CFO ESTIMATION FOR MULTIUSER OFFSET QAM-FBMC COMMUNICATION SYSTEMS

Kolli Nalini Kumari[1], Priscilla Dinkar Moyya[2], Jaya Prakash Allam[3]

[1]P.G Student, [2&3]Assistant Professor, Dept. of E.C.E, TPIST, Komatapalli, Bobbili (India)

ABSTRACT

In this paper, we study carrier frequency offset (CFO) estimation in the uplink of multi-user offset QAM filter bank multi carrier (FBMC) communication systems. A low complexity frequency-domain CFO estimator using periodical training sequences is proposed. We derive the theoretical mean square error (MSE) for the proposed estimator and computer simulations show that the derived MSE matches the simulated MSE closely. Compared with state-of-threat time-domain estimators, the proposed estimator achieves better performance with a much lower computational complexity.

Keywords: Carrier Frequency Offset (CFO), Filter Bank Multicarrier (FBMC), Mean Square Error (MSE)

I INTRODUCTION

Multicarrier modulation is an efficient technique for implementing broadband communication systems. The Filter Bank Multi Carrier (FBMC) communication system uses an effective signalling method that achieves high spectral efficiency over broadband channels. Orthogonal Frequency Division Multiplexing (OFDM) system is a special FBMC system with a rectangular prototype filter [1]. Besides OFDM, other types of FBMC systems have recently attracted more attention in the research community. In this paper, we consider a type of FBMC system often referred to as OFDM/OQAM, where OQAM stands for offset quadrature amplitude modulation. In [2] the term *staggered* QAM has also been used to refer to OQAM and a more concise name *staggered modulated multitone* (SMT) has been suggested. For consistency, in the rest of this paper, we will use the term SMT and accordingly use the name SMTMA (SMT multiple access) to refer to SMT-based multiple access systems. Similar to OFDM systems, SMT systems are also sensitive to carrier frequency offset (CFO), which leads to severe performance degradation [3]. The CFO is usually caused by the difference between local oscillator frequencies at the receiver and the transmitter and/or the Doppler frequency shift in the channel. Therefore, the accurate CFO estimation is essential to guarantee satisfactory performance in SMT systems.

Data-aided CFO estimation in SMT systems has been studied in [4]-[7]. In [4] and [5], data-aided CFO and timing offset estimation with robust acquisition properties in multipath channels was proposed. This algorithm exploits a periodical training sequence made up of identical blocks. In [6], a joint maximum likelihood (ML) CFO and timing offset estimator using a non-periodical training sequence in multipath channel was developed. Moreover, under the assumption that the CFO is sufficiently small, a closed form approximate ML (AML) CFO estimator was derived.

However, the performance of the CFO estimation is reduced when the CFO value is relatively large. Moreover, the performance of the CFO estimation is dependent on the training sequence used [6]. Finally, in [7] authors estimated CFO using spectral modelling. Interestingly, the CFO estimation is independent on the timing offset and also the training sequence used. However, the CFO is estimated using a maximization procedure through a 1-dimensional search, which leads to heavy computational complexity.

