Improved AMC using adaptive SIR thresholds in OFDM based wireless systems

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Abstract - **Adaptive modulation with coding (AMC) is often employed to enhance the throughput of OFDM based wireless systems. The AMC mode is usually adjusted according to the signal to interference ratio (SIR) of the received signal. Most of conventional schemes use fixed thresholds for the selection of AMC mode, yielding a large performance variation depending on the channel characteristics. This paper proposes the use of adaptive SIR thresholds for the mode selection in response to the channel condition, providing significant improvement in throughput performance in a wide range of channel environments.**

I. INTRODUCTION

The spectral efficiency of orthogonal frequency division multiplexing (OFDM) systems can be enhanced by employing an adaptive modulation with coding (AMC) technique, which adjusts the modulation level and coding rate according to the channel condition [1]. The AMC mode of each subcarrier can be chosen differently according to channel quality of the subcarrier such as the signal to interference power ratio (SIR). However, it may cause large feedback burden unless there are a small number of subcarriers.

In order to reduce the feedback burden, there have been a few literatures employing the same AMC mode for all the subcarriers [2,3]. The AMC mode can frequently be adjusted according to the instantaneous channel information, enabling the throughput enhancement over the scheme that uses average channel information [2]. However, as the channel varies fast, it may not be practical because of large feedback burden or performance limit of channel prediction. Therefore, many practical systems use AMC schemes that adjust the modes in an average sense considering statistical channel characteristics [1,3], where the AMC mode is determined by comparing the average SIR with thresholds determined for given performance constraints.

In this case, the use of fixed SIR thresholds may be useful if the channel impulse response (CIR) is unchanged within a transmission block. However, it may not be effective in fast fading and/or large frequency selective fading environments. Note that fading channel becomes more selective in time and frequency domain as the data bandwidth and carrier frequency increase in wideband OFDM based mobile systems such as the fourth generation (4G) systems [4]. In this case, it may be desirable to use adaptive SIR thresholds for the AMC mode [5,6].

The SIR threshold can be optimized by analyzing the packet error rate (PER) performance. However, it may involve practical difficulty due to the effect of channel coding and correlation between the adjacent symbols. As an alternative, the threshold can be adjusted based on the history of ARQ response [5]. However, it may take a long time for the convergence of threshold, making it impractical for burst mode transmission. In this paper, we consider the improvement of AMC performance by adjusting the SIR thresholds in response to the channel characteristics in the time and frequency domain. For ease of implementation, we consider two parameters; the root mean square (rms) Doppler frequency and the rms delay spread of the channel.

Section Ⅱ describes the system and channel model of a wideband OFDM system. The proposed AMC scheme is described in Section Ⅲ. The performance of the proposed scheme is also verified by computer simulation. Finally, conclusions are summarized in Section IV.

II. SYSTEM MODEL

Consider an OFDM system that employs K subcarrier symbols, $X[n,k]$, k = 0, 1, 2,…, K-1, which are converted into a time domain signal at the n-th symbol time by an inverse fast Fourier transform (FFT) process. A cyclic prefix (CP) is inserted to preserve the orthogonality between the subcarriers and to eliminate the intersymbol interference. Each data block contains s_t and s_f symbols in the time and frequency domain, respectively, where

1-4244-0270-0/06/$20.00 (c)2006 IEEE

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hopping and interleaving is employed to provide diversity effect. The AMC mode is adjusted for each frame that is respectively composed of tens to hundreds of data blocks and K/s_f blocks in the time and frequency domains to reduce the feedback burden. In addition, hybrid ARQ (HARQ) is employed to provide time diversity and to mitigate the effect of SIR estimation inaccuracy. The HARQ employs an incremental redundancy (IR) type, where the maximum number of retransmissions is n_r with an initial code rate of r_c.

