BLIND CHANNEL IDENTIFICATION WITH FRAME LENGTH AND OFFSET ESTIMATION

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ABSTRACT

We present a novel approach for blind frame length, frame offset, channel order and channel identification in null guard transmission scheme. We derived a deterministic maximum likelihood estimator for frame length and offset estimation and proposed computationally efficient suboptimum algorithms. These algorithms consider single and multi-channel systems. After frame length and offset are estimated, channel order and coefficients are found jointly by considering the maximization of a relative distance measure. Proposed method is shown to perform well leading to more efficient use of bandwidth in wireless systems.

1. INTRODUCTION

Blind channel estimation is an important problem of wireless communications. Previous research mainly focuses on channel identification where frame length and offset are assumed to be known perfectly. In this paper, we present a novel approach for frame length and offset estimation. In addition, we use a new method for finding the channel order and coefficients jointly in a blind manner.

Variable frame length transmission [1], [2], and frame synchronization are in general considered in data link layer since bit level operations lead to highly accurate estimates and convenient data protocols. On the other hand, pilot-symbol assisted frame synchronization is shown to be effective [3] for a realization in physical layer. In OFDM, cyclic-prefix (CP) or guard-interval transmission schemes are employed for frame synchronization for fixed frame length [4]. In OFDM systems, CP length should be greater than the channel order and each block is sent with a CP in order to preserve the orthogonality. There are also additional overhead for fine tuning as well [5]. Recently, it is shown that the length of the training signal should depend on the SNR for MIMO systems [6] for an efficient transmission. In this paper, we will exploit this fact and use variable frame length transmission in order to increase efficiency, throughput and robustness to channel impairments. The scenario for blind identification can be described by the following assumptions about the transmission.

a1.) Burst, null-guard (NG), or zero-insertion block transmission is used,

a2.) Perfect carrier and symbol timing is achieved.

Note that we have the a similar overhead as in OFDM systems by inserting NG intervals similar to CP. However, we can estimate frame length, frame start, channel coefficients and transmitted symbols with an overhead which involves only the nullguard interval as opposed to the OFDM systems which requires additional pilot symbols for frame synchronization [5]. The complete system for blind identification can be discussed in two parts. In the first part, frame length and offset are found jointly. In the second part, we find the channel order and coefficients blindly. In order to estimate the frame length and offset, we derive the deterministic maximum likelihood estimator (DML) for single and multi-channel systems. Single-channel approach is applicable to many systems including SISO, SIMO, and MIMO systems. However it is suboptimum when multi-channel systems are used since the information in all the channels should be taken into account. Therefore we also derived the multi-channel DML method for optimum performance. It turns out that the computational complexities of DML methods are large since the problem space is proportional with the frame length. This is a major drawback since the frame length and offset should be found as quickly as possible in blind systems. Therefore, we propose suboptimum algorithms that can be implemented efficiently.

Block transmission scheme can be implemented by using fixed frame length (FFL) and variable frame length (VFL) approaches. In FFL, a suitable frame length is selected in the transmitter each time a new transmission is started and this frame length is estimated blindly in the receiver. In VFL scheme, frame length can be changed during a transmission session depending on the SNR, channel distortion, etc. and receiver acquires the frame length blindly whenever it is changed. It turns out that frame length and offset is independent of the channel coherence. Channel coherence is especially important when the channel order and coefficients are to be estimated.

In the second phase of the proposed approach, we estimate the channel order and channel coefficients. This is done by using the derivative of a relative separation measure. This approach returns the channel order and channel coefficients jointly. As the last step, we combined all the algorithms and investigated the performance of the complete system for blind identification.

