Filtered-MultiCarrier Modulation Techniques for Vehicle-to-Vehicle Communication

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ABSTRACT- The high demand of wireless applications is increased day after day because of the increasing use of mobile devices, Internet-of-Things (IoT), machine types, and wireless nodes in Wireless Sensors Networks (WSN). This increasing demand makes the consideration of using advanced technology to enhance the network performance especially in Fifth Generation (5G) applications such as Vehicular communication that is called Vehicle-to-Everything (V2x) communication where the Vehicle-to-Vehicle (V2V) is one of its types.. The use of multicarrier waveforms to overcome this problem is essential such as using Orthogonal Frequency Division Multiplexing (OFDM). The problems appear from using OFDM are the high Out-of-Band (OOB) and the high Peak to Average Power Ratio (PAPR). This leads to the attention of using other types of multicarrier waveforms to enhance the OFDM responses. In this paper, the use of four different types of Multi-Carrier Modulation (MCM) is used which are Filter Bank Multi-Carrier (FBMC), Generalized Frequency Division Multiplexing (GFDM), Universal Filtered Multi-Carrier (UFMC) and Filtered OFDM (F-OFDM). These types of MCM based on the filtering process of symbols and subcarriers to eliminate the Cyclic Prefix (CP) effect on the OFDM performance in terms of Bit Error Rate (BER) and throughput. The simulation results show that the BER performance of the FBMC is better than any other simulated MCM in this paper while the throughput of the GFDM is enhanced at high SNR and the UFMC throughput is the better at low SNR values.

Keywords: OFDM , FBMC , GFDM , F-OFDM , UFMC

1. INTRODUCTION (10 PT)

In the mobility wireless networks, the communication between vehicles and other vehicles at the road and with other objects surrounding the vehicle is very important in research nowadays. These communications are called Vehicle-to-everything (V2x) which consists of Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I) and Vehicle-to-Roadside (V2R) communication system[1][2]. These contexts are parts of Intelligent Transportation Systems (ITS) that have increased attention in researching nowadays. The scope of ITS can contains the communication between everything on the roadside and also the aeronautical transportation systems as well with full control by the government which licensed the spectrum to each communication system[3][4] [5]. ITS includes different applications such as monitoring the area, relaying emergency messages, sensing the weather conditions and allows passenger entertainment by offering high-speed data transfer and an Internet connection. All of these come from the use of Internet-of-Things (IoT) as one of the 5th generation (5G) wireless system. Focusing on V2V communication as one of the cooperative communication systems depending on ITS, V2V is used to study the communication between vehicles in travelling road[6][7] . The communication link of V2V and/or V2I may be Line-of-Sight (LoS) and/or Non-LoS (N-LoS) depending on the traffic conditions[8][9][10]. This means that the speed of vehicles, the density of vehicles, the surrounding terrain/area, and the infrastructure distribution of the network can affect the quality of the channel between vehicles, especially that V2V uses low height antennas at transmitter and receiver[11][12][13]. It is important to know that the V2V channel is sever affected by the multiple scattering or rapid time variation, this can lead to consider this channel as stationary but in the small period of travelling and time. This is the main difference between V2V channel and most cellular fading model[14]. Thus, the channel characteristics may be optimized by using several techniques such as using coding and decoding algorithms for short-distance communication to minimize the Errors come from the channel characteristic, using Software Defined Radio (SDN) technology to past knowing the channel condition and using Multi-Carrier Modulation (MCM) as an air interface between vehicles as describes and simulates in this paper.[15] [16]In high mobility scenario of V2V communication, the network configuration is changing rapidly due to the fast speed of user along the road. This rapidly changing of the channel increases the error of communication between vehicles due to the time-frequency selective fading nature of the channel between vehicles[17][18][19].

