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An adaptive channel estimation scheme based on redundancy minimization for filtered OFDM networks

Ahmad Hasan, Sam Motakabber, Mohamed Hadi Habaebi, Farhat Anwar
Department of ECE, Faculty of Engineering, International Islamic University, Kuala Lumpur, Malaysia

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ABSTRACT

Filtered orthogonal frequency division multiplexing (F-OFDM), a technology which is being considered as a promising platform for beyond 4G era is expected to help deliver the new features at millimeter wave in the new 5th generation of cellular communication. Some of its key features notably better spectral utilization, enhanced throughput and immunity to interference can be enabling for the new cellular standards. These features of filtered OFDM comes with strict requirements of filter design, guard tone managements, and efficient channel state information harness. This paper is intended to propose an intuitive channel estimation scheme which will allow efficient acquisition of channel state information (CSI) through exploiting the redundant steps of the conventional pilot training-based algorithms and by also using an adaptive weight to expedite the minimization of the error between the estimated values and the actual values. Various simulations will follow to demonstrate the superiority of the scheme over traditional pilot-based algorithms and thus prove its utility in the current 5G cellular era.

Corresponding Author:

Ahmad Hasan
Department of ECE, Faculty of Engineering, International Islamic University
Gombak, Kuala Lumpur, Malaysia
Email: h.ahmad@live.iium.edu.my

1. INTRODUCTION

Filtered orthogonal frequency division multiplexing (F-OFDM) is increasingly becoming a worthy candidate for the current 5G cellular communication because of it's obvious advantages like flexible cyclic prefix (CP) length, adjustable sub-bands, better noise immunity and so on [1]-[4]. Fundamentally F-OFDM can be used with all the networks that are compatible with the OFDM scheme. As it is commonplace in 5G networks to use some kind of filtering, the critical point is to determine the optimal type of filtering or the process of how filtering works [1], [5], and [6]. Usually in conventional OFDM networks majority of the interference problems arise due to the nonexistence of any band separation, which is why F-OFDM was proposed at the first place [2], [7]. Because each sub-bands in F-OFDM has different bandwidth, systems that are opting for F-OFDM instead of general OFDM can use different CP lengths and also different sub-band modulation scheme which is immensely useful for rapid varying traffic [7]. With combination of these kind of sub-band flexibility and subcarrier spacing, very flexible structure of subframe can be created that is able to carry various types of service data within the same subframe. For instance, nowadays it is commonplace to use cellular data for IoT devices which are gaining popularity very rapidly, the data of different IoT devices can be easily transmitted along with the numerous user data specified in the 5G releases [6]. Since the total bandwidth is segregated into sub-bands and each one filtered separately allowing us to configure each sub-band with their own waveform parameters which is set considering the actual traffic state, also considering the high path loss and blockage of the millimeter wave it is very critical for the transmitter and the receiver have the ability to separate the data from the interference [8]. At the receiver these various sub-bands are combined to complete the transmission process, meaning that this aggregated 5G waveform would support dynamic soft parameter setup for the aerial interface for various traffic loads [8], [9].

The sub-band filter located on top of the CP of the original OFDM signal doesn't change the length of the sub-band since it's compensated as padding in the transmission. Because of the division in sub-bands, the length of the guard tone has to be lessened in order to make space for the transmitted data. But because of this separation by sub-bands, one of it's advantages is that it can support asynchronous inter-band transmission [2], [9]. So in short; unlocalized spectrum, fixed no of subcarrier spacing and CP, and also time domain adjustment are the main disadvantages which can be overcome with the application of F-OFDM. Another important feature of the F-OFDM is the backwards compatibility. As mentioned before, all of the modulation and networking aspects that are subjected to the OFDM can also be switched to F-OFDM filtered network [3], [10]. The co-existence of sub-bands with own OFDM preference and good out-of-band rejection are also quite attractive features for current cellular structure [1], [2].

