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OFDM Channel Estimation Enhancement using Null Subcarriers

Abdulmunem Ahmed Mohammed *

Department of Communications Engineering
College of Engineering
Diyala University
Diyala
Iraq

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A B S T R A C T

Orthogonal frequency division multiplexing (OFDM) is one of the popular techniques for high data rates nowadays. However, the channel transfer function estimation for OFDM based systems is essential, to increase the bit rate with low bit error rate (BER) degradation. Numerous algorithms are provided in the literature such as the pilot assisted channel estimation methods. This paper suggests to making use of the null subcarriers, such as the cyclic prefix interval, to make more occupation of the pilot subcarriers. Least squares estimator has been employed to estimate the channel frequency response. However, simulation results, using MATLAB programming, show that the BER performance has been improved, where the required signal to noise ratio (SNR) has been reduced by approximately 4dB, for different baseband mapping.

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تحسين تقدير قناة النقل لانظمة مضاعفة تقسيم التردد المتعامد باستخدام الحوامل الجزئية الفارغة

الخلاصة

مضاعفة تقسيم التردد المتعامد (OFDM) هي واحدة من التقنيات الشائعة لمعدلات البيانات العالية في الوقت الحاضر ومع ذلك، فإن تقدير وظيفة قناة النقل لأنظمة OFDM أساسي لزيادة معدل البت مع نسبة خطأ بت منخفضة (BER). تتوفير خوارزميات مختلفة في مجموعة الكتاب اتمثل طريقة التحكم ساعدت في طرق تقدير القناة. يقترح هذا البحث الاستفادة من الحوامل الجزئية الفارغة مثل فترة الفاصلة البادئة الدورية، لكسب المزيد من استغلال التحكم المساعد للحوامل الجزئية. قد طبقت مقدر أقل مربع لتقدير استجابة تردد القناة. ومع ذلك، أظهرت نتائج المحاكاة أن أداء BER قد تحسنت، حيث تكون نسبة الإشارة المطلوبة إلى نسبة الضوضاء (SNR) قد اخفضت بنسبة حوالي 4 ديسيبل لمختلف مخططات النطاق الاساسي.

1. INTRODUCTION

Modern wireless communication systems have been used in numerous applications, which should support high data rates and good quality of service. The orthogonal frequency division multiplexing (OFDM) has been proved to be the most appropriate based communication system. Hence, OFDM has been adopted in different modern communication systems, like local and metropolitan area networks [1], long term evolution (LTE) and LTE-Advanced (LTE-A) [2], due to the, almost, optimum spectrum usage, where high data rates can be supported. That is, wireless multipath propagation channels immunity, almost-optimum spectrum utilization, resistivity to narrowband-interferences are answer to the purposes of using OFDM technology [3].

However, speaking about wireless-channels, in general, wireless-channels are time-variant and frequency-selective, where in other words, the propagation channel in practice has more than one path between the transmitter and the receiver, thus, there is multi-propagation paths, which leads to frequency-selective fading channel. Furthermore, it is possible the transmitter and/or the receiver is not fixed at a certain location, in other words, there is a mobility, then the channel will behave as time-selective channel. To put it another way, the frequency selective propagation channel can be configured as power-delay-spread, while the time fading is managed as Doppler frequency [3].

According to the aforementioned scenarios, OFDM signals may overlap with each other causing intersymbol-interference (ISI) and intercarrier-interference (ICI), therefore, guard interval can be used to mitigate this

* *Corresponding author: E-mail* : abdulmunemmohammed@gmail.com

problem. This guard interval is implemented using cyclic prefix, which has to be longer than the order of the propagation channel as stated in [4-6]. Thus, the channel can be supposed to be invariant within the entire interval of the OFDM symbol, then, the orthogonality of the subchannels will be maintained [4].

Consequently, to alleviate the variations in the channel parameters, and to improve the BER performance, there should be a method to determine the channel impulse response (CIR), or the channel state information (CSI) which is also called channel frequency response (CFR). Thus, channel estimation process is essential. It is within reach to ignore channel estimation process, but there will be 3-4 dB losses in the transmitted power if differential detection was used as well as data limitation problem [3,7], that is, the coherent demodulation can provide better performance, in term of power consumption and enhanced data rates.