This problem requires a solution to enhance the throughput and decrease the errors. The increasing appears of this problem makes the communication between vehicles performed for short distances and times to avoid the severe doppler shift. To overcome this, narrowband measurement systems are used to determine the channel gain and response. For large distance communication, the use of MCM like OFDM is essential as one of the techniques used to solve the frequency selective fading problem in wireless communication. discusses the performance tradeoffs of two alternative waveform families which are being considered in many research activities targeting future 5G systems[20][21]: Filter Bank Multi-Carrier (FBMC) and Filtered-OFDM. also present an enabler for flexible waveform configuration, named as filtered-OFDM (F-OFDM) to improve spectrum utilization. The problem appears in the surface comes from the construction of most of the OFDM applications which depend on Cyclic Prefix (CP)[22] [23]. The problem here is the non-stationary property of the OFDM due to the high Out-Of-Band (OOB) and high Peak-to-Average Power Ratio (PAPR) that affect the spectral efficiency of the V2V communication[24]. Because of this, it is good to use filtered-MCM techniques in V2V communication to overcome the OFDM drawbacks and to enhance system performance.

In this paper, performance evaluation of the use of several multicarrier modulations based on filtering process to eliminate the CP is performed and simulated such as FBMC, Generalized Frequency Division Multiplexing (GFDM), Universal Filtered Multi-Carrier (UFMC) and Filtered OFDM (F-OFDM)[25]. All these waveforms responses are compared between each other and with the response comes from OFDM concerning Bit Error Rate (BER) and throughput of the system. All simulations are performed under high-speed communication.

The rest of the paper is organized as follows. Section II describes the system model and methodology for the study. The simulation results of the proposed algorithm concerning BER and throughput when changing the speed of vehicles are analysed and discussed in section III. The conclusion of this study and the illustration of some future works are given in section IV.

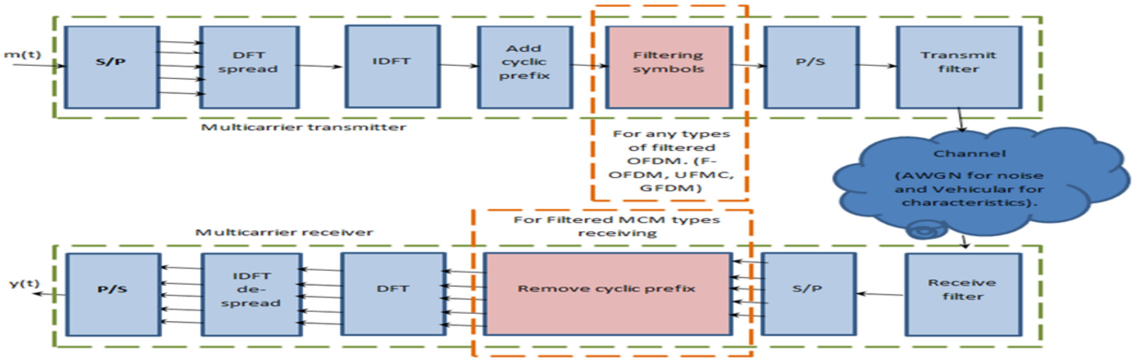
2 System Model and Methodology

The overall methodology of the proposed simulation under this paper is to consider several types of multicarrier modulation techniques used in modern wireless communication to reduce the PAPR and OOB that OFDM suffers from in the 2.6 GHz LTE network used for vehicular communication. The baseband modulation used in this paper is the Quadrature Amplitude Modulation (QAM) especially 16-QAM which is widely used. The main concept of the MCM techniques is the use of filtering to remove the CP of the OFDM. The three used techniques here are the F-OFDM which is the techniques uses filtering at the transmitter and receiver to reduce the effect of CP, the UFMC which is a Filtered-OFDM with sub-band-wise filtering as the use of Dolph-Chebyshev window, with the presence of CP and zero paddings, and GFDM which digitally implements the classical filter band approach. CP insertion is used to allow for low complex equalization at the receiver side.The fourth MCM technique is the FBMC which is based also on filtering approach of the OFDM but here the subcarriers itself are filtered to eliminate the CP and reduce the OOB. The proposed scenario of the work is as shown in **Error! Reference source not found.**. As mentioned, the main difference between all the used MCMs is the filtering process, that is, the scenario of the transmission information still the same for all types. To simplify the complexity comes from this orthogonality, simple equalization methods after demodulation such as Zero Forcing (ZF) is used to simplify the system computations. For high-speed scenario, the noise added to the symbols is the Additive White Gaussian Noise (AWGN) and the channel characteristic represents the vehicular communication which means represent the Doppler effect comes from the changeable channel characteristics due to travelling speed. Because of this, the transmitted signal s(t) of the proposed multicarrier system can be expressed in the time domain as:

