ADAPTIVE CYCLIC PREFIX LENGTH FOR CONVOLUITIONAL CODE OFDM SYSTEM IN FREQUENCY SELECTIVE CHANNEL

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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 mobile 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 study The influence of the cyclic prefix duration on the BER performance of an OFDM-VCPL (Orthogonal frequency division multiplexing - Variable Cyclic Prefix Length) system and the conventional OFDM system with frame 64-QAM modulation is evaluated by means of computer simulation in a multipath fading channel. The adaptation of CP is done with respect to the delay spread estimation of the channel.

الخلاصة:

النظام المبني على التقسيم المتعدد المتعامد للترددات (OFDM) هو احد الاساليب المبنية لمكافحة التداخل المرمز (Inter-Symbol-Interference) الذي يحدث نتيجة القنوات الراديوية التي تتغير خصائصها مع الزمن بسبب الانتشار المتعدد المسار. هذا البحث يدرس تاثير (Cyclic Prefix) وهو احد العوامل المؤثرة في مخطط نقل العناصر الممكن استخدامها في نظام التقسيم المتعددالمتعامد للترددات (OFDM-VCPL) على نظام اداء (convolutional coded OFDM) الذي يتم تقيمه عن طريق (64-QAM) وتكييف ال CP مع تقدير تأخير الامتداد (delay spread) للقناة (multipath Fading channel) والذي يتم عن طريق المحاكاة الحاسوبية .

INTRODUCTION:

Orthogonal frequency division multiplexing (OFDM) is an important broadband wireless communication scheme. Originally developed in the late 1950s and 1960s , is being used or considered in various wireless communication systems.(Peter Fertl,2009 & Gregory E. Bottomley ,2006) In a wireless communication the signals that are send from a sender to a receiver can follow multiple paths with each its own characteristics (attenuation, delay, etc.). This is called multi-path propagation. This multi- path propagation of a wireless channel often introduces Inter Symbol Interference (ISI).(Jeroen Theeuwes,2004)

To counteract the ISI, the high efficiency Orthogonal frequency division multiplexing (OFDM) modulation first splits the high- rate data stream into a number of parallel sub-streams and modulates them onto different orthogonal sub- carriers and thus lower the symbol rate, and then add a Cyclic Prefix (CP) to the head of each symbol to reduce the influence of adjacent symbol interference.(ZHANG Zhao ,2004)

Although the concept of Cyclic Prefix has been traditionally associated with OFDM systems, the CPs are crucial to OFDM system, they introduce significant overhead. For example, in 802.11 a wireless LAN, a fixed proportion of 1/5 of the energy and time is spent on CPs. As system design rule, the CP length should be about two times the RMS (Root- Mean- Squared) delay spread (Van Nee and Prasad,2000).

Obviously, the RMS delay spread is not constant in a wireless mobile communication environment. Conventional OFDM system usually chooses a fixed CP length based on the average or even maximum delay spread the mobile terminal may experience. According to a measurement conducted in (Van Nee and Prasad,2000), when the mobile terminal is in an office building room, the RMS delay spread is about 35ns, but when the mobile terminal moves into a factory, the RMS delay spread will change to 300 ns. If the receiver is designed based on the measurement in the office, it will undergo severe ISI when the user moves to a factory.

On the other hand, if the receiver is designed according to the measurement in the factory, some of the guard interval is unnecessary which will consume the scarce spectral and power resources but achieve no extra gain. So it is natural to think that if we can estimate the RMS delay spread and change the length of CP accordingly, the overhead of CPs will be reduced when delay spread becomes large. (ZHANG Zhao ,2004 & Van Nee and Prasad,2000)

THE BLOCK DIAGRAM OF OFDM:

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. 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.(Werner Henkel ,2002 & Marius Oltean ,2003)

CYCLIC PREFIX:

Cyclic prefix is a crucial feature of OFDM used to combat the Inter- Symbol-Interference (ISI) introduced by the multi-path channel through which the signal is propagated. The basic idea is to replicate part of the OFDM time- domain waveform from the back to the front to create a guard period. The duration of the guard period Tg should be longer than the worst- case delay spread of the target multi- path environment. 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) Fig-2- illustrates the idea. At the receiver, certain position within the cyclic prefix is chosen as the sampling starting point, which satisfies the criteria

