OFDM System with Variable Length CP

Ashwaq A. Abed Aljanaby *Malathe Salah AL-Deen*
University of Baghdad / College of Engineering
Email : ashwaq.aljanaby@yahoo.com *Email: malasdq73@yahoo.com*

Abstract:

Orthogonal Frequency Division Multiplexing (OFDM) is one of recent years multicarrier modulation used in order to combat the Inter Symbol Interference (ISI) introduced by frequency selective radio channel. The circular extension of the data symbol, commonly referred to as cyclic prefix is one of the key elements in an OFDM transmission scheme. This paper introduce a study of Variable Length Cyclic Prefix and its influence on the performance of the OFDM system under AWGN channel, flat fading channel and frequency selective channel with different path lengths. The 64-QAM modulation is used. The adaptation of CP is done with respect to the delay spread estimation of the channel which is evaluated by means of computer simulation. The simulation results shows that the performance of the system is increase as the number of path in channel increase, the length of CP must be at least equal to the length of the channel.

الخلاصة:

النظام المبني على التقسيم المتعدد المتعامد للترددات (OFDM) هو احد الأساليب المبنية لمكافحة التداخل المرمز (Inter-Symbol-Interference) الذي يحدث نتيجة القنوات الراديوية التي تتغير خصائصها مع الزمن بسبب الانتشار المتعدد المسار. (Cyclic Prefix) هو احد العوامل المؤثرة في مخطط نقل العناصر الممكن استخدامها في نظام التقسيم المتعدد المتعامد للترددات. هذا البحث يقدم دراسة تأثير تغير طول CP على أداء النظام في قنوات AWGN, Flat fading و Frequency selective بأطوال مسار مختلفة وباستخدام 64-QAM . يتم تكييف ال CP مع تقدير تاخير الامتداد للقناة والذي يتم عن طريق المحاكاة الحاسوبية. تبين نتائج المحاكاة إن أداء النظام يزداد مع زيادة عدد المسار للقناة وان طول الCP يجب على الأقل أن مساوي لطول القناة.

1. INTRODUCTION:

In digital wireless communication systems, transmitted information reaches the receiver after passing through a radio channel, which can be represented as an unknown, time-varying filter. Transmitted signals are typically reflected and scattered, arriving at the receiver through multiple paths. When the relative path delays are on the order of a symbol period or more, images of different symbols arrive at the same time, causing intersymbol interference (ISI). Traditionally, ISI due to time dispersion is handled with equalization techniques. As the wireless communication systems making transition from voice centric communication to interactive Internet data and multi-media type of applications, the desire for higher data rate transmission is increasing tremendously. The higher data rates, with narrower symbol durations experiences significant dispersion, requiring highly complex equalizers.

Orthogonal Frequency Division Multiplexing (OFDM), which is a multi-carrier modulation technique, handles the ISI problem due to high bit rate communication by splitting the high rate symbol stream into several lower rate streams and transmitting them on different orthogonal carriers. The OFDM symbols with increased duration might still be effected by the previous OFDM symbols due to multipath dispersion. Cyclic prefix extension of the OFDM symbol avoids ISI if the cyclic prefix length is greater than the maximum excess delay of the channel. Since the maximum excess delay depends on the radio environment, the cyclic prefix length needs to be designed for the worst case channel condition which makes cyclic prefix as a significant portion of the transmitted data, reducing spectral efficiency. cyclic prefix duration is determined by the expected duration of the multipath channel in the operating environment .One way to increase spectral efficiency is to adapt the length of the cyclic prefix depending on the channel environment. .(F. Sanzi and J. Speidel,2000, H. Schober, F. Jondral, R. Stirling-Gallacher, and Z. Wang,2001, Hűseyin Arslan and Tevfik Yűcek,2003,Krishna Sankar,2008).In this paper the Variable Length Cyclic Prefix of OFDM is analyzed under AWGN channel, flat fading channel and frequency selective channel for different number of path and cyclic prefix length

2. SYSTEM DESCRIPTION:

In the fig.1, a classical OFDM transmission scheme using FFT (Fast Fourier Transform) is illustrated. The input data sequence is baseband modulated, using a digital modulation scheme. Various modulation schemes could generally be employed such as BPSK, QPSK (also with their differential form) and QAM with several different signal constellations.(Werner Henkel ,2002) In our system, 64-QAM method is chosen in order to encode the binary information. Data is encoded „in-frame" (the baseband signal modulation is performed on the serial data, that is inside of what we name a , DFT frame", or equivalently an OFDM symbol). The data symbols are parallelized in N different sub-streams. Each sub-stream will modulate a separate carrier through the IFFT modulation block, which actually generates the OFDM symbol, performing the multicarrier modulation. A cyclic prefix is inserted in order to eliminate the inter-symbol interference. The data are back-serial converted, forming an OFDM symbol that will modulate a high-frequency carrier before its transmission through the channel. The radio channel is generally referred to as a linear time-variant system. To the receiver, the inverse operations are performed in order to estimate the transmitted symbols.(Marius Oltean ,2003).

