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Comprehensive Analysis of UFMC with OFDM and FBMC

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Abstract

Objectives: To design a novel waveform for 5G communications with less Peak to Average Power Ratio and high Spectral efficiency **Methods/Statistical Analysis**: In this paper, Orthogonal Frequency Division Multiplexing (OFDM), Filter Bank Multicarrier (FBMC)and Universal Filtered Multi-Carrier (UFMC) are compared and PAPR of these techniques is analyzed by applying different subcarriers and modulation techniques. **Findings:** The spectral efficiency is poor in OFDM due to the presence of cyclic prefix and the efficiency can be improved by FBMC and UFMC. The use of separate filters for individual subcarriers eliminates the cyclic prefix and an increase in the sub carriers reduces the PAPR further. The PAPR varies according to the modulation techniques used**. Application/Improvements:** UFMC is a better waveform technique for 5G communication when compare to OFDM and FBMC which will have less PAPR and the PAPR is further reduced by applying the optimization techniques.

Keywords: FBMC, OFDM, PAPR, UFMC

1. Introduction

The 4G technology LTE uses OFDM technique in which a large number of closely spaced orthogonal subcarriers are used to carry data. Although the sidebands from each carrier overlap, they can still be received without the interference because they are orthogonal each other. There is no need of guard bands to separate subcarriers. Cyclic prefix is the addition of some repeated bitsat the end of each OFDM symbol[1].Due to the addition of cyclic prefix, circular convolution takes place which eliminates the inter symbol interference. But due to the use of cyclic prefix, 10% of the bits are repeated which decreases spectral efficiency. OFDM also suffers from high PAPR. Because of these major drawbacks, it is not an efficient technique for 5G communications. The special features of 5G when compared to 4G are IoT(Internet of Things), M2X communications, Tactile Internet, WRAN (Wireless Regional Area Network) and Very large data rate wireless connectivity (upto 10Gb/s). These applications cannot be satisfied by OFDM technique. Hence there is a need of new techniques like FBMC and UFMC[2].

2. FBMC

This section compares the FBMC technique with OFDM.

In FBMC, each subcarrier is filtered individually. It uses the very narrow band filter with long time length[3]. Due to the use of filter for each subcarrier, OOB emissions are greatly reduced. In FBMC, first prototype filter is to be designed. After that filters are designed for each subcarrier based on the prototype filter by frequency shifting. All the filters together are called filter bank[4]. The main difference between OFDM and FBMC is OFDM uses one rectangular filter for all subcarriers whereas FBMC uses one filter for each subcarrier. FBMC has high spectral efficiency when compared to OFDM because cyclic prefix is not used in FBMC. Computational complexity is very high for FBMC because of usage of each filter for every subcarrier[5]. It is suitable for single user transmission but multiple input multiple output transmission is not possible efficiently. Due to these drawbacks, it is also not an efficient technique for 5G communications.

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3. UFMC

This section describes block diagram of transmitter and receiver of UFMC and compares UFMC with OFDM and FBMC.UFMC combines the advantages of OFDM and filter bank in FBMC. In UFMC, first the total bandwidth is divided into sub-bands. Each sub-band has some subcarriers. Instead of filtering each subcarrier like in FBMC, filtering a block of subcarriers is done in this technique.

The Figure 1 in the 8th shows the block diagram of UFMC transmitter. In UFMC, total bandwidth is first divided into B sub-bands. Each sub-band has k subcarriers. Now data bits are given to each subband[6]. After that the data bits become parallel by the use of serial to parallel converter. Now the output of s/p converter is given to symbol mapper. Symbol mapper assigns symbols to bits. The output of symbol mapper is given to IFFT. Here the IIFT acts as a modulator. It is very difficult to design modulators for every subcarrier. The output of IFFT is serialized by parallel to serial converter and that output will be filtered with pulse shaping filter of length L. The filter is chebyshev filter[7]. The output of each filter is added and the resulting signal is passed through channel. The input data represented by X is converted to B sub-blocks. And each sub-block is passed through N point IFFT representing with matrix 'V'. The output of IFFT will be serialized and passing through filter representing with matrix 'F'[8].

