The Research of Adaptive Modulation Technology in OFDM System

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Abstract. Orthogonal frequency division multiplexing (OFDM) as a special multi-carrier transmission technology has good resistance to narrow-band interference and frequency selective fading ability. Compared with traditional modulation techniques, adaptive modulation can enhance bandwidth efficiency and system capacity. Therefore, applying adaptive modulation in OFDM systems can take full advantage of spectrum resources, and it is suitable for the high-speed and reliable mobile communication systems in the future. The purpose of this paper is to improve traditional OFDM adaptive algorithms (Hughes-Hartogs, Chow) to realize bits allocation, power allocation better. In this paper, simulation results demonstrated that the improved Levin-Campello algorithm lowers algorithm's complexity greatly and owns better flexibility, at the same time, it guarantees good the bit error rate (BER) performance and can be applied to speech communication (fixed rate) and data communication (variable rate) in wireless communication systems.

Keywords: OFDM · Adaptive modulation · Bit allocation · Power allocation

1 Introduction

With the high speed data in wireless mobile communication business and the rapid development of multimedia services. The research is importance how to effectively use of spectrum resources to provide high-speed and reliable communication service. In this paper, the improved better Levin-Campello algorithm is researched for ensuring BER, better bit and power allocation by the comparing of two traditional adaptive modulation algorithm.

2 The Principle of OFDM System and the Realization of Adaptive Modulation [1]

The multicarrier transmission way is adopted by OFDM [2] technology after the high speed serial data is decomposed into several parallel data at low speed, then the width of each data element is widened, so that the influence of intersymbol interference can

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reduced. By Orthogonal function sequence is used as subcarrier, so the carrier spacing is reached the minimum, and the band utilization rate of the system is fully enhance. By making fully use channel state information (CSI) in adaptive modulation OFDM system, Low order modulation method is adopted in the smaller decline amplitude subcarrier, and high order modulation method is adopted in the larger decline amplitude subcarrier. and the corresponding power is distributed, so the efficiency of data transmission is greatly improved.

The adaptive modulation block diagram of OFDM system [3] is shown in Fig. 1.

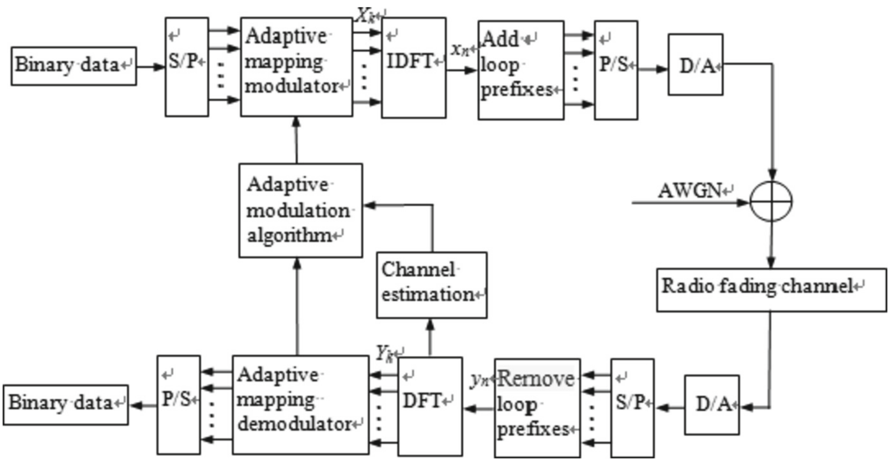

Fig. 1. The adaptive modulation block diagram of OFDM system

3 The Adaptive Modulation Algorithm of the Traditional Raditional OFDM System [4]

3.1 Hughes - Hartogs Algorithm

Optimization criterion of Hughes - Hartogs algorithm [5] is the minimum total power of the system in a condition of the guarantee target BER and data rate.

The algorithm is a kind of algorithm based on the channel gain, the basic idea is the bits of each channel number are set to zero, then all bit will be distributed are assigned to the corresponding sub-channels. Every time allocation, firstly, the channel increasing the minimum power will be found when adding a bit, then the number of bits of sub-channels will increased one, then the process is repeated, until all bits allocated are reached the requirements of a given target bit, finally, the required power of each channel are calculated.