$\tau_{max} < T_x < T_g$

where τ_{max} is the worst- case multi- path spread. As illustrated in the following figure, once the above condition is satisfied, there is no ISI since the previous symbol will only have effect over samples within [0, τ_{max}]. (Yun Chiu ,2000)

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:

$$ycp[n] = xcp(n) * h(n) \qquad (2)$$

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.(Chini A., 1994)

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:

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

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

$$Y(k) = DFT\{IDFT\{X(k)\}\}.DFT\{h(n)\} \quad (5)$$
$$= X(k).H(k) \qquad k = 0,1,..., N-1$$

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

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

FREQUENCY SELECTIVE CHANNEL MODEL:

In wireless communications systems, the transmitted signal typically propagates via several different paths from the transmitter to the receiver. This can be caused, e.g., by reflections of the radio waves from the surrounding buildings or other obstacles, and is typically called multipath propagation. Each of the multipath components have generally different relative propagation delays and attenuations which, when summing up in the receiver, results in filtering type of effect on the received signal where different frequencies of the modulated waveform are experiencing different attenuations and/or phase changes. This is typically termed **frequency-selective fading**. (Eero Maki-Esko,2007)

Frequency- selective channels are characterized by a constant gain and linear-phase response over a bandwidth that is smaller than the bandwidth of the signal to be transmitted. Equivalently, in the time domain, the length of the impulse response of the channel is equal to or longer than the width of the modulation signal.(Haris Vikalo,2004)

SYSTEM MODEL:

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.

The transmitter codes the input data by the convolutional coder, that is efficient in the multipath fading channel. The encoded data are punctured to generate high code rates from a mother code rate, The coded serial bit sequences are converted to the parallel bit sequences and then modulated. The OFDM time signal is generated by an inverse FFT and is transmitted over the Rayleigh fading channel after the cyclic extension has been inserted. In the receiver side, the received signal is serial to parallel converted and passed to a FFT operator, which converts the signal hack to the frequency domain. This frequency domain signal is coherently demodulated. Then the binary data is decoded by the Viterbi hard decoding algorithm.

Punctured Convolutional Codes

The characteristics of a wireless channel typically vary with time, and therefore to obtain optimal performance it is necessary to adapt the error coding scheme to the changing channel characteristics. Code puncturing allows an encoder / decoder pair to change code rates, i.e., code error correction capabilities, without changing their basic structure.

Code puncturing involves not transmitting certain code bits. The encoder for a punctured code can be fabricated using the original low-rate convolutional encoder followed by a bit selector which deletes specific code bits according to a given puncturing rule. Only the bit selection rule is changed to generate different rates of codes. At the receiver side, a Viterbi decoder based on the mother code decoder is used for decoding the punctured codes of the family.

To decode different rate codes, only metrics are changed according to the same puncturing rule used by the encoder (the deleted bits are not counted when calculating the path metrics). Fig-4- shows the puncturing pattern of IEEE802.11a used to generate 3/4 code rate, coming from the mother code rate **,** high lighted bits are the deleted bits (Fernando H. Gregorio,2006).

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:

$$Y(k) = H(k)P(k) + W(k) \qquad (7)$$

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 :

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

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)

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 $L \le N_g$ the maximum delay and by the noise nm,i assumed AWGN with variance σ2.