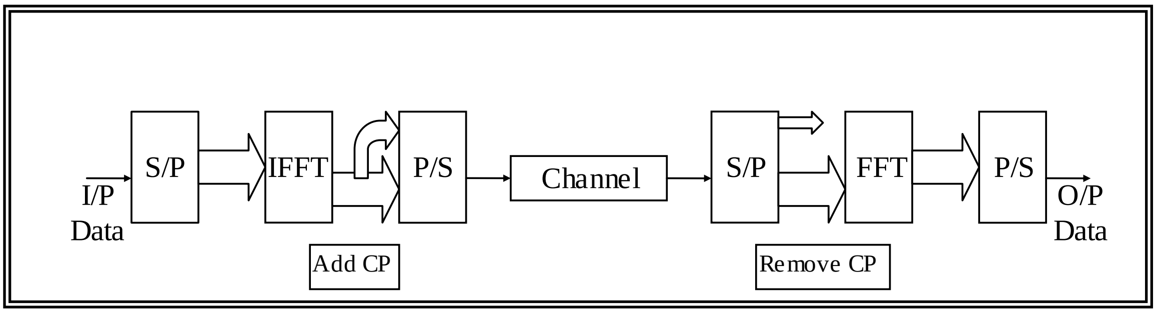
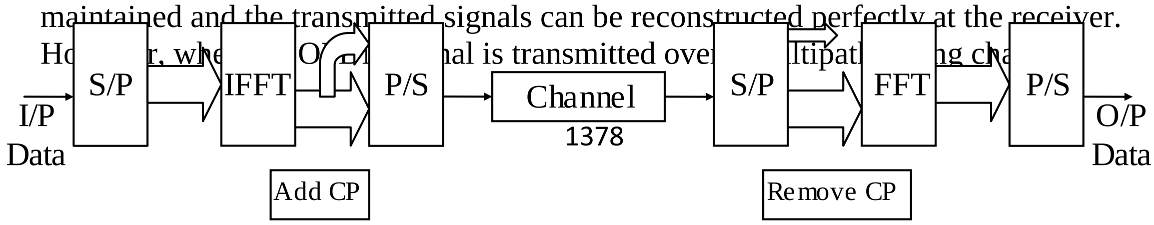


Fig.1 the block diagram of general OFDM system

3- CYCLIC PREFIX:

In a flat fading environment, the orthogonality between the subcarriers is maintained and the transmitted signals can be reconstructed perfectly at the receiver. Ho r, whe O nal is transmitted ove ltipat ng ch



the time dispersion of the channel leads to the loss of orthogonality between the subcarriers, and ICI and ISI will be introduced . For the purpose of eliminating the ISI, an empty guard interval could be introduced. As long as this guard interval is longer than the maximum delay spread of the channel, However the use of CP reduces the efficiency of the system by the factor N/ (N+*v*) "where *v* is the length of CP"(Buthaina Mosa Omran ,2007).The orthogonality between adjacent symbols on the same subcarrier will be preserved. However, the introduction of an empty guard interval will not help eliminate the loss of orthogonality between subcarriers caused by the multipath channel. This problem can be overcome by using a cyclic prefix (Thayaparan Thanabalasingham,2006).The cyclic prefix is constructed by copying the last part of the OFDM symbol and prefixing it as guard interval at the beginning of the OFDM symbol. The cyclic prefix consists of the last L samples of OFDM symbole that are copied in front of the data block, as we can see in the figure .2.

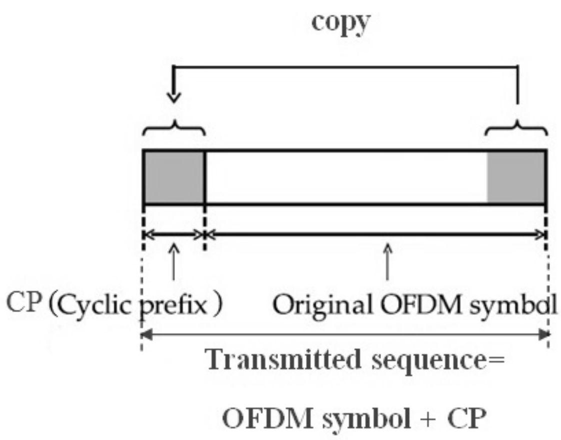


Fig .2 cyclic prefix (Marius Oltean, Miranda Nafornita,2003)

Generally, the radio channel exhibits both time variant and frequency selective characteristics. If we shall consider however that the channel parameters remain unchanged during the transmission of an OFDM symbol, the way that the transmission medium distorts each particular frame is similar to the distortion caused by an electric filter.(B.Sklar,1997) Under this assumption we can consider the equivalent discrete response of the channel as a linear FIR filter of order L, of which the equation is given below:

$$H(z) = \sum_{l=0}^{L} h(l) z^{-l} \qquad (1)$$

the equivalent baseband signal at the channel output can be obtained by the operation of convolution, as follows:

$$y_{cp}[n] = x_{cp}(n) * h(n) \qquad (2)$$

Discarding the L_{CP} samples from the received sequence, the remaining (useful) signal can be expressed as:

$$y(n) = x(n) \circledast h(n) \qquad (3)$$

Where " $\circledast$" denotes the circular convolution operator. The noticeable thing about the eq.3 is that the circular convolution preserves the temporal support of the signal. In our case , N transmitted signal samples convolved with L+1 channel impulse response samples will conduce to a received symbol of length N that will be used in the demodulation process. Since the circular convolution will not "spread" the signal, the receiver can independently process each data block. The interference from the previous transmitted blocks is totally eliminated through this operation of CP insertion/extraction. Furthermore, since x(n)= IDFT{X(k)} and taking into account the effect of the DFT demodulator, the received symbols Y(k) can be expressed as:

$$Y(k) = DFT\{IDFT\{X(k)\} \circledast h(n)\}, \qquad k=0,1..., N-1 \tag{4}$$

Since the DFT of a circular convolution of two discrete time signals will conduce to a spectral multiplication:

$$Y(k) = DFT\{IDFT\{X(k)\}\}.DFT\{h(n)\} \tag{5}$$

$$= X(k)\bullet H(k) \qquad k = 0,1,..., N-1$$

where H(k) represents the sampled frequency response of the equivalent baseband discrete channel, corresponding to the frequencies $w_k=k(2\pi/N)$. The crucial consequence of the relation above is that each modulation symbol X(k) could be recovered to the receiver by a simple point wise division operation, commonly referred to as a "one-tap frequency domain equalizer", as can be seen from the relation (6).

$$\hat{X}(k)=Y(k).H^{-1}(k) \qquad k=0,1,....,N-1 \tag{6}$$

3. Channel Estimation and Equalization

Channel estimation can be achieved by transmitting pilot OFDM symbol as a preamble. To design a channel estimator for wireless systems with both low complexity and good channel tracking ability, one must choose a way of how pilot information (data/signals known to the receiver) should be transmitted. These pilots are usually needed as a point of reference for such estimator.