① The initialization process

For all n = 1, 2,… N, make $C_n = 0$. Calculate $\Delta P(n) = P(C_{n+1}) - P(C_n)$.

② The iterative process of bit allocation

The minimum value of $\Delta P(n)(n = 1, 2, \ldots, N)$ is searched, and is recorded label the subcarrier for $\hat{n} = \arg\min$, then increasing power of the subcarrier are recalculated once again:

$$\Delta P(\hat{n})P(C_{\hat{n}+1}) - P(C_{\hat{n}}) \tag{1}$$

③ Repeat step ②, until the R bit allocation are completed.

$\{C_1, C_2, \cdots, C_n\}$ are calculated by the above steps is the last bit allocation scheme. Each bit of information is distributed by searching and sorting in Hughes - Hartogs algorithm, when the total bits number of the carrier and emission is larger, then the complexity of the algorithm is very high.

3.2 Chow Algorithm

Chow algorithm [6–8] is the adaptive bit allocation algorithm of subprime power minimization similar water flooding algorithm, this algorithm is suitable for large transmission capacity ASDL system, the performance is lower than the Hughes - Hartogs algorithm, but it has faster convergence speed, and bit allocation of Chow algorithm is based on the channel capacity of each channel. Its optimization criterion is the system's performance allowance is maked the largest on the premise of maintaining the target bit error rate. Bits are gradually allocated by the iteration process in this algorithm, and at same time the allowance system are gradually sete increased, until all the bits are allocated to complete. A maximum number of iterations is d for keeping the convergence rate of the algorithm. This algorithm has the following three steps to complete:

① Determine the threshold margin for achieving the optimal performance of the system;

② Determine the modulation way of each sub-carrier;

③ Adjust the power of each subcarrier.

4 Levin-Campello Algorithm

Drawbacks of the Hughes - Hartogs algorithm are high complexity, slow convergence speed and unsuitability real-time systems. Chow algorithm based on maximum data rate standard can not meet the sending power minimum requirements of the many systems. In view of the above two algorithms existing problems, and then the improved Campello algorithm based on Chow algorithm and Hughes - Hartogs algorithm is appeared, the improved Campello algorithm with the advantages of the two algorithms can achieve the minimizing sending power.

Levin – Campello [9, 10] algorithm is divided into three step implementation, the specific steps are as follows:

Step 1: Bit and power are initialized allocation according to Chow algorithm ideas, specific implementation process of this step is as follows:

① Calculate SNR of all sub-channels;

② Bit allocation of sub-channels according to the formula:

$$b_i' = \log_2\left(1 + \frac{SNR_i}{gap}\right) \tag{2}$$

where gap is coordinate parameters, it is the function of Coding scheme, the target ber and noise margin.

③ b_i' must be rounded for the integer bit allocation of communication system

$$b_i' = round\left(b_i'\right) \tag{3}$$

④ Because of the modulation mode is usually adopt even, so b_i has a value of 0, 1, 2, 4, 6, 8. Allocation energy of each subcarrier b_i bit is calculated by using the following formula:

$$e_i(b_i) = \frac{2^{b_i} - 1}{GNR_i} \tag{4}$$

where, $GNR_i = SNR_i/gap$.

Step 2: Adjust bit and power allocation according to the Hughes - Hartogs algorithm.

Firstly, an energy increment table must be built, table contained increase energy of average increase a bit in each channel on the original basis, For I sub-channels, originally allocated b-x bit is increased to x bits, and the energy increment is:

$$\Delta e_i(b)_x = e_i(b) - e_i(b - x) \tag{5}$$

Power increment of average every bit is $\Delta e_i(b) = \Delta e_i(b)_x/x$, because each subcarrier is only allocated 8 bits in the system, so bits increment from 8 bits to are set to a very high value, so it is avoided that the subcarrier distribution system is distributed any greater than 8 bits.