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:

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

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:

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

and

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

Where Po and P1 are integers ≥1.
Finally, the estimation of the delay spread can be deduced using equations (9),(10) and (11):

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

Decoding

There are several different approaches to decode convolutional codes. These are joined in two basic categories, Sequential decoding and Maximum Likelihood decoding (Viterbi decoding).
The Viterbi decoder examines an entire received sequence of a given length. The decoder computes a metric for each path and makes a decision based on this metric. All paths are followed until two paths converge on one node. Then the path with the higher metric is kept and the one with lower metric is discarded. The paths selected are called the survivors.
For an N bit sequence, the total number of possible received sequences is 2^N. The Viterbi algorithm applies the Maximum Likelihood principles to limit the comparison to 2 to the power of kL surviving paths instead of checking all paths. The most common metric used is the Hamming distance metric, *Hard Decoding*. This is just the dot product between the received codeword and the allowable codeword. **(**Fernando H. Gregorio ,2006)

SIMULATION RESULTS:

We evaluate the performance of the proposed scheme by choosing communication link of Tx/Rx for adaptive OFDM-VCPL system. The OFDM symbol period is 4µs (80 samples). The modulation is 64-QAM and the number of sub-channels is 64 carriesr, sampling frequency 20 MHz, and sampling time 50 nsec.The cyclic prefix duration 0.8 µs (16 samples) and the data duration is 3.2 µsec (64 samples). Using frequency selective channel with 8 paths Rayleigh fading channel Fig.-5-, sample time 50 nsec, max Doppler frequency is 30 Hz the
paths gains = [-1 -2 -3 -4 -5 -6 -7 -8] dB
and
Paths delay = [1 2 3 4 5 6 7 8] * T sec
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-6- 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 2* (max delay spread) according to the design rule(choosing the worst case of delay channel).

Fig. -7- shows the BER performance of the OFDM system. The BER is obtained under the assumption that synchronization and carrier recovery are perfect and only noise and channel estimation error is considered.

Fig. -8- is the maximum achievable coded data rates the system can get using 64 QAM as its modulation method. The system with fixed CP length can achieve 72 Mb/s. it is fixed no matter where the transceiver is. But for the OFDM-VCPL, its maximum coded data rates can be as high as 90 Mb/s. it achieves 18 Mb/s gain over fixed scheme. It is very desirable considering that the spectrum is very scarce.

As can be seen from the Fig.-9-, increasing the cyclic prefix duration improves the BER performance for the OFDM-VCPL system. Theoretically, if the cyclic prefix duration spans more than the maximum delay spread of the channel, the errors can be completely eliminated. This assumes however a perfect knowledge of the channel impulse response (or, equivalently, of the channel transfer function), which is a mandatory condition for implementing the eq.6. Since in our implementation channel estimation techniques are employed, the exact form of the channel impulse response constitutes information that can be exploited in the data estimation process. The correct detection is entirely based on the robustness and simplicity of the digital modulation scheme that is involved, namely 64-QAM. A noticeable thing resulting from the fig.-9- is that while identical for cyclic prefix lengths which cover the channel impulse response, the performance degrades for the cases where the cyclic prefix duration becomes insufficient. Thus, if a cyclic prefix of length 8 is used, the transmission offers the best performance between all the considered situations, but only starting with a value of the normalized delay that overtakes the length of the circular extension for all the other cases.

CONCLUSION:

An adaptive OFDM –VCPL system is described .the CP length is changed based on the estimation result. simulation result at fig.-8- show that the system with fixed CP length achieve 72Mb/s and with variable CP length can achieve as high as 90Mb/s. it achieve 18 Mb/s gain over fixed scheme. The cyclic prefix duration influences the performance of an adaptive OFDM system. The transmission is sensitive to the parameter obtained as multi-path delay of channel normalized by the cyclic prefix duration. A noticeable thing resulting from the fig.-9- is that while identical for cyclic prefix lengths which cover the channel impulse response, the performance degrades for the cases where the cyclic prefix duration becomes insufficient. Thus, if a cyclic prefix of length 8 is used, the transmission offers the best performance between all the considered situations, but only starting with a value of the normalized delay that overtakes the length of the circular extension for all the other cases.

