

Parametric Analysis of FBMC/OQAM under SUI Fading Channel Models

Amna Javed Tiwana

Department of Electrical Engineering

College of Electrical and Mechanical Engineering,

National University of Sciences and Technology (NUST),

H-12, Islamabad, Pakistan

ajtiwana17@ee.ceme.edu.pk

Muhammad Zeeshan

Department of Electrical Engineering

College of Electrical and Mechanical Engineering,

National University of Sciences and Technology (NUST),

H-12, Islamabad, Pakistan

ranazeeshan@ceme.nust.edu.pk

Abstract—Filter-bank Multicarrier (FBMC) modulation is the most promising 5th Generation (5G) waveform candidate in order to fulfill modern day requirements of ultra-high data rates with minimum latency. With lower side-lobes and faster spectral decay, FBMC is also well suited for reconfigurable radios such as Software Defined Radio (SDR) or Cognitive Radio (CR) for efficient spectrum utilization. In this paper, a performance as well as a parametric analysis of FBMC over Stanford University Interim (SUI) channel models has been analyzed. Performance is evaluated on the basis of Bit error rate (BER) using multipath fading environment that is characterized by Rician distribution, under different scenarios. The evaluation provides a useful basis for FBMC-based dynamic link adaptation in SDR wideband waveform.

Index Terms—5G, FBMC, SDR, CR, SUI channel models, Link adaptation

I. INTRODUCTION

The recent advances in the wireless communication technology as well as the growing number of wireless users have overburdened the radio frequency spectrum. At the same time, some of the spectrum bands are moderately utilized and some are under utilized. In order to overcome these spectral deficiencies and inefficiencies, some of the modern day paradigms like Software Defined Radio and Cognitive Radio have been introduced over the past few decades [1]. Thus a high data rate requirement by ensuring a desired Quality of Service (QoS) has become a necessity over time that needs to be addressed through wideband networking waveform having the ability to provide high data rate communication [2]–[4].

Wideband Code Division Multiple Access (W-CDMA) or Multicarrier Code Division Multiple Access (MC-CDMA) provide a scenario for sharing the available bandwidth among various users by utilizing orthogonal spreading codes [5], [6]. Although the spectrum utilization is significantly increased with these waveform, however, there comes a high risk of loss of orthogonality in case of fading channel environment such as Rician or Rayleigh fading channels. Multiple Access Interference (MAI) also rises with enhancement in bandwidth and the suppression of MAI introduces more complexity at the receiving end [5]–[7].

To combat the effects of inter-symbol interference (ISI) over a dispersive channel, another notable type of multicarrier modulation, Orthogonal Frequency Division Multiplexing (OFDM) was proposed under 3rd Generation Partnership Project (3GPP) [8]. Having the frequencies of the subcarriers closely overlapped and placed orthogonal to each other, a high data rate is achieved and the remaining ISI is removed by extension of OFDM symbol with the Cyclic Prefix (CP). Moreover, reducing the computational requirements of the spectrum sensing algorithm, efficient spectrum utilization, adaptation to the environment and better inter-operability makes it an attractive technology for CR-based systems [9]. However, due to large frequency domain ripples, MAI cancellation requirement, higher sensitivity to carrier frequency offset (CFO) and spectral leakage issues, OFDM definitely needed performance improvement [10].

In order to cater for high Peak to Average Power Ratio (PAPR) and spectral leakage issues, a more resilient form of OFDM, FBMC was proposed as a potential candidate for 5G communication. Instead of utilizing a single rectangular filter for all the subcarriers like OFDM, FBMC formulates a filter for each subcarrier collectively called as Filter Bank, obtained by frequency shifting in the particular Prototype Filter [11]. The spectral efficiency enhancement by disregarding CP, MAI repression due to excellent frequency localization of each subcarrier and less sensitivity to CFO as well as Doppler shift makes it most well-suited 5G technology [10]–[12].