The specific implementation steps of the steps are as follows:

① m_i is the maximum number of adjusted bits for each channel, m is the biggest adjustment step length, then the actual change length should satisfy $M_i = \min[m_i, m]$. The power increment is $\Delta e_i(b)_{M_i}$ by changing M_i, every bit power increment is:

$$\Delta e_i(b) = \Delta e_i(b)_{M_i}/M_i \tag{6}$$

② The largest or smallest element of energy table is drawn, and its bit is adjusted according to the corresponding adjustment step length M_i of sub-channels, so a new $\Delta e_i(b)$ is got, and new energy increment table is obtained.

③ If the purpose of the distribution don't reach, return step 2, or quit.

Detailed algorithm process is:

Firstly, initial bit numbers for each channel are summed: $B' = sum(b_i)$, then for the following operations:

while $B' \neq B$

if $B' > B$

$n = \text{argmax } \Delta e_i(b)$

$b_n = b_n - M_n$

$B' = B' - M_n$

else

$n = \text{argmax } \Delta e_i(b)$

$b_n = b_n + M_n$

$B' = B' + M_n$

End

Step 3: Optimize the last 1 bit.

Through step 1 and step 2, the last one bit may be assigned to subcarrier with the bit number greater than 2 and an even number of bits, so bits of the subcarrier number is odd number greater than 2, if the number of allocation bits of subcarrier is greater than 2, then the subcarrier is allocated an even number bits of less than or equal to 8, so a last bit need to specially treat.

Campello algorithm using RTLB (Resolve The Last Bit) algorithm. RTLB algorithm implementation steps are as follows:

① Check each subchannel, if there is the number bits due to the last 1 bit allocation isn't be supported. If it does not have this kind of channel, distribution is terminated; If the channel r exist, the next step $\Delta e_r(b(r))$ and $\Delta e_r(b(r)+1)$ are calculated.

② Search subcarrier given 1 bit or 2 bits, subcarrier with most energy reduction by decreasing 1 bit is denoted by i, the energy increment $\Delta e_i(b(i))$ is obtained, calculate the following formula:

$$E1 = \Delta e_r(b(r)+1) - \Delta e_i(b(i)) \tag{7}$$

③ Collect subcarrier allocated 0 bit or 1 bit, subcarrier with minimum energy increase by increasing 1 bit is denoted by j, the energy increment $\Delta e_j(b(j)+1)$ is obtained, calculate following formula:

$$E2 = \Delta e_j(b(j)+1) - \Delta e_r(b(r)) \tag{8}$$

④ Compare E1 and E2, if E1 is less than E2, the subcarrier i reduce a bit, subcarrier increase a bit at the same time; If the E2 is less than E1, the subcarrier j increase a bit, at the same time the subcarrier reduce a bit. At the same time, the corresponding energy allocation is adjusted, the algorithm is over.

5 Levin-Campello Algorithm Simulation and Performance Analysis

In order to verify the correctness of the theory analysis, the Levin - Campello algorithm, Hughes-Hartogs algorithm and Chow algorithm are simulated by using MATLAB, simulations are conducted in the case of the same parameters mentioned earlier, the simulation parameters [11, 12] are shown in Table 1.

Table 1. System simulation parameters

The subcarrier number N of OFDM	32
Cyclic prefix CP	16
The biggest sign bit number	8
Transmitting antenna number	1
Receiving antenna number	1
Fading channel type	Rayleigh

The subchannel gain simulation results, the bit allocation simulation results and the power allocation simulation results of three algorithm are shown in Fig. 2, 3 and 4. The BER simulation of Levin-Campello is shown in Fig. 5.