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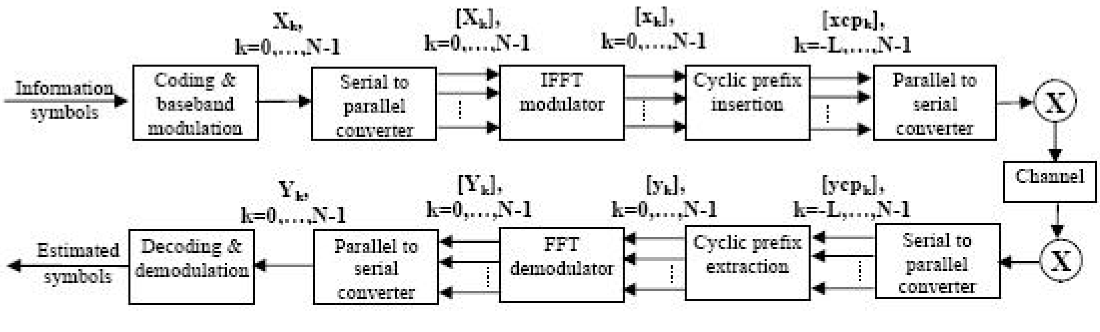


Fig-1- The block diagram of general OFDM system

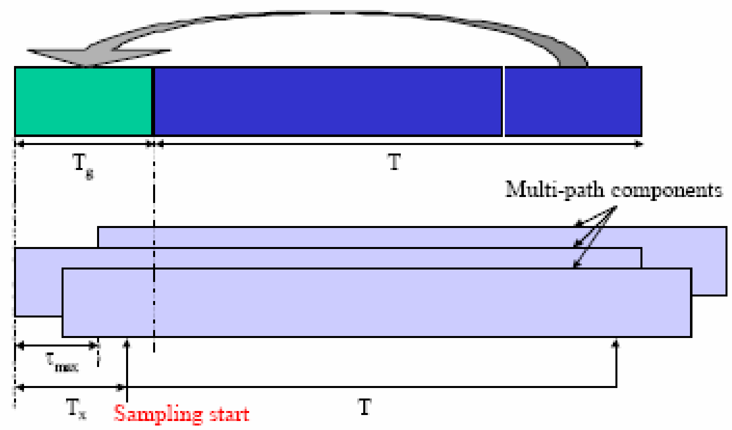


Fig-2- cyclic prefix