In this paper a parametric analysis has been presented based upon modulation schemes and convolutional encoding, varied in a Rician fading environment. The performance parameters under SUI models have been altered by considering a single-input single-output (SISO) model and is analyzed using MATLAB simulations by considering Bit Error Rate (BER) at different values of Energy per bit to Noise power spectral density ratio i.e. E_b/N_0 , also known as normalized Signal to Noise Ratio (SNR). The paper is organized in five sections. Section I provides an introduction, background knowledge and broad spectrum advantages of utilizing FBMC as an evolved Multicarrier Modulation (MCM) technique. Section II consists of a generic system model for FBMC, outlining the filter-bank analysis and how it addresses the spectral leakage issue

previously faced in OFDM. The additional requirements to ease the spectral analysis of simulated curves such as utilization of Offset Quadrature Amplitude Modulation (OQAM) instead of simple QAM, convolutional encoding and Minimum Mean Square Error (MMSE) equalization, along with a brief description of SUI channel models have been discussed as well in this section. Section III illustrates simulated BER performance curves of the system model along with their summarized results under various scenarios in all 6 SUI channels. Section IV discusses the parametric analysis of FBMC under various system parameters. Lastly, the conclusion is made in section V.

II. SYSTEM MODEL

A. Filter-bank Multicarrier (FBMC) Modulation

The theoretical and technical attributes of FBMC have been well explained in the specifically targeted research conducted by the collective collaboration of various countries under the project title Physical Layer for Dynamic Access and Cognitive Radio (PHYDAS) in the year 2010 [11]. The overall flow of the proposed FBMC system is shown in the fig. 1. The project highlights the basic aspects of FFT/IFFT application on the multicarrier techniques and the spectrum leakage issues related to this technique. This issue can be addressed by implementing an extended form of FFT approach, the Filter-bank approach. The time window is extended beyond the symbol period of a single multicarrier symbol and the overlapping is done in time domain. Polyphase Networking technique for extended FFT i.e. PPN-FFT is utilized to implement the concept of extended FFT where a set of digital filters are added alongside [11], [14], [15].

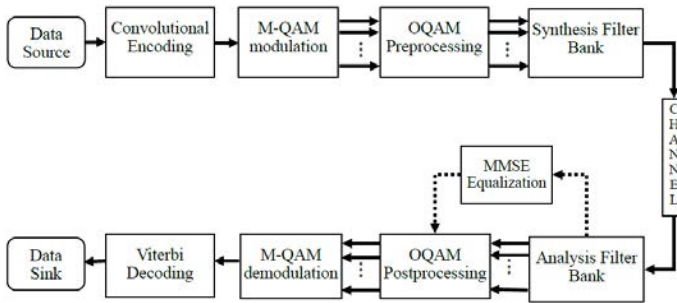


Fig. 1. FBMC/OQAM - System Model

The PPN-FFT brings Synthesis and Analysis Filter-banks into utilization, providing the major advantage of necessitating orthogonality between the neighboring subcarriers only, unlike OFDM that requires strict orthogonality among all the subcarriers, that has been validated by several researches over time [14]–[16]. The prototype filter impulse response is as follows, given by the IFFT of pulse frequency response [11].

$$h(t) = 1 + 2 \sum_{k=1}^{1-K} H_k \cos\left(2\pi \frac{kt}{KT}\right) \quad (1)$$

where K is the overlapping factor i.e. the ratio of the filter impulse response duration to the multicarrier symbol period T , H_k are the Nyquist frequency coefficients and k is the subcarrier index. The guard band and cyclic prefix is avoided by the combination of filter banks along with OQAM modulation. The constraint of neighboring orthogonality is further supported by the use of OQAM, that helps the overall exploitation of channel bandwidth [17].

