논문 05-30-12A-04 한국통신학회논문지 '05-12 Vol.30 No.12A

다중 반송파 시스템을 위한 양자화된 채널 상태 정보 피드백 기법

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Quantized Channel State Information Feedback Scheme for Multi-carrier Systems

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요 약

본 논문에서는 다중 반송파 통신시스템에서의 채널상태정보 피드백 기법에 관한 압축된 양자화 채널상태정보 피드백 기법을 제안한다. 각 단말기에서 순간순간의 채널 상태를 평가하되, 주파수 도메인의 채널평가치를 실효 수준을 기반으로 양자화하고 이 정보에 압축 부호화 알고리듬을 적용하는 방법으로 채널상태정보를 코딩함으로써 피드백되는 채널 상태 정보량을 현저히 감소시켰다. 컴퓨터 시뮬레이션을 통해 채널상태정보 비트가 기존 시스템과 비교하여 10% 정도까지 감소됨을 확인하였다. 또한 주파수 선택적 페이딩이 강한 경우에 대처하기 위한 제한된 압축 양자화 피드백 기법을 제안하여 vehicular B 채널 모델을 바탕으로 검증하였다.

Key Words : OFDM, multicarrier system, channel state information, CSI feedback, adaptive modulation

ABSTRACT

In this paper, we propose a compressed quantized channel state information (CQCSI) feedback scheme for multi-carrier mobile communication systems. The proposed CQCSI figures out the contiguous subsequences of equal QCSI's as separate types of runs across the subcarriers, and then encodes the types of runs using a truncated Huffman coding algorithm. Computer simulation shows that the proposed algorithm can reduce the QCSI feedback up to one tenth of the uncompressed, while providing a comparable performance with the conventional QCSI feedback schemes. To cope with special cases when the frequency selective fading is very high, we also propose a restricted CQCSI feedback scheme. The restricted CQCSI feedback has been proved under vehicular B channel model.

Ⅰ. INTRODUCTION

The multi-carrier communication system in conjunction with adaptive modulation technique is well known as a method to realize higher data-rate wireless communication systems under multipath fading environments. Especially in the orthogonal frequency division multiplexing (OFDM) system with adaptive modulation technique, the appropriate modulation mode for transmission in each subcarrier or subchannel is selected according to its instantaneous channel characteristics

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논문번호 : KICS2004-06-044, 접수일자 : 2004년 6월 4일

[1][3]. In other words, the system employs higher order modulation modes for subcarriers having good channel conditions so as to carry more bits, and employs lower order modulation modes for those subcarriers affected by deep fading to carry only one or even zero bit. To make such optimization possible the transmitter needs to get the instantaneous channel state information (CSI) for each subcarrier from the receivers[4]. Since the amount of CSI can be extremely large according to the frequency of update, a quantized CSI (QCSI) feedback scheme reporting only the best possible modulation mode for each channel entity has been proposed[1]. Even such QCSI feedback needs information bits directly proportional to the number of available modulation modes, the total number of subcarriers or subchannels included in one OFDM symbol, and the rate of CSI feedback. The increase of QCSI bits can become a large signaling burden and leads to the degradation of overall performance.

In this paper, we propose a compressed QCSI (CQCSI) feedback scheme by combining the QCSI representation and a source coding algorithm for data compression across subcarriers, which is based on the run-length coding along with modified Huffman coding algorithm. Since the QCSI's among adjacent subcarriers tend to be equal unless the frequency selectivity is very high, we compress the amount of QCSI feedback by introducing a lossless source coding mechanism.

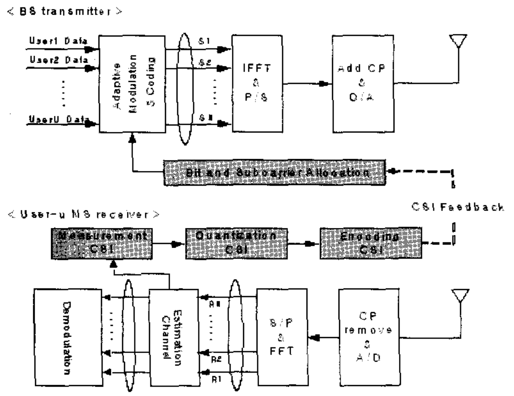

Fig. 1. The proposed multiuser OFDM system with adaptive modulation

We also propose a modified CQCSI scheme for the case when the frequency selectivity is very high.