In this paper, we study the data-aided CFO estimation in the uplink of an SMTMA system. In the uplink, the base station (BS) needs to estimate multiple CFO's from multiple users. The choice of CFO estimation methods in the BS is closely related to the adopted subcarrier allocation scheme [8]. However, the current trend in the industry, as reflected in the 3GPP LTE documents, is more towards block allocation, where a block of contiguous subcarriers are allocated to each user [9]. The goal of this paper is to propose a low-complexity data-aided CFO estimation for SMTMA with block allocation scheme. Some studies have been performed to estimate the CFO and timing offset in the uplink of SMTMA systems. In [10] the joint ML phase, CFO, and timing offset estimation using a non periodical training sequence in an additive white Gaussian noise (AWGN) was considered. Under the assumption that the CFO of each user is sufficiently small, an AML estimator was developed, using which the joint phase offset, CFO and timing offset estimation for different users can be carried out independently. The AML phase and CFO estimators are in closed-form, while the AML timing offset estimator requires a one-dimensional maximization procedure. By following an approach similar to that considered in [10], the estimator proposed in [6] for single-user SMT systems can be easily modified for SMTMA uplink in multipath channels. To distinguish it from the single user estimator proposed in [6], in the rest of the paper, we refer to the modified estimator as Fusco's multiuser CFO estimator. There are a couple of disadvantages in this estimator. Firstly, due to an approximation used in the derivation of the AML estimator, Fusco's multiuser CFO estimator works only for small CFO values. The MSE of CFO estimation will have an error floor when the CFO is relatively large. Secondly, the complexity of the estimator increases linearly with increasing the number of users and can be high when there are many users. Thirdly, the performance is sensitive to training sequence used. In this paper, by following the approach in [5][11], a CFO estimation using frequency-domain periodical training sequences is proposed. Different from [5], the proposed algorithm estimates CFO after DFT. By inserting some guard subcarriers between each pair of adjacent user's bands, this estimator can be used for uplink scenario with block subcarrier allocation scheme. We show that the performance of the proposed estimator is better than the time-domain estimator [6] for the uplink and requires much lower computational complexity. Moreover, the estimator in [6] requires special constraints on the real and imaginary parts of the training sequences for good performance. Using the proposed estimator, the training sequence can be freely chosen to meet specific system requirements, such as to minimize the peak to average power ratio (PAPR) of the training sequence
.

II SYSTEM SETUP

We consider the uplink of a SMTMA system where P active users are communicating with a BS. It is assumed that there are $N = P . Q$ subcarriers, where Q is the number of subcarriers allocated to each user, including both active and guard (null) subcarriers. The set of Q subcarriers assigned to the pth user is denoted by Sp, and we assume $\bigcup_{p=0}^{P-1} S_P$, $Sp = \{0, 1, \cdot \cdot \cdot , N-1\}$ and $Sp \cap Sq = \varnothing$, for $\forall p \neq q$. The transmitted signal from the pth user is represented by $xp[n]$, and the channel response between the pth user and the BS is denoted by the sequence $cp[n]$. It is assumed that

$cp[n]$ is nonzero only for $n = 0, 1, \cdot \cdot \cdot, Nc - 1$, where Nc is the maximum channel delay spread. Accordingly, the received signal at the BS can be written as

$$r[n] = y[n] + v[n] = \sum_{p=0}^{p-1} y_p[n] + v[n],$$

(1)

Where v[n] is an AWGN with variance σn2 and yp[n] is the received signal from the pth user as

$$y_p[n] = (x_p[n] * c_p[n])e^{j2\pi\varepsilon_p n/N},$$

(2)

Where $*$ denotes linear convolution and εp, p=0,.....,p −1 is the normalized CFO (with respect to the subcarrier spacing) of the pth user.

2.1 Poly phase Structure of the SMT receiver

Several polyphase structures have been proposed for efficient implementation of SMT systems. For the purpose in this paper, we have chosen the polyphase structure of [13] as shown in Fig(1). The components The components E0(z) through EN−1(z) are the polyphase components of a prototype filter H(z), based on which the SMT is implemented. We assume that H(z) has a length of β. N, thus, each polyphase components has a length of β. The DFT block performs the demodulation at the receiver side of the system. It is apparent that Fig.1 is different from a conventional analysis filter bank in the literature, where the polyphase components are often followed by an IDFT [13]. This difference arises, simply, because here we have chosen to feed the input signal from the bottom of a tapped delay line, i.e., opposite to the common practice where the tapped delay line is fed from the top. This puts the input samples in a reversed order and accordingly the IDFT has to be replaced by DFT. This arrangement is chosen, here, because it matches the common practice in the presentation of an OFDM receiver[1].

The N×1 input vector to the DFT block at the time instant l as shown in Fig.1 can be written as [14]

$$u[l] = \sum_{i=1}^{\beta} u^{(i)}[l]$$

(3)

Where,

$$u^{(i)}[l] = r[l+i]h[\beta - i] = (y[l+i] + v[l+i])h[\beta + i]$$

(4)

$$h[n] = \begin{bmatrix} h[nN + N + 1] \\ h[nN + N + 2] \\ \vdots \\ h[nN] \end{bmatrix}, \quad y[n] = \begin{bmatrix} y[nN - N + 1] \\ y[nN - N + 2] \\ \vdots \\ y[nN] \end{bmatrix},$$

$$v[n] = \begin{bmatrix} v[nN + N + 1] \\ v[nN + N + 2] \\ \vdots \\ v[nN] \end{bmatrix},$$

and ⊙ denotes point-wise multiplication of vectors. Further-more, the output vector of the DFT block is given by

