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Performance of LDPC Coded IEEE 802.11n OFDM System with Unequal Error Protection and Varying FFT Size

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Abstract

OFDM based systems have gained in popularity over the past decades as their data transmission rate is very high, especially when combined with standards such as the IEEE 802.11n. However, this standard is mostly employed for relatively small indoor environment use where the path delays are small. If this technique is used in large indoor environments, fading will significantly affect the signals as the delays are large. The aim of this paper is to analyse the Bit Error Rate (BER) performance of an IEEE 802.11n based OFDM system by varying the FFT size as well as the symbol duration (Ts). An Unequal Error Protection (UEP) scheme based on prioritized constellation mapping is also used to enhance the performance. The performance of the LDPC based OFDM system is first tested using the standard 64-point FFT, with block-length 648, code rate 1/2 for 16 and 64 QAM modulation. The system was then analysed with different FFT and Ts values. For the 16 QAM modulation, when comparing the E_b/N_0 values for Ts 5µs with FFT size 64 against Ts 9µs with FFT size 512, a gain of 13.6 dB is obtained at a BER of 2×10^{-2}, without using the UEP scheme, while an additional 0.4 dB is obtained when the UEP scheme is used. For the 64 QAM modulation, a gain of 22.4 is obtained at a BER of 10^{-1}, without using the UEP scheme, when comparing the E_b/N_0 values for Ts 5µs with FFT size 64 against Ts 9µs with FFT size 512, while an additional 0.6 dB is obtained when the UEP scheme is used. The results show that when the IEEE 802.11n needs to be used in large indoor environments, such as huge storehouses or shopping malls, higher FFT size together with UEP provides better performance.

Keywords: *Bit Error Rate, Fading, Low-Density Parity-Check, Orthogonal Frequency Division Multiplexing, Unequal Error Protection.*

1. Introduction

OFDM is a multi-carrier modulation (MCM) technique which has gained in popularity over the recent decades due to its distinguishing features of being highly tolerable to multipath and high data throughput. On the other hand, LDPC codes show BER performances approaching that of the Shannon's limit [3] over a wireless medium. This is the reason why this code is used in standards such as the WiMax and the IEEE 802.11. However, wireless mediums are susceptible to fading effects caused by the transmitted signal taking different paths in order to reach the receiver. Consequently, there is a need to enhance the efficiency of data transmission. This can be accomplished by using increasing number of sub-carriers, as well as using an unequal error protection (UEP) scheme. Several works have been proposed for improving OFDM transmission. An overview is given next.

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The authors in [4] demonstrated that OFDM-based systems showed better transmission rate and BER values compared to CDMA. In [7] a UEP scheme was proposed for LDPC codes for image transmission. Simulation results showed that the proposed UEP scheme outperformed the Equal Error Protection (EEP) scheme by a PSNR gain of about 30dB at low SNR values using the same rate. The authors in [2] considered using the unequal error protection (UEP) property to construct quasi-cyclic low-density parity-check (QC-LDPC) codes. The results obtained showed that constructed codes have much better BER compared to irregular UEP LDPC codes and randomly build EEP LDPC codes. In [1] a new UEP approach was devised to protect memories used in LDPC decoders. The results showed higher tolerance to errors compared to the most advanced decoder at that time, at a small energy cost and complexity. The authors in [5] designed a UEP technique by partial superposition transmission (PST), termed as UEP-by-PST.

Simulation results indicated that a greater coding gain for the MID was produced with UEP-by- PST with insignificant performance decrease for the LID compared to the traditional technique. An efficient joint source-channel coding (JSCC) was demonstrated in [6] by employing UEP based on protograph double LDPC (PD-LDPC) codes. Results showed that over AWGN the proposed scheme can obtain greater PSNR value of the received image, in comparison with alternative UEP schemes that used the same code rate. A modified RB-HARQ scheme for IEEE 802.11n LDPC codes was proposed in [9] and it was combined with UEP. With 16-QAM and a code-rate of ½, the proposed scheme provides a gain of 1.5 dB and 2% in throughout at a Bit Error Rate (BER) close to 10^{-1} over a scheme which uses conventional RB-HARQ without UEP. Moreover, with 64-QAM a maximum gain of 4.5 dB in E_b/N_0 is obtained. In [10], a hybrid UEP scheme is proposed for the LDPC codes with QAM. The scheme uses a statistical distribution of source symbols and the distribution of the bit node degree to respectively map the systematic and parity bits of the LDPC coded symbols codes.

Simulations for this proposed scheme shows that gain of up to 0.91 dB can be obtained compared with other UEP schemes. In [11], the performances of the IEEE 802.11n Low Density Parity Check codes are evaluated by combining three techniques: Unequal Error Protection, Optimized Scaling Factor and Failed Check Node. Simulation results showed that maximum gains of 0.9 dB and 1.35 dB could be achieved as compared to conventional Low Density Parity Check codes decoding with 16-QAM and 64-QAM respectively in the range BER ≤ 10^{-2}. The authors in [12] have proposed two enhanced pulse shaping filters which are used along with OFDM to reduce the effects of Intersymbol Interference (ISI). These 2 filters are Modified Flipped Exponential Pulse (MFEXP) and the Hybrid Flipped and Parametric Exponential Pulse (HFPEXP). Enhanced BER performance was obtained from the proposed filters when compared with conventional ones such as RC, SRCC, FEXP and PEXP for various ISI levels and smaller side lobes were observed in their impulse response.