In section II of this paper the system model is introduced, and the proposed CQCSI feedback scheme for the multi-carrier communication systems is described in section III. In section IV, the computer simulation results are analyzed, and some concluding remarks are given in section V.

Ⅱ. SYSTEM MODEL

The configuration of the multi-user OFDM system with adaptive modulation is shown in Fig. 1. At the transmitter, the modulator generates N data symbols, S_n that are multiplexed into the N subcarriers. The time-domain samples transmitted during one OFDM symbol are generated by the inverse fast Fourier transform (IFFT) and transmitted over the channel after the cyclic prefix has been inserted. Usually the channel can be modeled by its time-variant impulse response, $h(t,\tau)$ and additive white Gaussian noise (AWGN). The Complex baseband representation of a mobile wireless channel impulse response can be described by

$$h(t,\tau)=\sum_{k}\alpha_k(t)c(\tau-\tau_k)\,, \qquad (1)$$

where τ_k is the transmission delay of the k-th path, $\alpha_k(t)$ is the corresponding complex amplitude, and $c(\tau)$is the shaping pulse. Then the frequency response of the channel at time t is represented as

$$\begin{aligned} H(t,f) &\triangleq \int_{-\infty}^{+\infty} h(t,\tau)e^{-j2\pi f\tau}d\tau \\ &= C(f)\sum_{k}\alpha_k(t)e^{-j2\pi f\tau_k}\,, \end{aligned} \qquad (2)$$

where $C(f)\triangleq\int_{-\infty}^{+\infty}c(\tau)e^{-j2\pi f\tau}d\tau$. We assume a quasi-stationary channel environment, and the channel impulse response is assumed to be constant for the duration of one OFDM symbol. Then without loss of generality the channel characteristics for subcarrier n during a symbol duration can be characterized by the N-point Fourier transform of the impulse response, H_n. Then the frequency domain representation of the received OFDM symbols, R_n can be expressed as,

$$R_n = S_n \cdot H_n + w_n, \tag{3}$$

where w_n is an AWGN sample. A coherent detection is assumed for the receiver. Then, the received data symbols R_n have to be de-faded with the aid of an estimate of the channel transfer function, $\hat{H}_n$. This channel estimation $\hat{H}_n$ can be obtained from the characteristics of pilot subcarriers in the received OFDM symbol.

Since the channel is not reciprocal in general, to make an optimal decision at the transmitter, a set of parameters related to the downlink channel characteristics needs to be provided to the transmitter somehow. These CSI feedback bits are usually transmitted through a dedicated control channel or along the traffic channel as side information. Although a set of detailed parameters describing the $\hat{H}_n$ would be the best, quite a huge amount of data should be transmitted in the uplink repeatedly. So, in this paper we propose to define the CSI at some sampling instant as the instantaneous signal to interference and noise ratio (SINR) for each subcarrier. Then, the SINR for n-th subcarrier can be estimated as

$$\gamma_n = \frac{P_n}{I_n + \eta_n} \cdot \left|\hat{H}_n\right|^2, \tag{4}$$

where P_n is the transmitted power of subcarrier n at the base station, η_n and I_n represent the received noise power and interference power, respectively.

Now that the bandwidth of each subcarrier is same, if the transmission powers are same among all the subcarriers, the CSI feedback which is just sufficient to run the bit and subcarrier allocation algorithm at the transmitter can sufficiently represent the corresponding channel characteristics. That is, only with the CSI which is quantized according to the applicable modulation levels in the adaptive modulation, the transmitter can achieve a suboptimal performance[1][5]. The CSI thresholds for quantization are defined such that each threshold value represents the minimal required SINR for a certain modulation level, and they exhaustively representfor all possible choices in the given adaptive modulation scheme. For example, if the system applies the modulation modes of QPSK, 16QAM and 64QAM, the measured CSI can be quantized into 4 different cases, including NoTX, which means transmission is not recommended. So the system needs a 2-bit field for encoding the QCSI for each subcarrier. Assuming that there are N subcarriers in the multicarrier communication system, the total number of bits for a single shot QCSI feedback is as follows;

$$R_{QCSI\_feedback} = N \cdot b_{sub} \cdot f_{update}, \tag{5}$$

where b_{sub} is number of coded bits, and f_{update} is the update frequency of QCSI feedback.

