JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

5G Communication: Exploring Modulation Techniques Through Performance Analysis

[1]D. Muneendra, [2]P. Hima Sai, [3]B. Jahnavi,[4]R. Likith, [5]R. Jayasree, [6]K. Harivendra, [7]T. Kalyani

[1]Associate Professor, Department of ECE, Siddharth Institute of Engineering & Technology, Puttur, AP, India.

[23456&7]B.Tech. IV Year Student, Department of ECE, Siddharth Institute of Engineering & Technology, Puttur, AP, India.

Abstract : The rapid growth in the communication industry resulted in the formation of 5G (Fifth Generation) networks which made the interaction between humans, machines, and devices much easier and more consistent. The main aim of the 5G wireless communication system is to provide high reliability, low latency, faster data rates, and high network capacity around the base stations. In order for 5G wireless communication technologies to accomplish all of these objectives, advanced modulation techniques need to be used. In this work, we provide a summary of modulation techniques: OFDM (Orthogonal Frequency Division Multiplexing), FBMC (Filter Bank Multi-carrier), GFDM (Generalized Frequency Division Multiplexing), UFMC (Universal Filtered Multi-Carrier Modulation) and QPSK (Quadrature Phase Shift Keying). OFDM is a digital modulation technique that divides the available bandwidth into multiple subcarriers and modulates each subcarrier independently. FBMC is also similar to OFDM, but it uses filter banks to divide the available bandwidth into subcarriers. GFDM when combined with OFDM, an emerging kind of 5G carrier waveform candidates, nicely satisfies the requirements of 5G applications. In contrast, UFMC is a type of orthogonal frequency division multiplexing that uses a filter bank to shape the transmit and receive signals. QPSK provides good spectral efficiency while maintaining reasonable performance in noisy environments. In addition, we have introduced a novel modulation technique called RF-OFDM (Refined Filtered-OFDM) to address the shortcomings of the current modulation techniques. With a unique filter that outperforms previously used filters, RF-OFDM produces output with much higher quality. The properties of the modulation schemes are compared, including their Bandwidth Efficiency, Spectral Efficiency, Power Efficiency, Power Spectral Density (PSD), Bit Error Rate (BER), Transmitted Power, Peak Average Power Ratio (PAPR), Latency, Signal to Noise Ratio (SNR) and Frequency Range. Based on the performance metrics each modulation technique has been evaluated. Current state-of-the-art methods have been surpassed in performance by the suggested modulation approach.

IndexTerms - **5G wireless communication, Modulation techniques, OFDM, FBMC, GFDM, UFMC, QPSK, RF-OFDM, Bandwidth Efficiency, Spectral Efficiency, Power Efficiency, Power Spectral Density (PSD), Bit Error Rate (BER), Transmitted Power, Peak Average Power Ratio (PAPR), Latency, Signal to Noise Ratio (SNR), Frequency Range.**

I. INTRODUCTION

The project embarked on a comprehensive examination of various modulation techniques within the framework of 5G wireless communication systems. This thorough review primarily honed in on adaptive methods, including Orthogonal Frequency Division Multiplexing (OFDM), Filter Bank Multi Carrier (FBMC), Generalized Frequency Division Multiplexing (GFDM), Universal Filtered Multi Carrier (UFMC), and Quadrature Phase Shift Keying (QPSK). These techniques were scrutinized to address the evolving demands of advanced wireless networks, aiming to enhance efficiency and reliability.

A core objective of the program was to evaluate these modulation techniques across a spectrum of performance metrics. These included bandwidth efficiency, spectral efficiency, power efficiency, latency, peak-to-average power ratio (PAPR), bit error rate (BER), signal-to-noise ratio (SNR), transmitted power, and frequency range. Each parameter underwent meticulous examination to discern the effectiveness of the modulation strategies in optimizing data transmission within 5G networks.

The project's focal point was to identify the most suitable modulation strategy capable of augmenting data transmission efficiency, reliability, and spectral utilization in 5G networks. Through detailed investigation and analysis, the project sought to determine the modulation technique that best aligns with the multifaceted requirements of modern wireless communication systems. An integral aspect of the project was the evaluation and implementation of each modulation technique. This involved not only assessing their theoretical effectiveness but also practical application within the evolving 5G technology landscape. By delving into both theoretical and practical aspects, the project aimed to deliver valuable insights and solutions to enhance the efficiency and reliability of data transmission in 5G networks.

