Bit and Power Allocation Algorithm for OFDM UWB Systems

Haiyan Li
School of Information Engineering
Lanzhou University of Finance and Economics
Lanzhou, 730020, China
30614230@qq.com

***Abstract*—Ultra-wide-band (UWB) is a promising short-range indoor wireless communication technology for large communication capacity, high transmission rate, low power consumption, etc. Multi-band orthogonal frequency-division multiplexing ultra-wide-band (MB-OFDM UWB) system can achieve much higher anti-noise capability and flexibility. However, the transmission power of UWB systems is strictly restricted for avoiding the interference with other wireless communication systems existing in the same frequency spectrum range. It is necessary that adequately utilizes channel estimation to allocate bit and power effectively. According to the change of channel gain, UWB systems modify the allocation factor to optimize the performance of systems and reduce power allocation remainder. Simulation shows modified bit-power allocation algorithm can enhance power allocation efficiency. Furthermore, it is found that the power remainder of modified allocation factor algorithm is less influenced by the bit error rate.**

Keywords- UWB;OFDM;bit-power allocation;bit error rate

I. INTRODUCTION

Based on rapidly developing wireless communication technologies, the next generation mobile communication will achieve seamless overlay all over the world. It is going to support the multimedia communication with high speed data such as voice, text, image, video, and so on. The requirements and applications of Wireless Local Area Net work (WLAN) and Wireless Personal Area Network (WPAN) will increase inevitably. As a result, more efficient utilization and sharing of the spectrum can contribute to solve the radio spectrum resource shortage. Ultra Wideband (UWB) wireless communication technology is very suitable to construct WPAN because of its outstanding performance including high data rate, low power consumption, low equipment cost, and high position accuracy, etc. The UWB system has become an attractive candidate of short-range indoor wireless communication systems. At present, there are mainly two schemes to realize UWB communications which are impulse radio ultra-wide-band (IR-UWB) and multi-band orthogonal frequency-division multiplexing ultra-wide-band (MB-OFDM UWB) respectively. MB-OFDM UWB systems have not only prominent anti-noise capability, flexible and high data rate transmission but also abilities to provide greater bandwidth, and to capture the multipath energy efficiently. In addition, when combined with multiple–input multiple-output (MIMO) technology, MB-OFDM UWB systems will cope with multi-path fading signal effectively. Thus it can boost spectral efficiency as well as channel capacity. At the same time, UWB communication systems also suffer interference from other wireless communication systems as narrowband interference because the transmission power of UWB communications is restricted strictly and it will coexist with other wireless communication systems in the greater bandwidth. In such situation, if UWB systems will attain the high data rate and the good quality of communication, some technical difficulties need to be solved.

The Federal Communications Commission (FCC) in the United States defines UWB as the band where the signal relative band (namely signal band to center frequency ratio) is not less than 0.2 or absolute band not less than 500MHz and can make use of wide frequency from 3.1 GHz to 10.6 GHz found in [1]. UWB wireless communication technology will allow very high data rate applications such as the connection between computer and peripherals like displayer, printer and scanner, video and audio facilities' joint in home theater, anti-collision radar system in vehicle, and underground exploring imaging system, etc. The greater bandwidth of UWB has substantial potential to improve the transmission rate, reduce power spectrum density and thus is adopted in broad applications in wireless communications. In order to avoid interference between UWB systems and other communication systems, the FCC imposed regulation that limited the power spectral density of the UWB signal to be below -41.3dBmW/MHz, which unavoidably constrains the data transmission rate of the UWB communications and reduces the quality of communications.

High data rates and low signal transmission power require modulation and code technologies to optimize the performance of UWB communication systems such as the bit error rate, data transmission rate, channel capacity, communication quality and power efficiency. In this paper, efficient bit and power allocation algorithms of OFDM UWB systems are main research objects. Today, D. Hughes-Hartogs algorithm, B. S. Krongold algorithm and J.Jang algorithm are typical algorithms about bit and power allocation respectively reported in [2], [3] and [4]. Some modified algorithms based on J.Jang algorithm which is always called water-filling power allocation algorithm can be found in [5] and [6]. In particular, in [7], [8] and [9], Didem and others present an algorithm with two steps to realize subcarrier power allocation and power control.