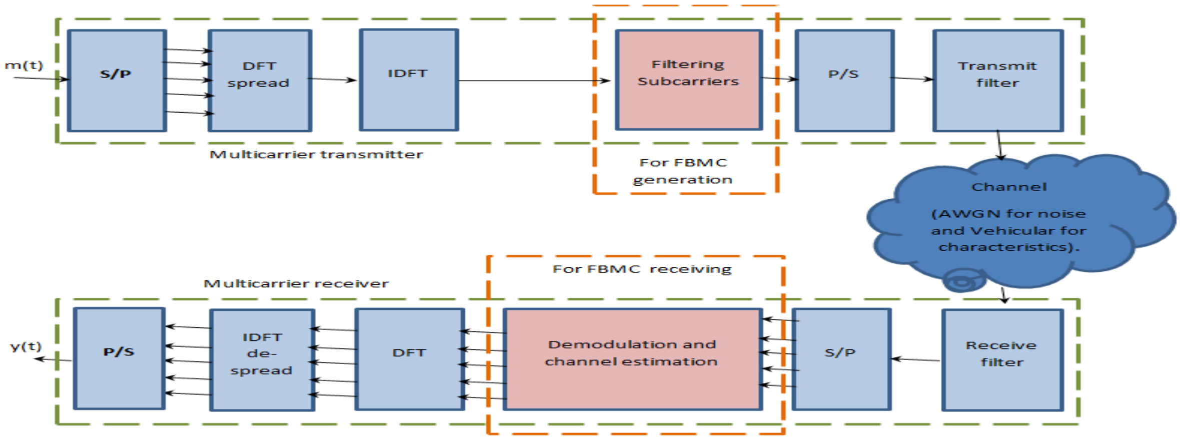
$$S(t) = \sum_{k=0}^{k=1} \sum_{l=0}^{l-1} g_{l,k}(t) x_{l,k} \qquad (1)$$

Where at position 1 for the subcarrier and time-position, the transmitted symbol xl,k is modulated via 16-QAM baseband modulation. From eq. **Error! Reference source not found.**), the transmitted basis pulse gl,k(t) which represent the time and frequency shifted version of the filter p(t) used at the transmitter for the MCMs techniques is defined as:

$$g_{l,k}(t) = p(t - kT) e^{j2\pi lF(t-kT)} e^{j\theta_{l,k}} \qquad (1)$$



(a) For any filtered MCM types



(b) For FBMC types

Where T represents the time spacing, F represents the subcarrier spacing and the θl,k represents the phase shift. The received symbols yl,k after transmission and adding noise to the transmitted signals r(t) is given by in time domain as:

$$y_{l,k} = \langle r(t), g_{l,k}(t) \rangle = \int_{-\infty}^{\infty} r(t) g^{*}_{l,k}(t) dt \qquad (2)$$

The scenario shown in Figure 1 considers two types of multicarrier modulations which are OFDM and FBMC with M-QAM of the baseband modulation for each type. The modulator consists of the general construction of the MCM as in OFDM construction. It starts from generating the OFDM symbols using IDFT followed by adding the cyclic prefix bits. The channel used is AWGN. The demodulator performs the opposite operation of the modulator; this means that it performs the DFT to regenerate the baseband bits after transmission.in case of generating FBMC, the only block should be added is the filtering after the CP block. This block is responsible to eliminate the effect of the CP to avoid high PAPR and high OOB. In the demodulator, at the beginning of the receiver, the filtering block responsible to remove the CP bits to recover the original symbols.

The simulation parameters are shown in Table 1. The carrier frequency used is 2.6 GHz to satisfy LTE. The reason for using this band is to satisfy all the communication scenarios for indoor and outdoor communication. The subcarrier spacing equals 15 kHz to mitigate interference between sub-carriers. This comes from the concept that each symbol in OFDM construction needs this spacing where FBMC also uses it. The Fast Fourier Transform (FFT) size used for is 1024 with available bandwidth 100 MHz. The SNR ranges from 0 dB to 40 dB to satisfy low and high SNR values. The speed of travelling is 40 Km/h, 80 Km/h, and 140 Km/h to satisfy travelling in the city centre, travelling in urban areas, and finally to satisfy highway travelling respectively.The simulation process starts by initializing the simulation scenario and simulation parameters shown in **Error! Reference source not found.**The simulation continues and the generated symbols upconverted to the 2.6 GHz band and ask about the MCM types used. If the waveform is chosen to be OFDM, the classical generation of the OFDM symbols started with CP adding. If other types of filtered OFDM techniques used, the filtering process is performed according to the MCM chosen. If the MCM is FBMC, the process of generating FBMC as described in chapter II is performed. The received symbols are determined by using eq. (2).