U (l) =F {u (l)},   (5)

Where F denotes the DFT operation. The output vector U (l) is then multiplied with a column vector g containing the one-tap equalizer coefficients =[g0 g1… gN−1]T . The equalizer output is then sent to the slicer and decisions on the

transmitted data symbols s l are obtained as shown in Fig.1. Data from different users are then separated through user separation.

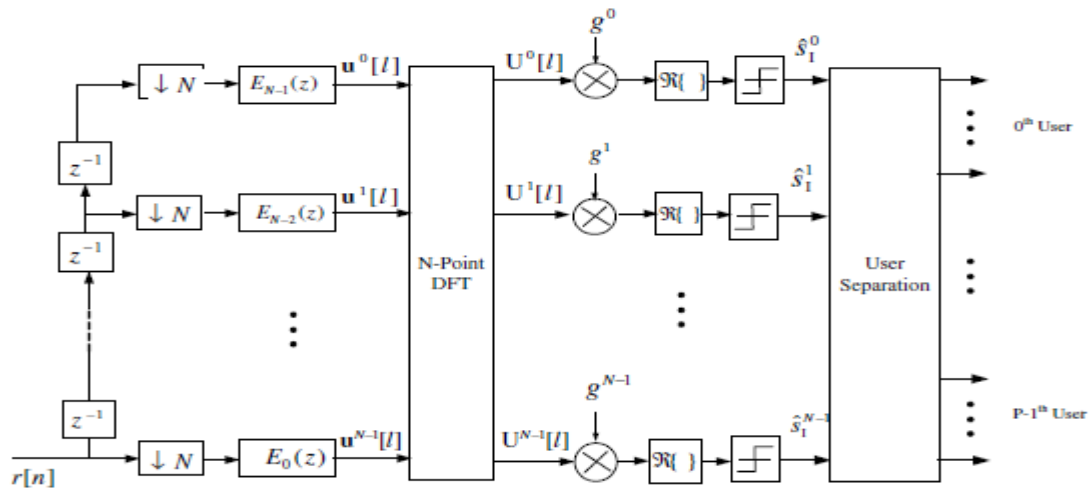## III CFO ESTIMATION

3.1 Fusco's multiuser CFO estimator

Fig.1.The in-phase part of an SMT receiver. The quadrate part has a similar structure with the following minor differences: (i) The inputs is backward delayed by one half of a symbol internal (samples), and (ii) the {.} blocks are replaced by {.} blocks. {.} Means imaginary-part of.

In the fusco's estimator is a joint CFO and timing offset estimator in the uplink using non-periodical training sequences. The CFO estimator for the pth user may be simplified to [7] ,[11].

$$\hat{\varepsilon}_p = \frac{1}{\pi} \angle \left\{ \sum_{i=0}^{N_c-1} A_i^* B_i \right\},$$

(6)

Where $\angle \{\bullet\}$ denotes the angle of a complex number and the parameters Ai and Bi are equal to

$$A_i = \sum_{n=0}^{\beta N-1} \left[r[n+i] \sum_{k \in S_p} x_I^{k*}[n] \right],$$

$$B_i = \sum_{n=0}^{\beta N-1} \left[r[n+i+\frac{N}{2}] \sum_{k \in S_p} x_Q^{k*}[n] \right]$$

(7)

and xIk n and xQk n are transmitted signals produced by the in-phase sIk and Quadrature phase sQk of the training symbol on the kth subcarrier. It should be noted that an underlying assumption in the deviation of (7) is that exp (-j2πNεpΔQ) ≈ 1, where ΔQ is comparable with the length of the prototype filter. As a result, this estimator only works well for small CFO values. From (7) and (8), it can be seen that the CFO for each user is estimated before the DFT. Since the CFO for different users can be estimated independently, the complexity of CFO estimation for each user is dependent on the total number of subcarriers N, rather than the number of subcarriers Q allocated to each user. This is inefficient, especially when the number of users P=NQ is large.

