach whereas the sequential decoding adopts a selective search approach.Because of exhaustive search approach Viterbi decoding does 2^k computations per decoded bit irrespective of the channel noise. Hence it does not utilise channel condition for the decoding operation and becomes more complex as the constraint length of the codes is increased. Sequential decoding on the other hand adjusts its computational load according to the channel noise. Under noisy conditions it resorts to backsearch and does many more computations per decoded bit than, when there is little noise in the channel. Under low noise conditions the sequential decoder does minimum number of computations and advances faster in the code tree. This involves a variable computational load on any sequential decoder. This variability of the computation has been the subject of study and many modifications and new approaches in sequential decoding have been reported [2-7], Fano algorithm by Wozencraft utilises a variable threshold T and a metric known as Fano metric or the tilted distance t(l), given by

$$t(l) = d(l) - p'.v.l \qquad ...(1.1)$$

where d(l) = Hamming distance between the received sequence and the path traced by the decoder up to a depth l in the code tree.

p' = a constant greater than channel transition probability p

v = reciprocal of the code rate.

The threshold parameter T is adjusted in the Fano algorithm to permit the decoder to advance as far as possible in the tree by eliminating the unlikely paths. The process of tree searching in Fano algorithm thus involves a search for a best match of the received sequence to any one of the possible paths in the tree. If the decoder ultimately decides a wrong path, then a decoding error results. The variability of the computational load on the part of any sequential decoder necessiates the use of a buffer in the decoder for storing the incoming channel bits, which generally arrive at a constant rate. Occasionally when the channel noise is more, because of the increased search effort of the decoder, buffer may get filled and over flow may result without any room for the incoming channel bits. Unless special means are provided in the system, to take care of this situation, data is lost. This naturally gives rise to additonal errors. Overall error performance of sequential decoder therefore depends on the probability of making a decoding error and the buffer overflow probability.

The studies on the overflow problems in sequential decoders have shown that the buffer overflow probability is a strong function of source rate and is almost independent of the size of the buffer and the speed of the logic involved in the decoder [3]. Therefore in the communication systems employing the real time sequential decoding, the throughput rate and the reliability are to be traded off. Any improvements to reduce the computational effort and its variability will give rise to an increased throughput rate for a given error rate. The computational effort or the search effort of any sequential decoder heavily depends on the metric employed in the decoding. From equation (1.1), both the factors on the right hand side of it affect the search operation of the Fano decoder. The effect of redefining and reinterpretation of these factors has been studied in detail and modifications to Fano algorithm has been suggested. This modification, discussed in more detail in chapter IV, helps the decoder under more noisy conditions to penetrate deeper into the tree for a given threshold value and involves lesser number of computational steps. This naturally provides speed advantages over the Fano decoder under noisy conditions of the channel. This algorithm is hereafter referred to as Modified-Fano algorithm.

1.2 ADAPTIVE TECHNIQUES IN COMMUNICATION

Apart from coded systems as mentioned earlier, diversity techniques and adaptive techniques have been found to counter the effect of channel impairments like fading. The diversity techniques utilise redundant 'branches' of diversity in which use of multiple frequencies, antennas separated in space or scattering at two different beam angles etc., are used [8]. The number of such branches are termed as 'order' in diversity. The idea behind all diversity techniques is the fact that statistically speaking different branches of the diversity scheme cannot fade simultaneously. Hence as the order of diversity increases the performance improves. However because of practical limitations such as bandwidth and equipment cost, not more than four diversity branches are generally employed, and these cannot completely overcome the effect of fading. In some sense the diversity techniques can also be treated as adaptive techniques, as in diversity schemes many a times the receiver adapts to the best branch of the diversity scheme.

Adaptive techniques which are relatively new, exploit the channel behaviour or its effect on the signal itself for improving the performance of the system. If the receiver utilises the received signal to modify its own structure or any of its parameters so as to improve its performance, the technique is called adaptive reception. On the other hand if the information regarding the channel, derived from the received signal is made use of in altering the parameters at the transmitter end, the technique is called adaptive transmission. With digital signalling, adaptive methods can be devised to measure the multipath structure and exploit it as an extra form of diversity to improve the performance [9-10]. Receivers employing adaptive singal processing schemes such as RAKE or different kinds of adaptive equalisation techniques can provide net diversity gains [10-13]. If the knowledge about the channel can be obtained at the transmitter, the transmitter can also adopt to the channel and adjust its parameter such as power and/or rate suitably. However rate adaptation schemes are shown to be superior and also offer better utility of the transmitter power. But it has been conjectured that, combined power and rate adaptation may be advantageous [14].

In all the adaptive schemes it becomes important to carefully utilise the received signal parameters and to derive the channel information from it. Theoretical investigations have already shown the importance of making such channel state measurements [15]. Once such an information about the channel state is available at the receiver, one can utilise the feedback channel and the optimum signals at the transmittter to improve the performance of the system operating over the fading channel. In fact under ideal condition of feedbacks, adaptive transmission can fully compensate the effect of fading. Even under nonideal condition involving finite delay in the feedback channel, Cavers has shown that the systems employing adaptive variable-rate transmission can provide substantial gain and their performance is superior to that of diversity systems [16].