Ⅲ. THE PROPOSED COMPRESSED QCSI FEEDBACK

From the above derivation, we note that even in the quantized information, the CSI feedback can be a big signaling burden because of the high frequency of update. For further reduction of information, we propose a CQCSI feedback scheme

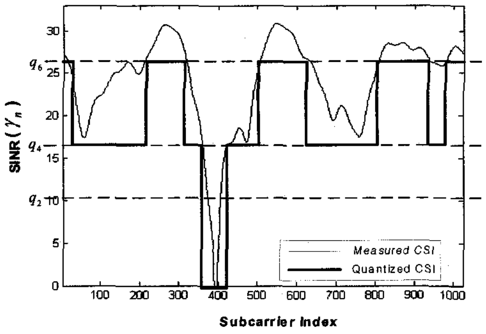

Fig. 2. An example of a measured CSI and the corresponding QCSI

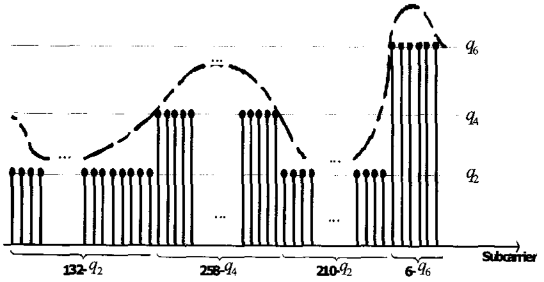

Fig. 3. Run-length descriptions for a snapshot of a QCSI

based on a cross-frequency run-length encoding mechanism. Fig. 2 shows examples of the CSI measurements and the corresponding QCSI levels under a pedestrian channel model[6]. Once a set of CSI thresholds for quantization has been designated according to the user's QoS requirements, the QCSI for each subcarrier is defined by taking the highest threshold level less than the CSI measurement. Note thatunless the frequency selectivity is very high, the QCSI's among adjacent subcarriers are equal with a high probability. Then, we can further encode the QCSI across the subcarriers with the cross-frequency source coding mechanism as follows: Given the QCSI estimates for N subcarriers in an OFDM symbol, we classify the subcarriers into several blocks of adjacent subcarriers which have equal QCSI levels.

Here we define the concept of "runs" as the subsequence of contiguous subcarriers having the same QCSI level across the subcarriers in one OFDM symbol. The average length of the runs largely depends on the frequency selectivity of the channel, not much on the total number of subcarriers.

Now, the proposed cross-frequency run-length encoding works by coding the types of runs, instead of coding each QCSI separately. If the adaptive modulation scheme were to choose one modulation scheme from the set of QPSK, 16QAM, 64QAM, and NoTX, the levels of the QCSI can be denoted by q_m, where $m \in \{0,2,4,6\}$ represents the number of data bits per symbol per subcarrier. An example snapshot of the QCSI feedback under a pedestrian channel model is shown in Fig. 3. The types of each run such as 132-q_2 are composed of the run length and the associated QCSI level. The run length describes the number of subcarriers in the run.

In order to encode the sequence of the run types, we first define a set of makeup codewords which identify runs with lengths of several powers of two, according to the characteristic distribution of the runs. We then define a set of terminating codewords which additionally identify the length of the remaining part in each run. That is, any run which is larger than or equal to the minimum of the makeup codewords is assigned one or more makeup codewords and a terminating codeword according to the size of the remaining portion of the run. We assume that the probability distribution of occurrence of each makeup codeword and the terminating conditions is previously known. Once the probability distribution is given, we apply a modified Huffman coding algorithm to optimally encode the makeup codewords and the terminating conditions. The terminating codeword for each terminating condition is coded as a fixed length binary code. Table 1 shows an example of a modified Huffman code table under the pedestrian A channel model. For example, the '132-q_2' is converted into a sequence of binary data which are composed of codeword of q_2 with length 128 and a terminating codeword of q_2 with length 4.