For the i^{th} sub-band the data blocks represent with $S_{i,k}$, IFFT matrix with $V_{i,k}$ and filter with $F_{i,k}$. The output of filter bank is shown in equation 1.

$$x_k = \sum_{i=1}^{B} F_{i,k} \cdot V_{i,k} \cdot S_{i,k} \tag{1}$$

where $S_{i,k}$ represents data blocks

$F_{i,k}$ represents Chebyshev filter

$V_{i,k}$ represents IFFT to eplitz matrix

$$\mathbf{F_{i,k}} = \frac{\cos\left\{\mathbf{M}\cos^{-1}\left[\boldsymbol{\beta}\cos\left(\frac{\boldsymbol{\pi}\mathbf{k}}{\mathbf{M}}\right)\right]\right\}}{\cos[\mathbf{M}\cosh^{-1}(\boldsymbol{\beta})]} \quad ,$$

$$\mathbf{k} = \mathbf{0}, \mathbf{1}, \mathbf{2}, \ldots\ldots\ldots \mathbf{M}-\mathbf{1} \tag{2}$$

$$\beta = \cosh\left[\frac{1}{M}h^{-1}(10^{\alpha})\right] \ , \alpha = 2,3,4$$

where α represents attenuation of side lobe

Figure 2 shows the block diagram of UFMC Receiver. The received data from the channel is given to the serial to parallel convertor and then passed through FFT to demodulate the data. After that the output of FFT is given to parallel to serial converter. It converts all the parallel data streams into single stream. The symbol demapper converts the symbols into bits and original data is retrieved[9].

UFMC has more spectral efficiency compared to OFDM. There is no cyclic prefix insertion like in OFDM. There is no repetition of the same bits, therefore it utilizes all the allocated spectrum efficiently[10]. UFMC has less side lobes than OFDM. As side lobes decreases the interference on adjacent subcarriers also decreased. In OFDM, the signal consists of a large number of independently modulated subcarriers which can give a large PAPR when they are added in phase. In UFMC, total bandwidth is divided into sub-bands. As the probability of number of subcarriers adding up in phase is less in UFMC, the maximum power decreases. Hence PAPR is low for UFMC when compared with OFDM[11].

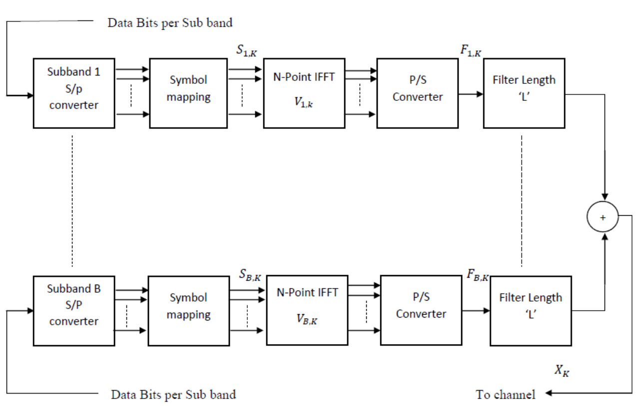

Figure 1. Block diagram of UFMC transmitter.

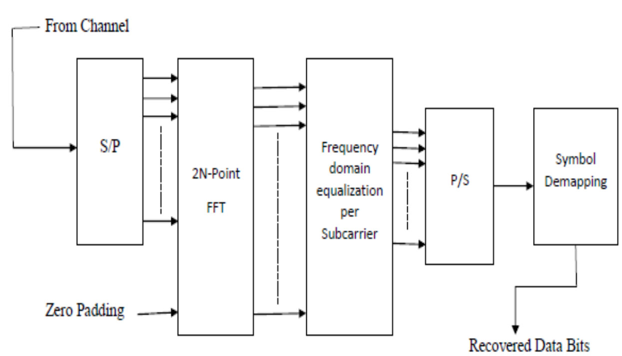

Figure 2. Block diagram of UFMC receiver.