2. FIXED FRAME LENGTH ESTIMATION

In this part, we will discuss the estimation of frame length and frame synchronization given the observed output samples. DML approach assumes no statistical model for the input sequence, or input is assumed to be an unknown deterministic signal. In our case, null-guard interval exists between each M samples of input symbols and NG intervals are composed of N_{NG} zeros. This signal is transmitted through a channel $h(n)$ with $L+1$ coefficients. The received signal is corrupted by noise and we have,

$$y(n) = \sum_{k=0}^{L} h(k)s(n-k) + w(n) = x(n) + w(n) \qquad (1)$$

Our target is to find the frame length $N_p = M + N_{NG}$ and the frame offset n_0. For each channel signal, we assume the followings:

a3)$N_{NG} > L$ or guard interval excess zeros are, $K = N_{NG} - L \geq 1$.

a4) Number of transmitted frames, N_{fr}, is greater than 2.

a5) Noise is zero-mean Gaussian with variance, σ_w^2.

a6) Frame length has bounds, $N_{pmin} \leq N_p \leq N_{pmax}$.

We will assume that frame synchronization is achieved when the estimated frame offset satisfies, $\hat{n}_0 \in [n_0 - K, n_0]$. In this case, input symbols can be obtained without ambiguity. In the following part, we will describe the single and multi-channel DML estimation.

2.1 Single Channel DML Estimation

We assume that the data frames are transmitted through a single channel. DML estimation assumes that the input is an unknown deterministic sequence and channel is also considered as an another parameter to be estimated. Then pdf function of $y(n)$ can be written as,

$$f_{N_p,n_0,s,h}(y) = \frac{1}{(2\pi\sigma_w^2)^{N_pN_{fr}/2}} \prod_{m=0}^{N_{fr}-1} \prod_{k=0}^{N_p-1} e^{-|y(N_pm+n_0+k)-x(N_pm+n_0+k)|^2/2\sigma_w^2} \quad (2)$$

Since we have no information on $x(n)$, we cannot use the above pdf directly. However, we have full knowledge of $x(n)$ for some parts of $y(n)$, namely $x(n) = 0, mN_p + n_0 \leq n \leq mN_p + n_0 + K, m = 0, \ldots, N_{fr} - 1$. Therefore we can extract a part of $f_{N_p,n_0,s,h}(y)$,

$$\tilde{f}_{N_p,n_0,s,h}(y) = \frac{1}{(2\pi\sigma_w^2)^{KN_{fr}/2}} \prod_{m=0}^{N_{fr}-1} \prod_{k=0}^{K-1} e^{-|y(mN_p+n_0+k)|^2/2\sigma_w^2} \quad (3)$$

The negative of log-likelihood function after removing some unnecessary constant terms is given as,

$$\tilde{L}_{N_p,n_0} = \sum_{m=0}^{N_{fr}-1} \sum_{k=0}^{K-1} |y(mN_p + n_0 + k)|^2 \quad (4)$$

Therefore maximization of the likelihood function is achieved by minimizing $\tilde{L}_{N_p,n_0}$. DML estimate of N_p, and n_0 can be found as,

$$\{N_p, n_0\}_{DML} = argmin\ \tilde{L}_{N_p,n_0} \quad (5)$$

It turns out that the above DML estimate is based on detection of noise at certain parts of the observed signal square, $|y(n)|^2$. DML estimates can be found by considering all the possible combinations of $\{N_p, n_0\}$ and choosing the pair which minimizes $\tilde{L}_{N_p,n_0}$. This process is computationally very expensive since the search space is proportional to the frame length. In this paper, we will propose suboptimum but computationally efficient alternative approaches to solve the same problem.

2.2 Multi-Channel DML Estimation

As long as the data blocks are transmitted with the same parameters (M,N_{NG},N_p, etc.) and the channels have approximately the same order, single channel DML can be extended to the multi-channel case. In the multi-channel system, we have more than one channel which carry the same information about the frame length and offset. We can take advantage of this information in a DML framework and obtain the optimum estimates. We will assume that the system is SIMO and noise at each channel is independent from the other channels with a variance $\sigma_{w_i}^2$. Therefore channel signals can be written as,

$$y_i(n) = x_i(n) + w_i(n) = \sum_{k=0}^{L} h_i(k)s(n-k) + w_i(n) \quad (6)$$

$i = 0, \ldots, P-1$ for a P channel SIMO system. Joint density function for $y_i(n)$ can be written as,