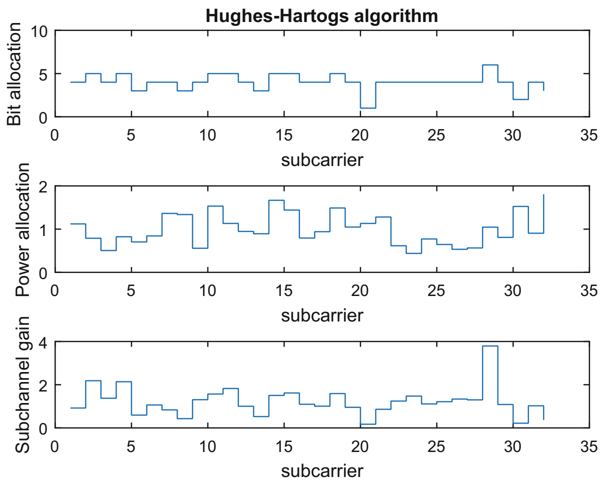

Fig. 2. The simulation results of Hughes - Hartogs algorithm

It can be seen from the simulation results of Fig. 2, Fig. 3 and Fig. 4 that bit allotment of each subcarrier are determined by algorithm according to the subcarrier channel gain, distribution of bit is more in the good channel conditions, Otherwise, distribution of bit is less or no in the poor channel conditions. Hughes - Hartogs algorithm can achieve the ideal performance, in every time for bit allocation, the additional power needed to ensure the transmission bit is minimal. Sorting and searching computation is very big, and complexity is high, and practicability is poor. Rate allocation of Chow algorithm is according to the capacity of each channel, large allowance system is needed, it don't conform to the actual demand. But complexity of Levin - Campello algorithm is not only greatly reduced, but also BER performance is good, it can be seen from Fig. 5 that the BER of system is significantly dropped, until almost don't make a mistake when the SNR is greater than 102, this is the biggest advantage of the algorithm.