Assume the signal transmission over a wireless channel whose impulse response is represented as

$$h(t,\tau)=\sum_{l=0}^{L-1} h_l(t)\delta(\tau-\tau_l) \qquad (1)$$

where L is the number of multipaths, $\delta(\cdot)$ is Kronecker delta function, and τ_l and $h_l(t)$ are the delay and complex-valued CIR at time t of the l-th path, respectively. Here, $\{h_l(t)\}$ is modeled as an independent complex Gaussian process with variance σ_l^2. Let $H(t,f)$ be the frequency response of the CIR at time t defined as

$$H(t,f)=\int_{-\infty}^{\infty} h(t,\tau)\mathrm{e}^{-j2\pi f\tau}d\tau. \qquad (2)$$

The CP is removed before the FFT process in the receiver. Let T_s and Δf_c be the symbol duration and subcarrier spacing, respectively. Assuming ideal synchronization in the receiver, we can represent the received symbol of the k-th subcarrier at the n-th symbol time by

$$Y[n,k]=X[n,k]H[n,k]+Z[n,k] \qquad (3)$$

where $H[n,k]$ $(=H(nT_s,k\Delta f_c))$ is the frequency response of the CIR at the k-th subcarrier and the n-th symbol time, $Z[n,k]$ is the background noise plus interference term, which can be approximated as zero mean additive white Gaussian noise (AWGN) with variance σ_Z^2.

III. PROPOSED SCHEME

The AMC mode can be determined for a desired condition (e.g., $\mathrm{PER}\le \mathrm{P}_{th}$, where P_{th} is a threshold). The receiver estimates the average SIR and then compares it with an SIR threshold for the AMC selection. As an example, Fig. 1 depicts the PER performance of the OFDM system in consideration, whose parameters are summarized in Table 1 [7]. When the channel has an rms delay spread (τ_{rms}) of 10 ns and maximum Doppler frequency (f_d) of 16 Hz, it can be seen that 64-QAM can be employed at an SIR higher than 21.0 dB, and 16-QAM and QPSK can be employed at an SIR higher than 17.0 dB and 13.0 dB, respectively, for $\mathrm{PER}\le 10^{-2}$. Otherwise, BPSK modulation is selected. On the other hand, the thresholds becomes much smaller when τ_{rms} = 436 ns and f_d = 1343 Hz. That is, the data signal in each transmission block experiences different degree of diversity in the time and frequency domain, resulting in substantially different PER curves according to channel condition.

Table 2 summarizes the optimum SIR threshold in different channel environments. It can be seen that the threshold decreases as the channel condition varies faster or becomes frequency selective. This implies that the performance can be improved if the SIR threshold for the AMC is properly adjusted according to the channel condition. However, most of conventional AMC schemes use a fixed threshold assuming that the channel variation is not significant in each transmission block interval [1,8].

The remaining issue is how to adjust the threshold scheme in an efficient manner. The channel characteristics can be described in terms of the autocorrelation function or its Fourier transform [9]. The time domain characteristics of a channel can be estimated from the Doppler spectrum $S_{H_t}(w)$ which is the Fourier transform of the time domain autocorrelation function $r_H(\Delta t,0)=E\{H(t+\Delta t,f)\, H^*(t,f)\}$. In a Rayleigh fading channel with uniformly distributed scatterers (e.g., classic or Jakes' spectrum), the distribution of Doppler spectrum can uniquely be determined by the maximum Doppler frequency f_d. However, f_d may not exactly represent the channel characteristics of all channels. For example, Ricean or non-Jakes' Rayleigh fading channels have different Doppler spectrum shapes at the same f_d.