The aim of this paper is to analyse the performance of an LDPC coded IEEE 802.11n OFDM-based system by varying the FFT size and the symbol period so that the system can combat the effect of multipath with 4 taps in very large indoor environments such a shopping malls where the path delays are very large. Simulations demonstrated that by increasing the Ts value as well as the FFT size better performance is observed. Moreover, BER performance can be further improved when UEP is applied before modulation and after demodulation. The UEP scheme is based on the prioritized QAM constellation mapping.

2. Proposed system model

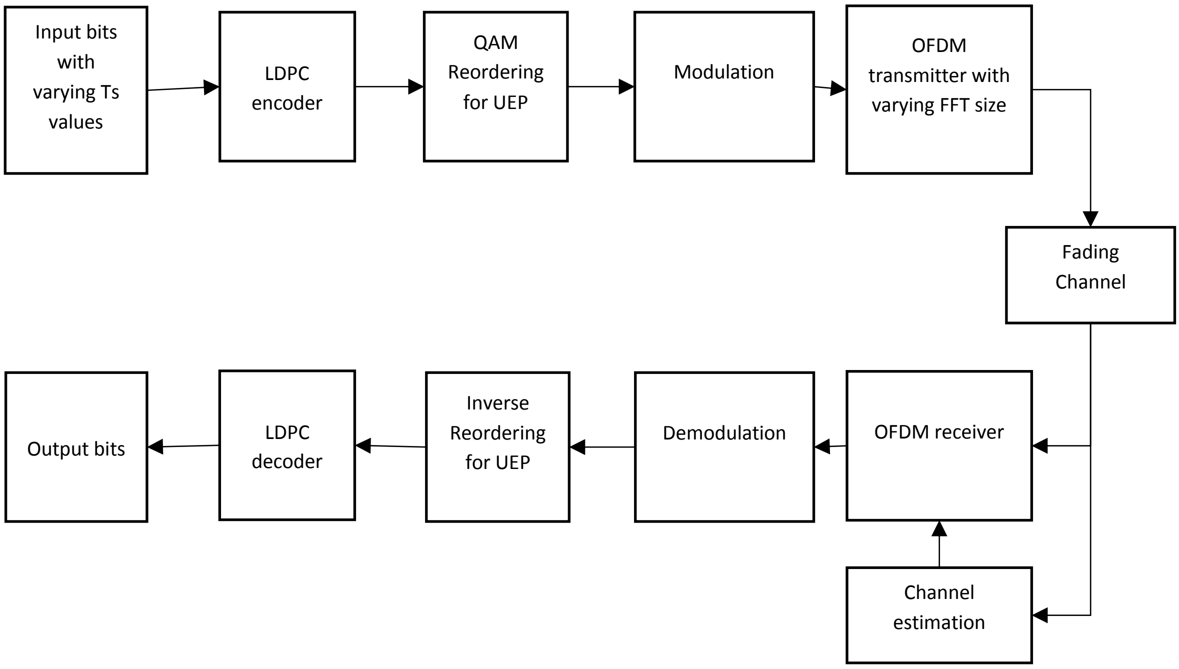

Figure 1: Block diagram for LDPC coded OFDM in frequency-selective fading channel with UEP

The information bits are fed into the system with varying symbol duration (Ts) values. The *LDPC encoder* block encodes a stream of data that is then passed through the *QAM Reordering* Block which reorders the systematic and parity bits, according to [9], to provide better protection to the systematic bits. This reordering can be explained as follows.

The UEP scheme used in this project is the same as the one used in [9], This scheme takes advantage of the intrinsic UEP characteristic of the QAM constellations in the 802.11n standard. For the 802.11n LDPC codes, the systematic bits are placed in the most protected areas of the 16 and 64 QAM constellation while the parity bits are placed in the less protected areas.

For the 16 QAM modulation, the systematic bits are placed in the first and third positions of the 16-QAM symbol. This positioning can be explained under the assumption that the constellation in Figure 1 can be separated into four quadrants. It is apparent that for all the four points located in each quadrant, the first and third bits are the same. For example, in the upper right quadrant, the first and third bits are 11 for all the four points. Therefore, by mapping the systematic bits on the first and third places, they will constantly be detected with great accuracy, if the receiver accurately detects the quadrant of the received symbol. This results in higher protection for the systematic bits compared to the parity bits, thus enhancing the receiver's performance.