II. UWB CHANNEL MODEL

Let us consider a UWB channel model with a single transmitter and receiver antenna. With the expanding bandwidth in UWB systems, the channel has superior multi-path resolution and few multi-path components overlap. Since the work of the system doesn't meet the condition of the central limit theorem and the small scale fading effects of the wireless channel doesn't fit for Rayleigh distribution or Rice distribution, the conventional narrow band wireless communication channel model can't be applied for UWB systems. Generally, a UWB communication channel can be expressed according to multi-path delays and corresponding fading gains as following [10]

$$h(t)=\sum_{l=0}^{L}\sum_{k=0}^{K}\alpha_{k,l}\delta(t-T_l-\tau_{k,l})\,. \tag{1}$$

where $h(t)$ is the impulse response of the physical channel, $\alpha_{k,l}$ is the multi-path fading coefficient, δ is the Dirac delta function, T_l is the lth cluster time delay, and $\tau_{k,l}$ is the kth time delay in the lth cluster multi-path based on T_l. The time of clusters follows Poisson distribution with Λ parameter. Other multi-path arrival time follows Poisson distribution with λ parameter. In general the quantity of multi-path is more than number of cluster thus $\lambda >> \Lambda$. Let $\tau_{01}=T_i$, then

$$\begin{cases} P(T_l|T_{l-1})=\Lambda\exp[-\Lambda(T_l-T_{l-1})], & l>0 \\ P(\tau_{k,l}|\tau_{(k-1),l})=\lambda\exp[-\lambda(\tau_{k,l}-\tau_{(k-1),l}], & k>0 \end{cases}. \tag{2}$$

Define channel fading coefficient $\alpha_{k,l}$ as $\alpha_{k,l}=p_{k,l}\beta_{k,l}$, where $p_{k,l}=\pm 1$ is the random pulses phase inversion due to signal reflection and $\beta_{k,l}$ is lognormal distribution fading effect with mean as $\mu_{k,l}$ and variance as $\sigma_1^2+\sigma_2^2$, then

$$20\log(\beta_{k,l}) \sim N(\mu_{k,l},\sigma_1^2+\sigma_2^2)\,. \tag{3}$$

Let us further define $\mu_{k,l}$ as

$$\mu_{k,l}=\frac{10\ln(\Omega_0)-10\frac{T_l}{\Gamma}-10\frac{\tau_{k,l}}{\gamma}}{\ln(10)}-\frac{(\sigma_1^2+\sigma_2^2)\ln(10)}{20}\,. \tag{4}$$

Multi-path energy distribution is $E[\beta_{k,l}^2]=\Omega_0 e^{-T_l/\Gamma}e^{-\tau_{k,l}/\gamma}$ accordingly, where Ω_0 is the first multi-path energy in the first cluster. IEEE 802.15.3a working group also draws up four channel models that are CM1, CM2, CM3 and CM4. The frequency band of MB-OFDM UWB communications which is between 3.1 GHz and 10.6 GHz is divided into 5 band groups and 14 sub-bands that each band occupies 528 MHz.

III. ADAPTIVE BIT-POWER ALLOCATION ALGORITHM

A. *Allocation Issue and Constraint Condition*

A hypothesis is a condition that the upper limit of the total power for OFDM systems is P, the number of subcarriers is N, the channel gain of the kth subcarrier is α_k where k=1,2,$\cdots$, N. The power of white Gaussian noise in each subcarrier is σ_n^2, the ceiling on codeless bit error rate of receivers is BER. If the kth subcarrier is allocated power that is p_k, it will be allocated b_k bits data on the subcarrier as following [4]

$$b_k=\log_2(1+\frac{\alpha_k p_k}{\sigma_n^2\beta})\,. \tag{5}$$

where β is signal to noise ratio (SNR) margin with codeless bit error rate less than BER. To acquire an integer of bits allocation, let us further define a nonnegative integer $\hat{b}_k$ as following

$$\hat{b}_k = floor(b_k)\,. \tag{6}$$

where $floor(\cdot)$ is a function that can round down to an integer, then

$$B=\sum_{k=1}^{N}\hat{b}_k\,. \tag{7}$$

where B is the total number of allocation bits on every subcarrier. The power allocation of the kth subcarrier which has $\hat{b}_k$ bits is $p_k(\hat{b}_k)$ as following

$$p_k(\hat{b}_k)=\frac{\sigma_n^2\beta(2^{\hat{b}_k}-1)}{\alpha_k}\,. \tag{8}$$

Consequently, the constraint condition of discrete bit allocation rate can be defined as

$$\sum_{k=1}^{N}p_k(\hat{b}_k)\le P\,. \tag{9}$$

At the same time, the surplus of power will be insufficient to allocate one bit.

