

The Block-Wise Adaptive Modulation Technique for Frequency-Selective Fading Channels



Yupeng Bao and Yanfei Lu

Abstract Orthogonal frequency division multiplexing (OFDM) technology has the advantages of high frequency band utilization and resistance to frequency selective fading. However, when using high-order modulation for symbol transmission, interference and fading in the channel can significantly degrade system performance. This paper designs a subcarrier-block based adaptive modulation technique in OFDM Systems, and it uses the data structure of the 802.16d protocol to transmit the result of the link state analysis at the receiving end to the transmitting end through the feedback link for adjusting the subcarrier block used for the next transmission. The simulation results show that the adaptive OFDM system based on the subcarrier block has a lower bit error rate than the ordinary OFDM system in the frequency selective fading channel. At the same time, the system performance is better than that of the ordinary OFDM system when moving at high speed and increasing the Doppler shift.

Keywords Orthogonal frequency division multiplexing · Subcarrier block · Frequency selective fading · Adaptive modulation

1 Introduction

Adaptive technology was first proposed in the 1960s, but was ignored at the time due to backward hardware conditions. In the 1990s, communications systems and digital signal processing technologies developed rapidly, and the application of Orthogonal frequency division multiplexing (OFDM) technology became increasingly widespread. Adaptive algorithms were gradually gaining importance [1]. The fundamental idea of adaptive technology is to make the transmission scheme match

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the channel as much as possible by properly adjusting and utilizing various parameters and resources when the transmitter knows some form of channel information [2].

In recent years, mobile communications have been continuously developed, while wireless services have been continuously increased, and high-speed and reliable data transmission has gradually become the goal and requirement of wireless communications [3]. The adaptive modulation technique dynamically allocates different transmission information bits and transmission power to subcarriers according to the instantaneous state information of the channel. When the channel state is good, the subcarrier adopts high-order modulation to increase the throughput of the system. Otherwise, the subcarrier will adopt low-order modulation to ensure system reliability [4]. In practice, the corresponding relationship between SNR and BER or SNR and system throughput will be established. According to the estimation of channel transmission quality, the optimal modulation and coding scheme will be selected [5]. Combining OFDM technology with adaptive modulation technology can significantly improve system performance. At present, typical adaptive modulation coding schemes are as follows. Water injection algorithm is not feasible in a practical system [6]. In reference [7], the proposed adaptive modulation algorithm makes it much easier to implement in hardware. Reference [8] makes full use of the channel capacity of the system under the condition of ensuring the BER performance of the system. The computational complexity of the algorithm is relatively low, and the information transmission rate of the system is improved at the same time. In reference [9], it reduces the computational complexity and enhances the real-time performance of the system. Reference [10] divides adjacent subcarriers into groups and uses the same modulation mode, which further reduces the computational complexity of the algorithm. However, these algorithms have the disadvantages of a large amount of calculation and a lot of feedback information [11].

Unlike the problems mentioned above, to make full use of the resources of the OFDM system to achieve the best match between the transmission rate and transmission reliability of the system, this paper introduces an adaptive transmission technology with low complexity, accurate estimation results and fewer iterations. Besides, a cross-layer sensing model is established through the joint Media Access Control layer (MAC), and channel state information is feedback through the cross-layer transmission. Based on this information, the transmitter can adjust the modulation mode used in each subcarrier block timely to minimize the bit error rate of the subcarrier block in the area of serious interference and deep fading, reduce the impact on data transmission, minimize the bit error rate and improve the transmission efficiency.

2 System Introduction and Algorithm Description

2.1 System Introduction

Figure 1 is the structure of the subcarrier adaptive modulation OFDM system. As can be seen from the figure, after the data is encoded at the transmitting end, it enters the subcarrier adaptive modulation module to allocate the modulation mode. Here, the corresponding modulation mode is allocated for each subcarrier according to the channel estimation result at the time of the last data transmission. After that, the data enters the IFFT module and becomes the data in the time domain and adds the cyclic prefix (CP), and then enters the wireless channel for transmission. At the same time, the anti-Doppler shift interference performance of the system can be verified by changing the motion rate parameter in the channel. At the receiving end, after removing the CP, the data from the FFT are equalized by the preamble data, and then the data from the FFT will enter the Error Vector Magnitude (EVM) module for signal quality estimation. The result of channel estimation serves as the basis for allocating modulation modes for each subcarrier block in the next transmission of data. Next, the receiving end acquires the transmitting parameters of the transmitting end through the link state analysis (LQA) module, thereby determining the modulation mode used by each subcarrier block, so that the demodulation module can correctly demodulate the data of each subcarrier. Finally, restore the original data by decoding.