4. Results

As per LTE specifications the preferred modulation techniques are QPSK, 16 QAM and 64 QAM. The bandwidth is 1.5MHz-20MHz. The length of cyclic prefix in OFDM is approximately equal to length of filter length in UFMC. The maximum number of subcarriers are 1200. When FFT size increases, more number of subcarriers can be sent. When the number of subcarriers increases, users will be more. Program is simulated by changing the parameters like number of subcarriers, FFT size and modulation technique.

Table 1 shows the comparison of PAPR values for UFMC, OFDM and FBMC. The parameters taken are size of FFT is 256 and number of subcarriers are 200. Values are taken for each modulation technique QPSK, 16 QAM and 64 QAM. The best result is obtained for 64 QAM modulation technique.

Table 2 shows the comparison of PAPR values for UFMC, OFDM and FBMC. The parameters taken are size of FFT is 512 and number of subcarriers are 300. Values are taken for each modulation technique QPSK, 16 QAM and 64 QAM. The best result is obtained for 64 QAM modulation technique.

Table 3 shows the comparison of PAPR values for UFMC, OFDM and FBMC. The parameters are size of FFT is 1024 and number of subcarriers are 900. Values are taken for each modulation technique QPSK, 16 QAM and 64 QAM. The best result is obtained for 64 QAM modulation technique.

Table 1. Comparison of minimum PAPR values for FFT length 256

No of bits per symbol	UFMC(dB)	OFDM(dB)	FBMC(dB)
2	3.6368	6.1493	7.4647
4	3.5198	6.0761	7.2234
6	3.3924	5.5573	7.1712

Table 2. Comparison of minimum PAPR values for FFT length 512

No of bits per symbol	UFMC(dB)	OFDM(dB)	FBMC(dB)
2	4.7975	6.7189	7.6498
4	4.3405	6.6277	6.8594
6	4.1744	6.4554	6.6705

Table 3. Comparison of minimum PAPR values for FFT length 1024

No of bits per symbol	UFMC(dB)	OFDM(dB)	FBMC(dB)
2	5.4396	7.3807	7.4235
4	5.2303	7.1278	7.2264
6	4.5297	6.9854	7.1691

Table 4 shows the comparison of PAPR values for UFMC, OFDM and FBMC. The parameters taken are size of FFT is 2048 and number of subcarriers are 1200. Values are taken for each modulation technique QPSK, 16 QAM and 64 QAM. The best result is obtained for 64 QAM modulation technique.

Figure 3 is obtained by taking the parameters – size of FFT is 256, number of subcarriers are 200 and modulation technique is QPSK. UFMC has low PAPR. UFMC curve is constant upto 4.3dB above average power. OFDM curve is constant upto 6.6dB above average power. FBMC curve is constant upto 7.5dB above average power. As power increases, probability of occurrence of signal at a particular power level decreases.

Figure 4 is obtained by taking the parameters – size of FFT is 256, number of subcarriers are 200 and modulation technique is 16 QAM.UFMC has low PAPR. UFMC curve is constant upto 4.3dB above average power. OFDM curve is constant upto 6.5dB above average power. FBMC curve is constant upto 7.5dB above average power.

Figure 5 is obtained by taking the parameters – size of FFT is 256, number of subcarriers are 200 and modulation technique is 64 QAM.UFMC has low PAPR. UFMC curve is constant upto 4.1dB above average power. OFDM curve is constant upto 6.5dB above average power. FBMC curve is constant upto 7.5dB above average power.

Figure 6 is obtained by taking the parameters – size of FFT is 512, number of subcarriers are 300 and modulation technique is QPSK.UFMC has low PAPR. UFMC curve is constant upto 5.2dB above average power. OFDM curve is constant upto 7dB above average power. FBMC is constant upto 7.4dB above average power.

Figure 7 is obtained by taking the parameters – size of FFT is 512, number of subcarriers are 300 and modulation technique is 16 QAM.UFMC has low PAPR. UFMC curve is constant upto 5.5dB above average power. OFDM curve is constant upto 6.9dB above average power. FBMC curve is constant upto 7.4dB above average power.