Several channel estimation concepts have been addressed in the literature [8,9] where in [8] a survey of channel estimation methods are given up to year 2007, while in [9] channel estimation methods were stated up to year 2014. Channel estimation process can be either blind or non-blind. Blind channel estimation schemes are those methods which do not employ pilot subcarriers, while non-blind algorithms employ pilot subcarriers. In pilot-subcarriers channel estimation algorithms, there are two schemes for the pilot-subcarriers distribution, block and comb pilot subcarriers scenarios. The block scenario is used when there is, almost, no mobility, where the entire subcarriers of the OFDM symbol will be completely occupied by pilot subcarriers, and then, such block of pilots will be transmitted periodically in a predefined time period. This criterion is helpful for low mobility devices, in other word, the channel may not change for a period of time.

Hence, the need to transmit pilot subcarriers with each OFDM symbol has vanished. Unlike comb-distribution of pilot subcarriers, the pilots will be multiplexed with each OFDM symbol, as stated in Fig. 1, equally spaced [10]. The comb distribution of pilot subcarriers is effective when the channel varies rapidly [11]. That is, for the last case, there must be aggressive channel estimation to get rid of BER performance degradation.

As it can be seen in Fig. 2, the OFDM signal constructed by first, mapping (MPA) the binary data to one of the constellation families, say M-QAM or M-PSK, then, the signal will be converted to parallel format, a pilot insertion operation will be achieved alongside with the frequency to time-domain conversion operation, then will be transmitted to the channel after inserting the cyclic prefix, CPI in Fig. 2, and will be removed in the receiver before the signal being corrected, CPR in the receiver part of Fig. 2. Furthermore, in Fig. 2, S/P and P/S are serial to parallel and parallel to serial operations, respectively. The modulation and demodulation operations have been achieved using the inverse fast Fourier transform (IFFT) and fast Fourier transform (FFT), respectively. However, in Fig. 2, the channel estimation can be accomplished using the least squares (LS) algorithm. Conventionally, the channel estimation will be processed for the pilot subcarriers, then, the data subcarriers will be interpolated to obtain the complete CFR.

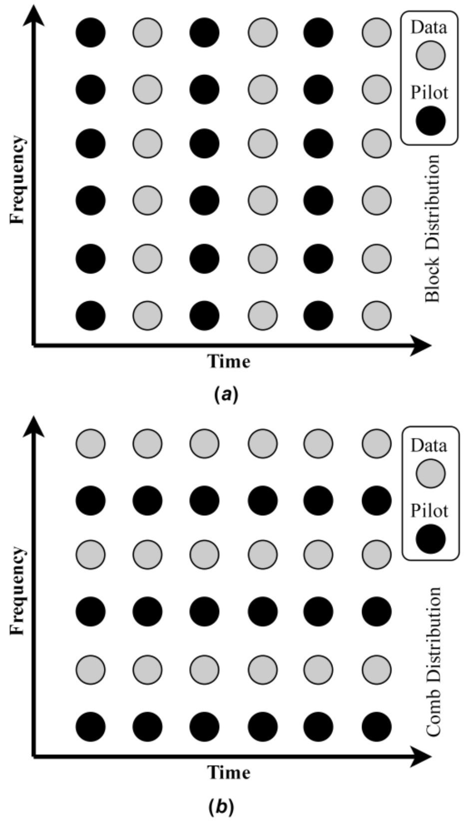


Fig. 1. Block and comb pilot distributions. The gray circles stand for data subcarriers, and the black circles represent the pilot subcarriers. (a) correspondsto the block pilot type and (b) configures the comb type pilot subcarrier distributions.

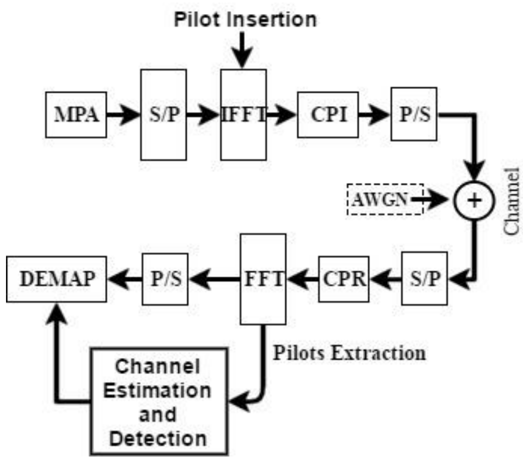


Fig. 2. OFDM system with pilot insertion/extraction and CP insertion and removal [3].