A fading channel requires constant tracking so pilot information has to be transmitted more or less continuously. However, an efficient way of allowing continuously update channel estimate is to transmit pilot symbol instead of data at certain location of the OFDM time frequency lattice.

Assuming P is the transmitted pilot data, the received signal after FFT is:

$$Y(k) = H(k)P(k) + W(k) \tag{7}$$

where w(k) is the noise components, and since, the pilot data is known at the receiver, then the simplest way to estimate the channel is by dividing the received signal by the known pilot :

$$\hat{H}(K) = Y(K)/P(K) \tag{8}$$

where $\hat{H}(K)$ is the estimate of the channel, and without noise, this gives the correct estimation. When noise is present, there could be an error (Buthaina Mosa Omran,2007).

The channel estimation can be performed by either inserting pilot tones into all of the subcarriers of OFDM symbols with a specific period or inserting pilot tones into each OFDM symbol.

Although the guard time which has longer duration than the delay spread of a multipath channel can eliminate ISI because of the previous symbol, but it is still have some ISI because of the frequency selectivity of the channel. In order to compensate this distortion, a one-tap channel equalizer is needed. At the output of FFT on the receiver side, the sample at each subcarrier is multiplied by the coefficient of the corresponding channel equalizer.(Kamran arshad,2002)

4. DELAY SPREAD ESTIMATION:

The knowledge about the delay spread of the channel can be used for designing better systems which adapt themselves to the changing nature of the transmission media.(Tevfik, 2006)

We consider a noisy time-varying channel characterized by its impulse response $h_{l,m}$(l=0,1,.....L) with L ≤ N_g the maximum delay and by the noise $n_{m,i}$ assumed AWGN with variance σ^2.

We propose a delay spread estimator based on the frequency correlation function of the channel estimate in frequency domain. According to the (El Kefi Hlel, 2003) the channel frequency correlation function at a given OFDM symbol is defined by:

$$r_{HH}(\Delta f) = \frac{\sigma_H^2}{1+j2\pi\tau_d\Delta f} \qquad (9)$$

where σ_H^2 is the variance of the channel frequency response, Δf is the sub-channel spacing of the OFDM symbol and τ_d is the channel delay spread.

Two ML estimates of σ_H^2 and $\hat{r}_{HH}(\Delta f)$ are given by the following expressions:

$$\hat{r}_{HH}(\Delta f) = \frac{1}{(N-1)Po}\sum_{k=0}^{N-2}\sum_{i=0}^{Po-1}\widehat{H}_{k,i}\widehat{H}_{k+1,i}^{*} \qquad (10)$$

and

$$\hat{\sigma}_H^2 = \frac{1}{NP1}\sum_{k=0}^{N-1}\sum_{i=0}^{P1-1}\widehat{H}_{k,i}\widehat{H}_{k,i}^{*} \qquad (11)$$

Where Po and P1 are integers ≥1.

Finally, the estimation of the delay spread can be deduced using equations (9),(10) and (11):

$$\hat{\tau}_d = \frac{\sqrt{\frac{1}{Re\left(\frac{\hat{r}_{HH}(\Delta f)}{\hat{\sigma}_H^2}\right)}-1}}{2\pi\Delta f} \qquad (12)$$

5. PROPOSED SYSTEM :

The proposed adaptive OFDM system used in the test is shown in Fig.(3).The system consists of a transmitter, a receiver and a frequency selective channel. At the receiving end, the channel estimation is performed and the channel frequency response is used in estimation of the delay spread. This delay spread is feedback to the transmitter to adapt the length of the cyclic prefix, so when the delay spread is large, the length of the CP increase and when it small the length of the CP decreases. We evaluate the performance of the proposed scheme by choosing communication link of Tx/Rx for adaptive OFDM-VCPL system. The OFDM parameters used are in table -1:-

Table -1

Parameters	Values
Symbol period	4µs (80 samples)

Number of samples	80
Type of modulation	64-QAM
Number of sub- channel N	64
Sample frequency fs	20 MHz
Ts	50 nsec

The channels used in the simulation are AWGN channel, flat fading channel and frequency selective channel with 4, 6 and 8 paths with 30 Hz Doppler frequency. The magnitude of the frequency response of these channels is shown in fig. .4, .5, .6 & .7 . In order to change the length of the cyclic prefix adaptively, we must estimate the channel impulse response, and the delay spread of it. Fig.8 shows the normalized mean square error (NMSE) of the delay spread estimation verses SNR.

When we know the delay spread of channel then the duration of the CP of the next transmission as ≥ (max delay spread) according to the design rule.