3.2 The proposed estimator

In [6], a time-domain CFO estimation algorithm using periodical training sequences was proposed for single user SMT systems. It was shown that a least square CFO can be obtained by estimating the phase difference between the two periods of the received signal. However this may not be extended to multiuser case, where signals from P users have been received with different CFO's at BS which cannot be easily separated in the time domain. To overcome this problem, in this section , we derive a frequency-domain CFO estimator for SMTMA uplink using periodical training sequences. To reduce the computational complexity of the estimator, we uses only real training sequences such that the estimator only uses the in-phase part of an SMT receiver. In most practical design of prototype filter h[n] takes significantly non-zero values only when $-N \leq n \leq N$. Then it can be shown easily that if the number of identical blocks in the training sequence of the pth user are chosen as $\beta+2$, the transmitted training signal $x[n]$ satisfies the following condition approximately

$$x_p[n+N] \approx x_p[n], n = N_1, \ldots, N_1 + \beta N - 1 \tag{8}$$

Where N_1 is the transient in the time domain. By calling (2), we have two $\beta N \times 1$ Successive overlapped signal vector from the pth user called $y_{p,1}$ and $y_{p,2}$ such that

$$y_{p,2} = e^{j 2\pi \varepsilon_p} y_{p,1}, p = 0,1,\ldots,p-1 \tag{9}$$

Accordingly N×1 vectors u_1 and u_2 are the received vectors at the input of DFT block due to r_1 and r_2 respectively as

$$\begin{cases} u_1 = \sum_{p=0}^{P-1} \sum_{i=1}^{\beta} y_{p,1}(l+1) \, \partial h(\beta - i) + w_2 \\ u_2 = \sum_{p=0}^{P-1} \sum_{i=1}^{\beta} e^{j 2\pi \varepsilon_p} y_{p,1}(l+1) \, \partial h(\beta - i) + w_2 \end{cases} \tag{10}$$

If we put some subcarriers as a guard between each pair of adjacent user's bands for multiuser case, the overlapping between adjacent users may be neglected, thanks to the excellent frequency localized filters used in the realization of FBMC systems. The CFO estimation may be preformed after DFT. Consequently the CFO for each user may be estimated separately by following the approach for OFDM in [12]

$$\widehat{\varepsilon_p} = \frac{1}{2\pi} \left(\sum_{k \in S_p} U_1^{k*} U_2^{k} \right) \tag{11}$$

Where U_1 and U_2 are the DFT outputs of vectors u_1 and u_2 respectively. While the estimation error depends only on total symbol energy, the algorithm works well in multipath channels. However it is required that the CFO as well as the channel impulse response remains constant during estimation. Moreover the training sequence may be chosen randomly so that to minimize its PAPR.

Using a similar approach as in [12], in the high SNR region, the mean square error (MSE) of the CFO estimation of the pth user can be approximated by

$$\text{MSE}(\widehat{\varepsilon_p}) = \text{E}\{(\varepsilon_p - \widehat{\varepsilon_p})^2\} = \frac{1}{4\pi^2 . SNR . \sum_{k \in S_p} |H^k|^2} \tag{12}$$

Where H_k is the channel frequency response on the kth subcarrier and SNR $\triangleq \sigma_{s2}\sigma_{n2}$, where σ_{s2} is the power of the transmitted signal.

IV SIMULATION RESULTS

Computer simulations were performed to compare the performance of the proposed estimator and Fusco's multiuser CFO estimator [6] for SMTMA uplink. We let N= 256 and assume that there are P = 4 users in the network, hence, Q= N/P = 64 subcarriers per user. The multiuser channel with delay 0, 0.31, 0.71, 1.09, 1.73, and 2.51 microseconds and relative powers 0, -3, -9,-10,-15, and -20dB is considered [6]. The CFO values are chosen randomly and independently for each user from a uniform distribution in the interval -0.5 < ε < 0.5. In all cases, one guard subcarriers is inserted between each pair of adjacent user's bands. Perfect power control is assumed. The prototype filter used in the SMTMA system is an isotropic orthogonal transform algorithm (IOTA) prototype filter with a length of 3N, designed accordingly to [14].