Table 1 Simulation parameters

Simulation parameter	*Values*
Bandwidth for 2.6 GHz	100 MHz
Carrier frequency	2.6 GHz
Subcarrier spacing	15 kHz
FFT size	1024
Modulation	16-QAM
Cyclic prefix	normal cyclic prefix
Multicarrier waveforms	OFDM, FBMC, F-OFDM, UFMC, GFDM
SNR	Up to 40 dB
Speed of travelling	40 Km/h, 80 Km/h, 140 Km/h

3 Simulation Results and Discussion

Figure2 shows the comparison of the Power Spectral Densities (PSD) between classical OFDM modulation and all other types of MCM over the frequency. The results from the figure show that the FBMC has the preferred spectral density because it shows a considerable reduction of OOB leakage compared to OFDM because of the use of filter before generating OFDM symbols. This means that there is a good chance to use asynchronous transmission without the need for perfect synchronization which leads to high spectral efficiency due to the absence of the CP effect. Compared the results from all MCMs PSD in Figure; it’s clear to say that the classical OFDM has the worst PSD over the frequency compared to other MCMs used. GFDM has a considerable PSD and gives low OOB and PAPR reduction compared to OFDM but with narrow bandwidth along with the frequency with complex computation process. The F-OFDM has an advanced PSD over the UFMC. It is important to say that besides the advantages of the PSD response of the FBMC, using long filters in constructing the FBMC leads to a long tail in the time domain which leads to a decrease in the overall energy efficiency and an increase in the delay of transmission.

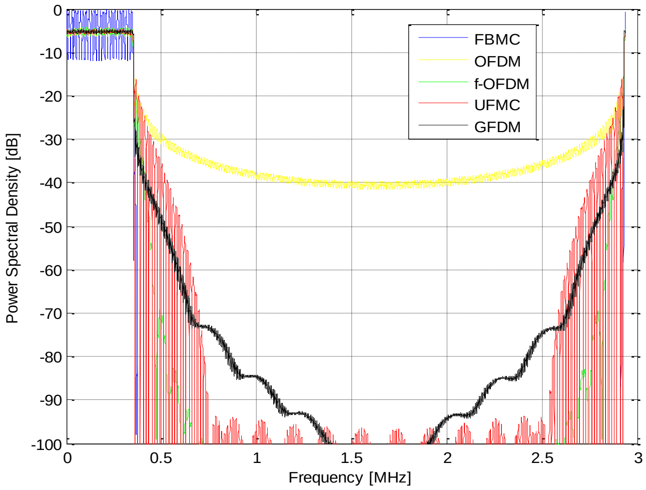


Figure 2 Spectral density of all types of MCM used

Figure shows the simulation results obtained from the use of all types of multicarrier modulations under this study at 2.6 GHz LTE carrier frequency. The first observation is that the FBMC response has a diversity issue compared with other types which means that FBMC can be used in different scenarios of channel characteristics better than any other MCM. The GFDM, UFMC, and F-OFDM have the same responses at low values of SNR below the 15 dB SNR value. This is because of the same concept of construction based on filtering the generating symbols at the transmitter. At high SNR, means above 15 dB SNR, the F-OFDM, UFMC, and OFDM continue to have the same response because of the CP availability on all of them. It's clear from the figure that the GFDM has the worst BER performance when using in vehicular channel characteristics because of its ability to affect by the doppler spread comes from the changeable channel characteristics. The FBMC BER reaches 10^{-4} at SNR equals 35 dB while the GFDM reaches near 10^{-2} and the remaining MCM reaches near 10^{-3} at the same value of SNR.

