Matched Filter Based detection over time varying fading channels with reduced complexity

Abstract: This article deals with the high speed data transmission techniques over time varying fading channels. In particular, the signal processing techniques that are to be carried out in the receiver of such systems, because the mobile radio channels are characterized by frequency selective fast fading. Thus, the signal transmission performance is severely degraded because of such factors. Specifically, this paper deals with the detection using a matched filter followed by light weight near maximum likelihood detector (NMLD) for the application of mobile radio environments. NMLD and its complexity depend on length and the numbers of stored vector. So, it is important to choose optimum NMLD i.e. , here we choose in this research four stored vectors while the length of the stored vector is of eight symbols length which is sometimes called as delay in detection. Finally the Bit Error rate (BER) is measured with signal to noise ratio

Keywords: Digital Matched Filter, Digital Signal Processing, Light weith NMLD, Radio Physics, Electronics communication.

1. INTRODUCTION

The current demand of user to access high speed data over their mobile device, detection process is one of key player to fulfill the requirements. Matched filter is a linear filter which is designed to provide the maximum signal to noise power ratio at its output for a given transmitted symbol waveform. When the ISI is not present in the received signal, the detection based on the matched filter is an optimum detection process in the sense that it minimizes the probability of error at the front end of the receiver. Matched filter based NML detection work has been carried out by Israil [1]. In this current work the complexity of the receiver is modified and it varies. In this research we have compare the system with varying complexity.

Matched filtering is a process known to be the optimum linear filtering for detecting a known signal in presence of random noise. In the matched filter, sets of consecutive samples from incoming signal are kept in memory of the receiver. At each matched-filter iteration stage, these samples are multiplied element wise to samples of known replica, and integrated to calculate correlation between the memorized set of input samples and local replica [2-3]. It is well known [4-8] that the optimum filter for a received signal with no ISI and additive white Gaussian noise (AWGN) is one matched to the signal.

In its basic form, the matched filter provides output signal, which is the maximum likelihood estimate of the signal sample [1]. After the processing of the received signal with matched filter, a simple threshold detector can be used for the detection at the output of the matched filter.
Unfortunately, in case of practical wireless channels, ISI is present in the received signal. Thus, the matched filter detector is then no longer had optimum essentially because the ISI creates unwanted data symbols at the output of the matched filter.

Matched filtering of a received signal with inter-symbol interference (ISI) will still maximize the signal to noise ratio (SNR) without altering the ISI, but will "color" the noise [1]. Any further filtering at this point to reduce the ISI will beat the expense of the SNR. Matched filter in conjunction with the various detector, provides excellent performance for delay spread from zero to one symbol interval [9].

A matched filter followed by the equalizer is the optimum linear system for a received signal with some ISI [1-5,10]. However, for severe multipath channels, a non-linear technique such as decision feedback equalization (DFE) or MLSE may be required [11]. In this paper, a matched filter, which is followed by NMLD, is used for the detection purpose for the channels, which are severely affected, by ISI as well as by phase.

The model of the data transmission system, which is based on 4-QAM modulation scheme, is given in the figure 1. The aim of this paper is to study the performance of the matched filter based NML detector and it is assumed that the channel is known to the receiver i.e. detector has the perfect knowledge of the channel at every time instant.

2. MATHEMATICAL MODELING OF MATCHED FILTER BASED NML DETECTOR

For a channel with $g+1$ fading paths, the received signal sample is given by

$$r_i = \sum_{h=0}^{g} s_{i-h}\ y_{i,h} + w_i \qquad (1)$$

Si is the transmitted signal, yi is the channel's impulse and wi is white Gaussian noise present in the signal.

To understand the importance of the matched filter, consider four paths mobile radio channel, the received signal is given by

$$r_i = s_{i-0}\ y_{i,0} + s_{i-1}\ y_{i,1} + s_{i-2}\ y_{i,2} + s_{i-3} y_{i,3} + w_i \qquad (2)$$

We assumed that the receiver is trying to detect s_i with the help of received signal sample r_i

at time instant $t = iT$.