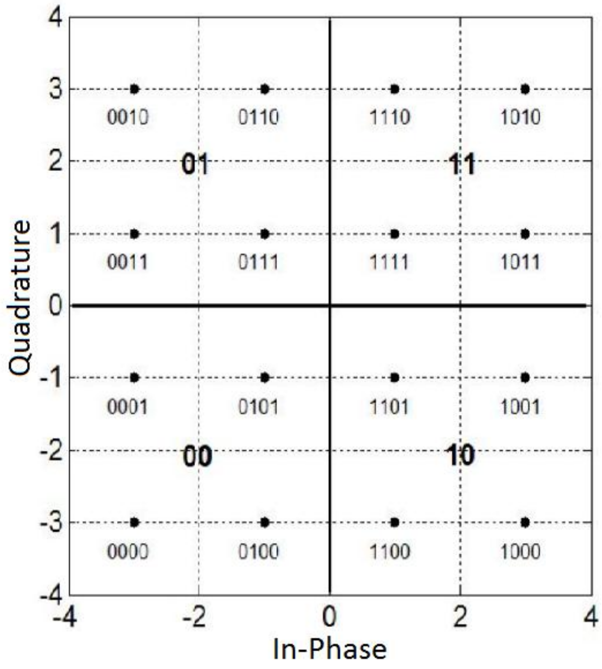

Figure 2: IEEE 802.11n 16-QAM constellation diagram [9]

For the 64 QAM modulation, the systematic bits are placed in the first, second, fourth, and fifth positions of the 64-QAM symbol. Once again, this positioning can be explained under the assumption that the constellation in Figure 2 can be separated into four major quadrants. It is apparent that for all the sixteen points located in each major quadrant, the first and fourth bits are the same. For example, in the upper left quadrant, the first and fourth bits are 01 for all the four points.

A further assumption is that the major quadrants are further separated into four minor quadrants. It is apparent that for all the four points located in each minor quadrant, the second and fifth bits are the same. For example, in the upper right minor quadrant the second and fifth bits are 10 for all the four points. Therefore, by mapping four of the systematic bits at the first, second, fourth, and fifth position, accurate detection is guaranteed if the receiver accurately detects the major and minor quadrants of the received symbol.

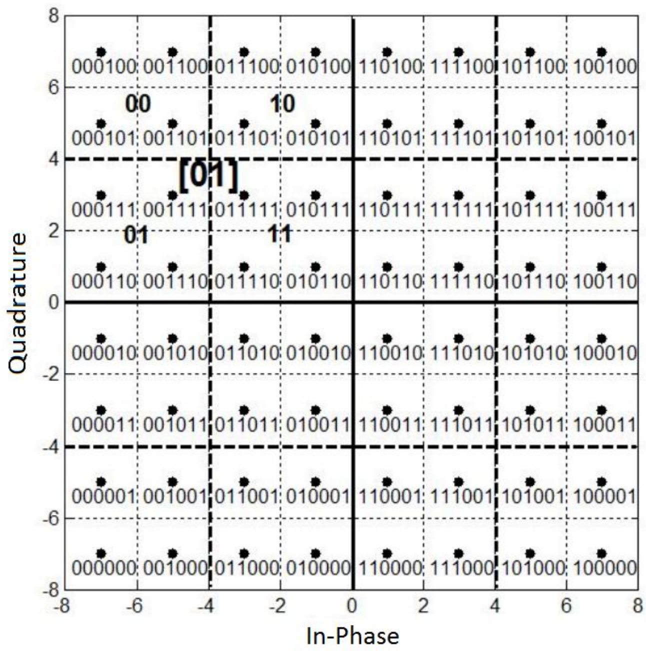

Figure 3: IEEE 802.11n 64-QAM constellation diagram [9]

The reordered bits are then modulated and passed in the *OFDM transmitter* block to go into the OFDM system, where 16 QAM and 64 QAM are applied, and also where the FFT size are changed. The OFDM symbols are transmitted in the *fading channel* block, where a frequency selective fading channel was simulated using 4 taps. The path delays for these 4 taps are chosen to be $0\mu s$, $1\mu s$, $3.5\mu s$, and $10\mu s$. In [8] it is said that typical indoor delay spreads are in the order of hundreds of *ns*, while those for outdoor condition can be up to $10\mu s$. Although the IEEE 802.11n standard is mostly used for indoor purposes, these values of delay spread were used in order to simulate very large indoor environments, for example the large storerooms or supermarkets. Later the bits are detected at the *OFDM receiver* block, where they undergo channel estimation to undo the effects of fading and then they are demodulated. The received signal goes through the *Inverse Reordering* block after which the *LDPC decoder* block decodes the output soft bits. Lastly, comparison is made between the output information bits and the original information bits in order to get the bit error rate.

3. Results and Analysis

The performances of the following schemes are analysed with the following simulation parameters:

- LDPC parameters: Block length = 648, Rate = ½.
- Modulation: 16 QAM, and 64 QAM.
- Symbol duration values: Ts = 5 µs, 7 µs, and 9 µs.
- FFT size: 64, 128, 256, and 512.