It is evident that the CP is to keep the orthogonality of the subcarriers and to remove the ISI due to channel impairments. However, CP will be removed before the conduction of the channel estimation process. That is, an energy waste due to this null subcarrier, where CP is considered as null subcarriers as well as the DC subcarrier or the zero subcarrier. The rest of this paper has been organized as follows; the next section is preserved for the literature review of related works, then OFDM system and the channel models description, afterword, our suggested approach will be presented, then the discussion of the results will be shown, last but not least, last section will conclude our work.

Amo in [12] displayed a proposition to expand the limit of Down-Link transmissions in LTE like frameworks. The increase of the information rate is accomplished with the aggregate or fractional concealment of the CP, which requires the utilization of a variable number of tests without passing on any data. The proposition depends on an iterative cancelation of the fundamental disabilities that the CP concealment assumes, the Inter Symbol and Inter Carrier Interferences. The obstruction relief methodology requests satisfactory direct estimations gotten in two distinct stages, however, the limitation of this method is the arising of the ISI and ICI interferences.

Amo [13] delivered a technique to enhance the channel estimation, within the sight of ISI and ICI occasioned by a lacking cyclic prefix, in other words, within the shorter CP scenario. The upgrade is achieved by the utilization of an iterative joint estimation methodology that progressively drops the impedances situated in the preface of the OFDM outline, which is utilized for the joint estimation and at first contains the obstructions due to a CP shorter than the channel length, thus, an increment in the computational complexity of the receiving part of the OFDM system will be the main drawback.

On the other hand, Li [14] explored asset designation in OFDM based cognitive radio networks with cyclic prefix control exchange. Thus, the CP could be shorter than the traditional size and could make use of its power.

Bin [15] has proposed to reduce the size of this CP, or null subcarrier, such that the wasted energy can be reduced without affecting the BER performance, with orthogonality maintaining of the OFDM symbol's subcarriers.

In this paper we suggested and simulated a method based on [15] that we have been motivated to reduce the transmitted energy of the null subcarriers as well as getting benefits of these samples, CP in our work. Thus, the subcarriers can be used to enhance the BER performance, if these null subcarriers have been occupied by pilot subcarriers, in this case the interpolation operation could produce outshine accuracy of the channel state information.

2. OFDM SYSTEM AND CHANNEL MODEL METHODOLOGY

OFDM is a multicarrier modulation scheme, by which the frequency spectrum will be divided into multiple sub channels, where overlap is allowed [11], therefore the utilization of the frequency spectrum will be improved dramatically. Basically, the OFDM system can be achieved using the inverse discrete Fourier transform (IDFT), using the fast version (IFFT) [11]. Thus, OFDM can be descried mathematically as in Eq. (1) [5,11]:

$$g(n)=\sum_{k=0}^{N-1} G(k)e^{j2\pi\frac{kn}{N}},\ n=0,1\cdots,N-1 \tag{1}$$

where N is the number of OFDM subcarriers, G is the randomly drawn samples from M-QAM or M-PSK constellation mappings, and M is the mapping order. Cyclic prefix is not shown in Eq. (1). However, $g(n)$ will be sent to the receiver through multipath channel, after removing the cyclic prefix the signal will be converted back to the frequency domain,

$$G(k)=\frac{1}{N}\sum_{n=0}^{N-1} g(n)e^{-j2\pi\frac{kn}{N}},\ k=0,1\cdots,N-1 \tag{2}$$

As it has been stated, the cyclic prefix will remove the ISI and ICI, if the size of the CP part is longer than the channel impulse response. Then, the signal will be expressed as [5],

$$Z(k)=G(k)H(k)+W(k) \tag{3}$$

where $H(k)$ is the channel frequency response $W(k)$ is the additive white Gaussian nose in the frequency domain. Afterword, the pilot subcarriers $Z_p(k)$ will be taken out from the received signal, $Z_p(k)$, to determine the channel frequency response, $H(k)$. Consequently, the transmitted symbols $G(k)$ can be concluded as,

$$\hat{G}(k)=\frac{Z(k)}{\hat{H}(k)},\ k=0,1,\cdots,N-1 \tag{4}$$

where $\hat{H}(k)$ is the CFR estimated value. Then the binary input data will be recovered. In the next section, the null subcarriers, which are represented here by the CP subcarriers will be explored more to develop the suggested work.