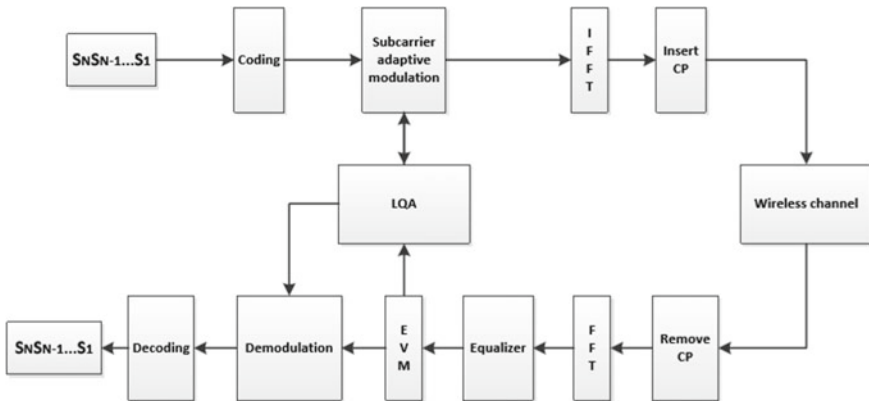


Fig. 1 Adaptive OFDM system structure diagram

2.2 Algorithm Description

Assume that all subcarriers in the system are divided into N blocks. The system assumes that each subcarrier can use the following three modulation modes according to channel conditions for each transmission: QPSK, 16QAM, 64QAM. Then the use of the subcarrier block can be described by the quaternary vector $\lambda = [\lambda_1, \lambda_2, \dots, \lambda_M]$, where $\lambda_1 \cdots \lambda_M$ can be 3, 2, 1, 0. Reference numeral 3 indicates that the modulation mode used by the subcarrier block is 64QAM, the same 2 represents 16QAM, 1 represents QPSK, and 0 represents no data transmission. The initial state can set all $\lambda_t=1$, $t \in [1, 2, \dots, M]$, this does not affect the result. There are various parameters for characterizing the transmission quality of the channel. The system uses the EVM value of the subcarrier modulation signal [12].

For an ideal constellation, the number of levels along the in-phase or quadrature axis is expressed as: $n = \sqrt{N}$. For example, since $N = 16$ for 16QAM, there are four symbol levels ($n = 4$) for both the in-phase and quadrature axes. The integer coordinate of the ideal constellation point for each symbol can be expressed as:

$$\begin{aligned} C_{ideal,pq} &= C_{I,ideal,pq} + C_{Q,ideal,pq} \\ &= (2p - 1 - n) + j(2q - 1 - n) \end{aligned} \quad (1)$$

Where $1 \leq p \leq n, 1 \leq q \leq n$.

The EVM value is the proximity of the I, Q component of the received modulated signal to the ideal signal component. To calculate the EVM value, we must compare the symbol values in the ideal constellation with the actual measured values.

In the measured case, calculate the total power of all symbols in the constellation within a given frame length:

$$P_V = \sum_{r=1}^T \left[(V_{I,meas,r})^2 + (V_{Q,meas,r})^2 \right] \quad (2)$$

Where $V_{I,meas,r}$ and $V_{Q,meas,r}$ are the root mean square values of the in-phase component and the quadrature component of the actual measured symbol value, respectively, T is the total number of symbols, generally $T \gg N$. Determine the normalized scale factor according to P_V :

$$|A_{meas}| = \sqrt{\frac{1}{P_V/T}} \quad (3)$$

Ideally, calculate the sum of the squares of all the symbols in the constellation:

$$\begin{aligned}
P_C &= \sum_{p=1}^n \left[\sum_{q=1}^n \left((C_{I,ideal,pq})^2 + (C_{Q,ideal,pq})^2 \right) \right] \\
&= \sum_{p=1}^n \left[\sum_{q=1}^n \left((2p-1-n)^2 + (2q-1-n)^2 \right) \right]
\end{aligned} \tag{4}$$