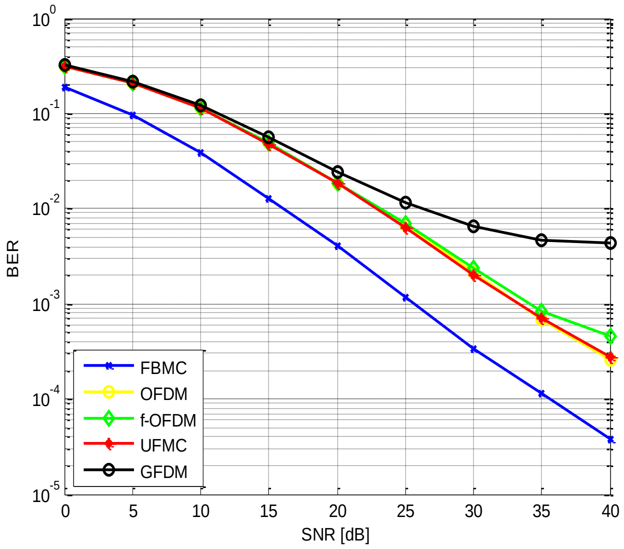


Figure 3 BER performance for 40 km/h

shows the performance of all the MCM types but with increasing the speed of travelling to simulate urban network. The speed reaches 80 km/h and the carrier frequency is 2.6 GHz. the 16-QAM is still applied and the 15 KHz subcarrier spacing is available. The performance says that the FBMC BER performance is still the preferable one to use with an important notice which is there is no high effect of speed travelling on its BER performance. This leads to using FBMC at any speed of travelling.

For the rest, MCM types, increasing speed affect the GFDM BER response while the OFDM and UFMC responses approached near the BER response of F-OFDM at high SNR. It is also cleared from the figure that the BER difference in responses appeared at 10 dB SNR compared to 15 dB SNR at 40 km/h. All these results are logical because the interference in fast travelling increases due to the increase of the doppler effect because of the very changeable channel characteristics.

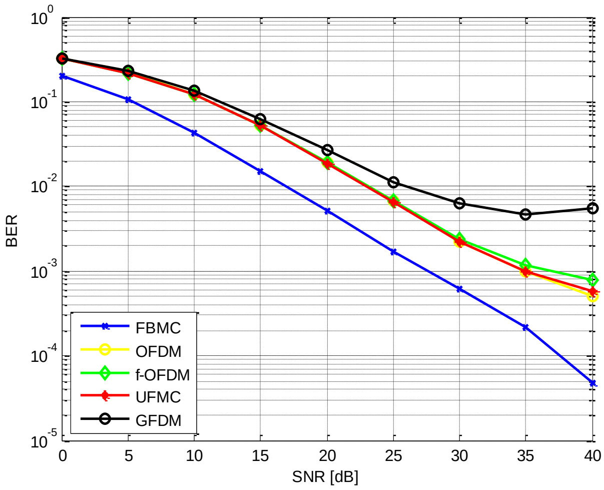


Figure 4 BER performance for 80 km/h

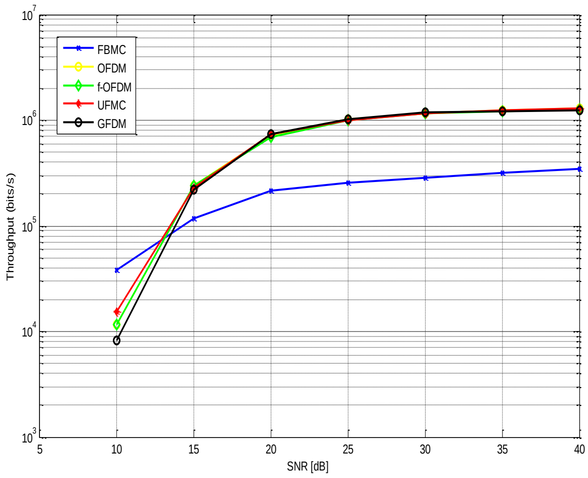
The same notice comes from Figure . The best BER performance comes from the FBMC with the same notice of robustness from the increasing speed effect. Figure shows the BER performance of all types of MCM at highway scenario. There is 2.5 dB difference of the FBMC responses comes from the use of 40 km/h compared to 80 km/h and 1.5 dB compared to 140 km/h. These values are small compared to the 10 dB difference of the GFDM responses comes from the 80 km/h and 140 km/h.