3. NULL SUBCARRIERS UTILIZATION

Null subcarriers are generally bearing not useful information. Therefore, they are removed out at the receiver before the demodulation process by the DFT. Such subcarriers are the zero subcarrier and CP subcarriers. In this paper, the CP will be explored to make more utilization of them. CP samples, which they are a copy of the last N_{CP} samples of the original OFDM symbol appended to the beginning of the OFDM symbol, as shown in Fig. 3, will alter the linear convolution of the OFDM signal with the channel to circular convolution. The circular convolution helps to simplify the receiver design by employing single-tap equalizer in the receiver [16-18].

Bin [15] suggested to reduce the energy of the CP part, to save the transmitted energy up to 8%. However, in this paper, the CP samples will be filled partially with pilot subcarriers, to make the estimated channel parameters more accurate. The suggested system is shown in Fig. 4, where the operation of the cyclic prefix generation will not have changed as in the conventional systems, which based on OFDM signals, but the receiver will not take them out without making them more useful.

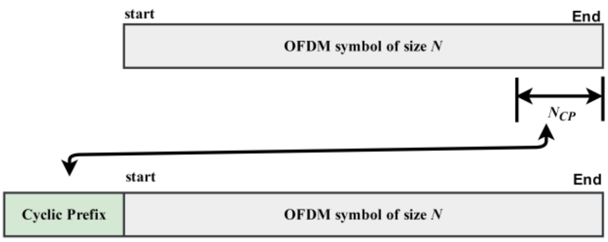


Fig. 3. Cyclic Prefix of an OFDM signal [14].

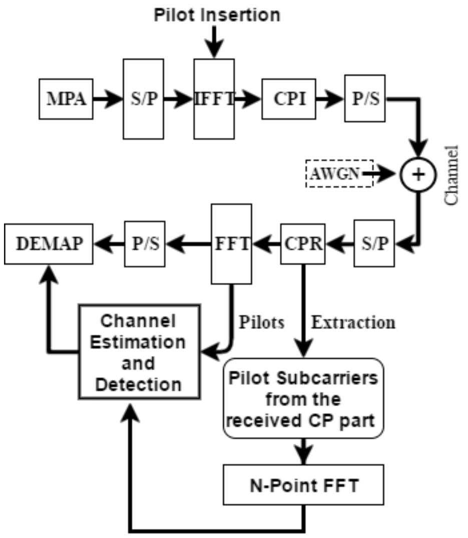
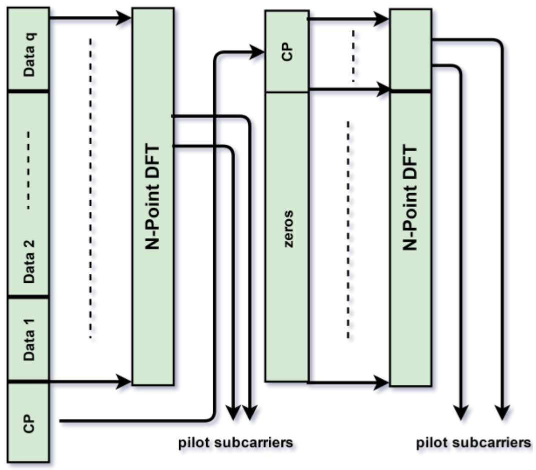


Fig. 4. OFDM system with more utilization of the CP interval.



4.