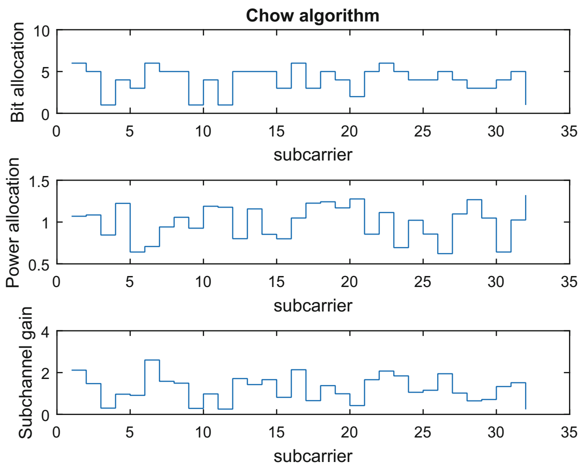

Fig. 3. The simulation results of Chow algorithm

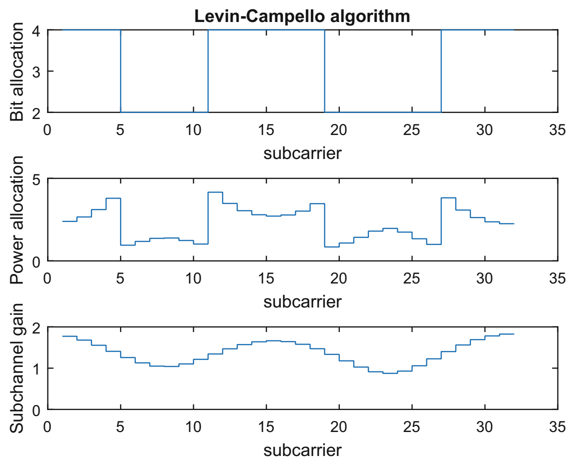

Fig. 4. The simulation results of Levin-Campello algorithm

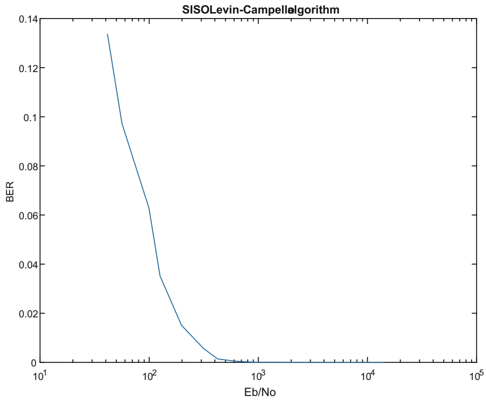

Fig. 5. The BER simulation of Levin - Campello algorithm

Table 2. Data simulation results data of three algorithm

Subcarrier	Hughes-Hartogs algorithm			Chow algorithm			Levin-Campello algorithm		
	Bit	Power	Gain	Bit	Power	Gain	Bit	Power	Gain
1	5	0.9374	1.5364	6	1.0376	2.3487	0	0	0.3362
2	3	0.7323	0.4452	6	0.7435	2.7746	0	0	0.4531
3	2	1.5777	0.1642	6	1.1514	2.2296	4	22.4173	0.5791
4	4	0.7363	0.8710	6	1.4632	1.9779	4	15.2963	0.7011
5	5	0.9220	1.5491	5	1.3796	1.4288	4	11.4332	0.8109
6	4	1.3471	0.6439	5	0.8020	1.8740	6	38.7352	0.9029
7	3	0.7347	0.4445	2	0.7829	0.5900	6	33.3724	0.9727
8	5	1.1318	1.3982	1	1.1034	0.2869	6	30.5020	1.0174
9	4	0.5992	0.9655	6	0.8999	2.5220	6	29.4578	1.0353
10	5	1.3746	1.2687	5	0.9006	1.7684	6	30.0069	1.0258
11	4	0.4819	1.0765	6	1.1381	2.2426	6	32.2414	0.9896
12	3	0.7366	0.4439	6	0.8356	2.6173	6	36.6048	0.9288
13	2	2.3071	0.1357	0	0	0.1038	6	44.0587	0.8466
14	6	0.9352	3.0727	4	1.0284	1.1512	4	13.4449	0.7478
15	3	0.5237	0.5265	2	0.9865	0.5256	4	18.4149	0.6389
16	5	0.9105	1.5589	4	0.8359	1.2769	4	26.8468	0.5292
17	4	0.4798	1.0790	4	0.7797	1.3221	0	0	0.4317
18	4	0.6523	0.9451	4	1.519	0.9494	0	0	0.3654

(*continued*)

Table 2. (*continued*)

Subcarrier	Hughes-Hartogs algorithm			Chow algorithm			Levin-Campello algorithm		
	Bit	Power	Gain	Bit	Power	Gain	Bit	Power	Gain
19	4	1.3765	0.6370	2	1.0170	0.5177	0	0	0.3480
20	5	0.7818	1.6824	4	1.5109	0.9497	0	0	0.3782
21	4	0.6980	0.8945	5	1.1593	1.5587	0	0	0.4340
22	5	0.8246	1.6381	4	1.1926	1.0690	4	30.9130	0.4931
23	4	1.0864	0.7170	3	0.7889	0.8979	4	25.6226	0.5417
24	5	0.5600	1.9878	0	0	0.1429	4	23.0080	0.5716
25	2	0.9118	0.2159	3	0.7466	0.9229	4	22.4430	0.5788
26	3	1.8894	0.2772	4	0.9954	1.1701	4	23.8501	0.5614
27	5	0.7683	1.6971	6	1.2356	2.1523	4	27.7966	0.5201
28	2	0.6752	0.2509	4	0.7497	1.3482	4	35.9475	0.4573
29	5	1.8648	1.0893	5	1.1362	1.5745	0	0	0.3791
30	5	0.8038	1.6592	2	1.3370	0.4515	0	0	0.2980
31	5	1.3302	1.2897	4	1.5187	0.9473	0	0	0.2418
32	3	1.3361	0.3296	4	1.2318	1.0518	0	0	0.2536

Data simulation results data of three algorithm is shown in Table 2, it can be seen from Table 2 that an obvious characteristic with Levin - Campello algorithm compared to Hughes - Hartogs and Chow algorithm is that subchannels of channel gain under a certain limit (Here is about 0.5) will be discarded, so the quality of the communication is improved.

6 Conclusion

Traditional algorithm of Hughes – Hartogs and Chow algorithm based on the adaptive modulation rule are researched in this paper, aim at the shortcomings of high computation complexity of Hughes – Hartogs and low power efficiency of Chow algorithm, Campello algorithm firstly initializes bit and power allocation on according to Chow algorithm ideas, and then bit and power allocation are adjusted according to Hughes - Hartogs algorithm, so the algorithm complexity is greatly reduced. It is found by the above analysis that Campello algorithm has low computation complexity and high power efficiency, at the same time, it has greater flexibility on condition of the BER, it is suitable for voice communication of the fixed rate in wireless communication system, and it can also be applied to variable speed data communication, so it conforms to the actual requirements of wireless communication system, and it is a kind of better adaptive modulation algorithm.

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