Table 4. Comparison of minimum PAPR values for FFT length 2048

No of bits per symbol	UFMC(dB)	OFDM(dB)	FBMC(dB)
2	6.0057	7.9231	7.4614
4	5.9010	7.8629	7.1735
6	5.3706	7.7245	7.1271

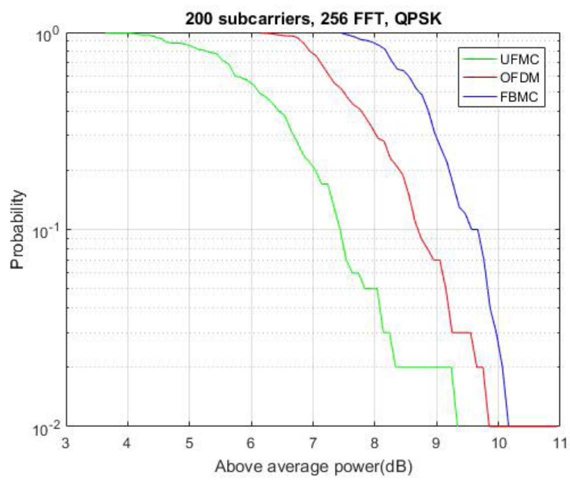

Figure 3. CCDF graph comparing PAPR for various techniques.

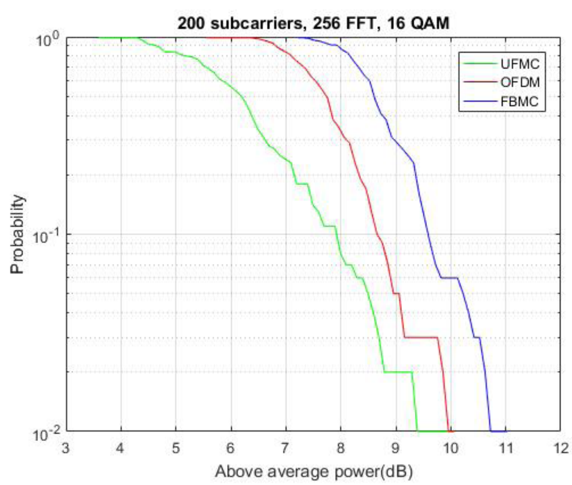

Figure 4. CCDF graph comparing PAPR for various techniques.

Figure 8 is obtained by taking the parameters – size of FFT is 512, number of subcarriers are 300 and modulation technique is 64 QAM.UFMC has low PAPR. UFMC curve is constant upto 4.9dB above average power. OFDM

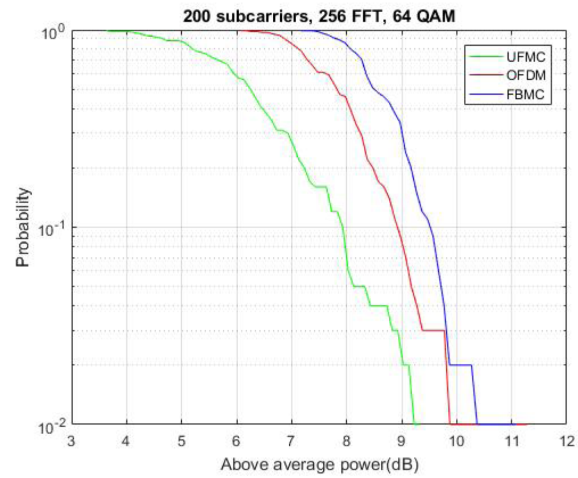

Figure 5. CCDF graph comparing PAPR for various techniques.