There are some implications though which are the concern for integrating F-OFDM in 5G cell structure. For instance, minimally truncated filter with fixed window is required to obtain the aforementioned benefits [9]. However, frequency domain filtering operation is usually applied for simple implementation [11]. Usually in most research works, double FOFDM links are implemented, if there are switchable filtering options, i.e. if the filter functions are turned off, the links will act like generic OFDM, otherwise they will be filtered. Both of the links usually are considered as separate OFDM variables, including CP and time to leave (TTL) duration and also subcarrier spacing. Furthermore, nearest frequency sub-bands are more often utilized by the dual links, and lastly guard tones are treated as reserved between the two sub-bands.

Compared to the legacy long term evolution (LTE) the 5th generation technology allows more diverse traffic situations [8], [12]. Considering these traffic scenario changes it is intuitive to dynamically setup waveform variables while one still can retain the features of the legacy CP-OFDM. This way, utilizing sub-band filtering applied on the traditional CP-OFDM it is viable to achieve the needs of the millimeter waveform for 5G networks[13]. In order to summarize, the novelty of this work can be enlisted:

- Adaptization of the legacy pilot based statistical estimation schemes. The algorithm works for any statistical scheme like the least squares (LS), min mean square error (MMSE), and linear min meansquare error (LMMSE).
- Intuitive reduction of redundancy before the removal of CP. This offsets any additional overhead.
- A simple yet attractive estimation scheme for the 5G era.

The contribution of this paper can be broadly divided into three points:

- An intuitive method that relies on adjustable weitght factor for the estimation of the channel parameters instead of a static weight scheme which has substantial effect on accuracy.
- A redundancy-free scheme that doesn't suffer from any substantial accuracy loss but reduces the system overhead.
- A scheme which will be vital for post LTE era in terms of data processing speed and accuracy.

The rest of the paper is divided into four sections. The next section is the methodology which discusses the foundation of the proposed algorithm and the workflow. The result section is dedicated for the demonstration of the superiority of the proposed method over trending methods via various simulations. The conclusion section summarizes the features and limitations of this work and also presents some potential research aspects. And finally, the reference sections contain the works cited in this paper.

2. PROPOSED METHOD

In this research, a flat block-fading F-OFDM system is assumed which is equipped with t, r – as the no of transmitting and receiving antennas respectively. A block-fading system means that the fading is considered ubiquitous during the transmission of each symbol. The distinct property of F-OFDM that allows it to contribute separate filters for each subband makes the system more specific but requires separate phase and amplitude compensations[14]-[16]. Since system bandwidth is divided into sub-bands and each one filtered separately, then each sub-band can be configured with different waveform parameters set according to the actual traffic scenario, especially considering the high path loss and blockage of the milimeter wave it is very critical for the transmitter and the receiver have the ability to separate the data from the inteference [13], [17]. With comination of these kind of subband flexibility and subcarrier spacing, very flexible structure of subframe can be created that is able to carry various types of service data within the same subframe. And of course different waveform parameters can be set for different sub-frames providing even more flexibility than conventional OFDM.

In our model, we attempt to increase the CP length by N_g, so if the no of subcarriers is n we can represent each OFDM symbol in the system as:

$$s(n) = \sum_{l=0}^{L-1} s_l\left(n - l(N - N_g)\right) \quad (1)$$

Where L is the no of OFDM symbols. Also leading from (1) a subset of symbols among them will be:

$$s_l(n) = \sum_{m=0}^{m+M-1} d_{l,m} e^{\frac{j2\pi mn}{N}}, N_g \leq n \leq N \quad (2)$$

In (2) $d_{l,m}$ is the data of the first l mapped OFDM symbols mapped on the subcarriers of the symbol number m which is the effective subcarrier mapping range. We know that before the filtering operation, each subband of the F-OFDM system can be regarded as OFDM type [18], [19]. And hence we can express any symbol in the i-th subband as:

$$x_i(n) = s_i(n) \times f_i(n) \; i = 1,2,3 \ldots k \quad (3)$$

Where $s_i(n)$ is the unfiltered data symbols of the ith subband and $f_i(n)$ is the impulse response of the transmit filter on that subband. The symbol in (3) generated by different subbands pass through the noisy channel and this effect can be shown in time domain.