$$f_{N_p,n_0,s,h_0,h_{P-1}}(y_0.y_{P-1}) = \frac{1}{(2\pi\prod_{i=0}^{P-1}\sigma_{w_i}^2)^{N_pN_{fr}/2}} \prod_{m=0}^{N_{fr}-1} \prod_{k=0}^{N_p-1} e^{-\sum_{i=0}^{P-1}|y_i(mN_p+n_0+k)-x_i(mN_p+n_0+k)|^2/2\sigma_{w_i}^2} \quad (7)$$

Similar to the single-channel case, we can find a regions of $y_i(n)$ where $x_i(n) = 0$. In other words,

$$\tilde{f}_{N_p,n_0,s,h_0,h_{P-1}}(y_0.y_{P-1}) = \frac{1}{(2\pi\prod_{i=0}^{P-1}\sigma_{w_i}^2)^{N_pN_{fr}/2}} \prod_{m=0}^{N_{fr}-1} \prod_{k=0}^{K-1} e^{-\sum_{i=0}^{P-1}|y_i(mN_p+n_0+k)|^2/2\sigma_{w_i}^2} \quad (8)$$

The negative of the log-likelihood function is given as below after some simplifications, i.e.,

$$\tilde{L}_{N_p,n_0} = \sum_{m=0}^{N_{fr}-1} \sum_{k=0}^{K-1} \sum_{i=0}^{P-1} |y_i(mN_p + n_0 + k)|^2 \quad (9)$$

DML estimate for multi-channel system can be found as,

$$\{N_p, n_0\}_{DML} = argmin\ \tilde{L}_{N_p,n_0} \quad (10)$$

DML estimation in multi-channel case uses the information related to the frame length and offset for each channel by summing the energy signals. In other words, sum of the energy signals $|y_i(m)|^2$ carries the most of the information regarding the frame length and offset.

2.3 Practical Methods for Frame length and Offset Estimation

In the previous section, we have described the DML estimation for single and multi-channel systems. Since these estimates require computationally intense algorithms, efficient alternative methods should be found. In this paper, we will present suboptimum alternatives to the DML methods. These methods are based on the DML estimation and they decrease the search space considerably by using some rough initial estimates. DML estimation requires roughly $O(N_p^2)$ operations while the proposed algorithms need only $O(N_p)$ operations. Therefore the efficiency for the proposed algorithms is significantly high and they are suitable for fast identification in wireless communications.

Proposed single and multi-channel algorithms are composed of two stages. The first stage of these algorithms consist of finding a rough estimate for the frame length by using the Fourier spectrum of the energy signal. In the second stage, a detailed search is done for both frame length and frame offset in the neighborhood of the initial frame length estimates.

Frame length estimation is closely related to the detection of periodicity in the observed signal for NG transmission. Since the NG interval is repetitive, we can use the period of NG interval to find N_p. It is possible to use Fourier Transform in order to identify the periodicity of a signal and the period. DML analysis shows that $|y(n)|^2$ carries period related information for optimum detection. We will use the Fourier Transform of $|y(n)|^2$ for periodicity detection. Even though Fourier Transform of $y(n)$ can also be used for period estimation, it does not return estimates as good as $|y(n)|^2$ signal. In the first stage of the proposed algorithms, we pick the largest N_{peak} peaks from the Fourier Transform of $|y(n)|^2$. If $w_j, j = 1, \ldots, N_{peak}$ are the frequency of these peaks, then N_{peak} initial estimates for frame length, N_p, are found as,

$$\hat{N}_{p,j} = \frac{2\pi}{w_j} \quad j = 1, \ldots, N_{peak} \quad (11)$$

In the second stage, we perform a neighborhood search for each $\hat{N}_{p,j}$ while we also consider all the possible frame offset values for each length estimate. Neighborhood search is done by considering a range of values for frame length estimate, $\hat{N}_p \in [\hat{N}_{p,j} - k_0, \hat{N}_{p,j} + k_0]$ where k_0 is a small positive integer. Given $\hat{N}_p$, we consider all the possible frame offset values, $\hat{n}_0 \in [0, \hat{N}_p - 1]$. (5) or (10) is evaluated for $\{\hat{N}_p, \hat{n}_0\}$ couples and we find the pair which maximizes the likelihood function.