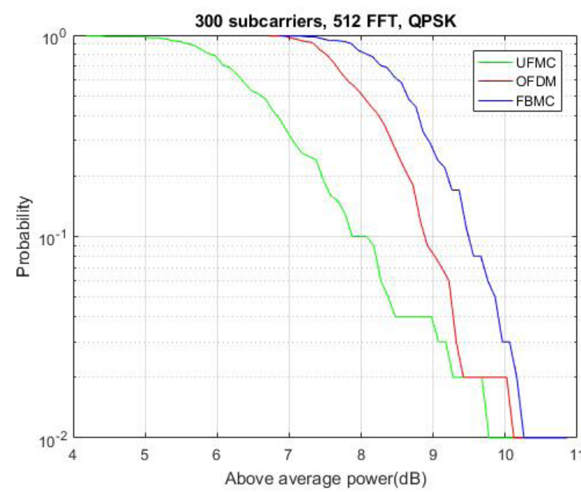

Figure 6. CCDF graph comparing PAPR for various techniques.

curve is constant upto 7.1dB above average power. FBMC curve is constant upto 7.8dB above average power.

Figure 9 is obtained by taking the parameters – size of FFT is 1024, number of subcarriers are 900 and modulation technique is QPSK.UFMC has low PAPR. UFMC curve is constant upto 5.5dB above average power. OFDM curve is constant upto 7.4dB above average power. FBMC curve is constant upto 7.4dB above average power. As power increases, probability of occurrence of signal at a particular power level decreases.

Figure 10 is obtained by taking the parameters – size of FFT is 1024, number of subcarriers are 900 and modulation technique is 16 QAM. UFMC has low PAPR.

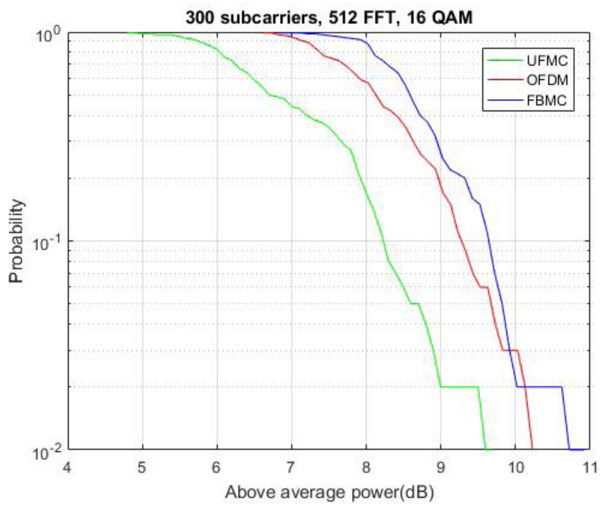

Figure 7. CCDF graph comparing PAPR for various techniques.

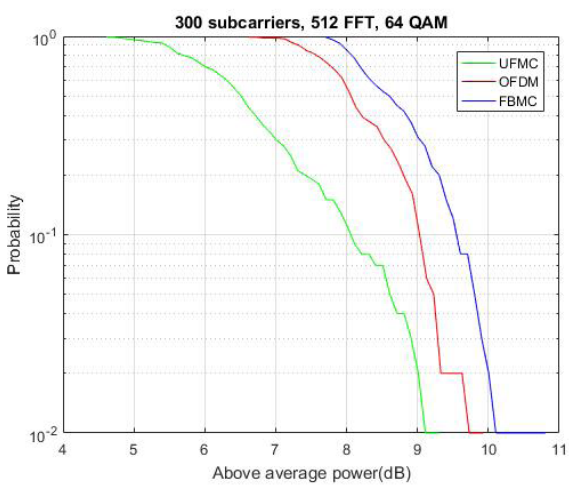

Figure 8. CCDF graph comparing PAPR for various techniques.

UFMC curve is constant upto 5.5dB above average power. OFDM curve is constant upto 7.8dB above average power. FBMC curve is constant upto 7.8dB above average power.

Figure 11 is obtained by taking the parameters – size of FFT is 1024, number of subcarriers are 900 and modulation technique is 64 QAM. UFMC has low PAPR. UFMC curve is constant upto 5.3dB above average power. OFDM curve is constant upto 7.7dB above average power. FBMC curve is constant upto 7.7dB above average power. As power increases, probability of occurrence of signal at a particular power level decreases.

