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Matched Filter Based Detection over Time Varying Fading Channels with Reduced Complexity

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

Challenges in high speed data transmission technology over time varying fading channels is addressed in this paper. More precisely, the signal processing at the receiver side has to be analyzed for such systems, as it is well known that the mobile radio channels are characterized by frequency selective fast fading is typically introduced error in the received signal. Thus, the performance of the receiver severely degraded because of such factors. Specifically, this paper deals with the detection using a matched filter followed by low weight near maximum likelihood detector (NMLD) for the application of digital signal processing in outdoor vehicular radio environments. Nearly Maximum Likelihood Detection depends on the length of the stored vectors as well as depends on the numbers of the stored vector. In [1] complexity is reduced by reducing the stored vectors, in this paper same NMLD used but the complexity of the matched filter is reduced by some variance. Finally, the bit error rate (BER) is measured with signal to noise ratio.

Keywords: Digital matched filter; digital signal processing; lightweight NMLD; radio physics; electronics communication.

1. INTRODUCTION

The current demand of user to access high speed data over their mobile device, the detection process is one of a key player to fulfill the requirements. For any received signal that comes out through the wireless channels need to be amplified, by the use of matched filtering the

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maximum signal power we received at the output of the matched filter. So, the matched filter is simply linearly filtering of the received signal. So if the intersymbol interference is not present in the received signal, probability of error at the front side of the receiver becomes optimized. Matched filter based NML detection work has been carried out by Israil [1]. In this current work, the complexity of the receiver is modified by means of some variable introduced in the matched filter. Results have to be investigated by changing the complexity of variables. In this research, we have compared the system with varying complexity.

Matched filtering is a process known to be the optimum linear filtering for detecting a known signal in the presence of random noise [1]. In the matched filter, sets of consecutive samples from the incoming signal are kept in memory of the receiver [1]. At each iteration of matched-filter samples multiplied with a known replica of the received signal sample, and integrated to calculate the correlation between the memorized set of input samples and local replica [1,2,3]. It is well known as mentioned in [4,5] that the optimum filter for a received signal with no ISI and additive white Gaussian noise (AWGN) is one matched to the signal [1,6].

In its basic form, the matched filter provides output signal, which is the maximum likelihood estimate of the signal sample [1,7,8]. Before signal sample processed at NMLD coupled Matched filter simple threshold detection is used for the basic detection to minimize the effect of noise. Unfortunately, in mobile wireless channels, ISI is always present in the received signal. Thus, the matched filter detector alone is no more effective detector. Because of the presence of ISI, detection based only on matched filtering will still maximize the signal to noise ratio (SNR) without altering the ISI but will increase the effect of noise [1]. However, the effect of ISI any further filtering at this point can be further to reduce but at 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 mentioned in [1,9].

A matched filter followed by the equalizer is the optimum digital linear system for a received signal with some ISI [1,10]. However, In the case of severe multipath fast fading channels, maximum likelihood sequence estimation or decision feedback equalization may be required, but it will be a very complex system hence, the delay will be introduced [11,12]. For such severely affected channels receiver with a matched filter followed by NMLD gives the impressive performance measured by Israil [1]. Furthermore, for the adaptive and less complex system the idea introduced in this paper by putting a parameter call cost parameter which makes it less complex and adaptive. It can vary the complexity as per requirement.

The model of the data transmission system, which is based on the 4-QAM modulation scheme, is given in Fig. 1 as mentioned in [1]. The aim of this paper is to study the performance of the matched filter in conjunction with NMLD along with variable cost parameter. The assumption made here that all the time channels know to the receiver.

2. MATHEMATICAL MODELING OF MATCHED FILTER BASED NML DETECTOR

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

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

s_i is the transmitted signal, y_i is the channel's impulse and w_i 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 equation (1) as mention in [1]:

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

We assumed that the receiver is trying to detect s_i with the help of the received signal sample r_i at time instant $t = iT$ [1]. Consider the case of the channel with impulse response by equation 3:

$$Y_i = [0 \quad 0 \quad 0 \quad 1] \tag{3}$$

In this case of the channel, the signal at the output of the channel is given by Israil [1]:

$$r_i = s_{i-3} + w_i \tag{4}$$

It can be seen that equation (3) has no information about the first three replicas of the transmitted signal s_i, s_{i-1}, s_{i-2}. This type of problem can be resolved with the help of a matched filter by considering four consecutive received signal samples [1].