3.1. Results for 16 QAM

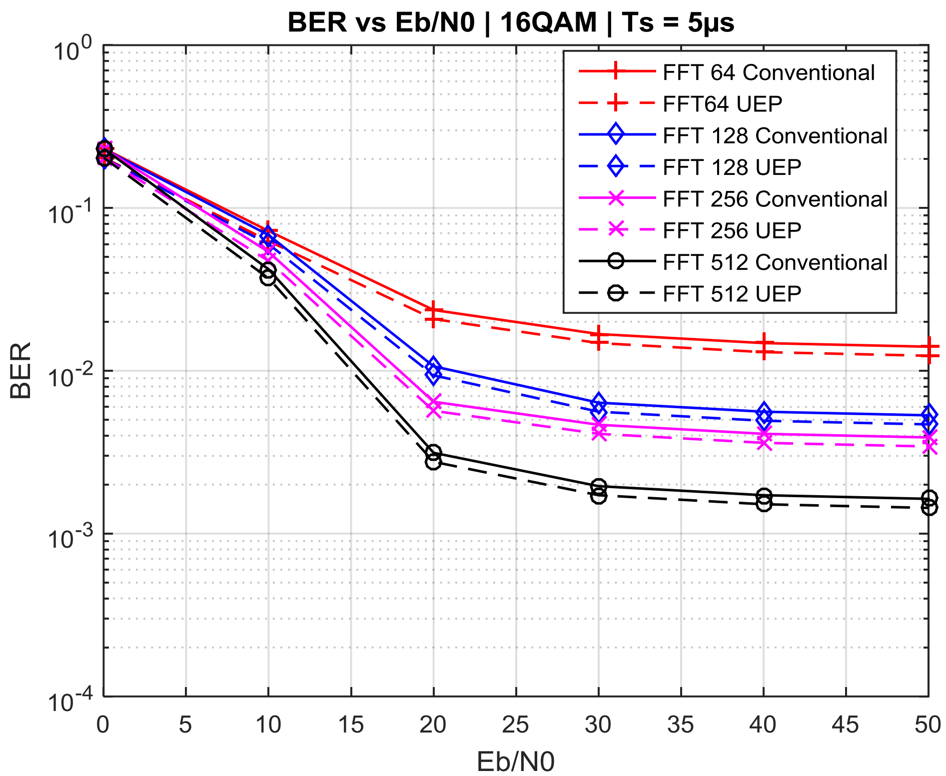

Figure Error! No text of specified style in document.**:** BER performance of LDPC-coded OFDM with 16QAM, rate ½, and different FFT sizes for Ts = 5μs.

Figure 4 shows the BER performance of the system with Ts = 5μs, 16 QAM and different FFT sizes. This value of Ts is the close to the third tap path delay value of the fading channel. This means that the system will experience higher ISI compared to the two other systems that have a higher Ts.

At a BER of 2×10^{-2}. For an FFT size of 64 without UEP, an E_b/N_0 value of 24.9 dB is obtained, while for an FFT size of 512, a value of 12.9 is obtained. This shows a remarkable gain of 12.0 dB.

It can be seen that the UEP based scheme performs better than the conventional scheme with an average gain of 0.6 dB for each FFT size, while the gain with an FFT size of 64 was as high as 3.8 dB. This is due to the fact the at a BER of 2 × 10^{-2}, the system with size 64 reaches its saturation level, because the effects of ISI can no longer be decreased by increasing the E_b/N_0 value.