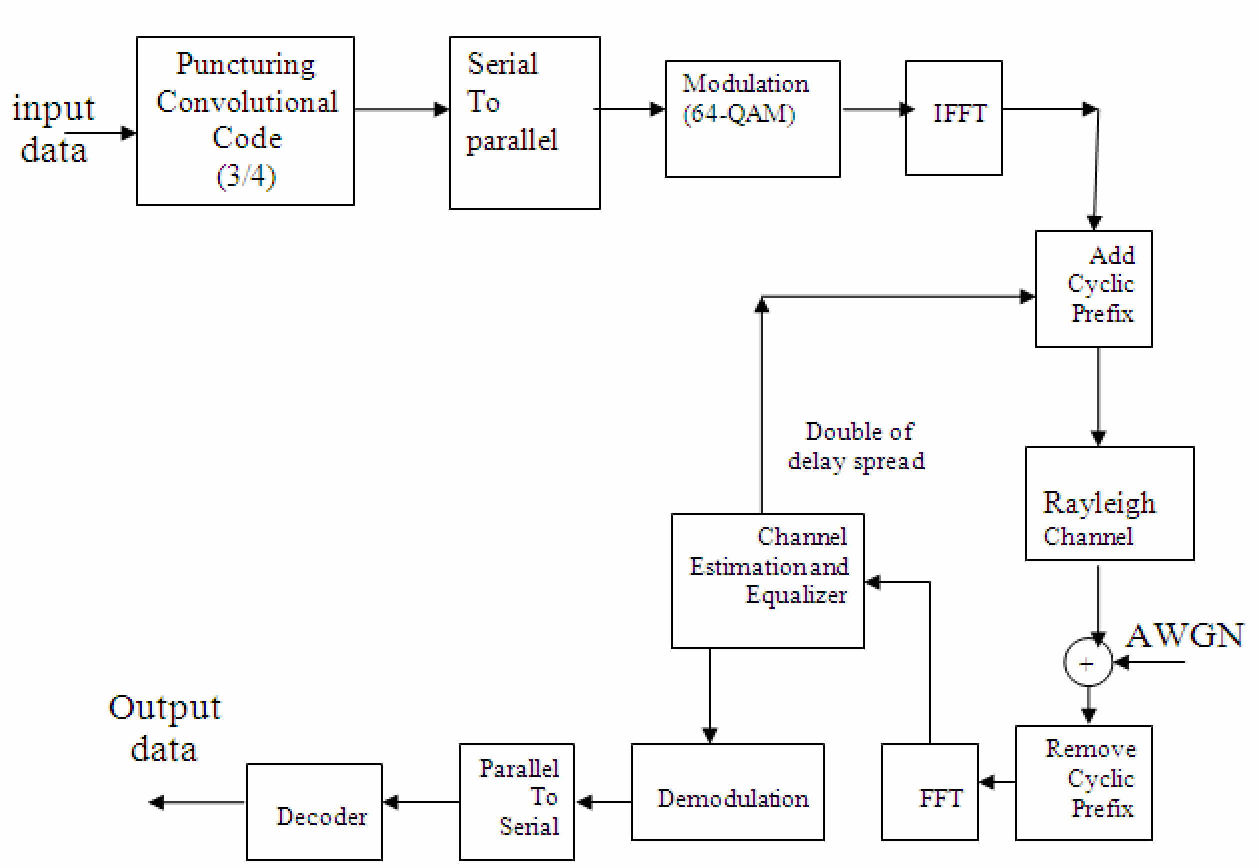


Fig-3- the proposed block diagram of an OFDM-VCPL system

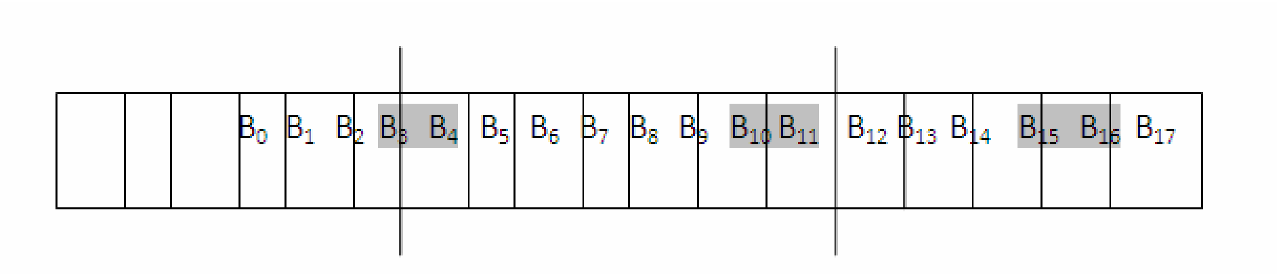


Fig-4- Puncturing patterns of IEEE802.11a, 3/4 code rate.