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:

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

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

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

$$r_{i,3} = r_{i+3} \tag{8}$$

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

$$r_{i,0} = s_i\, y_{i,0} + w_i$$

(9)

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

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

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

The 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]

$$\lambda_i = \frac{R_i\, Z_i^*}{|Z_i|^2} \tag{13}$$

$$\lambda_i = s_i \text{ + noise component} \tag{14}$$

Thus λ_i represents an unbiased estimate of the 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:

$$C_i = U_{i-1} + \Delta_i \tag{15}$$

Here Δ_i is the incremental cost, which is given by:

$$\Delta_i = |\lambda_i - x_i|^2 \tag{16}$$

Now, from the set of $k \times m$ expended $\{ P_i \}$, the vector with the smallest cost value is selected [1]. The value of x_{i-n} with the smallest cost is the detected symbol s'_{i-n} of the 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 is calculated using equation 17 as given by:

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

The smallest value of these cost function 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 [1]. 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 the 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 the last symbol in a message [1].

3. COST OPTIMIZATION IN MATCHED FILTER

Unlike systems [13-14], 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:

$$\Delta_i = \alpha \left| \lambda_i - x_i \right|^2 \tag{18}$$

α is the scaling constant, which is used to optimize the performance of the detector. The performance of the detector when the value of this scaling constant is 1 is given in Fig. 2. Now, from the set of $k \times m$ expended $\{P_i\}$, the vector with the smallest cost value is selected.

4. COMPUTER SIMULATION RESULTS

Performance of the mentioned detector is measured in BER versus SNR. Like in other papers [1,10,11] 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. To perform the comparative study of the receiver the same channels are being used in each measurement.

The complexity is highlighted in this article which is most likely based on the near maxi-mum likelihood detector. Particularly the NMLD used in this article is based on 4 numbers of stored vectors and length of the stored vectors have to be cut in short as eight numbers of stored vectors. The second important thing needs to be mentioned here about the multiple paths present in the channel for comparison about the performance, the channel used has equal power distribution in the four fading paths [9, 12]. Delay spread and other parameters of the channels are fixed as per the vehicular outdoor environment.

A modified form of system in [13] obtained after modification of cost calculations by the introduction of a scaling constant α. The results of the performance of this technique [1] are shown in Fig. 2 are for the system with no cost optimization, Fig. 3 depicted here pre-sents the performance of the detector with the variable value of scaling coefficient. Out of the four values of α tried in this work; it is found that the best results are obtained for $\alpha = 0.01$.