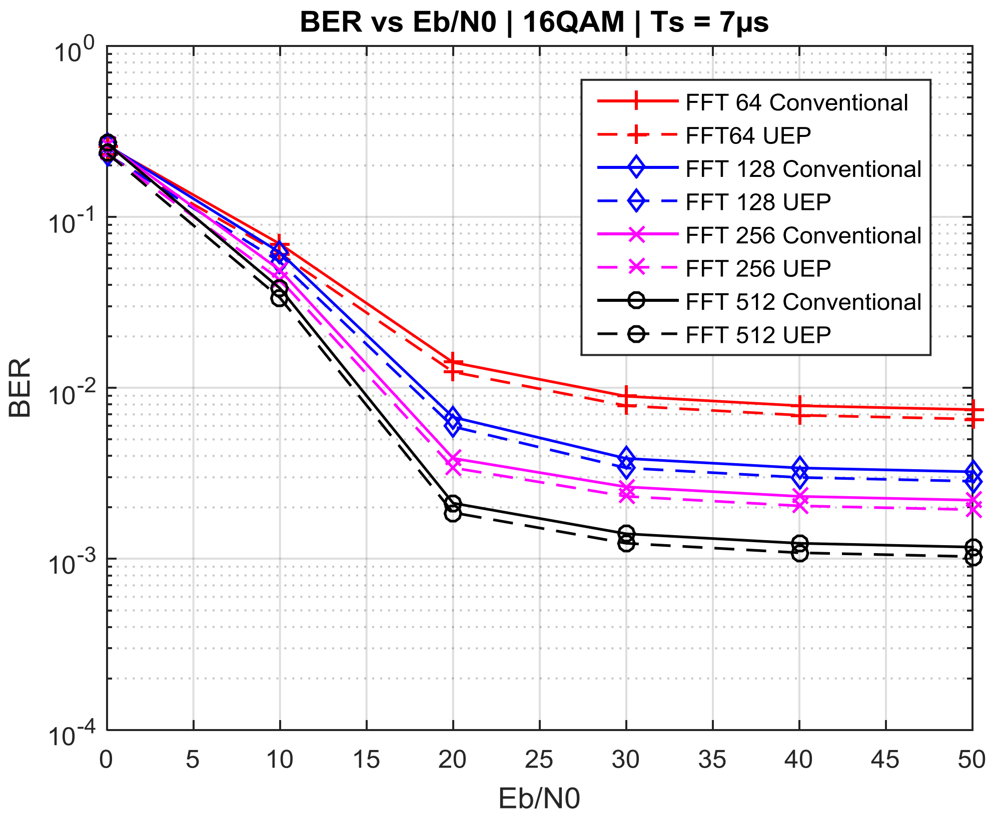

Figure 5: BER performance of LDPC-coded OFDM with 16QAM, rate ½, and different FFT sizes for Ts = 7µs.

Figure 5 shows the BER performance of the system with Ts = 7µs, 16 QAM and different FFT sizes. This value of Ts is a little higher than the third tap path delay value of the fading channel. This means that the system will experience lower ISI compared to the system with Ts of 5µs.

At a BER of 2 × 10^{-2}. For an FFT size of 64 without UEP, an E_b/N_0 value of 17.8 dB is obtained, while for an FFT size of 512, a value of 11.6 dB is obtained. This shows a gain of 6.2 dB.

The UEP based scheme is seen to perform better than the conventional scheme with an average gain of 0.6 dB for each FFT size. This time the Eb/N_0 value for an FFT size of 64 is comparable with the other FFT sizes because the saturation level decreases, so that at a BER of 2 × 10^{-2}, a much better comparison can be made between the four FFT sizes.

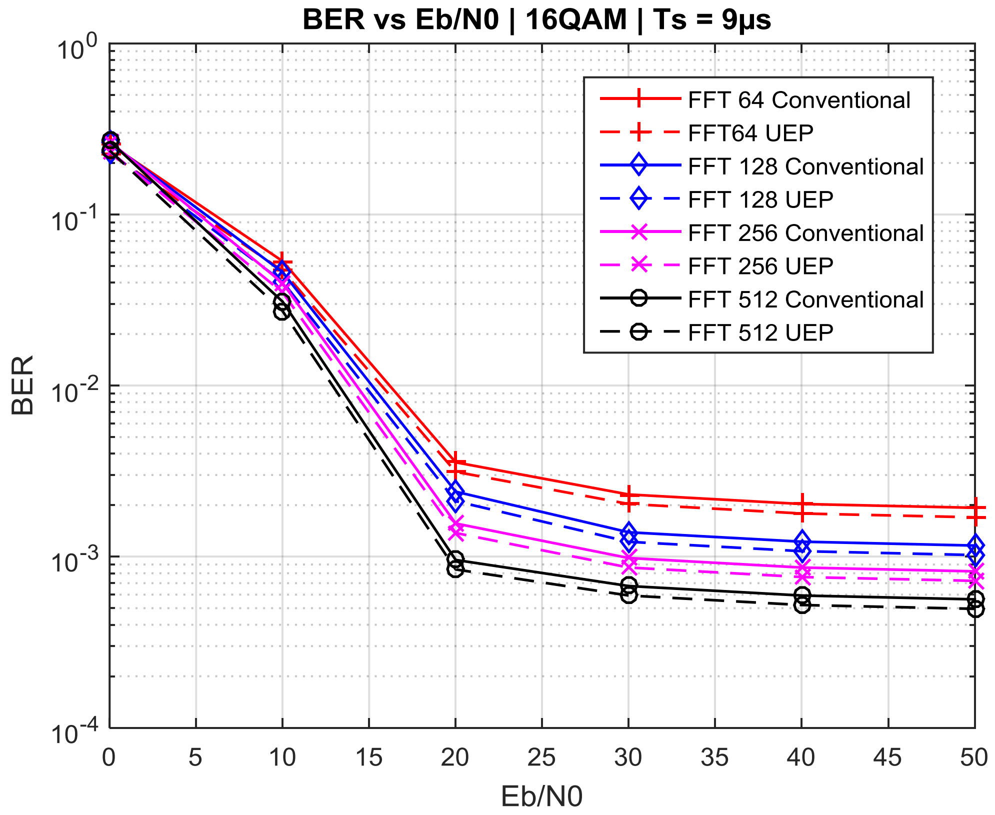

Figure 6: BER performance of LDPC-coded OFDM with 16QAM, rate ½, and different FFT sizes for Ts = 9μs.

Figure 6 shows the BER performance of the system with Ts = 9μs, 16 QAM and different FFT sizes. This value of Ts is a little higher than the third tap path delay value of the fading channel and closer to the fourth tap path delay. This means that system will experience even lower ISI compared to the system with Ts of 5μs and 7μs.