Analytical, experimental and the simulation techniques are employed for the evaluation of performance of communication systems incorporating different coding schemes. For this purpose, experimental methods on real channels are costly and time consuming. On the other hand, various performance bounds, that have been the results of analytical approach for the evaluation of system performance of coded communication systems are generally considered to be loose and therefore inaccurate. Simulation techniques are an attractive alternative for this purpose offering great flexibility and accuracy. Most of the investigations carried out in the present work, therefore employ this method.

The reliability of communication over difficult channels such as fading channels, therefore can be increased with the help of (i) FEC schemes involving sequential or Viterbi decoding (ii) Diversity techniques and (iii) Adaptive techniques.

1.3 OBJECTIVES AND APPROACHES OF THE THESIS

The theme of the present thesis work has been the study of communication systems over fading channels employing sequential decoding and adaptive techniques. With this theme in view, the study of different sequential decoding techniques and evaluation of performance of these techniques with special reference to the Fano algorithm and fading channel has been aimed at. A broad based comparison of the different sequential decoding methods is sought from the investigations.

Characterisation of fading channels and study of various methods used to estimate the design parameters required for the link design over fading channels is aimed at to understand the intricacies involved in the design of systems over fading channels to meet specific reliability objectives.

Study of adaptive systems over fading channels is done with a view to know the effectiveness of these techniques.

Novel idea of combining the adaptive transmission and coding over the fading channels to find out the efficacy of sequential decoding techniques is also kept as an objective.

The approaches that have been adopted to realise the objective mentioned above are, a thorough investigation of the Fano sequential decoding algorithm by way of computer simulation and also through microprocessor implementation on real-time basis. Different issues involved in the computational effort of the Fano decoder with special reference to Fano metric are investigated through simulation. Effects of reinterpretation of Fano metric and its redefinition in the implementation of Fano algorithm is also studied through simulation. This has led to the modified Fano algorithm.

Computer simulation study of another fast sequential decoding algorithm namely the minimum distance decoding algorithm is done to compare the performance of these algorithms.

In the above studies the computational effort associated with the sequential decoders has been investigated by finding the distribution of computational time for decoding a frame of 100 bits on the AWGN channel.

For the sake of understanding the problem associated with the fading media they have been studied through simple characterisation and a design example of a troposcatter link. All the three decoding methods namely the Fano algorithm, the modified Fano algorithm and the minimum distance decoding algorithms have been again investigated via computer simulation and their computational behaviour and error performance have been evaluated under the Rayleigh fading condition. A comparison has been drawn among these decoders along with the stack and Viterbi decoders.

The adaptive transmission over the fading channel under the slow and flat fading assumptions has been investigated through the computer simulation. The feedback channel considered is a delayless and noiseless one and fading is assumed to follow a Rayleigh distribution. The investigations of the performance of the adaptive transmission system, employing Fano, Modified-Fano and minimum distance decoding have been carried out to bring out the performance advantage of each method of decoding and also to establish the relative advantage of the uncoded and coded adaptive transmission systems over the conventional diversity schemes.

1.4 ORGANISATION OF THE THESIS

The thesis has been organised in seven chapters as follows:

In the second chapter a thorough review of the research works in the three major areas in the field of digital communication is done. The areas covered are sequential decoding, fading channel characterisation and systems over such channels and the adaptive communication systems over fading channels.

The third chapter deals with the implementation of Fano sequential decoder on computer as well as on microprocessor. The performance of this algorithm on real time basis is reported. Both error performance and computational effort in the form of distribution of computational time of the computer simulated version of the Fano algorithm are also reported in this chapter.

In chapter four the development of the new algorithm the Modified-Fano algorithm has been dealt with. The performance of this algorithm along with Fano and another fast sequential decoding algorithm namely the minimum distance decoding algorithm has been presentd. Other sequential decoding technqiues like stack and unquantised Fano sequential decoding algorithms have also been discussed. A comparison among different decoding techniques from the communication system point of view has been given at the end of this chapter.

Chapter Five deals with the fading channel communication, in which problems associated with characterisation and modelling of these channels have been dealt with a specific design example of a troposcatter link. Then the performance evaluation of the three sequential decoding algorithms namely modified Fano, Fano and the minimum distance decoding algorithm; have been reported and the results discussed. The adaptive techniques that are employed on fading channel have been discussed in this chapter. The details of simulation of adaptive variable rate transmission system has been described and the performances of these adaptive transmission systems have been evaluated and reported. Advantage of rate adaptation has been demonstrated.

In chapter six the ideas of coding and adaptive transmission have been combined and advantages of the combination have been discussed and the simulation results of such a combined system employing both systematic and non systematic codes have been reported.

The last chapter deals with the conclusions that have been drawn out of the present research work. Some problems which can be studied have also been outlined.

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