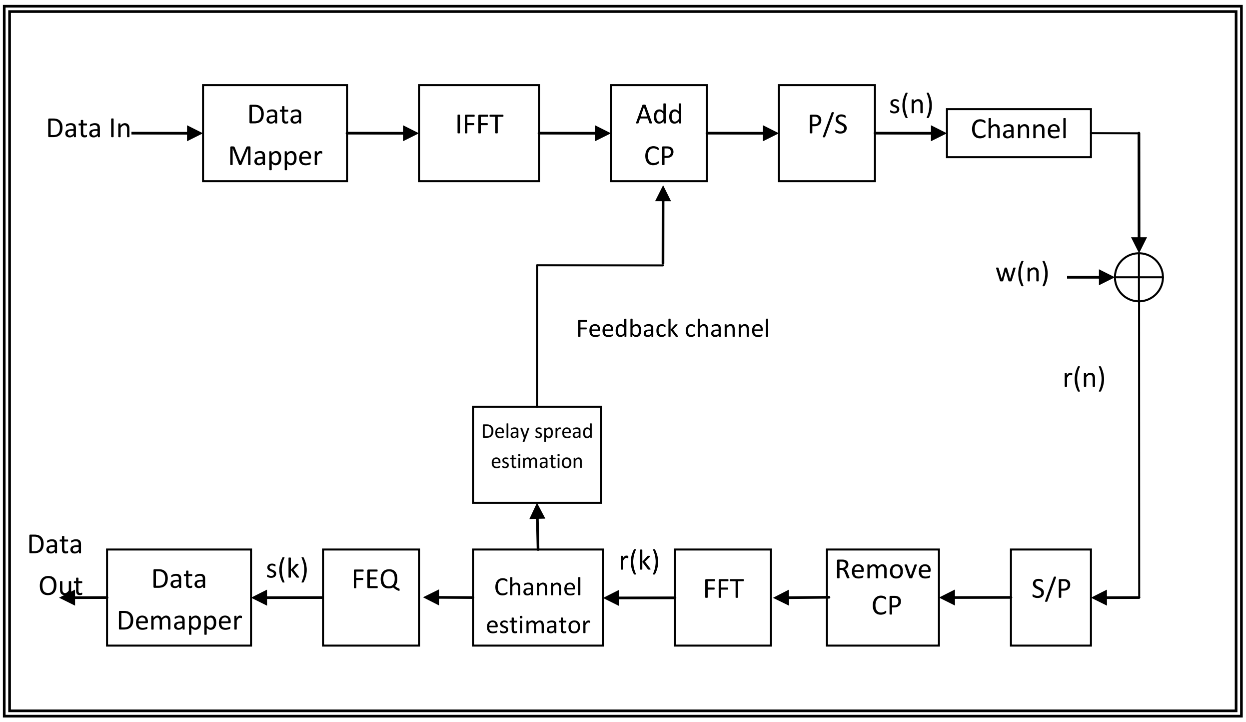


Fig .3 Block diagram of the proposed OFDM system

Different lengths of CP are used, in the AWGN channel 16, 8 and 0 CP length are used and the simulation results shows that there is no need to CP in this channel as shown in fig .9. The same result was obtained in flat fading channel as shown in fig .10.In the frequency selective channel, the performance is acceptable when the CP length equal or greater than the maximum delay spread of the channel. When the length of CP shortened below the maximum delay spread of the channel the performance of OFDM reduced and when we use 0 lengths CP the system does not work. These results can be shown in fig.11,.12 & .13 . In fig.13 for example, we can achieve BER of 10^{-5} in SNR 13 dB when use 16 lengths CP and when the length of CP decrease to 8 we need 18 dB SNR to achieve the same BER and so on. Fig.14 shows that as the no. of path increase we need large SNR to achieve an acceptable BER. This result is illustrated in Table 2.

Table-2

No. of Path (CP = length of paths)	SNR need to achieve BER $=10^{-6}$ in dB
0 (Flat fading)	9
2	12
4	15
6	17
8	20