$$x(n) = \sum_{i=0}^{k-1} x_i(n) \quad (4)$$

Again from convolution theory we can write:

$$\begin{aligned} r(n) &= x(n) \times h(n) + z(n) \\ &= \sum_{i=0}^{k-1} x_i(n) \times h(n) + z(n) \\ &= \sum_{i=0}^{k-1} \{(s_i(n) \times f_i(n) \times h(n) + z(n)\} \end{aligned} \quad (5)$$

Which is derived with the data from (4), $h(n)$ here is the channel impulse response and $z(n)$ is the additive white gaussian noise (AWGN). The receiver used by the F-OFDM system has a matched filter $f_i^*(-n)$ which has a filter in transmitter to decouple each subband signal. This can be characterized as:

$$\begin{aligned} r_i(n) &= r(n) \times f_i^*(-n) \\ &= f_i^*(-n) \times \sum_{i=0}^{k-1} s_i(n) \times f_i(n) \times h(n) + f_i^*(-n) \times z(n) \end{aligned} \quad (6)$$

Where $r_i(n)$ is the F-OFDM symbol with the ith subband filtered by the receiving terminal. Then each subband will go through the same process described in (6) as those in the OFDM systems. Because of this filtering process it's easier in F-OFDM to achieve specific goals with specific filter blocks and without losing synchronization [2], [20], and [21]. Having said that it makes sense to use F-OFDM instead of conventional OFDM system where large amount of user data has to be sent before any kind of communication between different users is established [22]. The proposed Algorithm 1 summarizes all the points discussed above. In the beginning it initializes and fixes the indices for data and pilot (step 1 to step 3). The residue is calculated at step 4. Step 5 to step 6 are the decisive parts where the matrices are updated according to the comparison. And in the last step we get the matrices for impulse response.

Algorithm 1. Proposed algorithm

Input: $\bar{x}$, $\bar{y}$, $\bar{z}$
Output: $\hat{h}$ for k attempts
Initialization: set residual $r_0 = \bar{y}$; $\hat{h} = 0$; $i = s$; $k = 1$; stage = 1
while ≠ (stopping condition)
- Step 1: start; initial select $s_k = max(|h * r_{k-1}, i|)$
- Step 2: create test vector $L_k = \emptyset \cup s_k$
- Step 3: finalize test vector $L = \max(|h_{L_k}^*|, i)$
- Step 4: residual $r = \bar{y} - h_L h_L^* \bar{y}$
- Step 5: if $\|r\|_2 < \|r_{k-1}\|_2$ → step 7 else → step 4 ; $i = i + 1$
- Step 6: update $L = i \times s$ or $L_k = L$; $r_k = r$; $k = k + 1$
- Step 7: $\hat{h} = h_L^* \bar{y}$; end loop ; Stop

To make it more comprehensible, it is taken that the carriers are inter symbol interference (ISI) free and the channel has a flat-fading response. ISI free means the symbols are synchronized properly in time domain and flat-fading means the fading can be accounted as constanct throughout the transmission. This simplifies the whole process. The entire process can be educated from Figure 1.

Hence, the channel can be modelled as a narrowband one which facilitates the estimation of phase. The out of bound emission (OOBE) has been a key problem in conventional OFDM systems because at least 10% of the allocated bandwidth has to be used as a guard band to allow to mask the signal leakage [16], [23], [24]. Also, to achieve an ISI free transmission, very stringent signalling is required which calls for heavy synchronization signalling [25]. This need is also avoided since the subcarriers are already divided into subbands and has separate CP length and also spacing which gives them immunity from ISI [26].