The distribution of Doppler spectrum can precisely be described by the moments of all orders as

$$\overline{w}_t^{(k)}=\frac{1}{2\pi}\int_{-\pi}^{\pi} w^k S_{H_t}(w)dw,\ \ k=0,1,\cdots,\infty. \qquad (4)$$

In fact, the maximum Doppler frequency f_d corresponds to the moment of infinite order. It is required to know the moments of all orders to exactly describe the Doppler spectrum, being impractical due to implementation complexity. In practice, the time-domain characteristics of a channel is approximated by the moments of a few low orders, which can accurately be estimated without much complexity [10-12]. In this paper, we consider the use of the rms value from the first and second moments, which enables the manifestation of the degree of channel variation [12]

$$f_{rms}=\frac{1}{2\pi T_s}\sqrt{\overline{w}_t^{(2)}-\left(\overline{w}_t^{(1)}\right)^2}. \qquad (5)$$

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Similarly, the frequency-domain characteristics of a channel can be represented by the rms delay spread as [12]

$$\tau_{rms} = \frac{1}{2\pi\Delta f_c}\sqrt{\overline{w}_f^{(2)} - \left(\overline{w}_f^{(1)}\right)^2} \tag{6}$$

where

$$\overline{w}_f^{(k)} = \frac{1}{2\pi}\int_{-\pi}^{\pi} w^k S_{H_f}(w)dw\,,\ k = 0,1,\cdots,\infty\,. \tag{7}$$

Here, $S_{H_f}(w)$ is the Fourier transform of the frequency domain autocorrelation function $r_H(0,\Delta f)$ = $E\{H(t,f+\Delta f)H^*(t,f)\}$, representing the power-delay profile. With estimated f_{rms} and τ_{rms}, the SIR thresholds can be determined by interpolating the nearest two threshold sets in Table 2. For the purpose of interpolation, it may be sufficient to use a simple two-dimensional linear interpolator.

To verify the proposed scheme, Fig. 2 depicts the throughput (goodput) performance as a function of the average SIR for different values of τ_{rms} and f_{rms}, assuming perfect measurement of the CIR for coherent detection. The moments of the channel spectrum as well as the average SIR are estimated as in [12]. Here, 'Ideal' indicates the case with the use of optimum SIR threshold, and 'Conventional' and 'Proposed' indicate the case with the use of fixed and proposed adaptive thresholds, respectively. The fixed threshold for the conventional scheme is optimally determined assuming that the channel within a block is unchanged in the time and frequency domain. It can be seen that the proposed scheme can provide performance similar to that of the ideal case, while the conventional scheme suffers from significant performance degradation. This performance difference increases as the delay and/or the Doppler spread increase.

IV. CONCLUSIONS

In this paper, we have proposed an improved AMC scheme that adjusts the SIR threshold according to the channel characteristics in the time and frequency domain. For ease of implementation, the channel characteristics are approximated by the moments of a few low orders of channel spectrum. The simulation results show that the proposed scheme provides substantial performance improvement.

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Table 1 System parameters

Parameters	Values
Carrier frequency	5.8 GHz
Bandwidth	100 MHz
Symbol duration	20.48 μs
Guard interval	5 μs
Number of subcarriers	2048
Modulation	BPSK, QPSK, 16QAM and 64 QAM
Channel coding	Zig-zag code
Block size	(S_t, S_f) = (8, 128)
Channel	Rayleigh (Jakes' spectrum)
Power delay profile	Exponential (path interval: 50 ns)
Hopping pattern	Equi-distant frequency hopping
H-ARQ	Initial code rate (r_c) = 3/4, maximum retransmissions (n_r) = 3
CIR estimation	Perfect