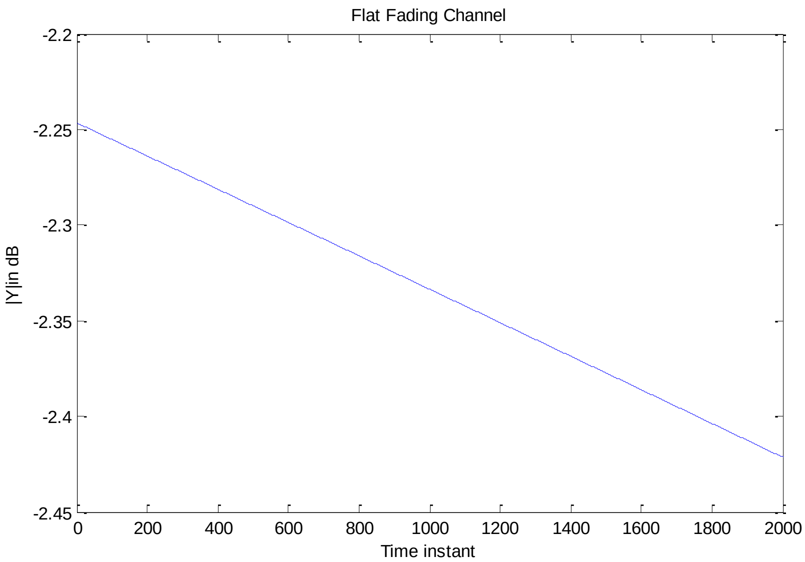


Fig .4 flat fading channel

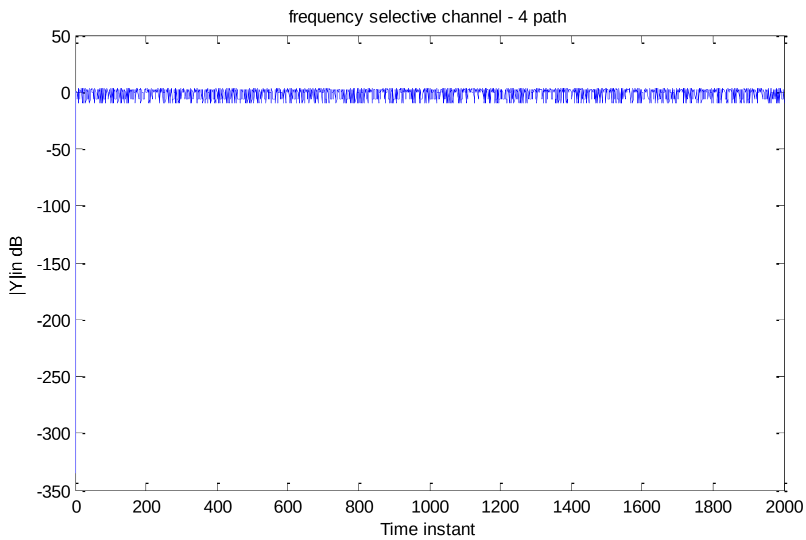


Fig .5 frequency selective channel -4 path

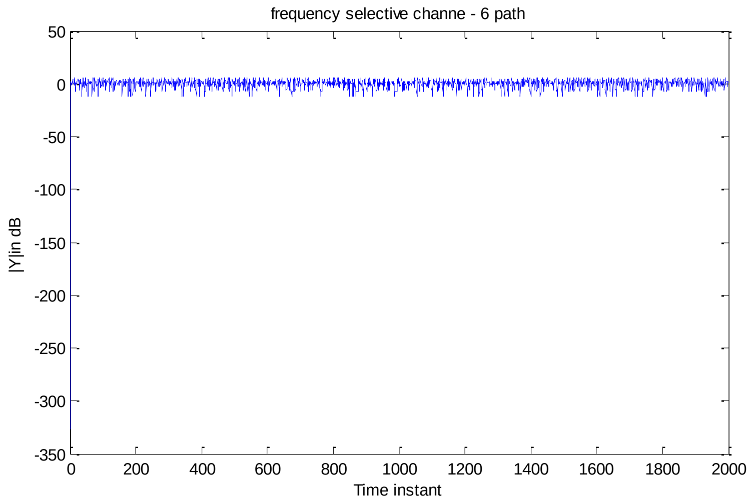


Fig.6 frequency selective channel – 6 path

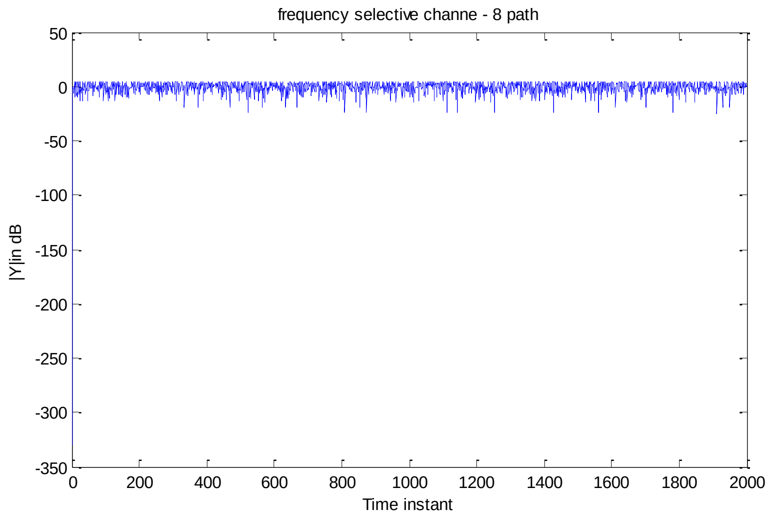


Fig .7 frequency selective channel – 8 path

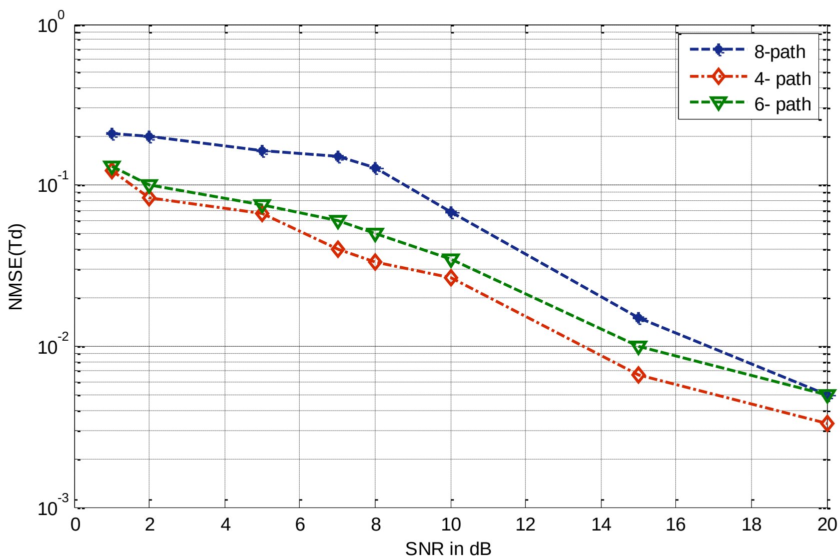


Fig .8 NMSE(τ_d) verses SNR

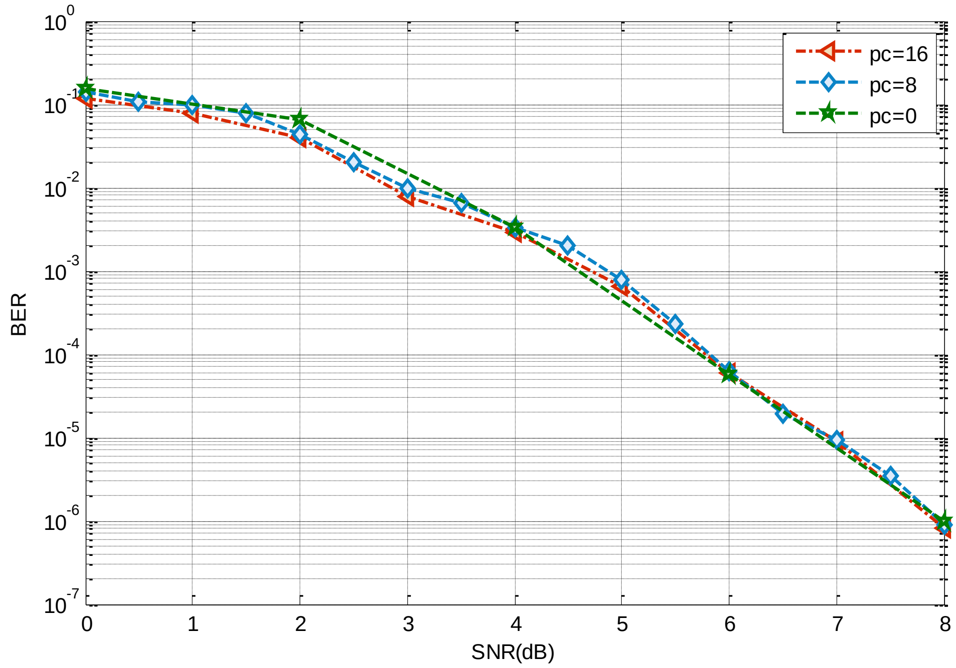


Fig.9 BER Verses SNR under AWGN channel

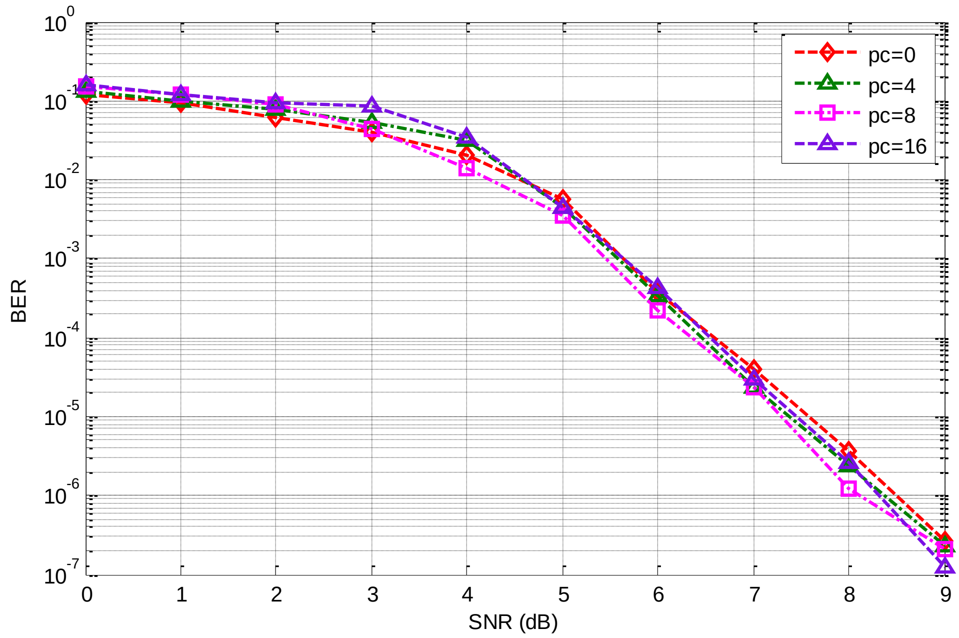


Fig.10 BER Verses SNR under flat fading channel

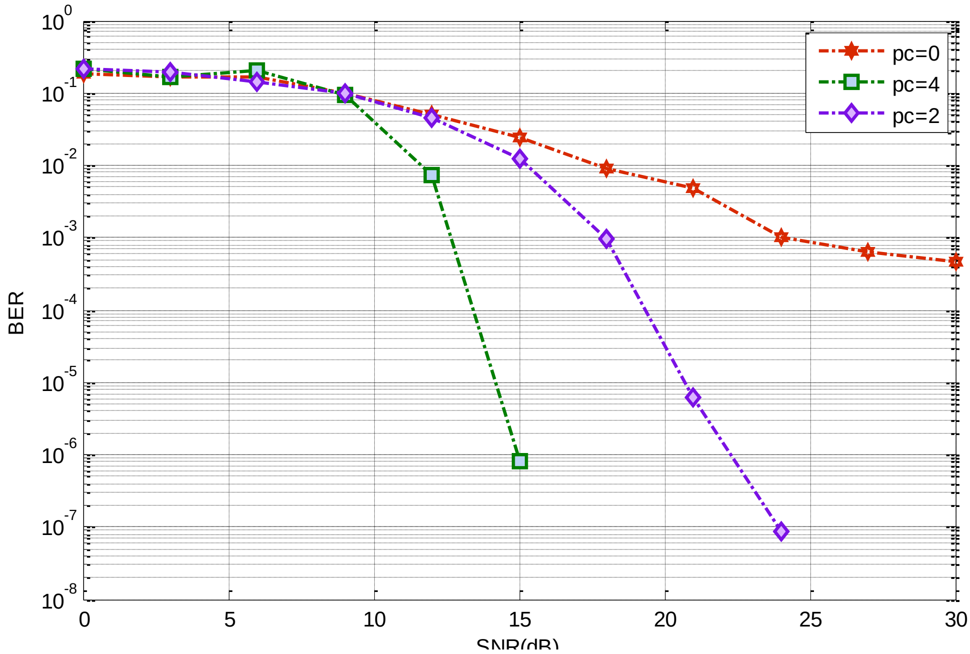


Fig.11 BER Verses SNR under frequency selective channel- 4 path

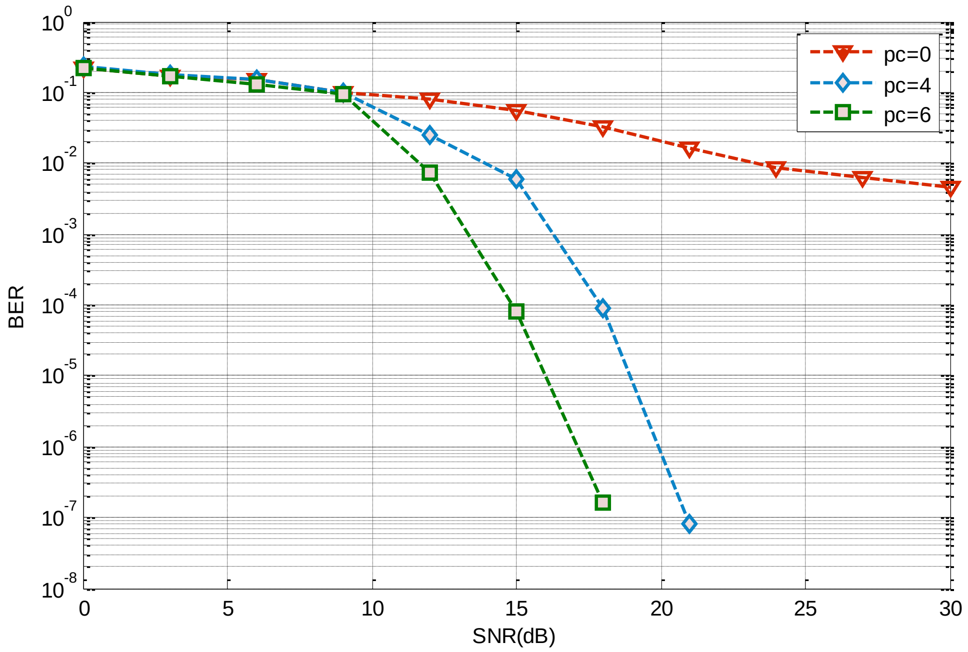


Fig.12 BER Verses SNR under frequency selective channel- 6 path

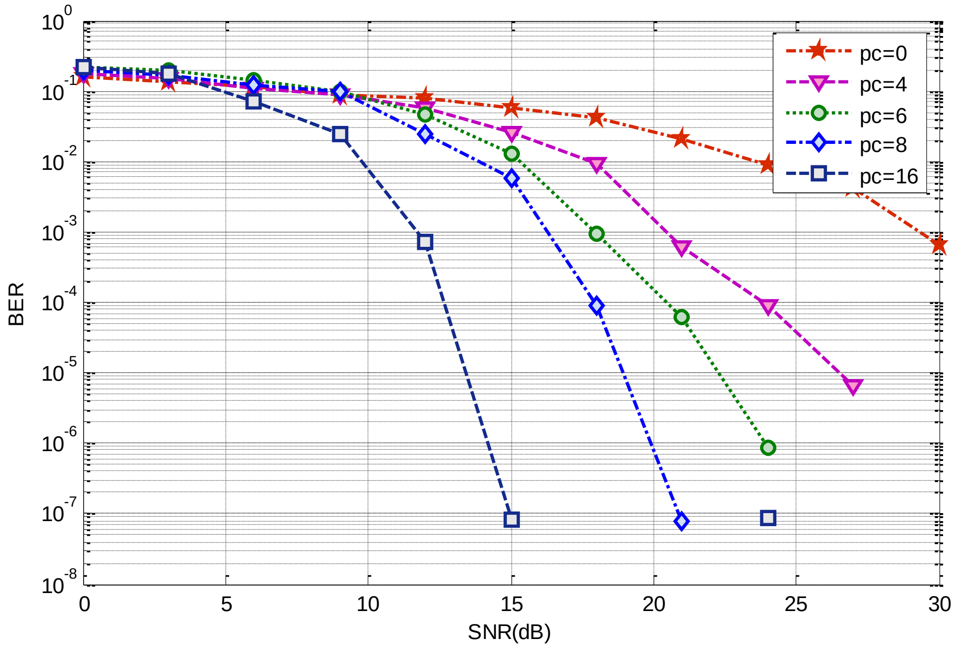


Fig.13 BER Verses SNR under frequency selective channel- 8 path

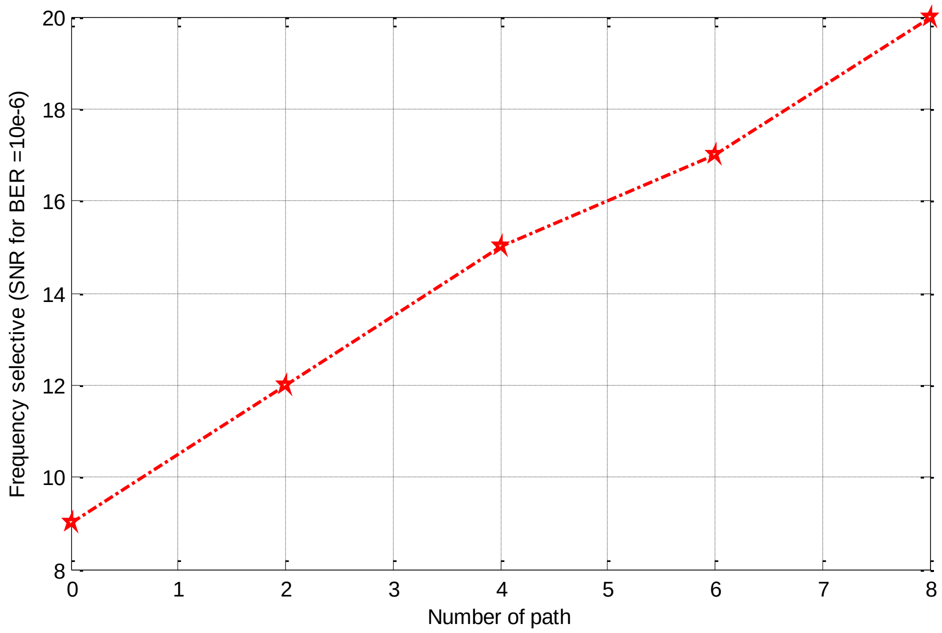


Fig.14 Number of path Verses frequency selective (SNR for BER ≈ 10 $^{-6}$)

6. Conclusion:

An OFDM System with Variable Length CP is described . In AWGN channel and flat fading channel the length of CP could be reset to zero. The SNR required to achieve acceptable BER is increase as the number of path in the channel increase. The length of CP must be at least equal to the length of the channel.

References:

B.Sklar, "Rayleigh Fading Channels in Mobile Digital Communication System"IEEE Commun.Mag., July 1997.

Buthaina Mosa Omran ,“IMPROVEMENT TECHNIQUES FOR SATELLITE DIGITAL VIDEO BROADCASTING USING OFDM”, P.HD. Thesis, in electronic and communication engineering, University of Baghdad, 2007.

Chini A., "Analysis and Simulation of Multicarrier Modulation in Frequency Selective Fading Channel", Ph.D.thesis, 1994.

Eero Maki-Esko, Mikko Valkama, and Markku Renfors,"Time-and Frequency – Selective Fading Channel",ICE University of Technology, Finland, 8 Jan 2007.

El Kefi Hlel, Fethi Tlili, Sofiane Cherif and Mohamed Siala” Channel Parameters Estimation for OFDM Systems”, Ecole Superieure des Communications de Tunis, 2003.

Fernando H. Gregorio,“802.11a - OFDM PHY Coding and Interleaving”, Helsinki University of Technology, Vol. 4, Issue 8,pp.1-6,2006.

F. Sanzi and J. Speidel, "An adaptive two-dimensional channel estimator for wireless OFDM with application to mobile DVB-T", IEEE Transactions on Broadcasting, vol. 46,pp. 128{133, June 2000.