The MSE of the proposed estimator and Fusco's multiuser CFO estimator are shown in Fig. 2. Due to the relatively large CFO values used, we can see that the MSE of Fusco's multiuser CFO estimator reaches an error floor for SNR larger than 20dB. The MSE for the proposed estimator outperforms than Fusco's multiuser CFO estimator and it can be accurately approximated by the theoretical MSE derived with (1/2) in high SNR regions. Fig. 3 presents bit error rate (BER) for both estimators, for different Eb/No values. The channel code is a rate 12 convolution code with constraint length of 5 and data symbols are from a 16- QAM constellation. We can see that the BER with the proposed estimator is much better than that with Fusco's estimator and is very close to the BER with perfect frequency synchronization.
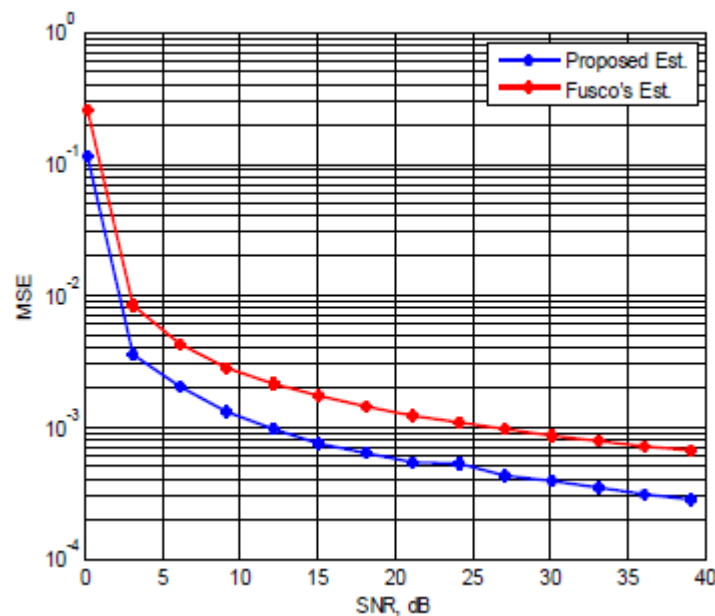

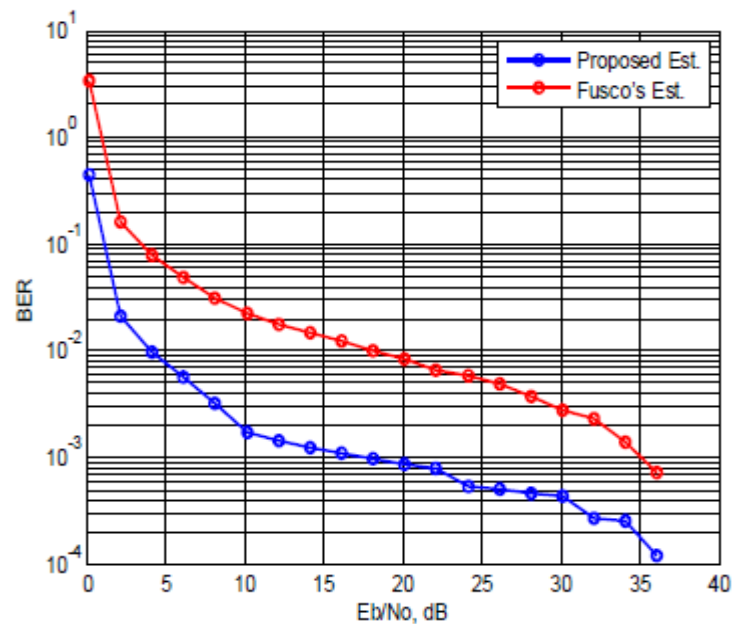**Fig.2. MSE of the proposed estimator and Fusco's multiuser CFO estimator**.

Fig.3. BER using the proposed estimator and Fusco's multiuser CFO estimator.

V CONCLUSION

In this paper, we are comparing both the estimators, the proposed estimator has a low-complexity and also it is a frequency domain CFO estimator for uplink by using periodical training sequences. In this CFO may be estimated after the DFT and signals for different users are separated at the end.this gives the low-complexity compared to the fusco's time-domain estimator, in which signals from different users are mixed up. Computer simulation results also showed that the performance of the proposed frequency-domain estimator is better in terms of both the estimation MSE and resulted BER compared with the Fusco's time-domain estimator. This concludes that the proposed estimator is better for the uplink system.