B. *Adaptive Bit-Power Allocation Algorithm*

Water filling algorithm found in [4] is a typical efficient power allocation scheme. It is a power and bit allocation algorithm in a fading channel by applying the Lagrange multiplier method. The power allocation of the kth subcarrier for OFDM systems in a fading channel is defined p_k as

$$p_k = \sigma_n^2 \beta [\lambda - 1/\alpha_k]^+ . \quad (10)$$

where $[x]^+$ is defined as $[x]^+ = \max(x,0)$, and λ is an adjustment coefficient to modify the power allocation, then

$$\sum_{k=1}^{N} p_k = P_s . \quad (11)$$

where P_s is the sum of the power allocation and define bits allocation as

$$\hat{b}_k = floor\{[\log_2(\lambda\alpha_k)]^+\} . \quad (12)$$

However, the initial value of λ and its step size increased are very important which will directly affect the power allocation efficiency and the computation speed. In this paper, it can be improved according to the change of channel parameters. The initial value of λ will base on the channel gain by channel estimation technologies. The channel of UWB systems can be seemed as a static situation because it is always applied to the short-range indoor wireless communications. If there is a $\hat{b}_k$ by equation (12) and $\hat{b}_k$ is an integer as $\hat{b}_k = b_k$, then

$$p_k(b_k) = \frac{\sigma_n^2 \beta (2^{b_k} - 1)}{\alpha_k} = \sigma_n^2 \beta [\lambda - \frac{1}{\alpha_k}]^+ . \quad (13)$$

$$[\lambda - \frac{1}{\alpha_k}]^+ = \frac{2^{b_k} - 1}{\alpha_k} . \quad (14)$$

$$\lambda = 2^{b_k}/\alpha_k \qquad , b_k \geq 1 . \quad (15)$$

Let us further define the power efficiency that is also used in the simulation of the paper as following

$$R_e = P_r/P = \left[P - \sum_{k=1}^{N} p_k(\hat{b}_k)\right]\Big/P . \quad (16)$$

where P_r is the remainder of the power allocation, as $P_r = P - P_s$. The initial value of λ needs to be adjusted for efficient power allocation, then

$$\lambda_i = 2^{b_k}/\max(\alpha_k) . \quad (17)$$

where λ_i is the initial value of λ, and $\max(\alpha_k)$ is the maximum of subcarrier channel gains.

IV. Simulation Results and Analysis

Simulations employ quadrature phase shift keying (QPSK) modulation to signify the mapping signal in OFDM UWB wireless communications. The CM3 (Non Line of Sight) channel model is used in the simulation, and other relevant simulation parameters are defined as follows: $\Lambda / ns = 0.4$, $\lambda / ns = 0.5$, $\Gamma = 5.5$, $\gamma = 6.7$, $\sigma_1 / dB = 3.3941$, $\sigma_2 / dB = 3.3941$

We presume that the total of subcarrier is 128, channel gain mean is 1, the power of white Gaussian noise on each subcarrier is 0.01 and the power of signal can be calculated by SNR. The bit error rate is BER as $BER = 10^{-3}$ and SNR margin with codeless bit error rate less than BER is β as $\beta = -\ln(5BER)/1.5$.

According to these parameters above, bit-power allocation algorithm simulation will define the initial value of λ as λ_i. From figure 1, ordinate means the amount of iteration calculation. It can be clearly observed that the amount of calculation enhances with SNR increasing. The modified bit-power allocation algorithm needs less computation than conventional water filling algorithm by adaptively modifying the allocation coefficient λ based on the change of channel gain.

Figure 2 shows the power allocation remainder of the adaptively modifying allocation factor algorithm is less than the conventional water filling algorithm prominently. Moreover, the former is impacted by SNR more feebly than the latter. With modifying allocation coefficient adaptively the bit-power allocation is more efficient from the result of simulation.