Fig. 5. Pilot subcarriers extraction from the original OFDM symbol and the cyclic prefix interval

In Fig. 4, the pilot extraction will be achieved in two steps; firstly, the pilots will be extracted from the normal OFDM received symbol, after removing the CP part, second, an extra pilot subcarriers are also available in the CP part, these pilots can be extracted as shown in Fig. 5, where an *N*-pints DFT will be employed in each pilot subcarrier extraction operation. As it has been stated previously, cyclic prefix is the last N_{CP} samples of the original OFDM symbol, which it has to be sent, appended at the beginning of the OFDM symbol. That is, CP is already has pilot subcarriers. This is true since the pilot insertion operation achieved in the transmitter part, the transmitter, of Fig. 2 or Fig. 4. Hence, the transmitter will not include other modification, only the receiver will have one more *N*-point DFT block, where the first N_{CP} samples will be available, while the other N-N_{CP} points will be zero inputs, as shown in Fig. 5.

It can see in Fig. 5 that the received OFDM symbol has $N+N_{CP}$ samples. To simplify the operation of the suggested system, the received OFDM symbol has been divided into multiple blocks, each block of data has the same size of the CP part, see Fig. 5, thus, the received symbol starts at CP block, which will be extracted out, then first data block up to data block number q. From data block number one to last data block, Data *q* in Fig. 5, the required size of the DFT block is *N*-points, and then, the extracted CP block will be fed to another DFT block of size *N*, where only the CP will be converted to the frequency domain, while the other inputs to the second N-points DFT will be zeros. Consequently, the frequency domain CP part will deliver more pilot subcarriers, which will be used to enhance the channel estimation process as depicted in Fig. 4.

The energy of the CP samples will be lower than the other samples of the OFDM symbols, as implemented in [15]. Thus, the same values of the pilot subcarriers will be defined in the receiver, that is, there will be energy saving of about 8% [15] as well as more pilot subcarriers will be available for channel estimation improvements. If the pilot spacing is 2, the size of the OFDM symbol is 64, and the CP part is of size N_{CP} = 16, then the number of pilot subcarriers of the CP interval, N_{CPp}, is 3. Therefore, the channel estimation process will be improved, where the interpolation operation will gain more pilot subcarriers, then the CFR will be more accurate, hence, the BER performance will be enhanced further as will be seen in the next section.

5. RESULTS AND DISCUSSION

In this section, the pilot subcarriers of the cyclic prefix interval will be included in the interpolation operation of the channel estimation process. Therefore, the BER performance will be enhanced significantly.

The least squares channel estimation will be employed to estimate the channel parameters, then a second order interpolation operation will be used to get the complete channel state information, where the pilot subcarriers due to CP part will be included in the interpolation operation. The simulation parameters of the proposed method will be an OFDM signal of size N = 1024, N_{CP} = 256, 16-Quadrature amplitude modulation (16-QAM) and 64-QAM as baseband modulation, mapping, four multipath and fading channel, and comb-type pilot subcarrier distribution, where the pilots will be equally spaced.

As stated in the last section, the transmitter part of the system has not further modification, where the pilot subcarrier insertion will be accomplished conventionally, but the receiver part will include one more *N*-DFT function. In Fig. 6, the BER performance depicts that the extended number of pilot subcarriers has achieved about 3dB reduction in the SNR, compared with the conventional number of pilot subcarriers.

Thus, the increased number of pilot subcarriers, due to the utilization of the cyclic prefix pilot subcarriers, has better performance, although the least squares channel estimator has been used in the channel estimation process.

That is, the conventional number of subcarrier's BER performance requires 36dB of SNR, to deliver the signal properly, while the suggested approach, with extending number of subcarriers using the CP part, requires 32dB. This reduction gain of SNR can be justified if the channel parameters of both approaches, traditional number of subcarriers and the extended one, are compared together.

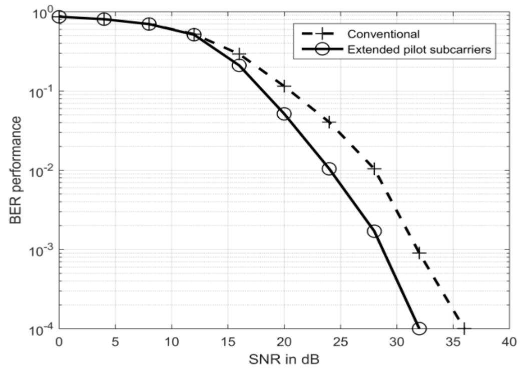


Fig. 6. BER performance for 16-QAM 1024-OFDM signals comparison of the extended number of subcarriers and the conventional one.