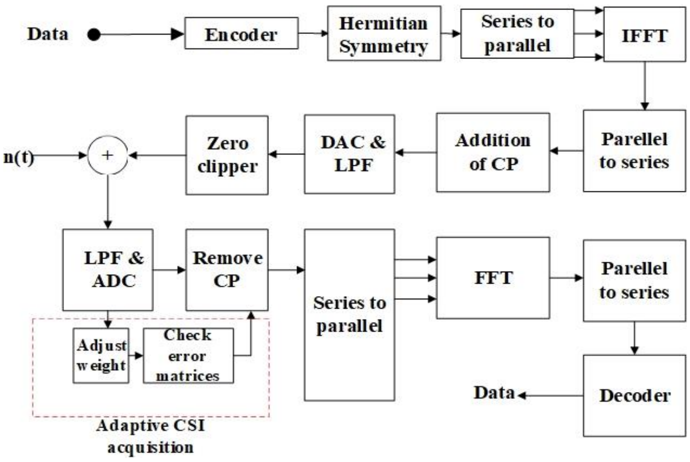

Figure 1. Diagram for the adaptive CSI acquisition process (note that for the sake of simplicity the process for only one sub-band is shown)

3. RESULTS AND DISCUSSION

In this simulation paradigm, Matlab Simulink(R) software is used. For the setup, upto 1000 subcarriers were used and each subcarrier is assumed ideal i.e. ISI and inter channel interference (ICI) free. And because of the orthogonality we can also remove adjacent channel interference (ACI) and co-channel interference (CCI) from our considerations [27]. For each simulation, only either no of subcarriers or no of taps per channel were changed. All of the simulations are based on a block fading assumption meaning that any kind of impairment caused by the environment is constant for one block of signal.

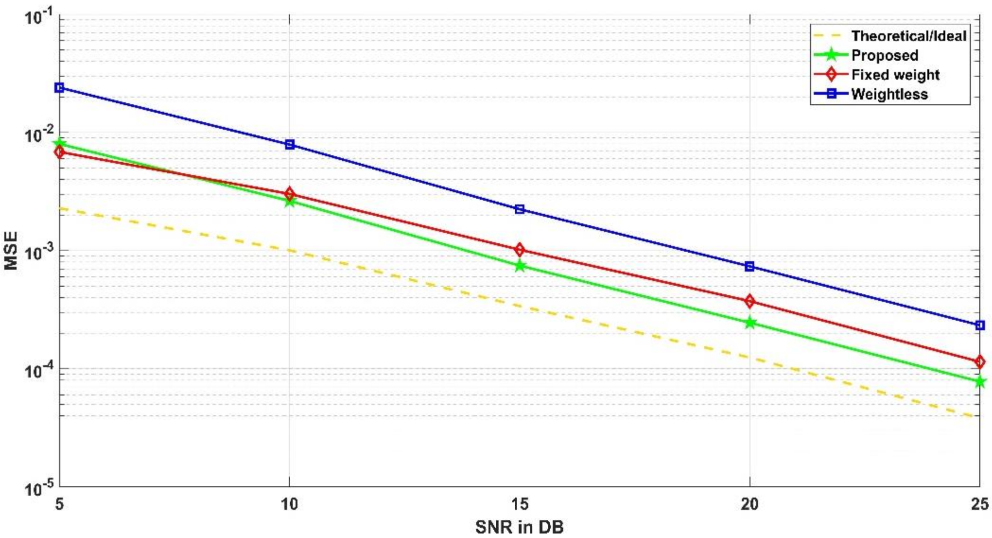

Figure 2. Mean square error comparison of proposed scheme with various other methods

From the different results, one can claim that the consideration of an adaptive weight function in determining the phase and amplitude of a signal block not only yields better performance in terms of mean square error as can be seen from Figure 2 but also reduces the overhead at the equalization since most of the out of band signal are already clipped at the time of acquiring channel state information (CSI). Also can be seen from Figure 3 that in terms of the symbols sent in packets or quanta the packet error rate is also better compared to the legacy OFDM and conventional F-OFDM methods and can be further ameliorated by adding more taps in the filter at the receiver [28]. Although adding more taps will require more strict symbol synchronization, but it is not the target of this study.