Furthermore, the project represented a significant step towards the modernization of telecommunications infrastructure. By leveraging advancements in modulation techniques, the project aimed to facilitate more efficient data movement and transmission. This modernization effort was geared towards enhancing the overall performance and capabilities of 5G networks, thereby contributing to the continuous evolution of telecommunications technology. In essence, the project was not merely a static analysis but rather a dynamic endeavor aimed at driving positive change within the telecommunications sector. By contributing to ongoing advancements and improvements in 5G technology, the project played a crucial role in shaping the future landscape of wireless communication systems. In conclusion, the project's comprehensive analysis of modulation techniques in 5G wireless communication systems, coupled with its focus on enhancing efficiency and reliability, underscores its significance in driving innovation and progress within the telecommunications industry.

II. Literature Survey

Abdullah, A. N. Ibrahim and M. F. L [1]., "The potential of FBMC over OFDM for the future 5G mobile communication technology," AIP Conference Proceedings 14 September 2017, 2017. The authors suggested that FBMC is a more acceptable solution after evaluating BER versus SNR in various forms of QAM over the typical noise type AWGN channel and the frequency response of FBMC and OFDM. The benefits of Universal filtered multi carrier (UFMC) when compared to Orthogonal frequency division multiplexing (OFDM) were presented, and also, where they compared their PSD and BER versus SNR and suggested UFMC as the best choice. Additionally, the comparison between FBMC, f-OFDM, and OFDM is presented in [16], which discuss the comparison between FBMC, f-OFDM, and OFDM in terms of Power Spectral Density and BER versus SNR, as well as comparisons in AWGN.

Jean-Baptiste Doré, Robin Gerzaguet, Nicolas Cassiau and Dimitri Ktenas [2], "Waveform contenders for 5G:Description, analysis, and comparison," Physical Communication, vol. 24, pp. 46-61, 2017. They concluded that FBMC is superior after doing a much more thorough analysis between Universal filtered multi carrier and Frequency division multiplexing with regard to Orthogonal Frequency Division Multiplexing in terms of Power Spectral Density and BER versus SNR under the ETU channel. However, the usage of the AWGN channel and the addition of CP to the UFMC to protect against ISI when subjected to a multipath channel limits the scope of this work.

Pooja Rani, Dr.Himanshu Monga and Silki Baghla [3], "Performance Evaluation of Multi-carrier Modulation Techniques for Next Generation Wireless Systems," International Journal of Advanced Research in Computer Science, vol. 8, no. 5, pp. 508-511, 2017. Provide an overview of the multi-carrier modulation schemes used in fifth generation. They also compare Filter bank multi-carrier, Universal filtered multi carrier, and Orthogonal frequency division multiplexing in terms of Power Spectral Density and Peak to Average Power Ratio, but only theoretically and with numerical results. This work's limitation is that the comparison was only done theoretically without graphs and left out the crucial BER versus SNR parameters.

K. Krishna Kishore, P. Rajesh Umar and V. Jagan Naveen, [4] "Comprehensive Analysis of UFMC with OFDM and FBMC," Indian Journal of Science and Technology, vol. 10, no. 17, pp. 1-7, 2017. A performance study of the Universal Filtered Multi-Carrier (UFMC) was carried out and its performance is compared with that of Orthogonal Frequency Division Multiplexing (OFDM) and Filter Bank Multi-Carrier (FBMC) in terms of Peak to Average Power Ratio (PAPR). Then they found that the Universal Filtered Multi Carrier (UFMC) had a superior PAPR than the others, but this paper's limitations prevented it from also being tested under the AWGN channel or with other parameters.