REFERENCES

1. Hamid Saeedi-Sourck ,Yan Wu ,J.W.M. Bergmans , Saeed Sadri , Behrouz Farhang- Boroujeny " Low complexity carrier frequency offset estimatation for multiuser offset qam filter bank multi carrier systems uplink " IEEE Commun. Mag., 2012, pp. 978-1-4673- 0990-5 pages, 12

2. B. Farhang-Boroujeny, R. Kempter, "Multicarrier communication techniques for spectrum sensing and communication in cognitive radios," IEEE Commun. Mag., vol. 48, no. 4, pp. 80-85, 2008.

3. B. Farhang-Boroujeny, and C.H. (George) Yuen, "Cosine-modulated and offset QAM filter bank multicarrier techniques: a continuous-time prospect," EURASIP Journal on Applied Signal Processing, 2010, vol. 2010, Article ID 165654, 16 pages, 2010. doi:10.1155/2010/165654.

4. H. Saeedi-Sourck, Y. Wu, J.W.M. Bergmans, S. Sadri, B.Farhang-Boroujeny "Sensitivity analysis of offset QAM multicarrier systems to residual carrier frequency and timing offsets", Elsevier Signal Processing, vol. 91, pp. 1604-1612, Jaun. 2011.

5. T. Fusco, A. Petrella and M. Tanda,"Data-aided time domain synchronization for filter-bank multicarrier systems," Proc.of EUSIPCO 2008, Lausanne, Switzerland, August 25-29, 2008.

6. T. Fusco, A. Petrella, and M. Tanda, "Data-aided symbol timing and cfo synchronization for filter-bank multicarrier systems," IEEE Trans. on Wireless Commun., vol. 8, no. 5, pp.2705-2715, 2009.

7. T. Fusco, A. Petrella, and M. Tanda, "Joint symbol timing and CFO estimation for OFDM/OQAM in multipath channels," EURASIP Journal on Advances in Signal Processing, vol. 2010, article ID 897607, 11 pages, doi:10.1155/2010/897607.

8.   P. Amini, B. Farhang-Boroujeny, "Packet design format and decision direct tracking methods for filtar bank multicarrier systems," EURASIP Journal on Advances in Signal Processing, vol. 2010, article ID 307983, 13 pages, doi:10.1155/2010/307983.

9. B.M. Morelli, C.C.J. Kuo, and M.N. Pun, "Synchronization techniques for orthogonal frequency division multiple access (OFDMA): A tutorial review, " Proc. of the IEEE, vol. 95, no. 7 , pp. 1394-1427, July 2007.

10. A. Larmo, M. Lindstrom, M. Meyer, G. Pelletier, J. Torsner, and H. Wiemann, "The LTE link-layer design," IEEE Commun. Mag., vol. 47, no. 4, pp. 52-59, April 2009.

11. T. Fusco, A. Petrella, and M. Tanda, "Joint symbol timing and CFO estimation in multiuser OFDM/OQAM systems," in Proc. of the 10th IEEE Workshop on Signal Processing Advances in Wireless Communications(SPAWC09), pp. 613-617, June 2009.

12. P. H. Moose, "A technique for orthogonal frequency-division multiplexing frequency offset correction," IEEE Trans. onComm., Vol.42, No.10, Oct. 1994, pp. 2908-2914.

13. N.J. Fleige, Multirate Digital Signal Processing, John Wiley & Son Ltd., 1994.

14. H. Saeedi-Sourck, Y. Wu, J.W.M. Bergmans, S. Sadri, B. Farhang-Boroujeny "Complexity and performce comparison of filter bank multicarrier and OFDM in uplink of multicarrier multiple access networks ," IEEE Trans. on Signal Process., vol. 59, no. 4, pp. 1907-1912, April 2011.

15. B. Le Floch, M. Alard, C. Berrou, "Coded orthogonal frequency division multiplex," Proc. of the IEEE, vol. 83, no.6, pp. 982-996, 1995.