In order to cope with the effects of frequency selective channels various types of equalization techniques have been presented especially over the past decade, from simplistic 1-tap and Zero-Forcing (ZF) equalizers to complex Maximum Likelihood Estimation (MLSE) and multi-tap MMSE equalization techniques [17]–[21]. For highly selective channels i.e. time and frequency selective, however, the implementation of an enhanced n -tap MMSE equalizer works optimally well compared to single tap or ZF equalizers, and proves to be an efficient interference cancellation scheme [22].

B. Stanford University Interim (SUI) Channel Models

The Stanford University Interim (SUI) channel models based upon three different types of terrain types (A,B,C), Doppler spreads, delay spread and line-of-sight/non-line-of-sight conditions that are typical of the continental US have been utilized for the purpose of bench-marking [13], [23]. Three categories of terrain types have been classified from a moderate-to-heavy tree density having a high path loss, hilly with light tree density having an intermediate path loss and a flat terrain type with light tree density having a low path loss, respectively. The multipath fading is characterized by the use of tapped delay line having 3-taps with non-uniform path delays. The gain associated with each tap is characterized by a Rician Distribution along with the maximum Doppler frequency. The values that have been selected for introducing multipath channel in our paper are for an omnidirectional antenna i.e. 90% cell coverage area, and are listed below in the Table I.

TABLE I
SUI CHANNEL MODELS SUMMARY

SUI No.	Terrain Type	Rician Factor ^a (K)	Path Delay Vector (μ s)	Path Gain Vector (dB)	Max. Doppler Spread (Hz)
1	C	4	[0 0.4 0.9]	[0 -15 -20]	0.5
2	C	2	[0 0.4 1.1]	[0 -12 -15]	0.25
3	B	1	[0 0.4 0.9]	[0 -5 -10]	0.5
4	B	0	[0 1.5 4]	[0 -4 -8]	0.25
5	A	0	[0 4 10]	[0 -5 -10]	2.5
6	A	0	[0 14 20]	[0 -10 -14]	0.5

^a Omni-directional Antenna

III. PERFORMANCE ANALYSIS OF FBMC UNDER SUI CHANNEL MODELS

The performance analysis has been done for four different scenarios; FBMC/QAM without convolutional encoding,

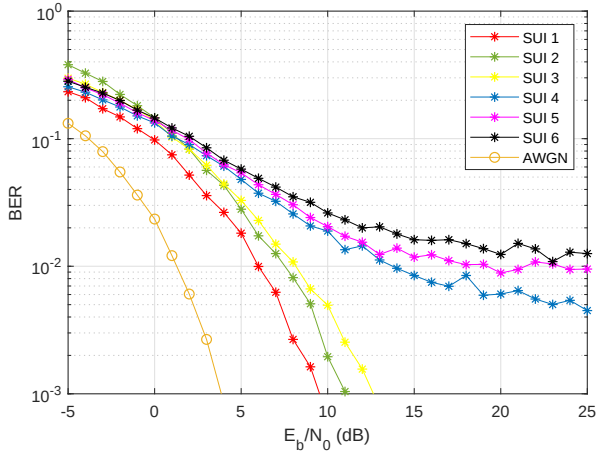


Fig. 2. FBMC/QAM without convolutional encoding

FBMC/QAM with encoding, FBMC/OQAM without convolutional encoding and FBMC/OQAM with encoding. The code rate is set to be at $1/2$ while a modulation order of 4 is set for 256 subcarriers.

A. FBMC/QAM without encoding

The simplistic Single Input Single Output (SISO) FBMC model based upon Quadrature Amplitude modulation provides the BER results as shown in the Fig. 2. The SNR per bit is set for the range of $-5:25$ dB.

B. FBMC/QAM with encoding

In order to provide immunity towards channel noise, channel encoder adds redundancy to the original signal according some specific rule. Convolutional encoder allows the discrete type convolution of the impulse responses of both the input and the encoder. The error correction code rule that we have utilized in our case is $1/2$, i.e. for every single bit fed into the encoder 2 output bits are generated. BER curve for this case is shown in the Fig. 3 keeping the constraint length i.e. delay for the input bit streams to the encoder, at 7 and soft decoding is done via viterbi decoder.