Determine the normalized scale factor of the ideal symbol according to (4):

$$|A_{ideal}| = \sqrt{\frac{1}{P_C/N}} \tag{5}$$

The estimated EVM can be expressed as:

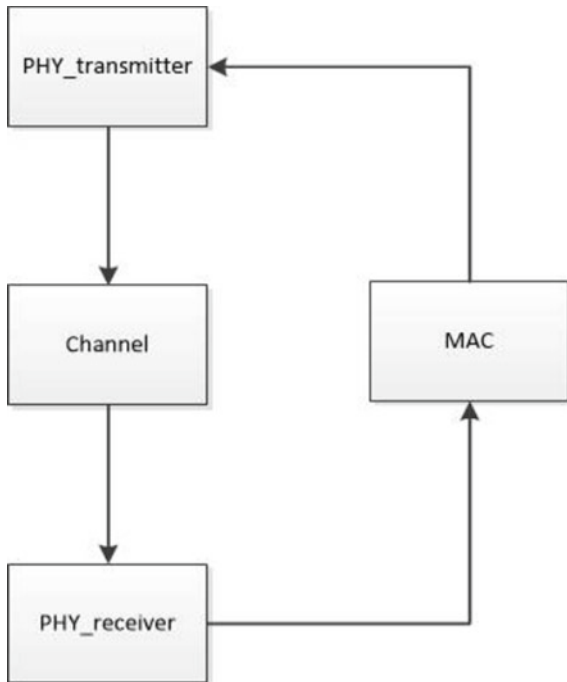
$$EVM_{RMS} = \left[\frac{\frac{1}{T} \sum_{r=1}^T \left(|V_I \bullet |A_{meas}|| - C_I \bullet |A_{ideal}|^2 \right)}{P_{S,avg}} + \frac{\frac{1}{T} \sum_{r=1}^T \left(|V_Q \bullet |A_{meas}|| - C_Q \bullet |A_{ideal}|^2 \right)}{P_{S,avg}} \right]^{\frac{1}{2}} \tag{6}$$

Where the $P_{S,avg}$ expression is:

$$P_{S,avg} = \frac{1}{N} \sum_{p=1}^n \left[\sum_{q=1}^n \left((2p-1-n)^2 |A_{ideal}|^2 \right) + \sum_{q=1}^n \left((2q-1-n)^2 |A_{ideal}|^2 \right) \right] \tag{7}$$

The algorithm uses the threshold setting method to evaluate the quality of the received data on the M-subcarriers. The smaller the value of the EVM, the closer the observation point is to the standard modulation point, and the smaller the deviation, the better the signal quality. The EVM vector is represented as $\rho = [\rho_1, \rho_2, \dots, \rho_M]$, Threshold range set according to EVM value: $\rho_k \in [0, 1, 2, 3]$, $k \in [1, 2, \dots, M]$. After obtaining the subscript K of each subcarrier, it is transmitted back to the transmitting end through the LQA, and the transmitting end allocates a corresponding modulation mode according to the condition of each subcarrier in the next transmission. As shown in Fig. 2, in the actual engineering application, the feedback link requires a MAC layer for coordination. The physical layer at the receiving end reports the channel information to the MAC layer, and the MAC layer aggregates the channel state information. Then send the physical layer to the transmitter. The physical layer of the receiving end reports the channel information to the MAC layer, and the MAC layer aggregates the channel state information and sends it to the physical layer of the transmitting end.