2.3.1 Single-channel Method

In the single-channel method, the method described above is applied over the noise corrupted signal. The algorithm steps can be summarized as follows:

a) Given the observed signal, we obtain N_{peak} peaks from the Fourier Transform of $|y(n)|^2$ and find the initial frame length estimates $\hat{N}_{p,j}$ from (11).

b) Frame length estimates are taken as, $\hat{N}_p = \hat{N}_{p,j} - k_0, \ldots, \hat{N}_{p,j} + k_0$. For each estimate $\hat{N}_p$, frame offset estimates are consider as $\hat{n}_0 = 0, \ldots, \hat{N}_p - 1$.

c) For each $\{\hat{N}_p, \hat{n}_0\}$ pair, (5) is evaluated by using a suitable value for K (ex. K=1 or 2) and the pair which returns the best likelihood is chosen as the true estimate.

Single-channel method decreases the complexity of the DML approach considerably. It is fast and simple and is suitable for blind wireless applications.

2.3.2 Multi-channel Method

Multi-channel method is very similar to the single channel method. The only difference between these two is the input signal supplied to the algorithms. In the single-channel method, $|y(n)|^2$ is used for the estimation while $\sum_i |y_i(n)|^2$ is used for the multi-channel case. The algorithm procedure is the same except (10) is used for the likelihood maximization.

3. VARIABLE FRAME LENGTH ESTIMATION

In block transmission, frame length is an important factor which can be used to increase the throughput, transmission efficiency, robustness to channel distortion, etc. VFL transmission is more problematic than the FFL transmission since, frame length can be changed at any time during transmission and the receiver should estimate it correctly. Frame length estimation under this condition can be done with acceptable accuracy only when we make additional assumptions.

a7) Given N_p, at least kN_{fr} frames are sent by the transmitter where $k \geq \lfloor \frac{N_{pmax}}{N_p} \rfloor$, $\lfloor\rfloor$ rounds to the largest integer.

a8) When frame length is changed, current frame length should be sufficiently different than the previous frame length.

The algorithmic steps for VFL estimation are as follows:

a) Frame length estimate is initialized to $\hat{N}_p = N_{pmax}$. The samples of N_{fr} frames are used and the new estimate $\hat{N}_p$ is found. If this is the start of the acquisition, $\hat{n}_0$ is also found.

b) Starting from the most recent $(N_{fr}\hat{N}_p + 1)$th sample, next N_{fr} frames are taken with $\hat{N}_p$ and the current frame length estimate is found.

c) If the current frame length estimate is significantly different than the previous one, algorithm starts from step a). Otherwise algorithm continues from step b).

Note that frame length estimation at a certain time is affected by the previous estimations. Figure 1 and 2 show the estimation performance for 100 trials with parameters $P = 3$, $M = 20$, $N_{NG} = 7$, $L = 4$, $N_{fr} = 5$, $K = 3$, $k_0 = 3$. Four different frame lengths $N_p = [20 \;\; 32 \;\; 25 \;\; 22]$ are selected during data transmission with $[2N_{fr} \;\; 4N_{fr} \;\; 3N_{fr} \;\; 2N_{fr}]$ frames at each case respectively. A random frame offset is produced at the beginning by using noise-like samples. As it is seen from these figures, frame length and offset are found with good accuracy even for low SNR. Frame offset estimation is better than frame length estimation since it is done only once during the transmission where the largest frame length estimate is used initially.