C. FBMC/OQAM without encoding

As stated earlier, the utilization of Offset QAM instead of QAM ensures further that the FBMC symbol overlaps with the neighboring symbol only bringing the neighbor orthogonality to the system. The complex QAM symbol is first separated between pure real and pure imaginary components and then the imaginary part is staggered by half the symbol period ($T/2$). This ensures that the real and imaginary parts of the data are not transmitted at the same time as in OFDM [24]. This helps avoiding a huge phase shift and thus zero-crossing to occur whenever both the bits change simultaneously. In this way huge spectral side lobes can be avoided and the condition of orthogonality is further strengthened [25]. The BER curves for this case are shown in the Fig. 4.

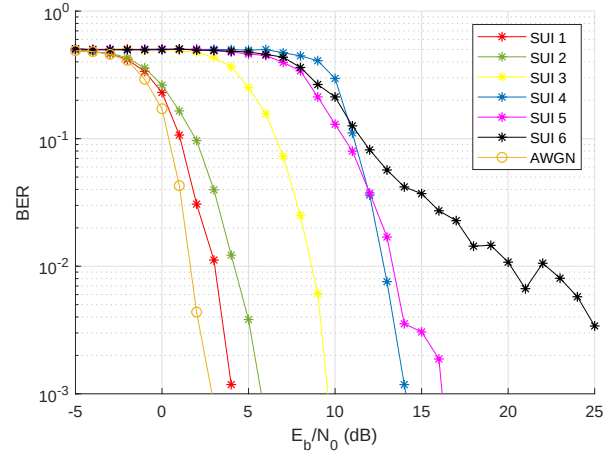


Fig. 3. FBMC/QAM with convolutional encoding

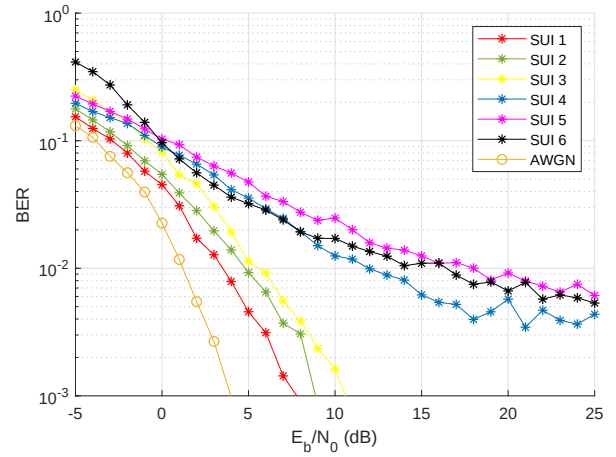


Fig. 4. FBMC/OQAM without convolutional encoding

D. FBMC/OQAM with encoding

Finally both the modifications are combined in case 4, where the OQAM modulation is accompanied with convolutional encoding. It should be noted that the basic SISO model remains same for all the simulations. The curves in final scenario are depicted in the Fig. 5.

The overall performance comparison is summarized in the Table II for all 6 SUI channels. The results are drawn by keeping the threshold value for BER at 10^{-2} .

IV. PARAMETRIC ANALYSIS OF FBMC UNDER SUI CHANNEL MODELS

In order to observe the effect of varying parameters the case 4 model has been subjected to different modulation orders, overlapping factors, number of subcarriers and encoding rates. The utilized parameters are summarized in the Table III.