Table 1. An example of the modified Huffman code table for the QCSI distribution under pedestrian A channel model.

	NoTx	QPSK	16QAM	64QAM
runs of 128	11010110	1101010	00	1111
runs of 64	11010111	110100	0101	01101
runs of 32	010011	11001	0111	01000
runs of 16	010010	11011	1000	11000
terminating condition	01100****	1110****	101****	1001****

****: Terminating code [0001~1111]

In this case only 16 bits are needed to represent '132-q_2', whereas 264 bits are necessary in the conventional QCSI scheme.

The total number of bits for a single shot feedback for the proposed CQCSI scheme can be represented as

$$R_{CQCSI\_feedback} = \alpha^{-1} \cdot N \cdot b_{sub} \cdot f_{update}, \quad (6)$$

where α represents the coding gain obtained by the proposed cross-frequency run-length encoding. We note that the coding gain of the conventional QCSI scheme is 1. Since the run-length encoding is a lossless source coding, the amount of QCSI feedback by the proposed CQCSI scheme is compressed without losing any information about the quantized channel state. Assuming an error free channel condition for the feedback, the transmitter can achieve a suboptimal performance of modulation for each subcarrier.

However when the mobility of users becomes very high, the channel experiences a severe frequency selective fading so that the correlations of the QCSI among adjacent subcarriers reduces. Then the efficiency of the proposed CQCSI decreases, and at some extreme cases it can generate more feedback information than the conventional QCSI scheme. We note, however, that at high mobility the receiver generally becomes unable to apply some of the highest levels of modulations. Therefore, in such case, we propose to adaptively restrict the CQCSI encoding subsystem at the receiver not to include a certain higher modulation schemes from the applicable set of modulation levels. For example, if the receiver restricts not to apply 64QAM at some mobility condition, the receiver chooses a modulation scheme from the reduced set of NoTX, QPSK and 16QAM. Then the cross correlations of the QCSI among adjacent subcarriers would be increased, so the average length of runs would also be increased. The threshold value to switch between the CQCSI and the restricted CQCSI depends on the service applications.

Ⅳ. PERFORMANCE EVALUATION

To analyze the performance of the proposed CQCSI feedback scheme, we assume an OFDM multiple access system employing adaptive modulation with NoTx, QPSK, 16QAM, and 64QAM. It is assumed that the bandwidth of the system is 20MHz, and the number of subcarriers is 1024 or 2048. For the channel models, we have applied several Rayleigh fading channels defined in International Telecommunication Union(ITU) M-1225 document, including indoor A/B, pedestrian A/B, and vehicular A/B channel models[6]. The two types of QCSI thresholds according to the required QoS which were applied for the quantization process are summarized in table 3[2]. Here we have assumed the target BER for the speech services as 10^{-2}, and the target BER for the multimedia data services as 10^{-4}.

Table 2. Threshold levels for adaptive modulation over Rayleigh fading channels

	threshold for speech service at target BER of 10^{-2}	threshold for multimedia data service at target BER of 10^{-4}
q_0	$-\infty$	$-\infty$
q_2	6.48	10.42
q_4	11.61	16.76
q_6	17.64	26.33

Table 3 compares the amount of CSI in bits per a sampling instant under different channel conditions for multimedia data services, and the CQCSI compression ratio which is achieved by the proposed algorithm. Here, the compression ratio is defined as the ratio of the average number of saved bits per a sampling instant to the amount of conventional QCSI feedback. As is shown in table 3, at one extreme example the required amount of CQCSI feedback is only about 75 bits in the case of the 1024-OFDM system, which is only about 4% of the information by the conventional QCSI feedback scheme.

Fig. 4 compares the amount of CQCSI feedback for the multimedia data services under all different channel models defined in ITU-M-1225 as a function of the average SINR for the 2048-OFDM system. In all cases, the proposed CQCSI feedback scheme outperforms the conventional QCSI feedback scheme. We note that for this case even in the severe channel condition such as the vehicular channels, the proposed CQCSI feedback scheme shows enough compression of information, although as the channel model becomes more frequency selective, the compression ratio becomes smaller.