Gregory E. Bottomley and Leif R. Wilhelmsson "Recycling the Cyclic Prefix in an OFDM System", IEEE 2006.

Haris Vikalo, Babak Hassibi, Bertrand HochWald,and Thomas Kailath "On the Capacity of Frequency –Selective Channels in Training-Based Transmission Schemes" IEEE transaction on signal processing, VOL,52,NO.9,SEPTEMBER 2004.

H. Schober, F. Jondral, R. Stirling-Gallacher, and Z. Wang,"Adaptive channel estimation for OFDM based high speed mobile communication systems", 3rd Generation Wirelessand Beyond Conference,San Francisco, USA, pp. 392397,May-June 2001.

Hũseyin Arslan and Tevfik Yũcek," ESTIMATION OF FREQUENCY SELECTIVITY FOR OFDM BASED NEW GENERATION WIRELESS COMMUNICATION SYSTEMS", University of South Florida 4202 E. Fowler Avenue, ENB-118, Tampa, FL, 33620,2003.

Jeroen Theeuwes, Frank H.P Fitzek, Carl Wijting,"Multihopping for OFDM Wireless Networks"Center for TeleInFrastruKtur (CTiF),Aalborg University,June 2004

Krishna Sankar," Cyclic prefix in Orthoganal Frequency Division Multiplexing", February 17,2008.