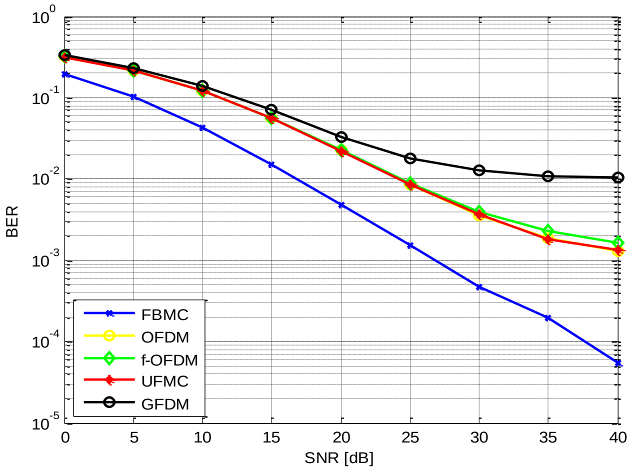
Figure shows the throughput performance of all types at 40 km/h travelling speed. It shows that the FBMC gives high throughput reaches 50 kbits/s at very low SNR values which are 10 dB while the other MCM types give around 10 kbits/s at the same SNR value. It is important to say that these values reach without using any types of coding process which means a very good response obtained without coding techniques. Figure shows that when the SNR increases, the throughput performance of OFDM, UFMC, F-OFDM, and GFDM increases and outcomes the FBMC throughput performance. This comes from that the complex construction and process of FBMC affect the spectral efficiency of it which leads to a reduction in throughput. There is a tradeoff between BER and throughput performances of the FBMC. The GFDM throughput reaches 1 Mbits/s at 40 dB SNR without any use of coding types.

Figure 6 Throughput performance for 40 km/h

Figure 5 BER performance for 140

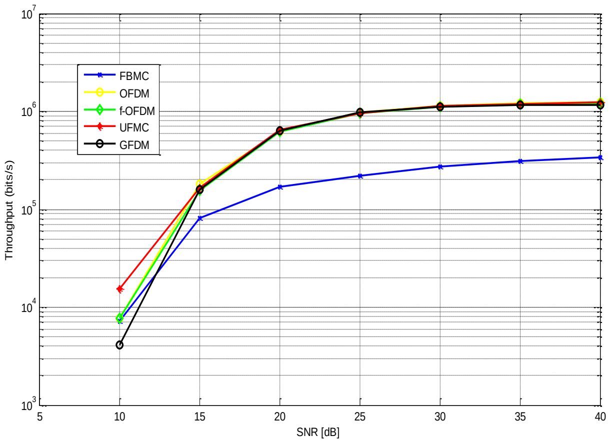
km/h





Error! Reference source not found. below shows the throughput response when the speed of travelling reaches 80 km/h. there are two main differences from Figure . The

first one is that increasing the speed of travelling leads to reduce the throughput of the FBMC at low SNR values. This is logical because of the increasing interference comes from the high Doppler effect. The second note is that the UFMC throughput response becomes more useful to use at low SNR than the FBMC because of the use of filtering techniques able to reduce the Doppler effect like sub-band-wise filtering and Dolph-Chebyshev window. It gives 15 kbits/s without any use of coding techniques. Figure 7 **Throughput performance for 80 Figure** shows the throughput performance at highway speed of travelling reaches 140 km/h. it is clear that when the speed of travelling increased, the throughput performance of all MCM types is decreased. This is logical because of the increasing interference comes from the increasing effect of Doppler spread and the very fast changeable channel characteristics. From this figure, we can conclude that for high-speed travelling, it is preferable to use UFMC for low values of SNR and GFDM for high values of SNR in case of throughput.