4. BLIND ORDER AND CHANNEL IDENTIFICATION

Blind channel order and coefficient estimation can be done jointly from a single frame for multi-channel systems. When the channel coherence time is long, several frames can be used in order to increase the performance of estimation. After the frame length and offset are estimated through the procedure outline above, joint order and coefficient estimation is done. We will use the cross relation method [7] for both channel order and coefficient estimation. According to this method, we can write an equation for blind estimation as follows,

$$\mathbf{X}\mathbf{h} = \mathbf{0} \tag{12}$$

where $\mathbf{X}$ is the data matrix and $\mathbf{h}$ is the channel vector. The solution for $\mathbf{h}$ can be found as the singular vector of $\mathbf{X}$ corresponding to the minimum singular value. When the channel order is not known, blind channel identification methods are in general find useless results. Therefore in this paper, we present an novel approach in order to jointly estimate the order and channel. To this end, we will first present a theorem to point the relation between eigenvalues of data matrices which form a basis for the algorithm. Let $\mathbf{X}^{(k)}$ and $\mathbf{R}_x^{(k)}$ be the data and correlation matrices built by assuming that the channel order is k.

Theorem 1: $\mathbf{X}^{(k)}$ is a complex matrix as in (12) where $k \in [L_{min}, L_{max}]$. $\mathbf{R}_x^{(k)} = (\mathbf{X}^{(k)})^H \mathbf{X}^{(k)}$ and $\lambda_{min}^{(k)}$ is the minimum eigenvalue of $\mathbf{R}_x^{(k)}$. Then

$$\lambda_{min}^{(L_{min})} \geq \lambda_{min}^{(L_{min}+1)} \geq \ldots \geq \lambda_{min}^{(L_{max})} \geq 0 \tag{13}$$

Considering the eigenvalue relations and the relative distance in perturbation theory, we will define a measure, $DRS(k)$, and find the channel order estimate L_e as,

$$L_e = \arg\max_k \; DRS(k) = \arg\max_k \left| \frac{\lambda_{min}^{(k+2)}}{\lambda_{min}^{(k+1)}} - \frac{\lambda_{min}^{(k+1)}}{\lambda_{min}^{(k)}} \right| \tag{14}$$

where $k \in [L_{min}, L_{max}]$. It turns out that the above measure is pretty effective when compared with the alternative approaches and its performance for noisy observations is very good. In figure 3, we present the performance of the proposed measure in estimating the true channel order. The same experimental settings are used as described in section 3. However FFL transmission with $M = 20$ is used in this case. Note that in this case, we use the estimated frame length and offset as described in the previous sections and the channel order is found based on these estimated values. In figure 4, the LSE performance for channel estimation is shown. In this case, the error is computed for the cases when the true channel order is found correctly.

5. CONCLUSION

We presented a novel approach for blind frame length and synchronization estimation in a NG transmission scheme. We derived the DML estimators for single and multi-channel systems and proposed suboptimum but efficient alternatives for these estimators. We investigated the performance of these algorithms for fixed and variable frame length transmissions. It is shown that proposed algorithms perform well for low SNR and the estimation accuracy is significantly high for practical SNR values. Channel order and coefficients are also estimated in a blind manner by using a relative separation measure. The performance for this case is also good for low SNR. The proposed blind identification system increases the bandwidth efficiency, throughput and robustness to channel distortions.

REFERENCES

[1] R.L. Kirlin, “Variable block length and transmission efficiency,” *IEEE Trans. Comm. Technology,* Vol.17, No.3, pp. 350-355, June 1969.

[2] F.C. Schoute, “Dynamic frame length ALOHA,” *IEEE Trans. Comm.,* Vol.31, No.4, pp. 565-568, April 1983.

[3] J.A. Gansman, M.P. Fitz, J.V.Krogmeier "Optimum and sub-optimum frame synchronization for pilot-assisted modulation," *IEEE Trans. Comm.,* Vol.45, No.10, pp. 1327-37, Oct.1997.