Fig. 2 Cross-layer adaptive system structure diagram



3 Algorithm Performance Analysis

3.1 Complexity Analysis

Low complexity algorithms are practical and easy to implement and can improve communication efficiency. The EVM calculation method mentioned in II is more complicated in practical applications. This value is a measure of how close the I and Q components of the received modulated signal are to the ideal signal component. The result can be reduced to the ratio of the root mean square of the average power of the error vector signal to the root mean square of the ideal signal:

$$EVM = \left[\frac{\frac{1}{T} \sum_{r=1}^T |S_{ideal,r} - S_{meas,r}|^2}{\frac{1}{T} \sum_{r=1}^T |S_{ideal,r}|^2} \right]^2 \quad (8)$$

Where $S_{ideal,r}$ represents the ideal constellation point coordinates of the received symbol labeled r , and $S_{meas,r}$ represents the measured constellation point coordinates of the received symbol labeled r . For QPSK, 16QAM and 64QAM modulation modes, the power $|S_{ideal,r}|^2$ of the modulation signal corresponding to each

constellation point is different. However, in this system, the number of received symbols T is large enough (each OFDM symbol contains 192 subcarrier symbols and at least 8 OFDM symbols per burst), and the signal is random. The number of modulations to the constellation points is similar, and the power of the three modulation methods at the transmitting end is normalized. Therefore, the average power of the ideal signals at the receiving end is the same. Therefore, only the average power of the error vector signal can be calculated instead of EVM, simplifying the calculation and reducing the implementation complexity. So only two additions (subtractions), one addition and two squares are needed in EVM calculation. The calculation results show that the algorithm has a lower complexity.

3.2 Simulation Analysis

According to the principle of block-wise adaptive OFDM (BA-OFDM) system, we simulated it in the software of MATLAB, analyzed the performance of frequency selective channel, and adjusted the motion rate to change the anti-jamming performance of Doppler frequency shift verification system. System simulation parameters are shown in the Table 1.

Figure 3 and Fig. 4 compare the performance curves of OFDM over AWGN channel and frequency selective channel using RS-CC coding. The modulation modes of the two graphs are 16QAM and 64QAM. As can be seen from Fig. 3, the performance of 16QAM modulation is better than that of frequency selective channel in AWGN channel. In AWGN channel, the BER is less than 10^{-3} after SNR is greater than 15 dB, while in frequency selective channel, the BER is less than 10^{-3} after SNR is greater than 18 dB, in Fig. 4, the performance of 64QAM modulation over AWGN channel is also better than that over frequency selective channel. When the bit error rate is 10^{-3} , the SNR required for the AWGN channel is 14 dB less than that for frequency selective channel. According to the above results, the noise power of the two channels is the same, and the performance difference is

Table 1 Parameters of simulation

Number of subcarriers	256
Number of OFDM symbols	8
Coding type	RS+CC
Coding rate	133/192
Modulate type	QPSK 16QAM 64QAM
Carrier frequency	600 MHz
Sample rate	9 MHz
CP length	32
Channel type	AWGN and Frequency Selective Channel
Number of subcarriers	256

