A NEW FREQUENCY-DOMAIN LINK ADAPTATION SCHEME FOR BROADBAND OFDM SYSTEMS

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Abstract

This paper proposes an OFDM-oriented link adaptation scheme with new frequency-domain-based link quality estimation functions. System throughput of an OFDM system can be enhanced by using link adaptation; the best set of modulation scheme and FEC coding rate is dynamically selected to achieve the target PER before ARQ. An important practical issue in applying link adaptation is how to estimate the link quality precisely. Link quality is well assessed by CNR and the delay spread. Two link quality estimation functions, one examines the correlation between subcarriers while the another considers CNR, are introduced. Both are simple to implement in combination with the frequency-domain initial equalizer. Simulation results verify that the proposed link adaptation scheme is effective in improving system throughput in a practical manner.

1. Introduction

The broadband wireless access scenario has been drawing attention given the demands for ubiquitous multimedia communications. Several standardizing bodies and research institutes are actively working toward establishing the wireless asynchronous transfer mode (WATM) or high-speed wireless local area networks (WLANs) [1][2][3]. These mostly aim at an aggregate user service rate of 20-Mbps or more, and are supposed to use the 5-GHz radio frequency (RF) band (e.g., [3][4]).

The key to successfully deploying broadband wireless systems is securing a low packet error rate (PER) over the frequency-selective fading channels that can be expected. High rate transmission incurs multipath delays that can range over several times the clock period even in indoor environments [5]. Numerous attempts have been made to lower the PER, and orthogonal frequency division multiplexing (OFDM) is known to counter the effects of severe frequency-selective fading channels with reasonable complexity. Consequently, OFDM is seen as one of most promising techniques by the major standardizing bodies targeting broadband wireless access (see [6]).

Further, link adaptation is beneficial in enhancing system throughput; the most appropriate set of modulation scheme and FEC coding rate is selected to match the link quality. An important issue in applying link adaptation is how to precisely estimate the link quality. In the case of a single carrier system, the link quality can be estimated from the estimated channel impulse response using a time-domain PN sequence [7]. However, when systems use no PN sequence as their preamble, as specified in [6], a different approach must be applied.

Given the above-mentioned background, this paper proposes new link quality estimation functions incorporated with the simple frequency-domain initial equalizer (SFD-IE) [8], which calculates carrier phase and amplitude in each subcarrier in the frequency-domain by sending a pre-determined bit series. Specifically, an appropriate PER must be set as the target value to perform link adaptation. In practice, to satisfy the final PER (e.g., PER=1E-5 for TCP/IP), automatic repeat request (ARQ) is often used in addition to FEC. An excess number of retransmissions, however, decreases the system throughput and also incurs long transmission delay. In this paper, a PER around 10% before ARQ is considered as the target PER, since it is assumed that the number of retransmissions used by ideal selective repeat (SR) ARQ is 4. The performance of the proposed link adaptation scheme is examined by computer simulation.

2. Configuration and Operating Principle of Link Adaptation for OFDM System

The proposed link adaptation scheme is based on TDMA-TDD; uplink and downlink use same frequency. The burst format with the preamble needed for coherent detection is shown in Fig.1 [6]. The operating principle of link adaptation in the downlink channel is shown in

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Fig.2. The mobile terminal (MT) user estimates the link quality of the downlink channel using the received downlink signal transmitted from the access point (AP). According to the measured link quality, the next downlink packet from the AP to the MT is transmitted using the most appropriate set of modulation scheme and FEC coding rate. It is assumed that the signal indicating the set of modulation scheme and FEC coding rate desired is transmitted from the MT to the AP perfectly. For the uplink channel, link adaptation proceeds in the same way.