On the other hand it can be seen from Figure 4 that compared to conventional estimation schemes the proposed scheme boasts a significant offset of performance in terms of bit error rate due to a good estimation lower bound. The simulation time was proportional to the no of subcarrier taken. For this reason, it was kept at an optimal value for the setup. Keep in mind that this method also uses adaptive weight factor to minimize the estimation error quicker than conventional fixed weight method which is simpler in sense but needs more iterations [29].

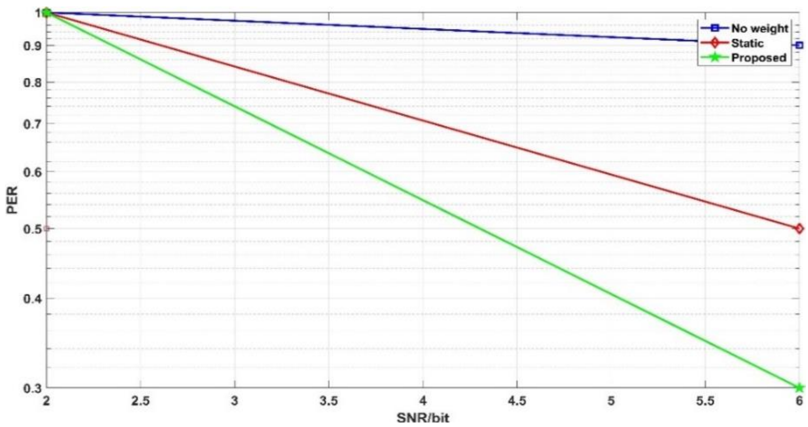

Figure 3. Packet error rate comparison

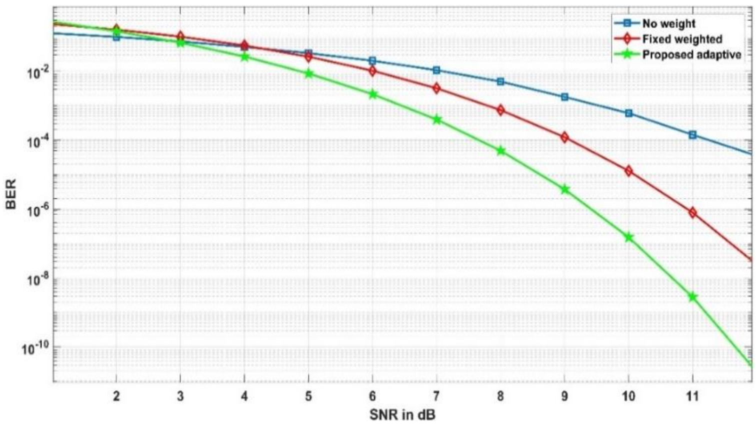

Figure 4. Bit error rate comparison between different schemes

4. CONCLUSION

In this paper an intuitive channel estimation method which exploits the redudancy in the pilot-based algorithms has been proposed. The result is a scheme which arguably has the same effect on system overload while minimizing the estimation error. From the algorithm one can also confer that because of the reduction of the redundancies in the algorithm which contribute very little to the performance the bit processing speed is also enhanced. Demonstrating analytically the effect of adaptive weight on iteration scheme has been left as a potential research work. Since in the post LTE 5G era the cellular standards have changed and now a lot more user data has to be processed everytime a user registers in a network, even a small change in signal processing performance can lead to substantial network promptness.