At a BER of 2×10^{-2}. For an FFT size of 64 without UEP, an E_b/N_0 value of 13.6 dB is obtained, while for an FFT size of 512, a value of 11.3 dB is obtained. This shows a gain of 2.3 dB.

It is observed that the UEP based scheme performs better than the conventional scheme with an average gain of 0.4 for each FFT size. Once again the Eb/N_0 value for an FFT size of 64 is comparable with the other FFT sizes because the saturation level decreases, so that at a BER of 2×10^{-2}, a much better comparison can be made between the four FFT sizes.

For the 16 QAM, it is observed that when the FFT size increases, a better BER performance is seen for the system. It can also be seen that when Ts increases, the BER performance also increases. As a whole, when comparing the E_b/N_0 values for Ts = 5μs with an FFT size of 64 against Ts = 9μs with an FFT of size 512, a gain of 13.6 dB is obtained at a BER of 2×10^{-2}, without using the UEP scheme, while an additional 0.4 dB is obtained when the UEP scheme is used.

3.2. Results for 64 QAM

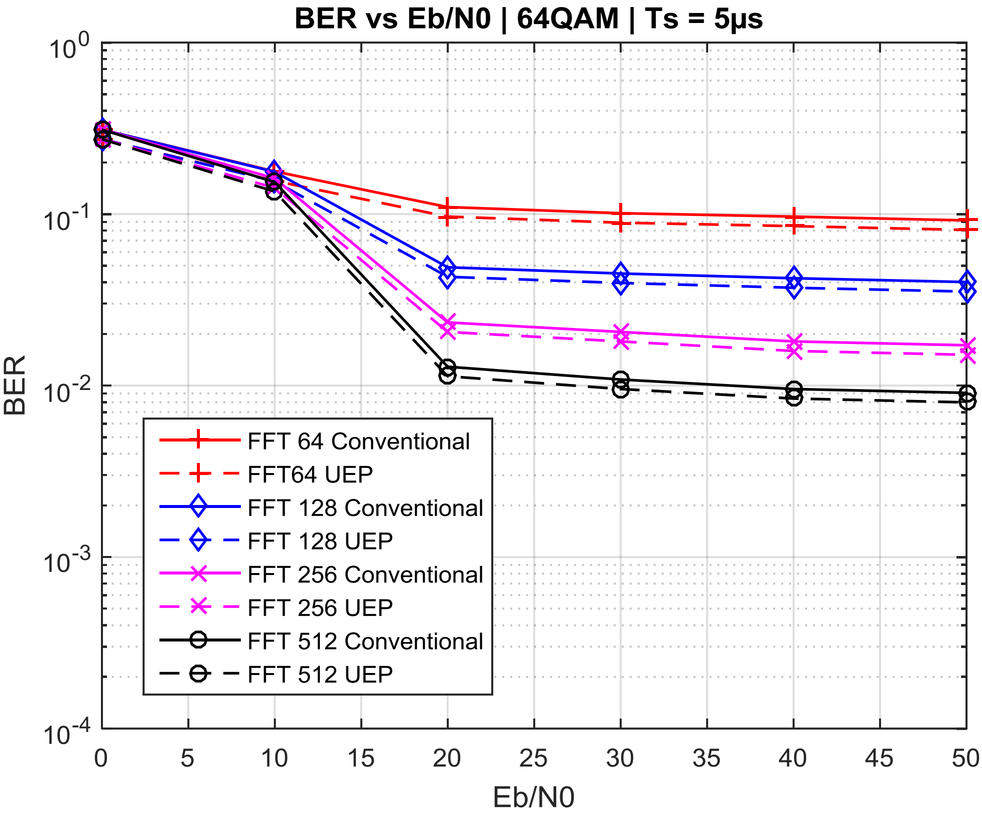

Figure 7: BER performance of LDPC-coded OFDM with 64QAM, rate ½, and different FFT sizes for Ts = 5µs.

Figure 7 shows the BER performance of the system with Ts = 5µs, 64 QAM and different FFT sizes. This value of Ts is the close to the third tap path delay value of the fading channel. This means that the system will experience higher ISI compared to the two other systems that have a higher Ts.

At a BER of 10^{-1}. For an FFT size of 64 without UEP, an E_b/N_0 value of 32.6 dB is obtained, while for an FFT size of 512, a value of 11.7 is obtained. This shows a remarkable gain of 20.9 dB.

A better performance is seen from the UEP based scheme compared to the conventional scheme with an average gain of 0.7 for each FFT size, while the gain for an FFT size of 64 was as high as 13.3 dB. This is due to the fact the at a BER of 10^{-1}, the system with an FFT size of 64 reaches its saturation level, because the effects of ISI can no longer be decreased by increasing the E_b/N_0 value.

It is also observed that the BER performance of the 64 QAM is worse than that of the 16 QAM for the same Ts value of 5µs. One possible reason for that is that the QAM symbols are too close to each other creating additional ISI.