Let us consider the case of the channel with impulse response:

$$Y_i = [0 \quad 0 \quad 0 \quad 1] \qquad (3)$$

In this case of the channel, the signal at the output of the channel is given by

$$r_i = s_{i-3} + w_i \qquad (4)$$

Thus, the above equation has no information about s_i, s_{i-1}, s_{i-2}. This type of problem can be resolved with the help of matched filter by considering four consecutive received signal samples.

These four components $r_{i,0}$, $r_{i,1}$, $r_{i,2}$ and $r_{i,3}$ as given in equation 5-8 as given below with the all the terms containing already detected symbols $s^{'}_{i-1}$, $s^{'}_{i-2}$ and $s^{'}_{i-3}$ removed. Thus, $r_{i,0}$, $r_{i,1}$, $r_{i,2}$ and $r_{i,3}$ are given by

$$r_{i,0} = r_i - (x_{i-1}\ y_{i,1} + x_{i-2}\ y_{i,2} + x_{i-3}\ y_{i,3}) \qquad (5)$$

$$r_{i,1} = r_{i+1} - (x_{i-1}\ y_{i+1,2} + x_{i-2}\ y_{i+1,3}) \qquad (6)$$

$$r_{i,2} = r_{i+2} - (x_{i-1}\ y_{i+2,3}) \qquad (7)$$

$$r_{i,3} = r_{i+3} \qquad (8)$$

If the earlier decisions made by the detector are correct, then {x_{i-h}} are same as {s_{i-h}}. Thus, the above equations can be modified as given:

$$r_{i,0} = s_i\ y_{i,0} + w_i s \qquad (9)$$

$$r_{i,1} = s_{i+1}\ y_{i+1,0} + s_i\ y_{i+1,1} + w_{i+1} \qquad (10)$$

$$r_{i,2} = s_{i+2}\ y_{i+2,0} + s_{i+1}\ y_{i+2,1} + s_i\ y_{i+2,3} + w_{i+2} \qquad (11)$$

$$r_{i,3} = s_{i+3}\ y_{i+3,0} + s_{i+2}\ y_{i+3,1} + s_{i+1}\ y_{i+3,2} + s_{i+3}\ y_{i+3,3} + w_{i+3} \qquad (12)$$

Channel impulse response is given by Zi

If Z_i is given by

$$Z_i = [y_{i,0}\ y_{i+1,1}\ y_{i+2,2}\ y_{i+3,3}]$$

$$Z_i^* = \begin{bmatrix} y^*_{i,0} \\ y^*_{i+1,1} \\ y^*_{i+2,2} \\ y^*_{i+3,3} \end{bmatrix}$$

$$\begin{aligned} R_i\ Z_i^* = {} & (s_i\ y_{i,0} + w_i)\ y^*_{i,0} \\ & + (s_{i+1}\ y_{i+1,0} + s_i\ y_{i+1,1} + w_{i+1})\ y^*_{i+1,1} \\ & + (s_{i+2}\ y_{i+2,0} + s_{i+1}\ y_{i+2,1} + s_i\ y_{i+2,2} + w_{i+2})\ y^*_{i+2,2} \\ & + (s_{i+3}\ y_{i+3,0} + s_{i+2}\ y_{i+3,1} + s_{i+1}\ y_{i+3,2} + s_i\ y_{i+3,3} + w_{i+3})\ y^*_{i+3,3} \end{aligned}$$

This equation can be simplified as given below.

$$
\begin{aligned}
R_i\ Z_i^* = s_i\ (\ & y_{i,0}\ y_{i,0}^* + y_{i+1,1}\ y_{i+1,1}^* + y_{i+2,2}\ y_{i+2,2}^* + y_{i+3,3}\ y_{i+3,3}^*) \\
& + s_{i+1}\ (y_{i+1,0}\ y_{i+1,1}^* + y_{i+2,1}\ y_{i+2,2}^* + y_{i+3,2}\ y_{i+3,3}^*) \\
& + s_{i+2}\ (y_{i+2,0}\ y_{i+2,2}^* + y_{i+3,0}\ y_{i+3,3}^*) \\
& + s_{i+3}(\ y_{i+3,0}\ y_{i+3,3}^*) \\
& + (w_i\ y_{i,0}^* + w_{i+1}\ y_{i+1,1}^* + w_{i+2}\ y_{i+2,2}^* + w_{i+3}\ y_{i+3,3}^*)
\end{aligned}
$$