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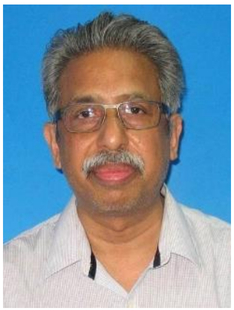
BIOGRAPHIES OF AUTHORS

Ahmad Hasan Ahmad Hasan was born in Mymensingh, Bangladesh and completed his Degree at Rajshahi University of Engineering & Technology (RUET) in 2018. He started his Masters program at International Islamic University Malaysia (IIUM) Gombak campus in February 2020. During his degree his research included hollow fiber optics especially NC-HCF. Now he is doing his Masters in wireless communication. His research interests include channel estimation, adaptive CSI acquisition, and sparse signals. Currently he's pursuing his Masters at Gombak campus Kuala Lumpur. He can be contacted at email: h.ahmad@live.iium.edu.my.

Sam Motakabber Sam Motakabber who was born in Naogaon, Bangladesh received the BSc (Honours) and Master's degrees from the University of Rajshahi in 1986 and 1987, and Ph. D from University Kebangsaan Malaysia in 2011. He served as a scientific officer at the Bangladesh Atomic Energy Commission, and Bangladesh Scientific and Industrial Research, Dhaka from 1991-1992 and 1992-1993, respectively. He started his teaching career as a lecturer in the Department of Applied Physics and Electronics, University of Rajshahi in 1993. The following year he was appointed an Assistant Professor in the same department. He joined as an Associate Professor in the Department of Computer and Communication Engineering at International Islamic University Chittagong in 2003; also served as Head of the Department and Dean of the Engineering Faculty. He served as an Associate Professor in the Department of Applied Physics and Electronic Engineering from 2008 to 2012 at the University of Rajshahi. Dr. Motakabber joined as an Assistant Professor in the Department of Electrical and Computer Engineering at the International Islamic University Malaysia (IIUM) in 2012. He's currently teaching as an Associate Professor there. He can be contacted at email: amotakabber@iium.edu.my.

Mohamed Hadi Habaebi Professor. Dr. Mohamed Hadi Habaebi, a graduate (1991) of the Civil Aviation and Meteorology High Institute, Tripoli-Libya, started his career as a Radio Engineer pacing gradually through several positions of senior RF and Microwave Engineer, Technical Manager and finally CTO in several government and private companies working for the Telecom sector in Tripoli-Libya, and Kuala Lumpur, Malaysia, throughout 1991 -2003. He obtained the Master of Science (RF, Communications Engineering) from UTM in 1994 and Ph. D in Computer Communications Engineering from UPM in 2000. He was a visiting lecturer at UPM from 2000 to 2003 where he joined the Department of Computer Engineering, University of Tripoli-Libya, the same year and was an Associate Professor until 2011 heading the Students Affairs and Examination Unit for three consecutive years. He joined the department of Electrical and Computer Engineering, IIUM, Gombak in 2011. He was the Post Graduate Academic Advisor of the department since then until December 2017. He has been the Head of Department since January 2018 until 30 June 2021. He can be contacted at email: habaebi@iium.edu.my.



Farhat Anwar Professor Farhat Anwar was awarded a Commonwealth Scholarship to pursue his Ph. D in Electronic and Electrical Engineering at the University of Strathclyde, UK and obtained the degree in 1996. Earlier, he earned his Master's and Bachelor (with Honours) degrees in Applied Physics and Electronics from the University of Dhaka, Bangladesh. Prof. Anwar started his teaching career as a lecturer at the Department of Applied Physics and Electronics, University of Dhaka, Bangladesh in 1988. He has been with IIUM since 1999 and is currently working as a Professor in the Department of Electrical and Computer Engineering (ECE). He was appointed Head of the ECE Department from July 2003 to June 2005, Postgraduate Academic Advisor for ECE from June 2010 to May 2012, Internal Reviewer for the CIE programme (2007- 2008) and Student Advisor for the CIE programme (2001-2003). He is also actively involved as a member of the Accreditation Committee, Curriculum Committee and Board of Studies for CIE and CE programmes of the ECE department. Prof. Anwar is the coordinator of the Computer Networking Research Group. Prof. Anwar is a member of many professional organizations including IEEE and ACM. He can be contacted at email: farhat@iium.edu.my.