Fig. 5 compares the amount of CQCSI feedback bits for the multimedia data services as a function of the average SINR for the 1024-OFDM system. In this case we encounter a crossover phenomenon in Vehicular B channel when the frequency selectivity becomes very severe, mainly because of higher user mobility, where the compression ratio becomes negative. In such a case, we can gradually restrict the CQCSI encoding at the receiver by adaptively removing the highest modulation from the applicable set of modulation levels. As is shown in the figure, the restricted CQCSI feedback scheme achieves the positive compression ratio.

As is shown in fig. 6, assuming that the feedback channels are error free, the throughput performance of the proposed CQCSI scheme is same as that of the conventional QCSI scheme, except in the restricted CQCSI case. It means that the amount of QCSI feedback information is drastically reduced by the proposed CQCSI scheme without much performance degradation.

Tabel 3. Comparison of the amount of QCSI and the corresponding compression ratio

	Indoor A channel		
	Feedback bits		compression ratio (%)
	conventional QCSI	proposed CQCSI	
1024 OFDM	2048	75.0	96.3
2048 OFDM	4096	96.0	97.7
	Pedestrian A channel		
	Feedback bits		compression ratio (%)
	conventional QCSI	proposed CQCSI	
1024 OFDM	2048	89.0	95.7
2048 OFDM	4096	107.0	97.4
	Vehicular A channel		
	Feedback bits		compression ratio (%)
	conventional QCSI	proposed CQCSI	
1024 OFDM	2048	433.0	78.9
2048 OFDM	4096	496.0	87.9

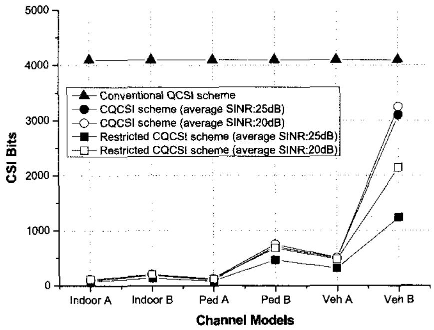

Fig. 4. Number of CSI bits for 2048 OFDM system under different channel conditions

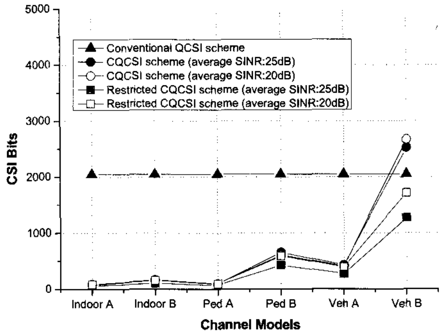

Fig. 5. Number of CSI bits for 1024 OFDM system under different channel conditions

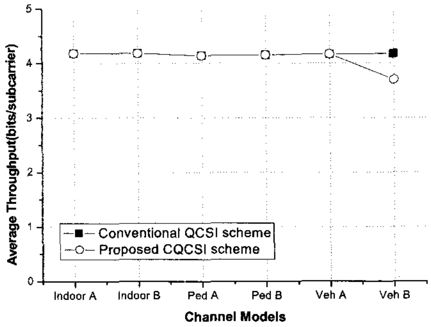

Fig. 6. Average throughput for 1024 OFDM system under different channel conditions (Restricted CQCSI scheme in vehicular B channel model)

V. CONCLUSION

In this paper, we have proposed an efficient CQCSI feedback scheme for multi-carrier communication systems using adaptive modulation. The proposed CQCSI feedback scheme is based on the quantization of the measured CSI and data compression by cross-frequency run-length encoding method. The proposed CQCSI feedback scheme has been proved to reduce the amount of QCSI feedback information extensively according to the channel characteristics, and outperforms the conventional QCSI feedback scheme under most wireless channel models recommended in ITU-M-1225 documentation. To apply for the severe frequency selective fading channel we have also proposed the restricted CQCSI feedback scheme. The proposed algorithm can be utilized for the bit and power allocation process in multi-carrier communication systems.

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