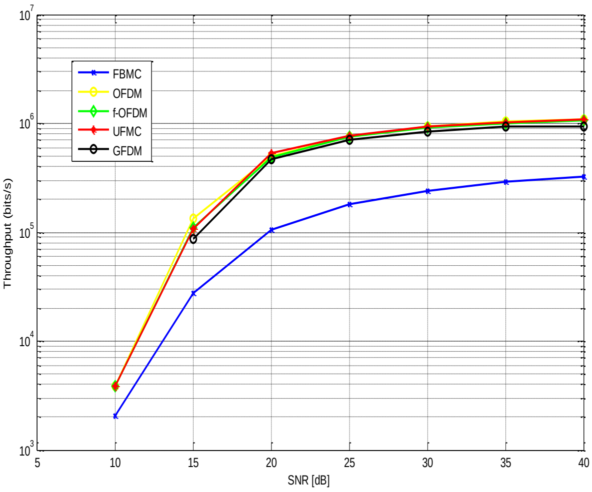


Figure 7 Throughput performance for 80

Figure 8 Throughput performance for 140 km/h km/h

4 Conclusion

In this paper, the use of different types of multicarrier modulation is discussed and reviewed. The four types of MCM are the FBMC, GFDM, F-OFDM, and UFMC used and compared with the classical OFDM performance. All results in the review show that FBMC has better BER performance than all the other MCM techniques with some diversity issue that makes it useful to use in any LTE networks but with some increase in process complexity. This BER enhancement makes the FBMC suitable to use in 5G networks but with some constraints that it gives low throughput values compared with other MCM techniques. FBMC is the suitable multicarrier techniques to eliminate the ICI caused by OFDM while the GFDM is the technique that is suitable to use with high speed travelling with high spectral efficiency performance. It is clearly shown that the FBMC overcomes most of the OFDM drawbacks, the only thing that should be into consideration is the added process when generating FBMC which causes some increase in the latency especially when using FBMC in mobility scenario which it appears in the throughput performance here in this paper. It gives the low throughput performance at high-speed scenario while the UFMC and GFDM give the high throughput at low SNR and high SNR respectively. It is important to use these MCM techniques with mmwave bands to enhance the throughput of them because of the huge spectrum available that mmwave give. The challenge here is how to minimize the interference comes from serving a high number of users.

Refrences

[1] B. C. Nguyen, T. M. Hoang, and L. T. Dung, “Performance analysis of vehicle-to-vehicle communication with full-duplex amplify-and-forward relay over double-Rayleigh fading channels,” *Veh. Commun.*, vol. 19, p. 100166, 2019.

[2] A. Kumar, D. Chaturvedi, and S. Raghavan, “Low-profile substrate integrated waveguide (SIW) cavity-backed self-triplexed slot antenna,” *Int. J. RF Microw. Comput. Eng.*, vol. 29, no. 3, 2019.

[3] R. Ali, D. N. Hakro, M. R. Tanweer, and A. A. Kamboh, “Simulation based Vehicle to Vehicle and base station communication,” in *2019 International Conference on Information Science and Communication Technology (ICISCT)*, 2019, pp. 1–6.

[4] A. T. Al-heety, M. Singh, J. Singh, M. T. Islam, and A. H. Ahmed, “MM - wave backhauling for 5g small cells,” vol. 7, no. 4, pp. 6233–6237, 2018.

[5] F. Arabian, G. P. Nordin, and M. Rice, “On Polarization Dependent Equalization in 5G mmWave Systems,” *2020 Int. Conf. Comput. Netw. Commun. ICNC 2020*, pp. 1058–1062, 2020.

[6] D. Chaturvedi, A. Kumar, and S. Raghavan, “A substrate integrated waveguide based antenna-triplexer,” *Asia-Pacific Microw. Conf. Proceedings, APMC*, vol. 2018-Novem, no. November, pp. 10–12, 2019.

[7] M. N. Sial, Y. Deng, J. Ahmed, A. Nallanathan, and M. Dohler, “Stochastic geometry modeling of cellular V2X communication over shared channels,” *IEEE Trans. Veh. Technol.*, vol. 68, no. 12, pp. 11873–11887, 2019.

[8] C. S. Pradeep and R. R, “Investigation of Secret Key Capacity in MIMO-OFDM Wireless Systems,” *Procedia Comput. Sci.*, vol. 143, pp. 776–785, 2018.

[9] J. J. Rubia, B. R. Lincy, and B. R. Lawrence, “Enhanced Modified Booth Recoding Technique for Signal Processing Application,” no. January 2017, 2020.