[4] M.H. Hsieh, C.H. Wei "A low complexity frame synchronization and frequency offset compensation scheme for OFDM systems over fading channels," *IEEE Trans. Vehicular Tech.,* Vol.48, No.5, pp. 1596-1609, Sep.1999.

[5] "IEEE Std 802.11a/D7.0-1999, Part11: Wireless LAN-Medium Access Control (MAC) and Physical Layer (PHY)specifications: High Speed Physical Layer in the 5GHz Band."

[6] J.H.Kotecha, A.M. Sayeed, "Transmit signal design for optimal estimation of correlated MIMO channels," *IEEE Trans. Signal Proc.,* Vol.52, No.2, pp. 546-557, Feb. 2004.

[7] L. Tong, S. Perreau, "Multichannel blind identification: from subspace to maximum likelihood methods, " *Proc. of IEEE*, Vol.86, pp.1951-1968, Oct. 1998.

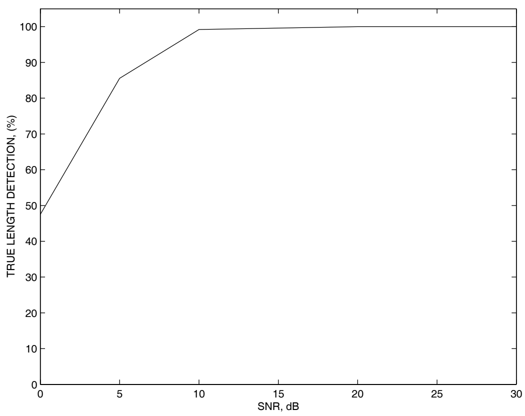

Figure 1: True frame length estimation performance for VFL transmission.

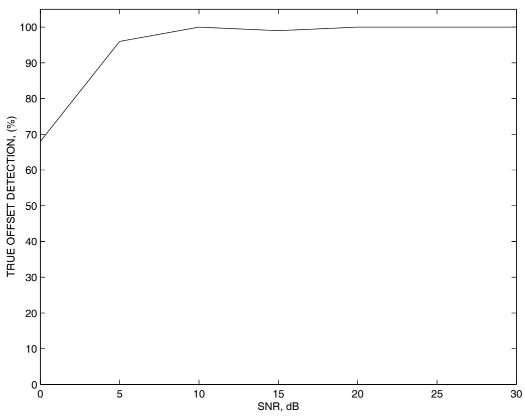

Figure 2: True frame frame offset estimation for VFL transmission.

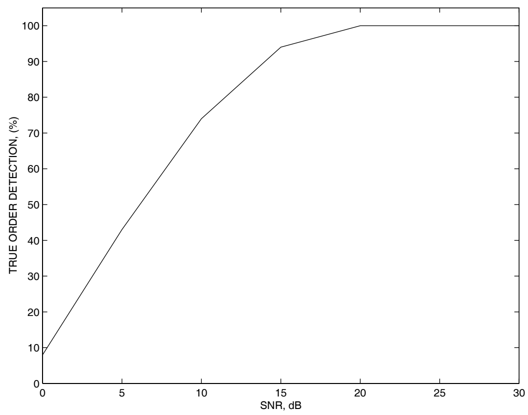

Figure 3: True channel order estimation performance for FFL transmission.

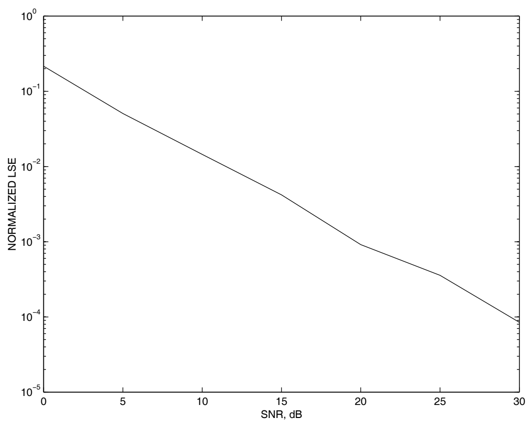

Figure 4: True channel estimation performance for FFL transmission.