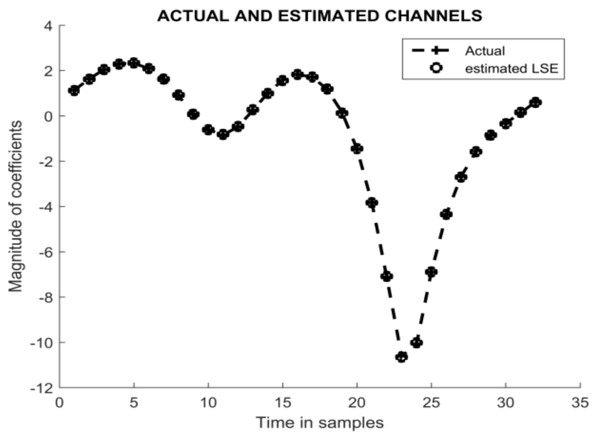


Fig. 7. Channel parameters estimation through four multipath fading channel for 16-QAM 1024-OFDM signals comparison of the extended number of subcarriers and the conventional one.

Hence, Fig. 7 shows the comparison of the estimated channel parameters and the actual one. It can be seen in Fig. 7 that the estimated channel parameters are identical to that of the actual one, that is why the BER performance has gained 4 dB in terms of SNR.

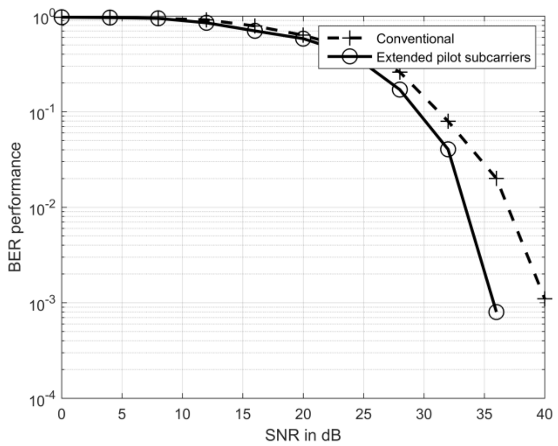


Fig. 8. BER performance for 64-QAM 1024-OFDM signals comparison of the extended number of subcarriers and the conventional one.

The same behavior can be seen in Fig. 8, where the BER performance of the same size of the OFDM signal, $N = 1024$, with four multipath fading channel, but for 64-QAM as the baseband mapping. It is shown in Fig. 8 that the SNR has been reduced by 4dB, from 40dB for the conventional number of subcarriers, to 36dB, for the extended number of pilot subcarriers. Furthermore, Fig. 9 explains the depiction of the estimated channel parameters compared with the actual channel parameters. It is shown that both parameters are identical to each other.

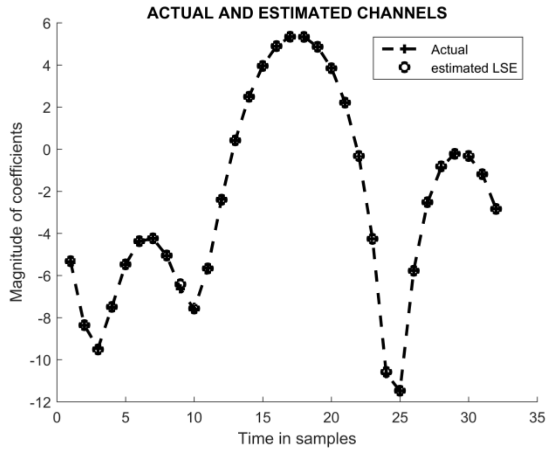


Fig. 9. Channel parameters estimation through four multipath fading channel for 64-QAM 1024-OFDM signals comparison of the extended number of subcarriers and the conventional one.

6. CONCLUSIONS

This work makes use of the cyclic prefix interval to enhance the channel estimation of the OFDM system. By making extension to the number of pilot subcarriers, using the cyclic prefix part, the interpolation operation produced improved results, which will create the channel frequency response. Thus, the BER performance has been improved by 4dB for the 16-QAM and 64-QAM baseband mapping of 1024 points OFDM signal, through four multipath and fading channel. There were no restrictions to the constellation order as stated above.

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