Basically, the proposed link adaptation scheme applies with coherent detection which employs an initial equalization technique that estimates and initializes the multipath-causing amplitude and phase alternation in each subcarrier, c_n. Assuming pre-determined bit-pattern d_n for the estimation preamble, the SFD-IE estimates $s_{n,i}$ as

$$s_{n,i} = \frac{r_{n,i} \bullet d_n^*}{|d_n|^2} \tag{1}$$

where $r_{n,i}$ is the FFT output corresponding to the nth subcarrier and ith symbol. The averaging in the preamble enhances the accuracy of estimating $s_{n,i}$ and results in c_n used for coherent detection:

$$c_n = \frac{1}{2}\sum_{i=1}^{2} s_{n,i} \tag{2}$$

3. Operating Principle of Proposed Link Quality Estimation Functions

An important issue in applying the link adaptation is how to precisely estimate the link quality. Considering that OFDM systems may be used various situations including indoor and outdoor environments, the delay spread of channels varies widely. Moreover, the PER performance of an OFDM system is dependent carrier-to-noise ratio (CNR) and also the delay spread of the channel [8]. Therefore, link quality assessments must include CNR and the delay spread information of channels.

To estimate the link quality, we propose two link quality estimation functions: (1) a function to estimate the correlation between subcarriers, and (2) function in proportion to CNR. First function, f_{delay_spread}, indicates the correlation among the amplitudes of each subcarrier, and is expressed as

$$f_{delay\_spread} = \frac{\sum_{n=1}^{N-1}\left||c_n| - |c_{n+1}|\right|}{\sum_{n=1}^{N}|c_n|} \tag{3}$$

where N is the number of subcarriers. When the rms delay spread is long, function f_{delay_spread} becomes large because of the resulting notches in the frequency domain. When the rms delay spread is short, function f_{delay_spread} becomes small. The second function, f_{CNR}, is expressed as

$$f_{CNR} = \frac{\sum_{n=1}^{N}|c_n|}{\sum_{i=1}^{2}\sum_{n=1}^{N}\left||s_{n,i}| - |c_n|\right|} \tag{4}$$

where the denominator corresponds to the noise component (the difference between the instantaneous received signal and the averaged signal is related to noise magnitude), and the numerator corresponds to the carrier amplitude. As described above, the set of two functions f_{delay_spread} and f_{CNR} can be used for estimating the rms delay spread and CNR. Note that, since c_n in Eqs. (3) and (4) is calculated using the SFD-IE and two functions are calculated by not power of c_n and $s_{n,i}$ but amplitude of them, implementing functions f_{delay_spread} and f_{CNR} entails only slight complexity.

4. Performance Evaluation

4.1. Simulation parameters

ODFM–related simulation parameters are summarized in Table 1. The simulations considered exponentially-decaying multipath channels where σ_τ = 50, 100, 150, and 250 ns (σ_τ : the rms delay spread). Channels of σ_τ = 50, 100 ns correspond to typical office environments. Channels with σ_τ = 150 ns correspond to large-hall-or-factory-like environments. Channels with σ_τ = 250 ns correspond to the metropolitan micro-cell environment [9]. The Doppler frequency f_D is 50 Hz for the channels with σ_τ = 250 ns and 20 Hz for the other channels, since it is considered that in the outdoor environments v = 3 m/s while in the indoor environments v = 1.2 m/s. It is assumed that the downlink packets are transmitted at 2 ms intervals. This paper assumes that FEC is convolutional encoding. Four sets of modulation scheme and coding rate are examined here: BPSK (R = 1/2), QPSK (R = 1/2), 16QAM (R = 1/2), and 16QAM (R = 3/4). The respective transmission rates are 6 Mbps, 12 Mbps, 24 Mbps, and 36 Mbps.

4.2. Proposed link quality estimation functions

Characteristics of the proposed link quality estimation functions were examined by simulation. The results are shown in Fig. 3. Function f_{CNR} is only weakly dependent on the rms delay spread and all four sets yield virtually identical CNR plots. On the other hand, function f_{delay_spread} depends on both the rms delay spread and

CNR. For function f_{delay_spread}, dependence of the rms delay spread is small at low PER. This indicates that the influence of noise is stronger than that of the delay spread at low CNR. Therefore, the rms delay spread and CNR can well be estimated by utilizing the functions f_{delay_spread} and f_{CNR}. Table 2 shows the required-CNR, the target PER is 10%, for the 4 sets with the four delay spread values.

Figure 4 shows the set selection criteria for the required PER of 10%, as obtained from the f_{delay_spread}-and-f_{CNR} characteristics shown in Fig. 3 and Table 2. As an example, Fig. 4 indicates that the selection of BPSK (R = 1/2) or QPSK (R = 1/2) is independent of function f_{delay_spread}, since they are robust modulation schemes with suitable coding rates for multipath channels and the influence of noise is stronger than that of the delay spread. However, the selection of 16QAM (R = 1/2) or 16QAM (R = 3/4) is dependent on function f_{delay_spread} because of the error floor in 16QAM (R = 3/4) when σ_τ = 250 ns.