$R_i\ Z_i^* = s_i\ |Z_i|^2$ + ISI term + Noise Term (12-A) [1]

$$\lambda_i = \frac{R_i\ Z_i^*}{|Z_i|^2} \qquad (13)$$

$\lambda_i = s_i$ + noise component (14)

Thus λ_i represents an unbiased estimate of signal transmitted. Thus, for finding which particular value of x_i is closest to λ_i, a temporary cost value C_i, which is based on the matched filter, is calculated with the help of accumulated permanent cost value U_{i-1} and it is given by

$$C_i = U_{i-1} + \Delta_i \qquad (15)$$

Here Δ_i is the incremental cost, which is given by

$$\Delta_i = |\lambda_i - x_i|^2 \qquad (16)$$

Now, from the set of $k \times m$ expended $\{P_i\}$, the vector with the smallest cost value is selected. The value of x_{i-n} with the smallest cost is the detected symbol s'_{i-n} of transmitted symbol s_{i-n}. Now, any vector in $\{P_i\}$ whose first component is different from s'_{i-n} is then discarding by assigning it to a higher value of cost C_i. Now k-vectors are selected from the remaining set of vectors in $\{P_i\}$ including that from which s_{i-n} was detected. The first component x_{i-n} of each of these selected vectors $\{P_i\}$ is now omitted without changing their costs. Once the selection of k-vectors is complete, the permanent cost U_i of these selected are calculated using the equation 17 as given by

$$U_i = U_{i-1} + \left| r_i - \sum_{h=0}^{3} x_{i-h}\ y_{i,h} \right|^2 \qquad (17)$$

The smallest value of these costs is now subtracted from each of the k-cost in order to avoid an unacceptable increase in the value of the costs over a long transmitted message. This operation does not create the difference between the permanent costs. These k-selected vectors in Q_i are then stored along with the value their cost function $\{U_i\}$. Now the detector is ready for the next step of detecting next symbol i.e. s_{i-n+1} on the receipt of the symbol r_{i+4}. This process will continue until the detection of last symbol in a message.

3. COST OPTIMIZATION IN MATCHED FILTER

Unlike systems [13], in this article a matched filter detector based on two received signal samples r_i and r_{i+1} given by equations 9 and 10. However, the cost calculations are now slightly modified. A scaling constant (α) is introduced in this system, which is used to optimize the results obtained from the matched filter. Thus, the incremental cost is given by:

$$\Delta_i = \alpha \left| \lambda_i - x_i \right|^2 \qquad (18)$$

α is the scaling constant, which is used to optimize the performance of the detector. The performance based on this constant is given in figure 2. Now, from the set of $k \times m$ expended $\{P_i\}$, the vector with the smallest cost value is selected. The value of x_{i-n} with the smallest cost is the detected symbol $s_{i-n}^{'}$ of transmitted symbol s_{i-n}. Now, any vector in $\{P_i\}$ whose first component is differs from $s_{i-n}^{'}$ is then discarded by assigning it to a higher value of cost C_i. Now k vectors are selected from the remaining set of vectors in $\{P_i\}$ including that from which s_{i-n} was detected. The first component x_{i-n} of each of these selected vectors $\{P_i\}$ is now omitted without changing their costs. The remaining part is same as discussed in the previous systems.

3. Computer Simulation Results

BER versus SNR curve for various schemes of the matched filter based detector. Like in other papers one important assumption is also considered which that the detector has the perfect knowledge of the channel i.e. the perfect channel estimation is considered. In order to facilitate the proper comparison of the various schemes of the detector, the same fading sequences have been employed throughout the simulation tests. BER and SER are measured at different SNR so that the performance of the detector is not influenced by the choice of the particular fading sequence. Finally, the BER versus SNR curves plotted for each schemes.