Muhammet Tahir Guneser, A. S. Sahab and C. Seker [5], "Performance analysis of modulation techniques in 5G communication system," China Communications, vol. 19, pp. 100-114, 2022. The research offers an investigation of the performance of many modulation methods for 5G, including FBMC, Filtered-OFDM, and UFMC. Cyclic Prefix-OFDM is contrasted with FBMC, Filtered-OFDM, and UFMC based on PSD, BER, Transmitted Power, PAPR, and Bit Error Rate. The transmitted output had the same characteristics and travelled over the same way in every instance. The outcomes show each modulation scheme's benefits and shortcomings. The Bit Error Rate performance of FBMC, Filterized-OFDM, and Cyclic Prefix-OFDM is significantly similar, but Universal Filtered Multi Carrier, BER is significantly better than others with a low Signal to Noise Ratio (SNR) value. The PSD performance was better with FBMC than with UFMC, Filtered-OFDM, and Cyclic Prefix-OFDM, and with UFMC and F-OFDM in the midway between FBMC and Cyclic Prefix-OFDM. In terms of transmitted power, UFMC differs from FBMC, Filtered-OFDM, and Cyclic Prefix-OFDM since it filters each subcarrier more than once. The FBMC outperforms the competition, as seen by the PAPR graph. Finally, the FBMC and Filtered-OFDM have a greater bit error rate than the other UFMC and Cyclic Prefix - OFDM, which gives them an edge over the UFMC and the CPOFDM. All of the results point to Filter bank multi carrier modulation approaches as an intriguing option. Since it is quite comparable to OFDM in all other respects, including superior PSD, PAPR, and bit rate, FBMC can be simply implemented.

Eslam Mansour Shalaby, Saleh Ibrahim Hussin and Moawad Ibrahim Dessoky [6], "Performance Evaluation of 5G Modulation Techniques.," Wireless Personal Communications 121, p. 2461–2476, 2021. The authors examined an overview of the modulation waveforms utilized in 4G communication systems, including SC-FDM and OFDM. Additionally, it showed the UFMC, FBMC, and GFDM systems for cellular networks of the future. For each of the four systems, the terms power spectral density (PSD), (BER) bit error rate in relation to various signal-to-noise ratios, and (PAPR) peak-to-average power ratio are shown. Results indicate that the FBMC system significantly performs better other schemes in terms of PSD performance. In contrast, the BER performance of the UFMC scheme is better than that of other schemes. In comparison to other systems, the PAPR performance is enhanced by the GFDM method. Previous findings show that UFMC with PAPR reduction needs various modifications to be taken into account in the proposed plan for the future generation of wireless technology communication systems.

T Padmavathi, Kusma Kumari Cheepurupalli and R Madhu [7], "Analysis of Multi-Carrier Modulation Techniques for 5G Physical Layer Communications Estimation of KPI," Journal of Scientific & Industrial Research, vol. 81, pp. 12241232, November 2022. Making effective use of the full extent discontinuous spectrum for varied network deployments would be a major problem for future 5G networks. To conserve resources and maximize SE, PSD, and air interface technology for 5G must be compliant and capable of matching different services. Therefore, frequency localization and physical layer modulation flexibility are essential needs. In a conventional framework, a non-discriminatory comparison of different 5G MCM (UFMC, FBMC-QAM, and OFDM) is taken into account. Throughput, BER, SE, PAPR, and PSD are assessed. In comparison to OFDM, UFMC Modulation provides superior SE and has a pulse-shaping capability that makes it easier to synchronize an approach. Furthermore, UFMC keeps its backward compatibility with widely used and favored OFDM techniques (MIMO detectors, channel estimation). Additionally, FBMC offers superior SE, SIR, and reduced BER and PAPR. Performance and equalization complexity are significantly impacted by prototype filter type. While FBMC-OQAM outperforms with improved PSD, SE, SIR, and BER and gives strength against both asynchronous communication and wider delay spread channel circumstances, UFMC enhances OFDM while keeping backward compatibility. By altering intercarrier spacing, FBMC can gain improved KPI characteristics. With less PAPR than OFDM UFMC, FBMC offers tiny packet sizes. Without a guard period, broadcast transmission is more efficient and may send larger packets. A complicated FBMC transceiver that implements embedded digital and analog filtering functions can do this.

III. EXISTING SYSTEM

Orthogonal Frequency Division Multiplexing (OFDM): OFDM is a essential modulation method that divides the available bandwidth into more than one orthogonal subcarriers, every independently modulated. It has been broadly followed due to its capacity to provide excessive-speed facts transmission, efficient spectrum usage, and advanced overall performance in numerous verbal exchange systems along with Wi-Fi, virtual tv, and 4G/5G mobile networks.