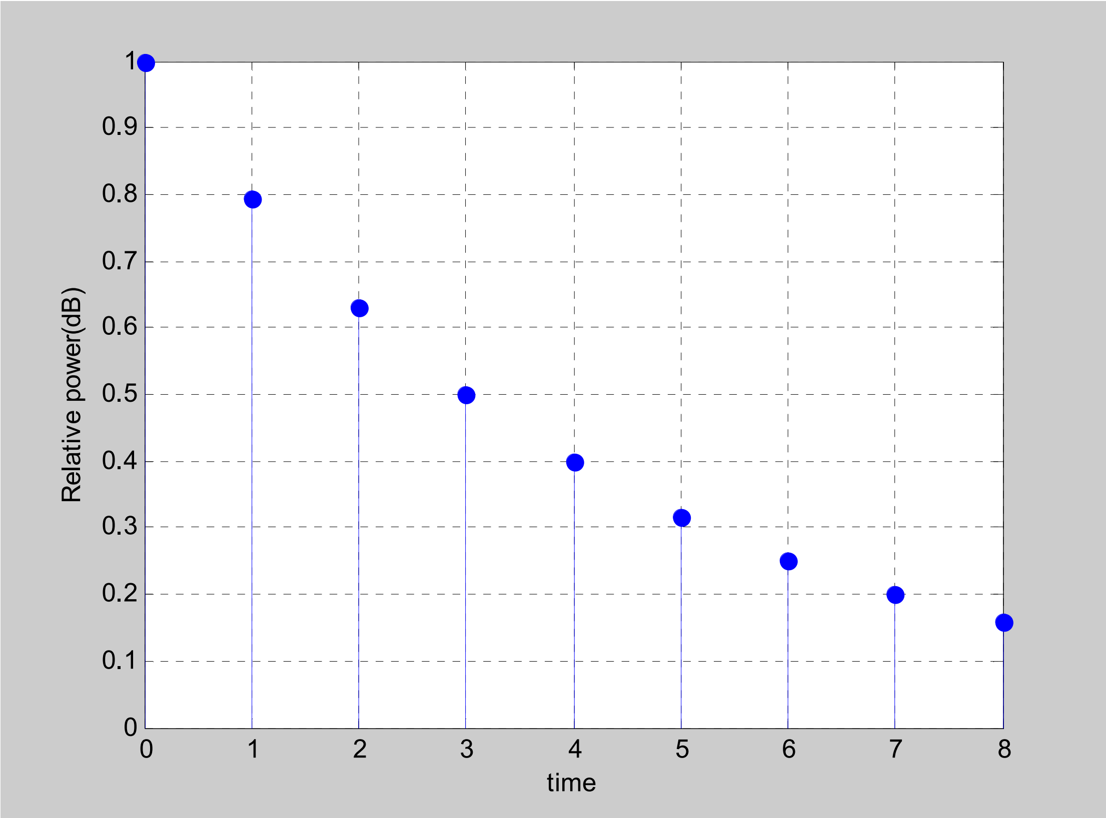


Fig-5- Channel model

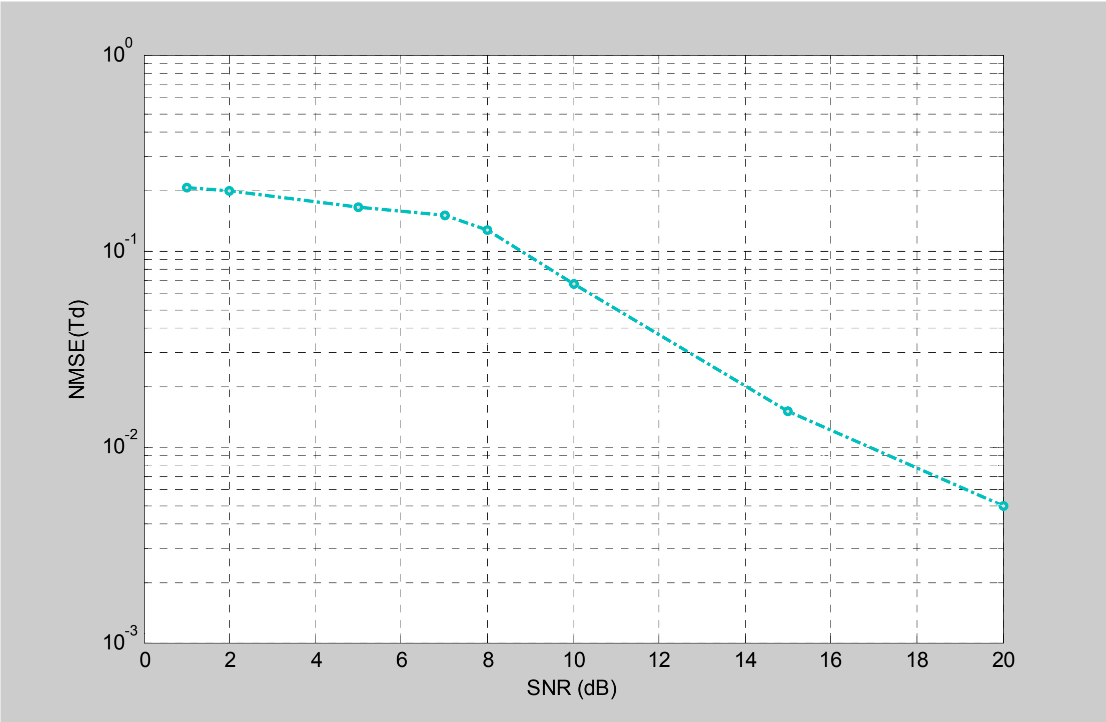


Fig- 6- NMSE(T_d) verses SNR

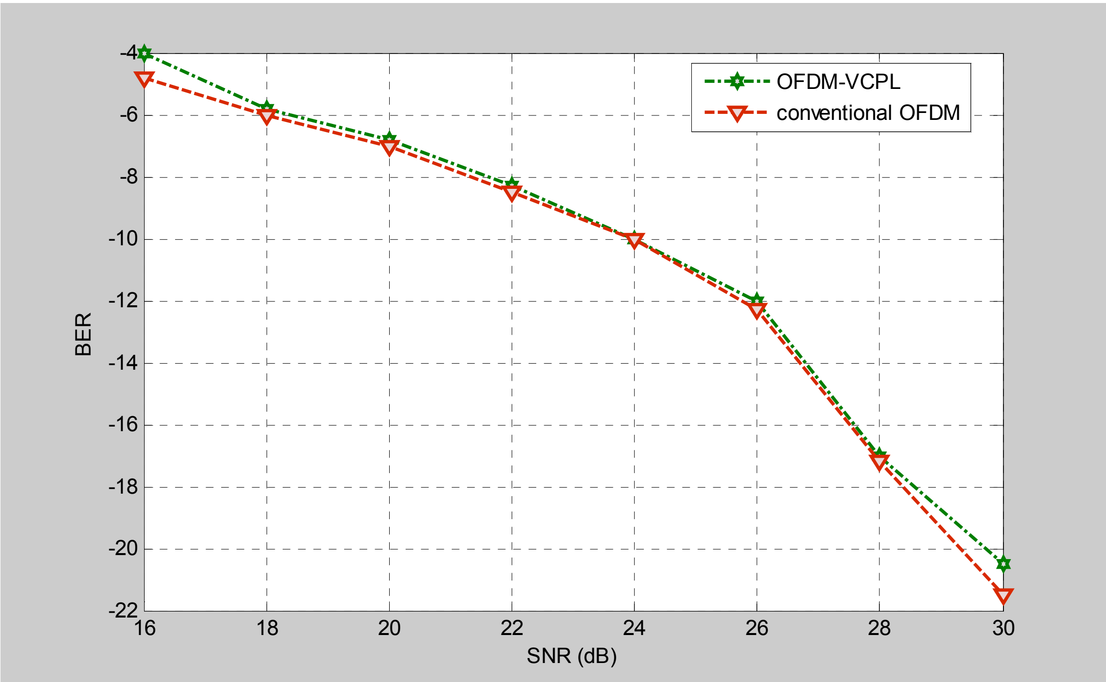