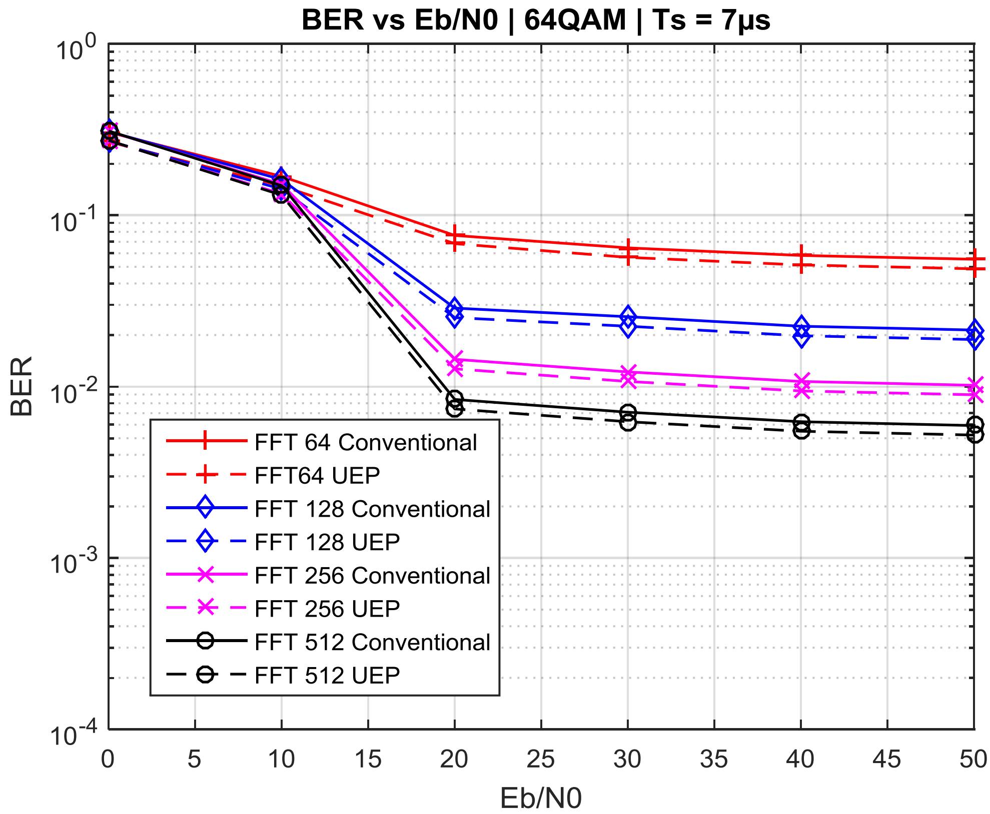

Figure 8: BER performance of LDPC-coded OFDM with 64QAM, rate ½, and different FFT sizes for Ts = 7µs.

Figure 8 shows the BER performance of the system with Ts = 7µs, 64 QAM and different FFT sizes. This value of Ts is a little higher than the third tap path delay value of the fading channel. This means that the system will experience lower ISI compared to the system with Ts of 5µs.

At a BER of 10^{-1}. For an FFT size of 64 without UEP, an E_b/N_0 value of 16.6 dB is obtained, while for an FFT size of 512, a value of 11.2 dB is obtained. This shows a gain of 5.4 dB.

The UEP based scheme performs better than the conventional scheme with an average gain of 0.75 dB for each FFT size. This time the Eb/N_0 value for an FFT size of 64 is comparable with the other FFT sizes because the saturation level decreases, so that at a BER of 10^{-1}, a much better comparison can be made between the four FFT sizes.