The BER results obtained by varying the above mentioned parameters have been illustrated in the Table IV. The SNR per bit E_b/N_0 values thus gained indicate the various trends that

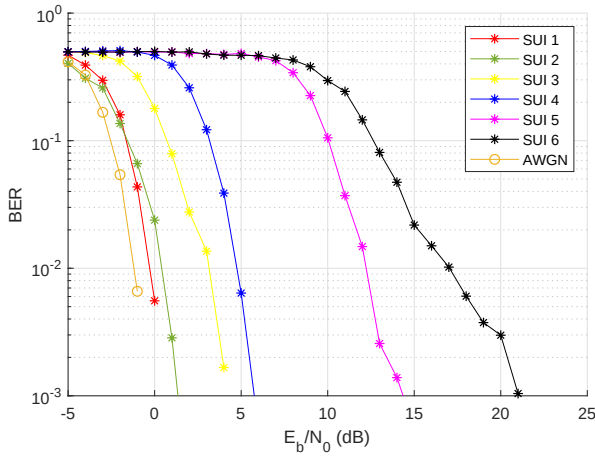


Fig. 5. FBMC/OQAM with convolutional encoding

TABLE II
PERFORMANCE ANALYSIS OF FBMC UNDER SUI CHANNEL MODELS
WITH DIFFERENT SCENARIOS

Case No.	AWGN	SUI-1	SUI-2	SUI-3	SUI-4	SUI-5	SUI-6
1	1.319	5.793	7.481	8.52	13.72	18.07	23.07
2	1.642	3.041	4.165	8.152	12.8	13.34	20.15
3	1.191	3.506	5.008	5.863	12.04	16.02	15.03
4	-1.207	-0.2768	0.4017	3.16	4.752	12.22	17.06

TABLE III
SIMULATION PARAMETERS

Parameters	Values
Modulation Order	2QAM, 4QAM
Number of Subcarrier	128, 256, 512
Overlapping Factor	2, 3, 4
Encoding Rate	1/2, 2/3

the model tends to follow. The increment in the overlapping factor and number of subcarriers improve BER performance. The overlapping factor can also be defined as the number symbols that overlap in the time domain. Having a large value of overlapping factor depicts longer filter impulse response duration extending it over to various symbols [11] and thus, improving the BER. Although the decoder efficiency increases with the constrained length, however, large constraint length results in efficient encoding [26]. The convolutional code generates a code word of n symbols from a message block of k symbols [27]. The constraint length is kept at 7 for a code rate k/n of $1/2$ and then varied for a code rate of $2/3$. As the rate is lower in the former case, it has improved BER as well.

CONCLUSION

In this paper, a comparative parametric analysis of FBMC over SUI channel models has been discussed. The utilization of convolutional encoding and OQAM has been analyzed alongside FBMC as well. The simulations results indicate that the performance clearly deteriorates when going towards higher SUI models. The effect of these distorting channels can be significantly compensated by replacing QAM with OQAM. The results are further improved by using convolutional encoding alongside OQAM. The higher values of parameters such as number of subcarrier and overlapping factor, while a lower value of modulation order and encoding rate, contribute towards better BER performance. This provides a profound basis, by utilizing the overall impact of these cases, for the development of Adaptive Modulation and Coding (AMC) and Link Adaptation in SDR waveform analysis.