The detection schemes investigated in this paper are based on the matched filter used in conjunction with NMLD. The matched filter based NMLD studied in this chapter uses k (number of stored vectors) =4 and n (length of stored vectors) =8. All the systems studied in this paper have been simulated for the channel with four independent fading paths in outdoor vehicular environment. The channel used has equal power distribution in the four fading paths [9, 12].

System with modified cost value gives the enhanced results as compared to contemporary estimation techniques [1, 13]. A modified form of system in [13] obtained after modification of cost calculations by introduction of a scaling constant α. The results of performance of this technique are shown in figure 2 are for the system with no cost optimization, where as the results in figure are given for different values of α. Out of the four values of α tried in this work; it is found that the best results are obtained for $\alpha = 0.01$.

In view of the significant change in results observed for various value of α, it may be concluded that this is a useful parameter, which helps in controlling the level of ISI through modified cost calculations of stored vectors.

4. Conclusions

The channel we have considered is a worst case scenario that means ISI of such channels studied here are really those which are less likely to occur in practice. However, the idea here is that if the ISI mitigation methods work well for these worst case wireless channels, then they are likely to perform better in practical channels with lesser degree of ISI. The data rates of 384 kbps used in this work may possibly appear to be small for future and next generation wireless systems under study. But a lot of next generation and future systems are likely to use OFDM where an incoming serial bit stream is split up into multiple parallel bit streams each of which then travels over a separate carrier. The reduced signal element duration on any of these individual carriers would however be of the same order as that used in this work, which is also another motivation behind this work. The NMLD used in this work is very least complex and thus the NMLD with the conjunction of matched filter can be used for the current mobile/wireless applications.

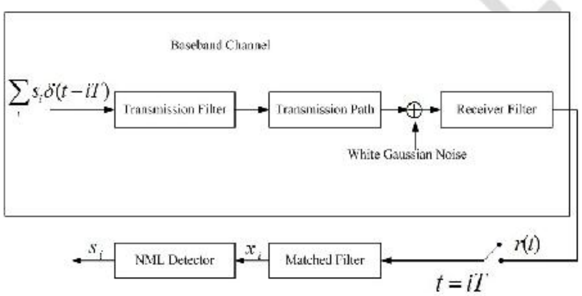

Fig. 1 Model of data transmission system with Matched filter

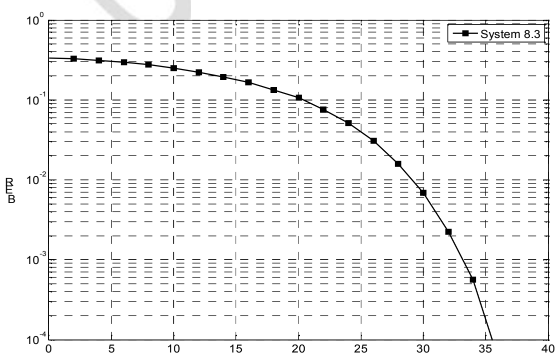

Fig. 2 Performance of matched filter based NML detector without optimization

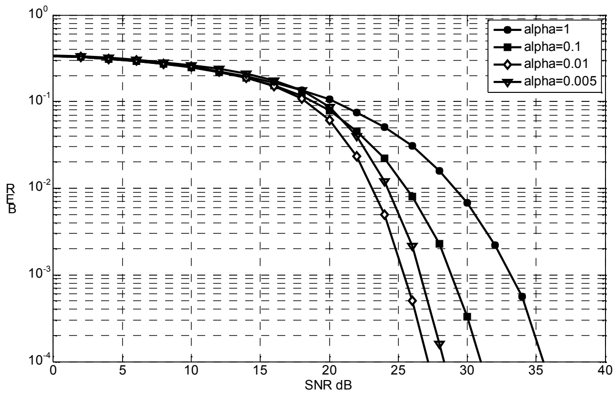

Fig. 3 Performance of matched filter based NML detector without optimization with cost optimization

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