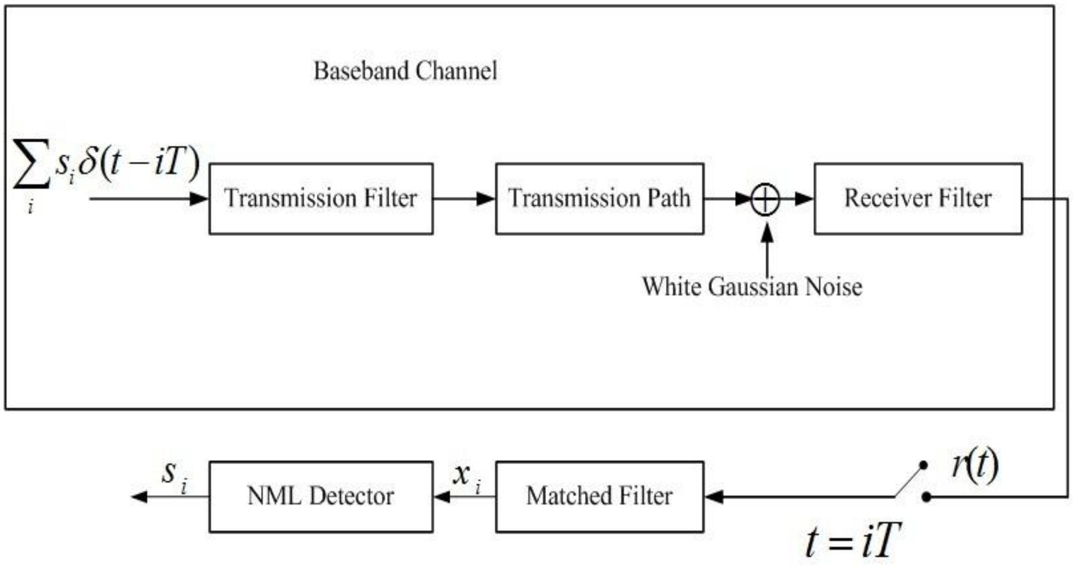

Fig. 1. Model of the data transmission system with Matched filter [1]

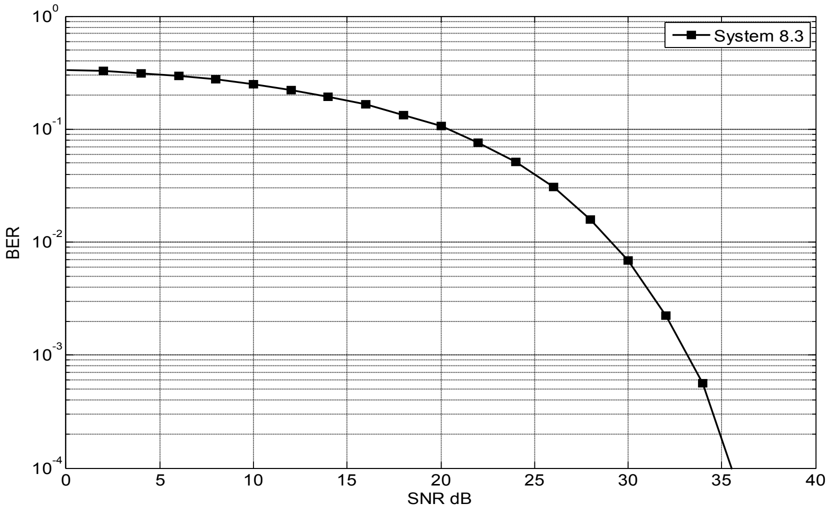

Fig. 2. Performance of matched filter based NML detector without optimization [1]

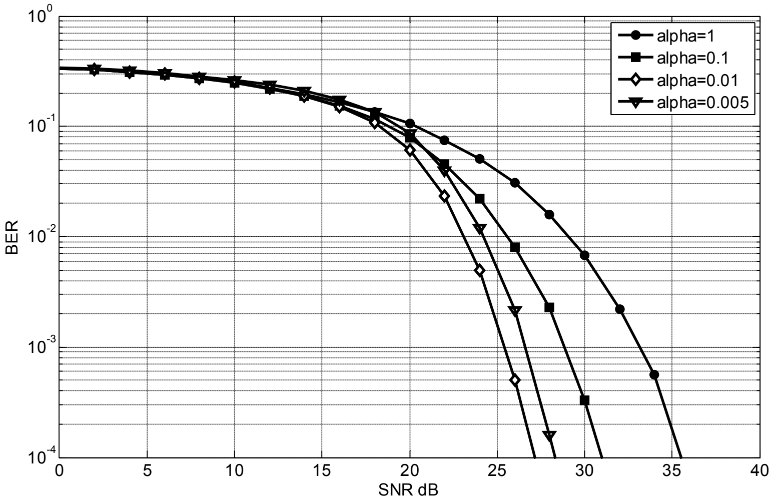

Fig. 3. Performance of matched filter based NML detector with cost optimization

5. CONCLUSIONS

Performance of the receiver with varying complexity is excellent, although the performance measured here are based on the worst case scenario that means channels are severely affected by ISI, but still the performance is acceptable. However, such worst channels are practical less likely present. Hence our idea here is that if the ISI mitigation methods work well for these worst-case wireless channels, then they are likely to perform much better in case of channels present with acceptable inter-symbol interference. The motivation behind this work to get develops the receiver which is less complex and optimum. 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 performance of the receiver mention here is quite impressive as well as less complex.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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