REFERENCES

- [1] J. Rohde and T. S. Toftgaard, "Adapting cognitive radio technology for low-power wireless personal area network devices," *Wireless Personal Communications*, vol. 58, no. 1, pp. 111–123, 2011.
- [2] S. Kundrapu, S. I. Dutt, N. K. Koilada, and A. C. Raavi, "Characteristic analysis of OFDM, FBMC and UPMC modulation schemes for next generation wireless communication network systems," in *2019 3rd International conference on Electronics, Communication and Aerospace Technology (ICECA)*. IEEE, 2019, pp. 715–721.
- [3] B. Farhang-Boroujeny and R. Kempter, "Multicarrier communication techniques for spectrum sensing and communication in cognitive radios," *IEEE Communications Magazine*, vol. 46, no. 4, pp. 80–85, 2008.
- [4] A. Gupta and R. K. Jha, "A survey of 5G network: Architecture and emerging technologies," *IEEE access*, vol. 3, pp. 1206–1232, 2015.
- [5] L. B. Milstein, "Wideband code division multiple access," *IEEE journal on selected areas in communications*, vol. 18, no. 8, pp. 1344–1354, 2000.
- [6] M. Masud, M. Samsuzzaman, and M. Rahman, "Bit error rate performance analysis on modulation techniques of wideband code division multiple access," *arXiv preprint arXiv:1003.5629*, 2010.
- [7] H. A. Mahmoud, T. Yucek, and H. Arslan, "OFDM for cognitive radio: merits and challenges," *IEEE wireless communications*, vol. 16, no. 2, pp. 6–15, 2009.
- [8] R. N. Mitra and D. P. Agrawal, "5G mobile technology: A survey," *ICT Express*, vol. 1, no. 3, pp. 132–137, 2015.
- [9] D. Bepari and D. Mitra, "Improved power loading scheme for orthogonal frequency division multiplexing based cognitive radio," *IET Communications*, vol. 9, no. 16, pp. 2033–2040, 2015.
- [10] B. D. Tensubam, N. L. Chanu, and S. Singh, "Comparative analysis of FBMC and OFDM multicarrier techniques for wireless communication networks," *International Journal of Computer Applications*, vol. 100, no. 19, 2014.
- [11] M. Bellanger, D. Le Ruyet, D. Roviras, M. Terré, J. Nossek, L. Baltar, Q. Bai, D. Waldhauser, M. Renfors, T. Ihalainen *et al.*, "FBMC physical layer: a primer," *Phydyas*, vol. 25, no. 4, pp. 7–10, 2010.
- [12] H. Jebbar, S. El Hassani, and A. El Abbassi, "Performance study of 5G multicarrier waveforms," in *2017 International Conference on Wireless Networks and Mobile Communications (WINCOM)*. IEEE, 2017, pp. 1–6.
- [13] K. Hari, D. Baum, A. Rustako, R. Roman, and D. Trinkwon, "Channel models for fixed wireless applications," *IEEE 802.16 Broadband wireless access working group*, 2003.
- [14] K. Shao, J. Alhava, J. Yli-Kaakinen, and M. Renfors, "Fast-convolution implementation of filter bank multicarrier waveform processing," in *2015 IEEE International Symposium on Circuits and Systems (ISCAS)*. IEEE, 2015, pp. 978–981.
- [15] A. Ibrahim and M. Abdullah, "The potential of FBMC over OFDM for the future 5G mobile communication technology," in *AIP Conference Proceedings*, vol. 1883, no. 1. AIP Publishing, 2017, p. 020001.
- [16] A. E. Agoni, "Performance analysis of FBMC over OFDM in cognitive radio network," Ph.D. dissertation, University of Cape Town, 2017.

TABLE IV
PARAMETRIC ANALYSIS OF FBMC UNDER SUI CHANNEL MODELS WITH VARIOUS PARAMETERS

Parameters		AWGN	SUI-1	SUI-2	SUI-3	SUI-4	SUI-5	SUI-6
Modulation Order	2	-1.401	-0.738	1.448	2.102	6.528	10.46	13.63
	4	-1.217	-0.2768	2.327	4.305	7.201	12.22	16.17
	128	-1.028	1.868	4.463	6.381	8.143	10.42	19.62
Number of Subcarriers	256	-1.217	-0.2768	2.327	4.305	7.201	9.962	16.17
	512	-1.341	-0.8858	1.766	2.601	5.697	8.922	10.06
	2	-1.045	1.955	6.281	7.559	11.32	15.48	22.84
Overlapping Factor	3	-1.089	1.137	3.259	6.238	10.23	13.81	18.36
	4	-1.217	-0.2768	2.327	4.305	7.201	12.22	16.17
	1/2	-1.217	-0.2768	2.327	4.305	7.201	12.22	16.17
Encoding Rate	2/3	-0.4791	0.6101	3.823	7.196	8.512	14.95	19.48