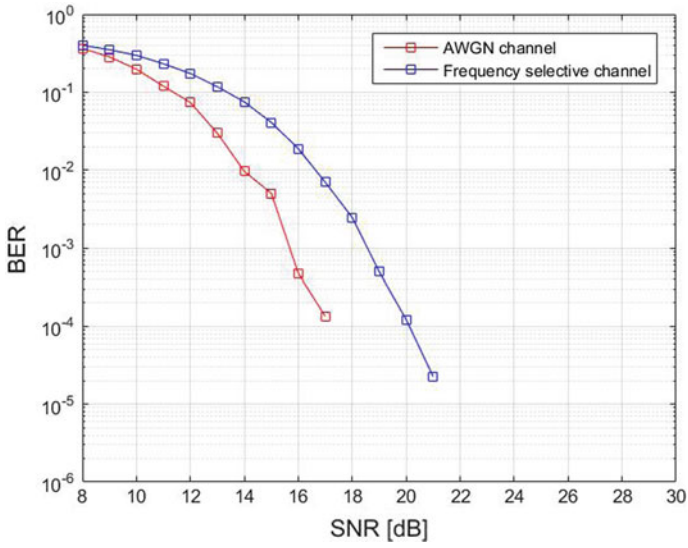


Fig. 3 BER of two channel conditions under 16QAM mode

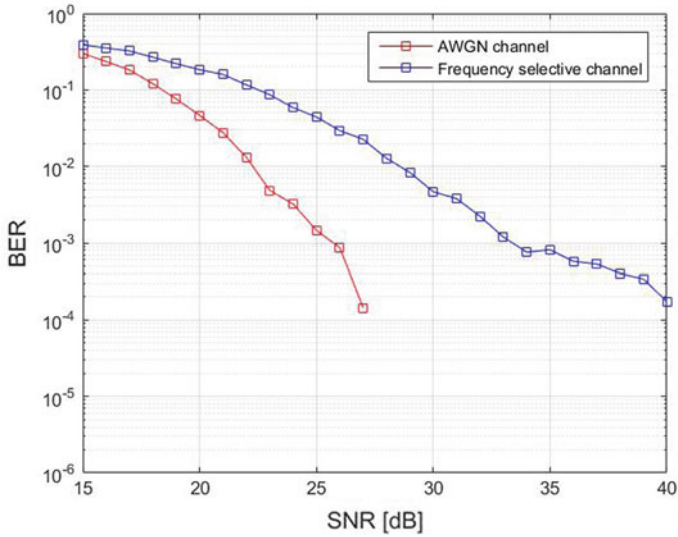


Fig. 4 BER of two channel conditions under 64QAM mode

only caused by the frequency selective fading of the channel. Therefore, it is necessary to estimate the quality of each subcarrier, allocate appropriate modulation modes for each subcarrier adaptively, and reduce the impact of frequency selective fading on the signal.

Figure 5 , 6, 7 and 8 are performance comparison curves of BA-OFDM and OFDM in frequency selective channels. Figure 5 and Fig. 6 are the error performance comparison curves. As shown in Table 2, in practical applications, when the EVM and SNR values meet the requirements, the high-order modulation method is preferred. When SNR is less than 20 dB, OFDM uses 16QAM modulation mode, while BA-OFDM adaptively uses QPSK modulation mode on subcarrier blocks with poor quality according to EVM threshold. Therefore, the BER of OFDM is less than 10^{-3} after the SNR is greater than 16 dB, and OFDM can only be achieved after the SNR is greater than 19 dB, similarly, when SNR is greater than 20 dB, OFDM uses 64QAM modulation mode, while BA-OFDM adaptively uses 64QAM, 16QAM or QPSK on different subcarrier blocks according to EVM threshold. When the bit error rate is 10^{-3} , the signal-to-noise ratio of BA-OFDM is 10 dB less than that of OFDM. Figure 7 and Fig. 8 show the performance comparison between BA-OFDM and OFDM throughput. Because of the large amount of data, the ordinate coordinates are expressed by the normalization method on the premise that the transmitted data can be decoded correctly: $K_{BA-OFDM} = B_{BA-OFDM}/B_{AWGN}$, $K_{Fading} = B_{Fading}/B_{AWGN}$, where $B_{BA-OFDM}$ represents the amount of data correctly transmitted in frequency-selective channels using adaptive modulation based on subcarrier blocks. B_{AWGN} represents the amount of data correctly transmitted over an AWGN channel using a fixed modulation mode within

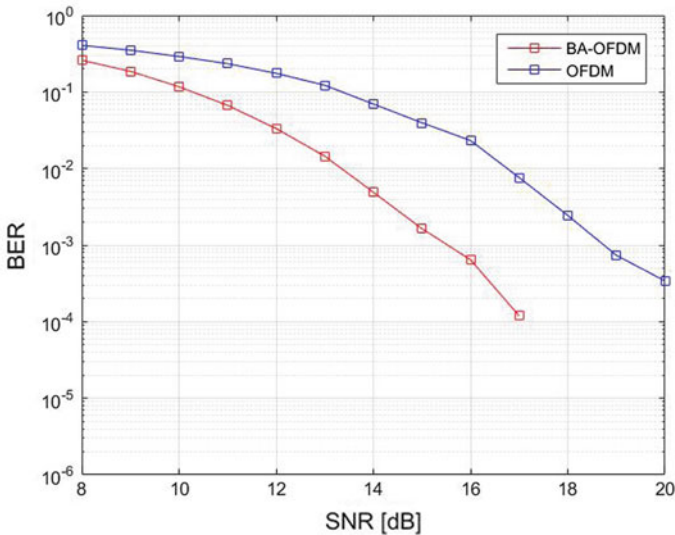


Fig. 5 BER performance in frequency selective channels ($SNR \leq 20$ dB)