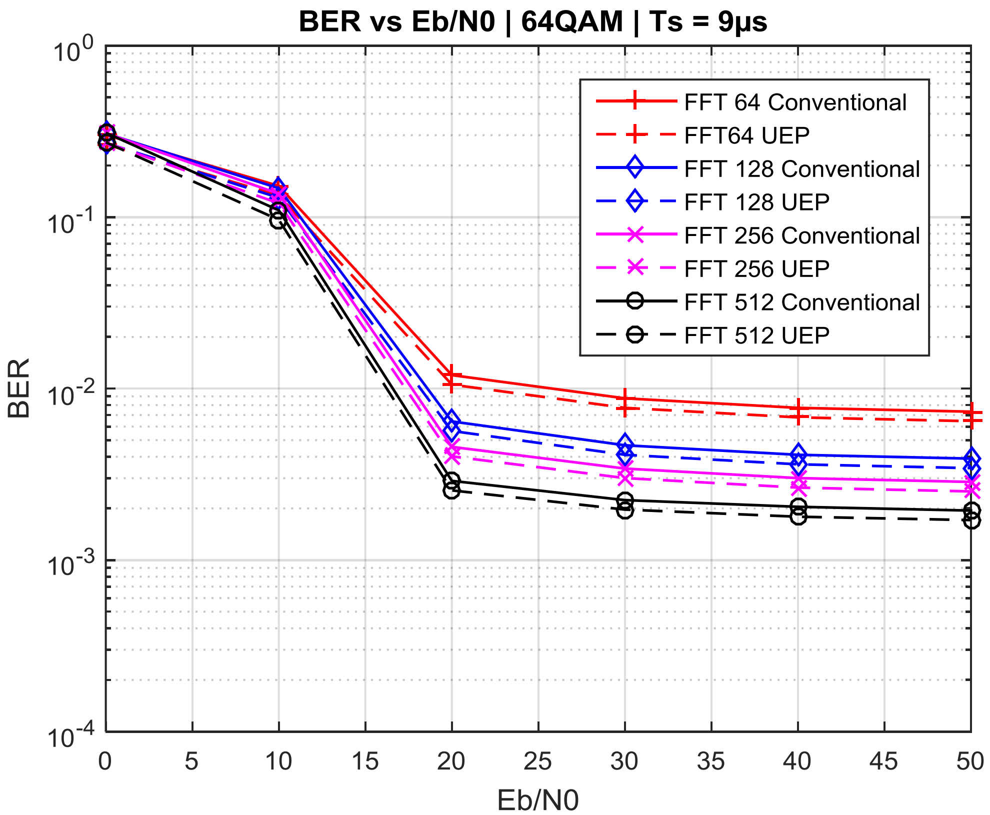

Figure 9: BER performance of LDPC-coded OFDM with 64QAM, rate ½, and different FFT sizes for Ts = 9µs.

Figure 9 shows the BER performance of the system with Ts = 9µs, 64 QAM and different FFT sizes. This value of Ts is a little higher than the third tap path delay value of the fading channel and closer to the fourth tap path delay. This means that the system will experience even lower ISI compared to the system with Ts of 5µs and 7µs.

At a BER of 10^{-1}. For an FFT size of 64 without UEP, an E_b/N_0 value of 11.6 dB is obtained, while for an FFT size of 512, a value of 9.6 dB is obtained. This shows a gain of 2.0 dB.

Again the UEP based scheme performs better than the conventional scheme with an average gain of 0.4 dB for each FFT size. Once again the Eb/N_0 value for an FFT size of 64 is comparable with the other FFT sizes because the saturation level decreases, so that at a BER of 10^{-1}, a much better comparison can be made between the four FFT sizes. For the 64 QAM, it is observed that when the FFT size increases, a better BER performance is seen for the system. It can also be seen that when Ts increases, the BER performance also increases. As a whole, when comparing the E_b/N_0 values for Ts = 5µs with FFT size 64 against Ts = 9µs with FFT size 512, a gain of 22.4 dB is obtained at a BER of 10^{-1}, without using the UEP scheme, while an additional 0.6 dB is obtained when the UEP scheme is used. However, it should be noted that the saturation level for the graphs of the 64 QAM are lower than those of the 16 QAM indicating that more ISI occurs in the 64 QAM due to the symbols being closer together.

Conclusion

The aim of this paper was to investigate the performance of an OFDM system in a frequency-selective fading channel using different symbol period as well as different FFT size, and to use LDPC codes and UEP to further increase the performance of the OFDM system. The IEEE 802.11n OFDM system was tested with the various symbol periods, Ts, of 5µs, 7µs, and 9µs.

The fading channel used in the simulations was a 4 tap channel which contains path delay values of 0µs, 1µs, 3.5µs, and 10µs. These large delay values are used to simulate very large indoor environments such as shopping malls. These tests were carried out using the FFT sizes of 64, 128, 256, 512.

These different symbol periods and FFT size schemes were then implemented using conventional LDPC codes with block length of 648 at code rates of 1/2 using 64-QAM and 16-QAM as digital modulation techniques. UEP was also used in order to further improve the performance. The results obtained showed that when the FFT size increases, a better BER performance is seen for the system. It can also be seen that when Ts increases, the BER performance also increases.

As a whole for the 16 QAM, when comparing the E_b/N_0 values for Ts = 5µs with FFT size 64 against Ts = 9µs with FFT size 512, a gain of 13.6 dB is obtained at a BER of 2×10^{-2}, without using the UEP scheme, while an additional 0.4 dB is obtained when the UEP scheme is used.

On the other hand, for the 64 QAM, a gain of 22.4 dB is obtained at a BER of 10^{-1}, without using the UEP scheme, when comparing the E_b/N_0 values for Ts = 5µs with FFT size 64 against Ts = 9µs with FFT size 512, while an additional 0.6 dB is obtained when the UEP scheme is used. However, it should be noted that the saturation level for the graphs of the 64 QAM are lower than those of the 16 QAM indicating that more ISI occurs in the 64 QAM due to the symbols being closer together.

The main implication of the results is that by using a 512-point FFT, with 16 QAM modulation, and with UEP, the LDPC coded IEEE 802.11n standard can be used in very large indoor environments having large path delays. Moreover, better performance is obtained when the number of sub-carriers is increased in an OFDM-based IEEE 802.11n system using LDPC coding, and this can be further enhanced by using UEP scheme.

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