Filter Bank Multi Carrier (FBMC): FBMC makes use of filter banks to divide the available bandwidth into subcarriers, providing an opportunity to OFDM. This method plays a vital role in addressing the constraints of OFDM, mainly in eventualities which includes machine-tosystem (M2M) communique and the Internet of Things (IoT) in which the demand for increased information price, strength spectral density (PSD), and height-to-common power ratio (PAPR) is high.

Universal Filtered Multi-Carrier (UFMC): UFMC employs filter out banks to shape transmitted and acquired signals, contributing to superior overall performance, especially within the context of 5G wi-fi verbal exchange. This approach gives capability benefits in addressing the particular requirements of superior conversation structures by using efficaciously using frequency spectrum assets.

Generalized Frequency Division Multiplexing (GFDM): GFDM stands proud as an emerging waveform that, whilst mixed with OFDM, represents a promising candidate for 5G provider programs. It is designed to fulfill a wide spectrum of 5G utility wishes and is considered to be well-ideal for addressing the needs of numerous communication eventualities.

IV. PROPOSED SYSTEM

RF-OFDM is an innovative modulation method added to cope with the restrictions of the prevailing techniques. It makes use of a unique filter that outperforms formerly used filters, ensuing in considerably better satisfactory output. The positive properties of RF-OFDM, consisting of stepped forward bandwidth efficiency, spectral efficiency, and power performance, role it as a compelling answer for assembly the requirements of 5G wireless verbal exchange systems.

This proposed method the development of a voice-activated home automation system for bedridden patients. The system utilizes voice recognition technology and smart home devices, such as lights, fans, TVs, and doors, to provide control and convenience to patients who are unable to move around freely. The system also incorporates IoT sensors to detect patient movements, enabling the automation of certain tasks based on their needs. The customized voice commands used by the system ensure that patients can operate the devices easily and without assistance, thereby increasing their independence and improving their overall quality of life. The proposed system has the potential to significantly enhance the comfort and well-being of bedridden patients, and its development represents a promising application of technology in the healthcare sector.

4.1 Block Diagram

The block diagram of the proposed system shown in figure 1, details the specific signal processing operations, including but not limited to parallel-to-series conversion, filtering, IDFT (Inverse Discrete Fourier Transform), synthesis filter bank, modulators, demodulators, signal conditioning, and RF-to-baseband conversion for the respective modulation techniques. Each block diagram showcases the unique architecture and processing elements specific to the corresponding modulation technique. This evaluation will provide valuable insights into the operational structure and characteristics of each modulation technique, facilitating a comprehensive comparison and analysis of their potential performance in the context of 5G wireless communication systems.