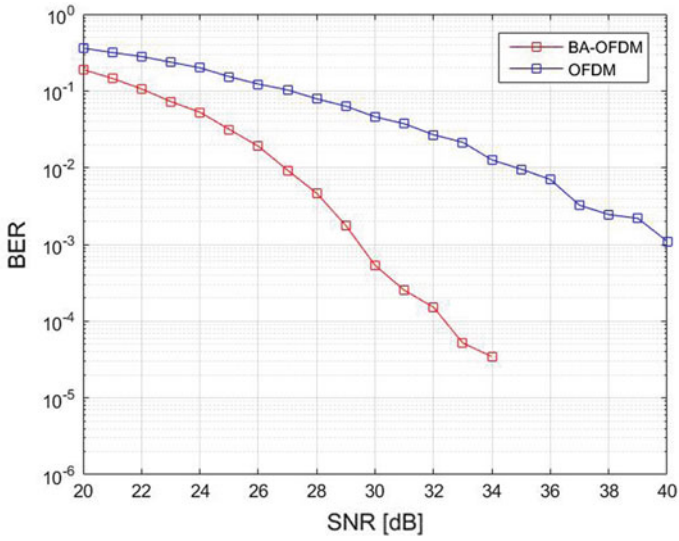


Fig. 6 BER performance in frequency selective channels ($SNR \geq 20$ dB)

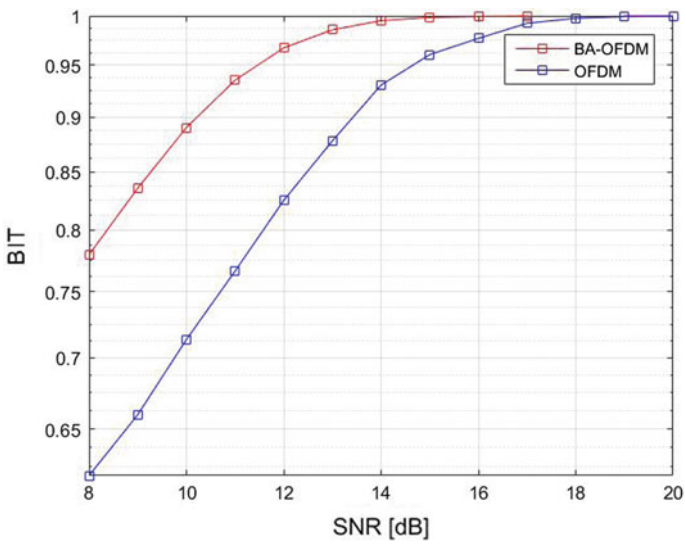


Fig. 7 Throughput performance in frequency selective channels ($SNR \leq 20$ dB)

Table 2 Threshold parameters of BA-OFDM

Modulation	EVM
64QAM	$EVM \leq 2$
16QAM	$EVM \leq 5$
QPSK	All values

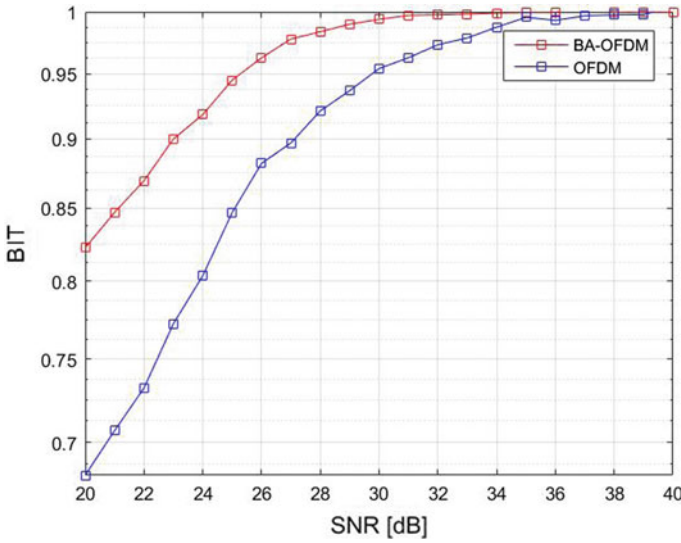


Fig. 8 Throughput performance in frequency selective channels ($SNR \geq 20$ dB)

the SNR range. Similarly, B_{Fading} represents the amount of data correctly transmitted by a fixed modulation mode in the SNR range over frequency-selective channels. As can be seen from these figures that the performance of BA-OFDM is better than that of OFDM in a frequency selective channel. Therefore, BA-OFDM can estimate the quality of each subcarrier well in one frame, select the best quality subcarrier block to use high order modulation, and select the bad quality subcarrier block to use low order modulation. The above can conclude that BA-OFDM has a better performance against frequency selective fading.