- [17] A. F. Isnawati, V. O. Citra, and J. Hendry, "Performance analysis of audio data transmission on FBMC-Offset QAM system," in *2019 IEEE International Conference on Industry 4.0, Artificial Intelligence, and Communications Technology (IAICT)*. IEEE, 2019, pp. 81–86.
- [18] T. Stitz, T. Ihalainen, A. Viholainen, and M. Renfors, "Pilot-based synchronization and equalization in filter bank multicarrier communications," *EURASIP Journal on Advances in Signal Processing*, vol. 2010, no. 1, p. 741429, 2010.
- [19] C.-W. Chen and F. Maehara, "An enhanced MMSE subchannel decision feedback equalizer with ICI suppression for FBMC/OQAM systems," in *2017 International Conference on Computing, Networking and Communications (ICNC)*. IEEE, 2017, pp. 1041–1045.
- [20] L. Marijanović, S. Schwarz, and M. Rupp, "MMSE equalization for FBMC transmission over doubly-selective channels," in *2016 International Symposium on Wireless Communication Systems (ISWCS)*. IEEE, 2016, pp. 170–174.
- [21] C.-Y. Liu, E. W. J. Leong, C.-T. Wu, M.-S. Sie, H. Lopez, C.-W. Jen, and S.-J. Jou, "A MMSE Joint Feedback Feed-forward Equalizer for FBMC-OQAM Baseband Receiver in the 60 GHz Band," *IEEE Journal on Emerging and Selected Topics in Circuits and Systems*, vol. 7, no. 4, pp. 558–568, 2017.
- [22] M. Schellmann, Z. Zhao, H. Lin, P. Siohan, N. Rajatheva, V. Luecken, and A. Ishaque, "FBMC-based air interface for 5G mobile: Challenges and proposed solutions," in *2014 9th International Conference on Cognitive Radio Oriented Wireless Networks and Communications (CROWNCOM)*. IEEE, 2014, pp. 102–107.
- [23] R. Jain, "Channel models: A tutorial," in *WiMAX forum AATG*, vol. 10, 2007.
- [24] M. Bellanger, "Transmit diversity in multicarrier transmission using OQAM modulation," in *2008 3rd International Symposium on Wireless Pervasive Computing*. IEEE, 2008, pp. 727–730.
- [25] W. Khrouf, M. Siala, and F. Abdelkefi, "How much FBMC/OQAM is better than FBMC/QAM? a tentative response using the POPS paradigm," *Wireless Communications and Mobile Computing*, vol. 2018, 2018.
- [26] A. Dholakia, *Introduction to convolutional codes with applications*. Springer Science & Business Media, 2012, vol. 275.
- [27] B. Clerckx and C. Oestges, *MIMO wireless networks: channels, techniques and standards for multi-antenna, multi-user and multi-cell systems*. Academic Press, 2013.



Amna Javed Tiwana is currently pursuing the M.Sc. degree in electrical engineering with specialization in wireless communication from the College of Electrical and Mechanical Engineering, National University of Sciences and Technology (NUST), Pakistan, since 2017. She received her B.Sc. degree in electrical engineering from the University of Engineering and Technology, Taxila, Pakistan,

in 2017. Her research interests include wireless communica-

tions, filter-bank multicarrier modulation and software defined radio.



Muhammad Zeeshan received the B.Sc. degree from the University of Engineering and Technology, Taxila, Pakistan, in 2008, and the M.Sc. and Ph.D. degrees with a specialization in wireless communications from the College of Electrical and Mechanical Engineering, National University of Sciences and Technology (NUST), Pakistan, in 2010, all in electrical engineering. Since 2008, he has

been actively involved in research in the fields of software defined radio, wideband waveform design, and radar signal processing. He is currently an Assistant Professor with the Department of Electrical Engineering, College of Electrical and Mechanical Engineering, NUST. His research interests include spread spectrum-based wireless communications, synchronization techniques, and digital design of communication systems.