Figure 12 is obtained by taking the parameters – size of FFT is 2048, number of subcarriers are 1200

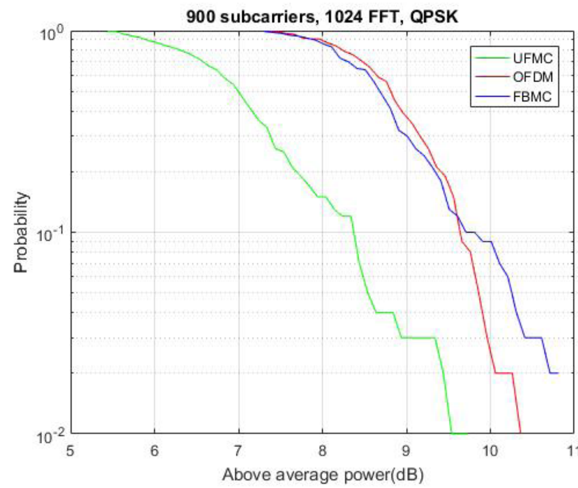

Figure 9. CCDF graph comparing PAPR for various techniques.

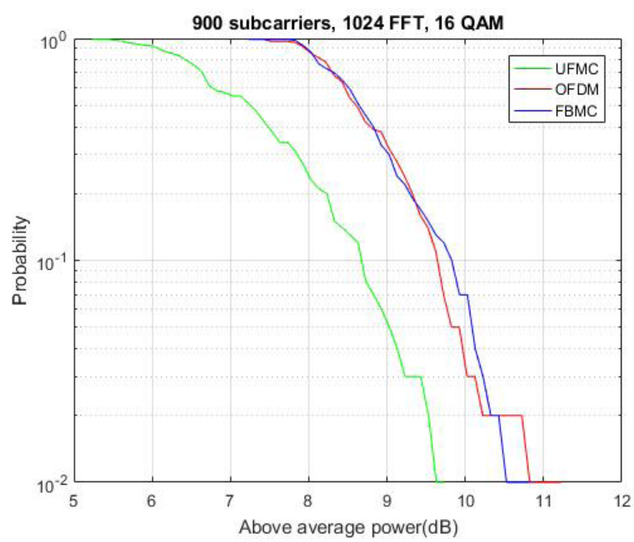

Figure 10. CCDF graph comparing PAPR for various techniques.

and modulation technique is QPSK. UFMC has low PAPR. UFMC curve is constant upto 6.3dB above average power. OFDM curve is constant upto 8.2dB above average power. FBMC curve is constant upto 7.6dB above average power. As power increases, probability of occurrence of signal at a particular power level decreases.

Figure 13 is obtained by taking the parameters – size of FFT is 2048, number of subcarriers are 1200 and modulation technique is 16 QAM. UFMC has low PAPR. UFMC curve is constant upto 6.3dB above average

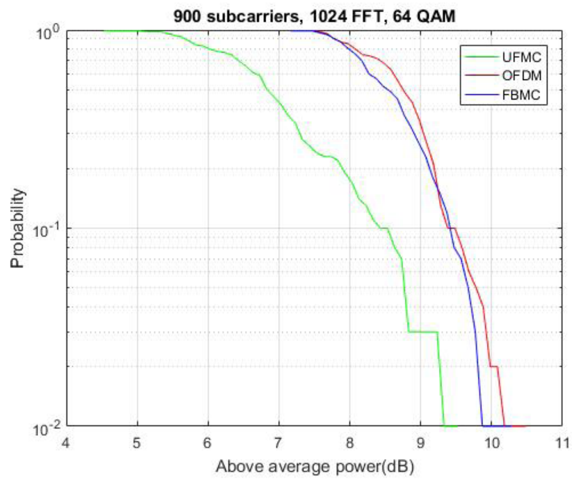

Figure 11. CCDF graph comparing PAPR for various techniques.