Figure 9 and Fig. 10 are test results for increasing the Doppler shift. The method of calculating Doppler shift in this paper is as follows: $f_d = \frac{f}{c} \times v \times \cos \theta$, Where f is the carrier frequency, here set to 600 MHz, c is the electromagnetic wave propagation speed, here is 3×10^8 m/s, v represents the motion rate, set here as 0. It can be seen from the BER curve of the two figures: Under the Doppler shift interference with a motion rate of 300 km/h, the performance of BA-OFDM is the same as that of frequency selective channel OFDM. This phenomenon occurs because the motion rate is too fast and the channel time becomes strong, which causes the feedback channel state information to be unable to estimate the quality of the next channel. At this time, the adaptive modulation based on subcarrier is no longer applicable.

As can be seen from Fig. 9, the performance of BA-OFDM is better than that of ordinary OFDM when the SNR is less than 20 dB. At the rate of 200 km/h, the performance gain of at least 1 dB is obtained at the bit error rate of 10^{-3} , and at the rate of 100 km/h, the performance gain of at least 2 dB is obtained at the bit error rate of 10^{-3} . As can be seen from Fig. 10, when SNR is greater than 20 dB, the

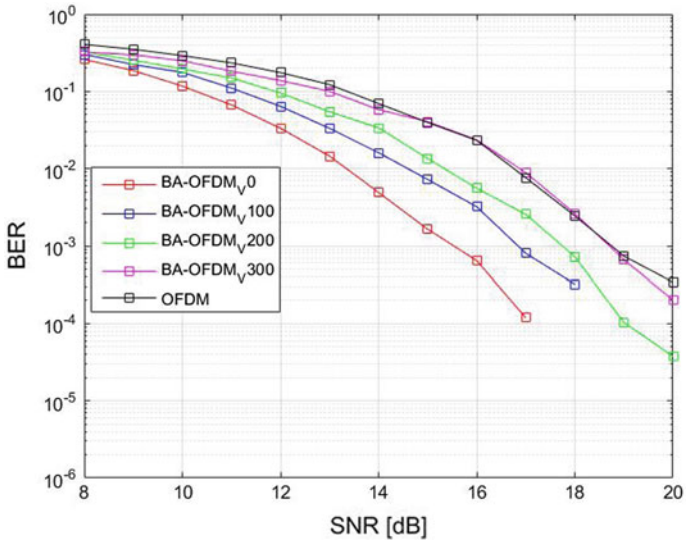


Fig. 9 BA-OFDM test results at different motion rates ($SNR \leq 20$ dB)

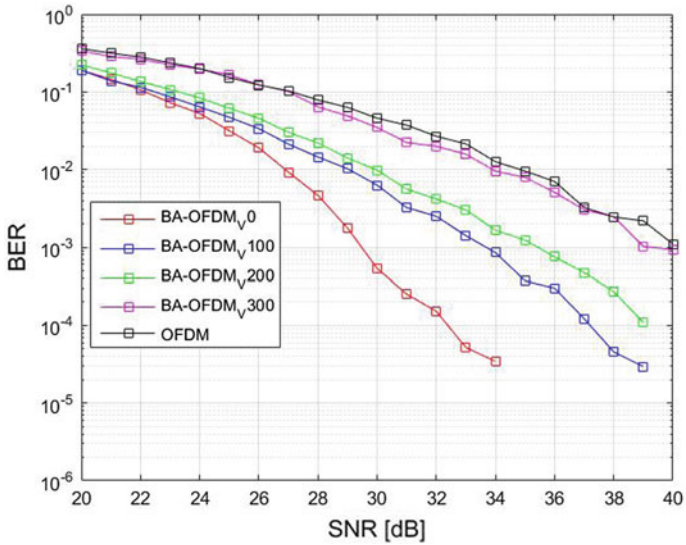


Fig. 10 BA-OFDM test results at different motion rates ($SNR \geq 20$ dB)

performance of BA-OFDM is also better than that of ordinary OFDM. At the rate of 200 km/h, the performance gain of at least 4 dB is obtained at the bit error rate of 10^{-3} , and at the rate of 100 km/h, the performance gain of at least 6 dB is obtained at the bit error rate of 10^{-3} .