Fig-7- BER versus SNR

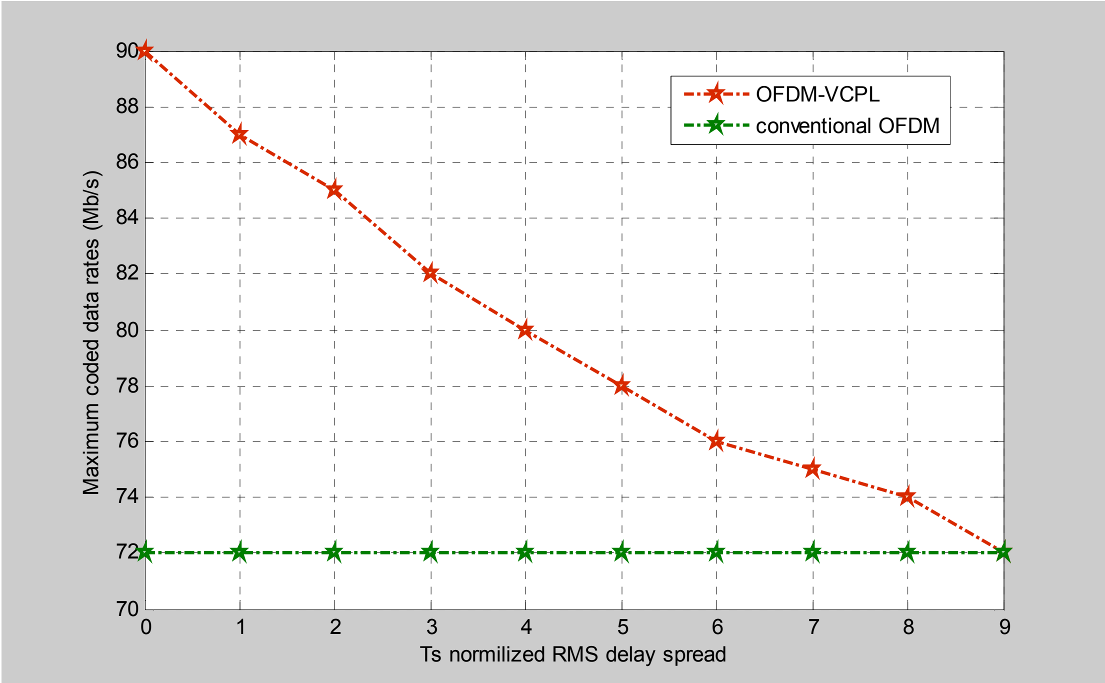
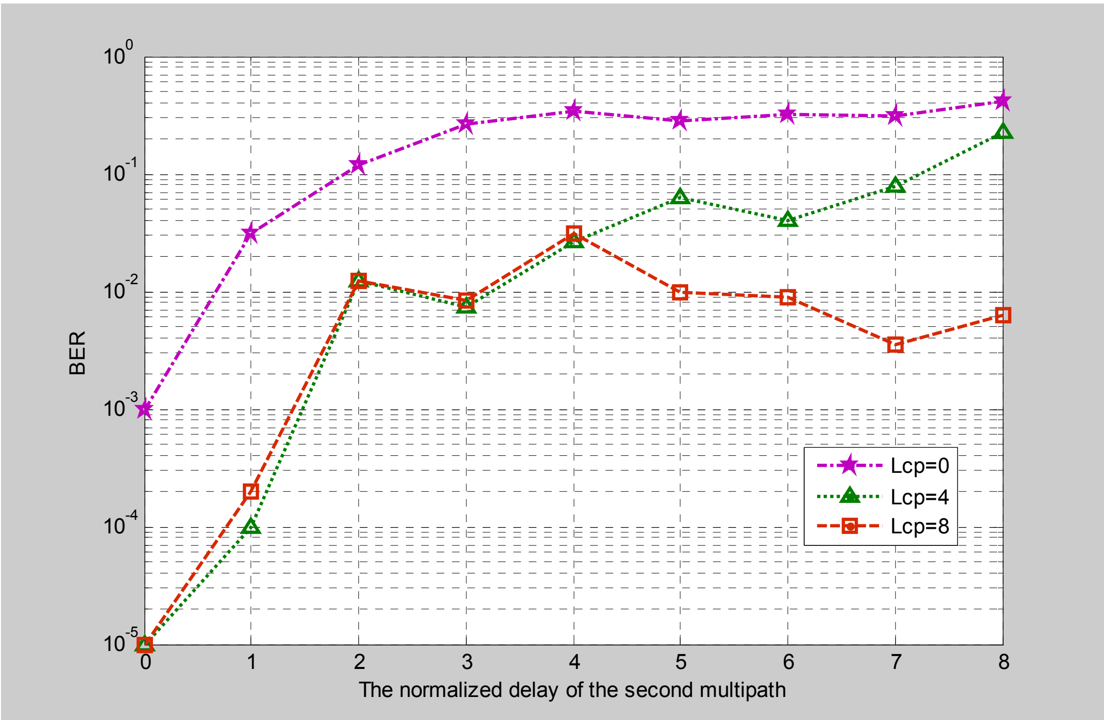


Fig-8- Maximum achievable data rates versus delay spread



The normalized delay of the second multipath

Fig-9- The influence of the cyclic prefix duration on BER performance for 64-QAM-OFDM system, Rayleigh channel