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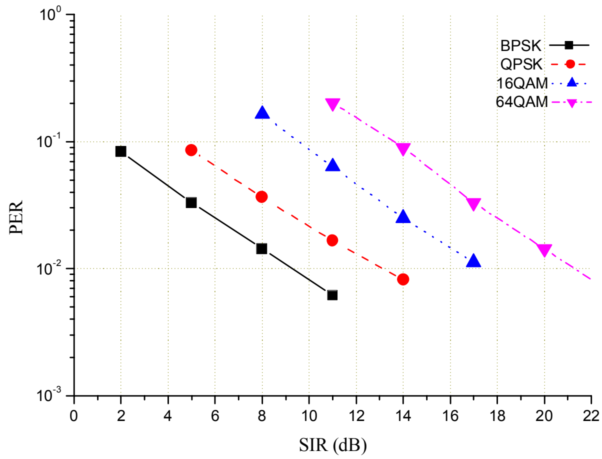
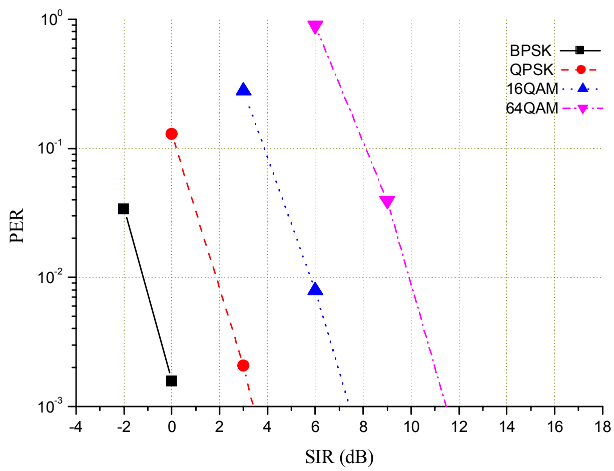
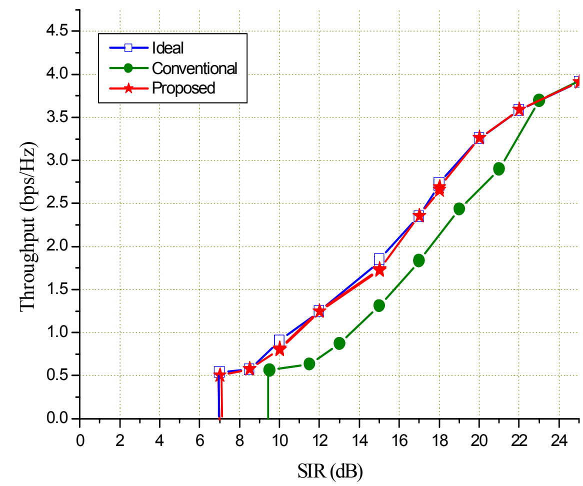


(a) When τ_{rms} = 10 ns and f_d =16 Hz (3 km/h)

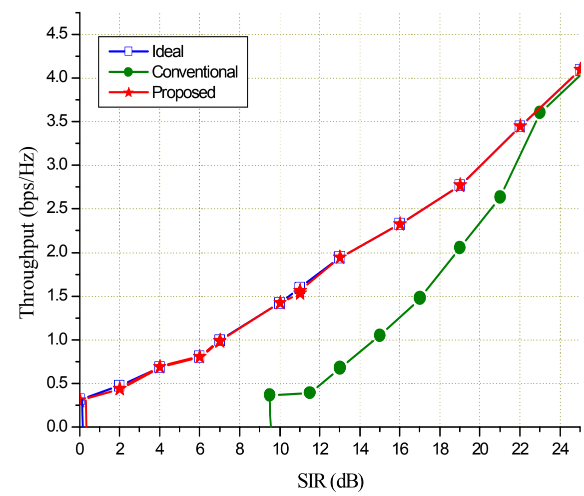


(b) When τ_{rms} = 436 ns and f_d = 1343 Hz (250 km/h)

Fig. 1 PER performance



(a) When τ_{rms} = 41 ns and f_d = 57 Hz (10 km/h).



(b) When τ_{rms} = 270 ns and f_d = 644 Hz (120 km/h).

Fig. 2 Throughput performance

Table 2 Optimum SIR thresholds for the mode selection (dB)

τ_{rms} (ns) / f_d (Hz)	10			167			436		
	64QAM-16QAM	16QAM-QPSK	QPSK-BPSK	64QAM-16QAM	16QAM-QPSK	QPSK-BPSK	64QAM-16QAM	16QAM-QPSK	QPSK-BPSK
16	21.0	17.0	13.0	16.5	12.5	8.1	14.7	10.7	5.2
322	14.0	11.0	6.2	12.7	8.7	4.1	10.3	6.0	2.2
1343	12.5	8.8	3.2	11.3	7.1	2.7	10.0	5.7	1.8

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