Any simulation above is based on the fixed bit error rate. Then the effect of BER on the bit-power allocation is showed in figure 3, where SNR is invariable by selecting the value between 0 and 10. The same result is found that the power allocation remainder of the adaptively modifying bit-power allocation factor algorithm is less than the conventional water filling algorithm and is affected feebly by the value of BER.

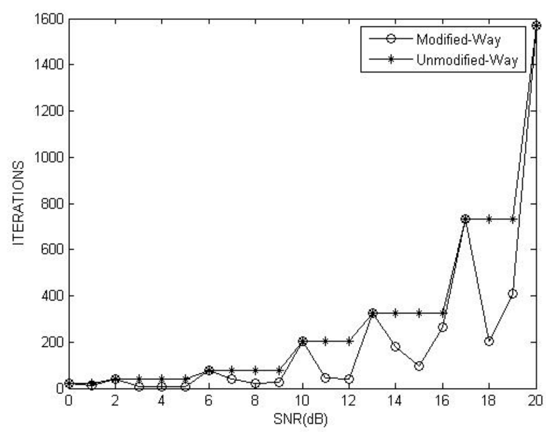

Figure 1. Comparison of the total calculation between conventional water filling and adaptively modifying power allocation.

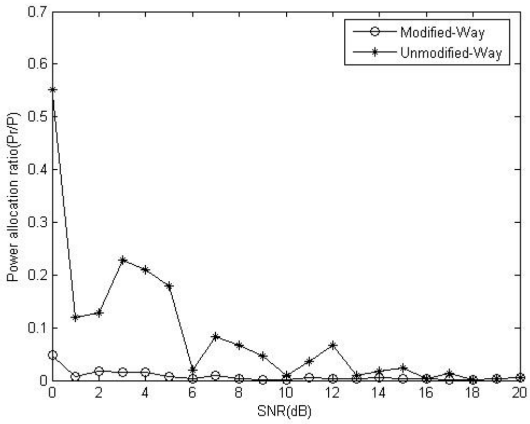

Figure 2. Comparison of power allocation surplus between conventional water filling and adaptively modifying power allocation.

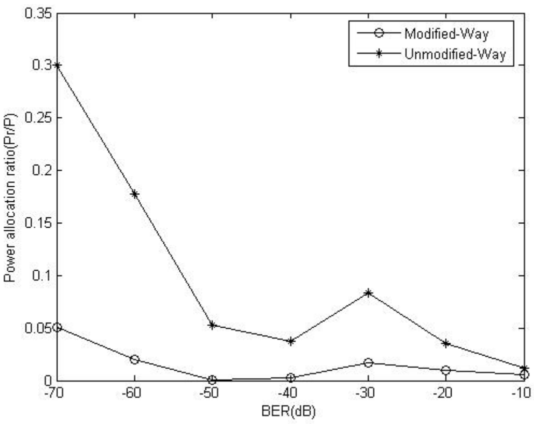

Figure 3. Comparison of power allocation surplus between conventional water filling and modifying power allocation as variable bit error rate.

V. Conclusions

Efficient power control is very important for UWB wireless communications performance. The signals should be transmitted with the lowest possible power level, which maintains the required quality. In this paper, the efficient bit-power allocation algorithms have been researched for the transmission power of UWB systems restricted sternly. The greedy algorithm is the optimal method but has a large computation. The initial value of coefficient and its step size will directly affect the power allocation efficiency and the speed of calculation in the conventional water filling algorithm. The bit-power allocation remainder is reduced to improve power allocation efficiency relying on the allocation coefficient and the step size. With the change of fading channel gains the bit-power allocation coefficient is modified adaptively. All of research results about channel detection and channel estimation technologies can be properly utilized which will help communication systems modify bit-power allocation coefficient including the initial value and the step size. The channel performance will vary slowly if OFDM UWB is employed as a short-range indoor wireless communications technology. Thus the channel gain by channel estimation can be used in the bit-power allocation of the moment. Simulation shows the adaptively modifying bit-power allocation coefficient algorithm is a suboptimum solution and has less computation. It can decrease power allocation remainder distinctly and have the less impact with changeable SNR. The effect of BER on the bit-power allocation is investigated and simulated by comparing with the conventional water filling algorithm. Therefore, the combination of channel estimation and bit-power allocation will not only improve the efficiency of transmission power allocation but also likely entail vast and promising applications in multiuser OFDM UWB systems.

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