Kamran arshad, “Channel Estimation In OFDM Systems”, M.Sc. Thesis, King Fahd University of Petrleum and Minerals, Dhahran, Saudi Arabia,2002

Marius Oltean, Miranda Nafornita " The Cyclic Prefix Length Influence on OFDM-Transmission BER", tom 48(62),Fascicola 2,2003.

Peter Fertl and Gerald Matz , "EFFICIENT OFDM CHANNEL ESTIMATION IN MOBILE ENVIRONMENTS BASED ON IRREGULAR SAMPLING" Gusshausstrasse 25/389,A-1040 Vienna,Austria,2009.

Tevfik Yücek and Hüseyin Arslan “Delay Spread and Time Dispersion Estimation for Adaptive OFDM Systems” , WCNC 2006 procedings.

Thayaparan Thanabalasingham" Resource Allocation in OFDM Cellular Networks" , UNIVERSITY OF MELBOURNE, AUSTRALIA, December 2006.

Van Nee,R.,Prasad,R.,2000 "OFDM for Wireless Multimedia Communications" Artech House, Boston,p.46.

Werner Henkel, Georg TaubÖck, Per Ödling, Per Ola BÖrjesson, Niklas Petersson" the Cyclic Prefix of OFDM/DMT-An Anaqlysis"2002 International Zurich Seminar on Broadband Communication Access-Transmission-Networking February 19-21,ETH Zurich,Switzerland.

Yun Chiu, Dejan Markovic, Haiyun Tang, Ning Zhang " OFDM Receiver Design", 12/12/2000.

ZHANG Zhao-yang, LAI Li-feng " Anovel OFDM transmission scheme with length-adaptive Cyclic Prefix",2004.