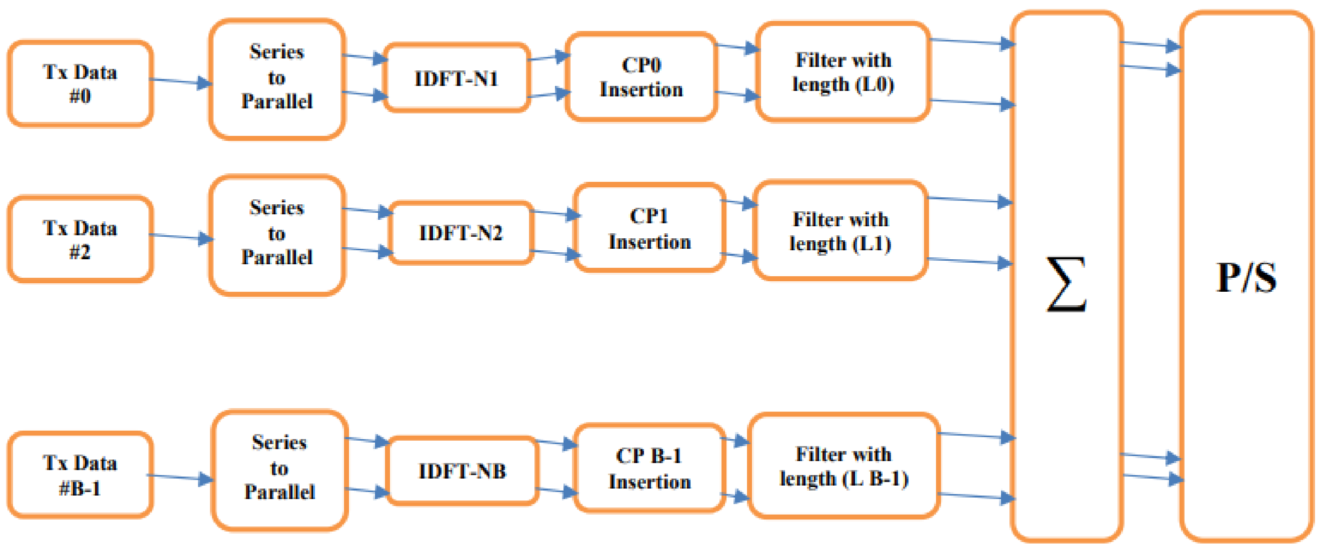

Fig.1: Proposed Block Diagram

4.2 Methodology

1. Understanding RF-OFDM Principles: - Gain a comprehensive understanding of Refined Filtered-OFDM (RF-OFDM), focusing on the principles of its signal processing, spectral shaping using filters, and efficient utilization of sub-bands.
2. Identifying Key Input Parameters: - Define and identify the crucial input parameters required for the analysis, including the number of subcarriers, filter design characteristics, subcarrier spacing, and signal-to-noise ratio (SNR).
3. Block Diagram Analysis: - Analyze the block diagram of RFOFDM to understand the specific components and processing flow involved in the modulation and demodulation processes, taking into account the input parameters and how they influence the signal processing stages.
4. Simulation Environment Setup: - Set up a simulation environment using tools such as MATLAB to model the RFOFDM system and the impact of the defined input parameters on the signal processing and spectral characteristics.
5. Data Generation and Processing: - Generate simulated data streams in the defined simulation environment and apply them through the RF-OFDM block diagram to observe the impact of the input parameters on the signal processing, sub-band utilization, and spectral shaping.
6. Measurement of Output Parameters: - Define the key output parameters such as Bandwidth Efficiency, Spectral Efficiency, Power Efficiency, Latency, Peak-to-Average Power Ratio (PAPR), Bit Error Rate (BER), Signal-to-Noise Ratio (SNR), Transmitted Power, and Frequency Range.
7. Performance Evaluation: - Evaluate the defined output parameters by analyzing the simulated data processed through the RF-OFDM block diagram, observing the influence of the input parameters on the output performance metrics.
8. Comparative Analysis: - Conduct a comparative analysis of the results to assess the impact of the input parameters on the output performance metrics, identifying the relationships and dependencies between the defined input and output parameters.
9. Documentation and Reporting: - Compile the findings, comparisons, and insights into a comprehensive report detailing the impact of the input parameters on the performance and characteristics of RF-OFDM.
10. Conclusion and Recommendations: - Conclude the analysis with recommendations on the most suitable input parameter configurations for achieving optimal performance of RF-OFDM, outlining the dependencies and trade-offs.

4.3 Mathematical Expression

The derivation of Refined Filtered OFDM (RF-OFDM) involves incorporating a filter function into each subcarrier of the conventional Orthogonal Frequency Division Multiplexing (OFDM) system. The use of a spectrum shaping filter is limited to the entire passband due to the uniform expressions and the presence of only one sub band the structure of the RF-OFDM transmitter after applying a well-designed spectrum shaping filter to the entire sub-band. The RF-OFDM waveform can be represented as a convolution operation. The content enters the input at a specific rate with information bits gathered and mapped to symbols in the MQAM constellation for multicarrier modulation. Once the complex samples are generated, CPs are inserted, and the sampled data is transmitted through digital-to analog conversion at a defined rate based on the length of the CP on OFDM.
Overall, the mathematical expression for RF-OFDM incorporates a filter function into the standard OFDM system to reduce out-of-band emissions and improve spectral efficiency. The resulting signal can be demodulated using a matched filter and processed using standard signal processing techniques.

$$s(t) = \sum_{n=-\infty}^{\infty} s_n(t - nT) \quad (1)$$

$$s(t) = \sum_{N=-\infty}^{\infty} * \left(\left[\sum_{k=0}^{k=1} a_{n,k} e^{j2\pi k \Delta f (t-nT)} \right] \otimes h(t - nT) \right) \quad (2)$$

V. RESULTS AND DISCUSSION

A comparative analysis of the results to assess the impact of the input parameters on the output performance metrics, identifying the relationships and dependencies between the defined input and output parameters. BER vs SNR is shown in figure 2.