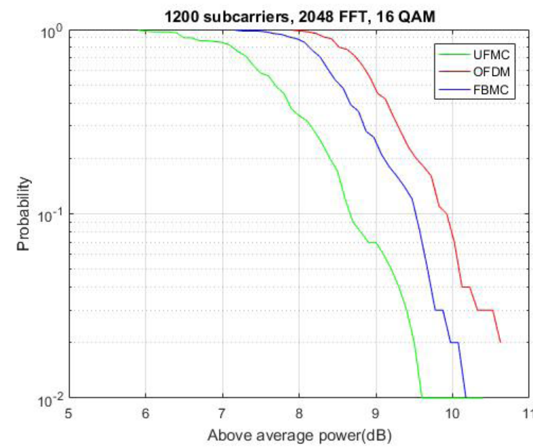

Figure 13. CCDF graph comparing PAPR for various techniques.

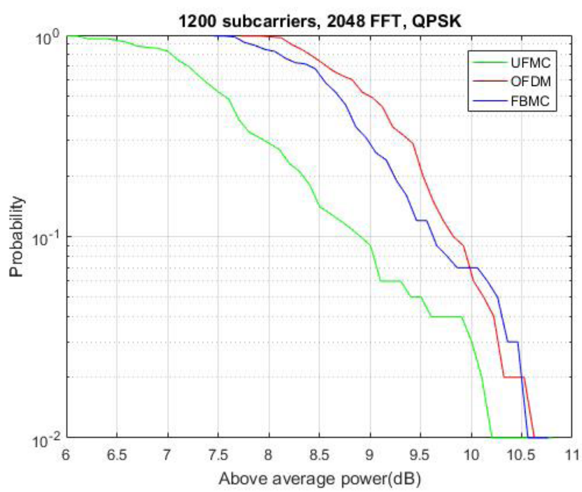

Figure 12. CCDF graph comparing PAPR for various techniques.

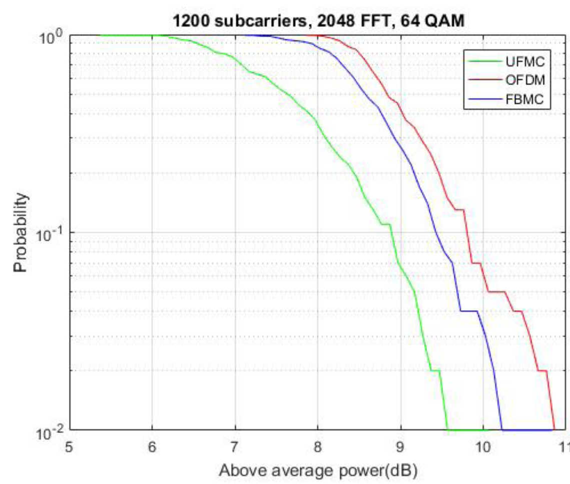

Figure 14. CCDF graph comparing PAPR for various techniques.

power. OFDM curve is constant upto 8dB above average power. FBMC curve is constant upto 7.6dB above average power.

Figure 14 is obtained by taking the parameters – size of FFT is 2048, number of subcarriers are 1200 and modulation technique is 64QAM. UFMC has low PAPR. UFMC curve is constant upto 6.2dB above average power. OFDM curve is constant upto 8.1dB above average power. FBMC curve is constant upto 7.5dB above average power. As power increases, probability of occurrence of signal at a particular power level decreases.

5. Conclusion

The 4G technology uses OFDM technique which has some drawbacks like high PAPR and low spectral efficiency. These drawbacks are addressed by UFMC. Due to the use of cyclic prefix in OFDM, 10% of the bits are repeated, where as in UFMC, cyclic prefix is not used. This increases spectral efficiency. In UFMC, total bandwidth is divided into sub-bands. As number of subcarriers adding up in phase will be fewer in UFMC, the maximum power decreases. As a result of this, PAPR is less for UFMC. In this paper, PAPR of UFMC, OFDM and FBMC are compared by changing the parameters like number of subcarriers, size of FFT and modulation technique. It is observed from all the results that UFMC has low PAPR when compared to OFDM and FBMC. The minimum PAPR values are obtained for 64 QAM modulation technique.

6. Future Scope

The PAPR of UFMC is further decreased by using PAPR reduction techniques like PTS (Partial Transmit sequence), SLM (Selective Mapping) etc., and optimization algorithms like PSO (Particle Swarm Optimization), firefly etc.

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