[10] A. T. Al-Heety, M. T. Islam, A. H. Rashid, H. N. A. Ali, A. M. Fadil, and F. Arabian,

"Performance Evaluation of Wireless data traffic in Mm wave massive MIMO communication," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 20, no. 3, 2020.

[11] P. K. Singh, S. Sharma, S. K. Nandi, and S. Nandi, "Multipath TCP for V2I communication in SDN controlled small cell deployment of smart city," *Veh. Commun.*, vol. 15, pp. 1–15, 2019.

[12] M. Olyaee, M. Eslami, and J. Haghighat, "Performance of maximum ratio combining of fluctuating two-ray (FTR) mmWave channels for 5G and beyond communications," *Trans. Emerg. Telecommun. Technol.*, vol. 30, no. 10, pp. 1–14, 2019.

[13] M. Saideh, Y. Alsaba, I. Dayoub, and M. Berbineau, "Performance Evaluation of Multi-Carrier Modulation Techniques in High Speed Railway Environment with Impulsive Noise," in *2019 IEEE 2nd 5G World Forum (5GWF)*, 2019, pp. 243–248.

[14] A. Molina-Galan, B. Coll-Perales, and J. Gozalvez, "C-V2X Assisted mmWave V2V Scheduling," in *2019 IEEE 2nd Connected and Automated Vehicles Symposium (CAVS)*, 2019, pp. 1–5.

[15] I. M. Al-joboury and E. H. Al-hemiary, "Performance Analysis of Internet of Things Protocols Based Fog / Cloud over High Traffic," vol. 10, no. March, pp. 176–181, 2018.

[16] S. Hu, X. Wang, and M. Z. Shakir, "A MIH and SDN-based Framework for network selection in 5G HetNet: Backhaul requirement perspectives," in *2015 IEEE International Conference on Communication Workshop (ICCW)*, 2015, pp. 37–43.

[17] A. Bhattacharyya, B. Sardar, and D. Saha, "Effect of mode-switching on TCP short flows during D2D communication in LTE-A networks," in *2017 IEEE International Conference on Advanced Networks and Telecommunications Systems (ANTS)*, 2017, pp. 1–6.

[18] H. Ye, G. Y. Li, and B.-H. F. Juang, "Deep reinforcement learning based resource allocation for V2V communications," *IEEE Trans. Veh. Technol.*, vol. 68, no. 4, pp. 3163–3173, 2019.

[19] H. Wang, F. Lu, C. Liu, X. Liu, and J. Kang, "Frequency Domain Multi-Carrier Modulation based on Prolate Spheroidal Wave Functions," *IEEE Access*, 2020.

[20] Y. Ge, W. Zhang, F. Gao, and H. Minn, "Angle-Domain Approach for Parameter Estimation in High-Mobility OFDM With Fully/Partly Calibrated Massive ULA," *IEEE Trans. Wirel. Commun.*, vol. 18, no. 1, pp. 591–607, 2019.

[21] R. G. R. Jeya, B.Amutha, Roshni Patra, "Channel Estimation for MIMO OFDM Systems using LS and MMSE Channel Estimation Techniques," *Int. J. Adv. Sci. Technol.*, vol. 29, no. 8, 2020.

[22] P. Datta and R. Rohilla, "Optimization and Performance matrices in 5G Networks," in *2019 2nd International Conference on Power Energy, Environment and Intelligent Control (PEEIC)*, 2019, pp. 312–317.

[23] F. Arabian, W. Harrison, C. Josephson, E. Perrinsy, and M. Rice, "On peak-to-average power ratio optimization for coded APSK," *Proc. Int. Symp. Wirel. Commun. Syst.*, vol. 2018-Augus, no. 4, pp. 1–6, 2018.

[24] A. H. Ahmed, A. T. Al-Heety, B. Al-Khateeb, and A. H. Mohammed, "Energy Efficiency in 5G Massive MIMO for Mobile Wireless Network," in *2020 International Congress on Human-Computer Interaction, Optimization and Robotic Applications (HORA)*, 2020, pp. 1–6.

[25] T. Yamazato *et al.*, "The Uplink Visible Light Communication Beacon System for Universal Traffic Management," *IEEE Access*, vol. 5, pp. 22282–22290, 2017.