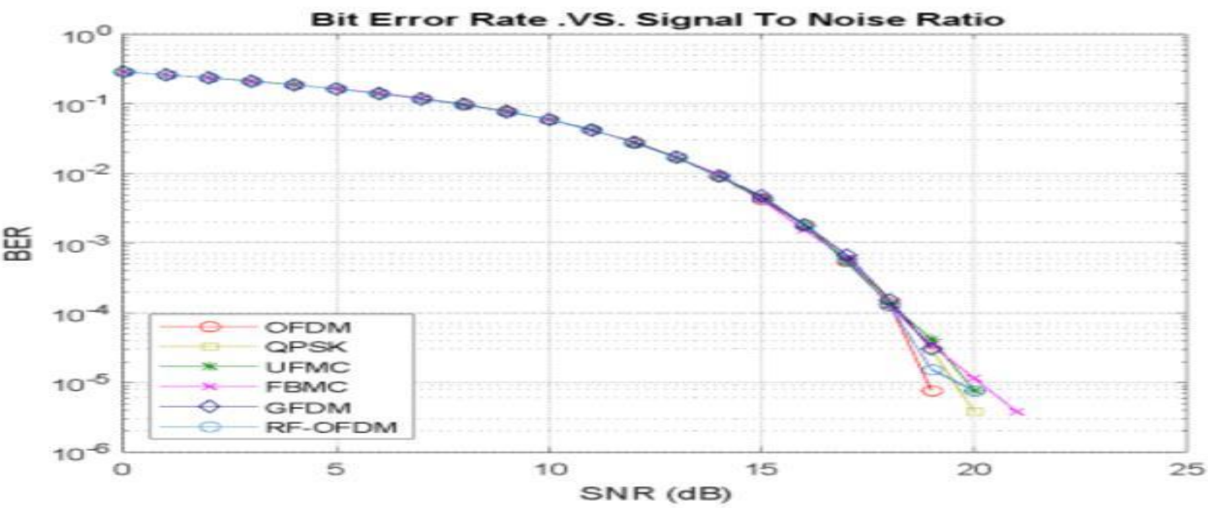

Fig 2: Simulation results

VI. CONCLUSION

The transition to 5G networks necessitates increased data rate, PSD, and PAPR compared to 4G technologies like OFDM, especially to support emerging services like M2M and IoT. Researchers explore alternative modulation schemes like OFDM, FBMC, GFDM, UFMC, and QPSK to meet these evolving demands. Evaluation of FBMC, GFDM, UFMC, OFDM, and QPSK against RF-OFDM reveals RF-OFDM's superior BER performance and lower SNR value, indicating its robustness. RF-OFDM exhibits favorable PSD compared to UFMC, GFDM, OFDM, and QPSK, while excelling in transmitted power efficiency by filtering each subcarrier meticulously. Furthermore, RF-OFDM outperforms competitors in PAPR, and alongside GFDM, demonstrates higher bit rates than UFMC and OFDM. Overall, the analysis supports RFOFDM as a promising modulation approach for 5G systems due to its superior performance metrics across multiple parameters.

VII. Future Scope

The research proposes expanding the analysis of modulation strategies to encompass scenarios with multiple users, aiming to enhance wireless connectivity. Additionally, acknowledging potential synchronization issues in real-world systems as opposed to assumptions of perfect synchronization would be critical for a comprehensive evaluation. Furthermore, considering a broader spectrum of criteria such as Signal Strength, Connection Density, Data Traffic, Peak Data Rates, and computational complexity of modulation methods could significantly enhance the scalability and practical application of the system's performance evaluation.

VIII. ACKNOWLEDGMENT

We are grateful to our guide Associate Prof. Mr. D. MUNEENDRA for this continuous support and guidance. Through his guidance, we were able to successfully complete our project. Our sincere thanks go to our Head of the Department of Electronics and Communication Engineering at Siddharth Institute of Engineering and Technology, for her support and time.

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