4 Conclusion

To effectively enhance the system's ability to resist frequency selective fading, this paper introduces the OFDM subcarrier block adaptive modulation technology into the physical layer of the system. By calculating the EVM value of each subcarrier block at the receiving end, it allocates appropriate modulation modes to each subcarrier block for minimizing the impact of interference and fading bands on it and improving the bit error rate and throughput of the system. In the case of keeping the original system complexity unchanged, it is only necessary to increase the EVM calculation module and the channel information feedback module to effectively function and obtain good performance gain. Compared with the common non-adaptive OFDM technology, it effectively perceives the channel quality and performs adaptive modulation on each subcarrier block, which improves the transmission efficiency to a great extent. The simulation results show that BA-OFDM technology possesses better error performance in the frequency selective fading channel than the OFDM system, and can improve system performance within a certain range of motion rates. In the future of mobile communications, it will become an effective means of adaptive transmission.

References

1. Yu, Q., & Wang, Y. (2010). Improved chow algorithm used in adaptive OFDM system. In *2010 International Conference on Communications and Mobile Computing, Shenzhen* (430–432).
2. Pandit, S., & Singh, G. (2015). Channel capacity in fading environment with CSI and interference power constraints for cognitive radio communication system. *Wireless Networks*, *21*(4), 1275–1288.
3. Hwang, Y. T., Tsai, C. Y. & Lin, C. C. (2005). Block-wise adaptive modulation for OFDM WLAN systems. In *2005 IEEE International Symposium on Circuits and Systems, Kobe* (Vol. 6, pp. 6098–6101).
4. Karaarslan, G., & Ertuğ, Ö. (2017). Adaptive modulation and coding technique under multipath fading and impulsive noise in broadband power-line communication. In *2017 10th International Conference on Electrical and Electronics Engineering, Bursa* (pp. 1430–1434).
5. Tato, A., Mosquera, C. & Gomez, I. (2016). Link adaptation in mobile satellite links: field trials results. In *2016 8th Advanced Satellite Multimedia Systems Conference and the 14th Signal Processing for Space Communications Workshop, Palma de Mallorca* (pp. 1–8).
6. Willems, F. M. J. (1993). Elements of Information Theory [Book Review]. *IEEE Transactions on Information Theory*, *39*(1), 313–315.

7. Webb, W. T., & Steele, R. (1995). Variable rate QAM for mobile radio. *IEEE Transactions on Communications*, 43(7), 2223–2230.
8. Chow, P. S., Cioffi, J. M., & Bingham, J. A. C. (1995). A practical discrete multitone transceiver loading algorithm for data transmission over spectrally shaped channels. *IEEE Transactions on Communications*, 43(2/3/4), 773–775.
9. Fischer, R. F. H. & Huber, J. B. (1996). A new loading algorithm for discrete multitone transmission. In *Proceedings of GLOBECOM'96. 1996 IEEE Global Telecommunications Conference* (Vol. 1, pp. 724–728).
10. Grunheid, R., Bolin, E., & Rohling, H. (2001). A blockwise loading algorithm for the adaptive modulation technique in OFDM systems. In *IEEE 54th Vehicular Technology Conference. VTC Fall 2001. Proceedings* (Cat. No.01CH37211) (Vol. 2, pp. 948–951).
11. Keller, T., & Hanzo, L. (2000). Adaptive multicarrier modulation: a convenient framework for time-frequency processing in wireless communications. *Proceedings of the IEEE*, 88(5), 611–640.
12. Qijun, Z., Qinghua, X. & Wei, Z. (2007). Notice of violation of IEEE publication principles a new EVM calculation method for broadband modulated signals and simulation. In *2007 8th International Conference on Electronic Measurement and Instruments* (pp. 2-661–2-665).