The receiver calculates two functions by using the received signal and selects the appropriate set of modulation scheme and FEC coding rate based on the selection criteria shown in Fig. 4.

4.3. PER and average transmission rate

The PER performance and average transmission rate obtained with the proposed link adaptation scheme are shown in Fig. 5 to 8 and Fig. 9 to 12, respectively, where the rms delay spread is 50ns in Fig. 5 and 9, 100 ns in Fig. 6 and 10, 150 ns in Fig. 7 and 11, and 250 ns in Fig. 8 and 12. Note, in Fig. 9 to 12, the average transmission rate (regarded as system throughput) is defined by counting non-error packets. Specifically, Fig. 5 to 8 show that PER is constant at about 5E-2 with σ_τ = 50, 100, and 150 ns and about 8E-2 with σ_τ = 250 ns, so that the proposed link adaptation scheme satisfies the target PER of 10 %. However, the required-CNR degradation, compared to BPSK (R = 1/2), at the PER of 10 % is about 0.2, 0.2, 0.6 and 1.7 dB for σ_τ values of 50, 100, 150 and 250 ns, respectively. Furthermore, it is clear from Fig. 9 to 12 that the average transmission rate obtained with the proposed link adaptation scheme is almost the same as that of modulation scheme offering the highest average transmission rate for all the delay spread cases. This verifies that the proposed link adaptation scheme with the new frequency-domain link estimation functions performs well in selecting the appropriate set of modulation scheme and FEC rate and enhancing the system throughput.

5. Conclusion

This paper proposed an OFDM-oriented link adaptation scheme with new link quality estimation functions that provide link-quality information on the rms delay spread and CNR. The proposed link quality estimation functions well suit OFDM system (especially when SFD-based coherent-detection is applied), and are simple to implement. A criteria for selecting a set of modulation scheme and FEC coding rate was established using these functions. Simulation results verified that the proposed link adaptation scheme was effective in improving system throughput in a practical manner. This paper assumed that the ARQ used was ideal SR-ARQ, and that the target PER was 10 %. When a fewer number of retransmissions is required for shorter delay time, the proposed scheme can easily be applied with a different PER target.

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Table 1 Coded-OFDM Related Items and Radio Channel Parameters

Number of subchannels	52 (4 for pilot signals)
Guard interval	800 ns
Sampling rate	20 MHz
FEC	Conv. coding/Viterbi dec. (R=1/2, K=7)
Inter(/deinter)leaving	OFDM-symbol period
Radio channel model	Exponentially decaying model
Rms delay spread	50,100,150, 250 ns
Doppler Frequency	20 Hz (Indoor Environments)
	50 Hz (Outdoor Environmets)
Transmitted data length	72 bytes

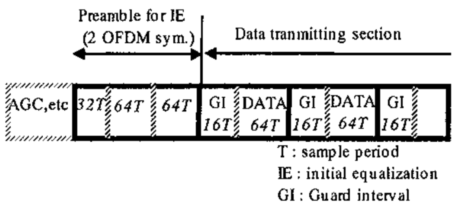

Fig. 1 Burst Format

Table 2 Requred-CNR at PER of 10 %

	BPSK (R = 1/2)	QPSK (R = 1/2)	16QAM (R = 1/2)	16QAM (R = 3/4)
σ_T=50ns	7.8 dB	10.6 dB	15.7 dB	20.4 dB
σ_T=100ns	6.8 dB	9.7 dB	14.7 dB	19.5 dB
σ_T=150ns	6.4 dB	9.3 dB	14..3 dB	19.8 dB
σ_T=250ns	6.1 dB	9.2 dB	14.8 dB	22.0 dB

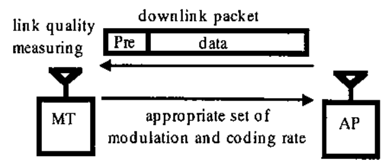

Fig. 2 Operation Principle of the Link Adaptation (downlink channel)

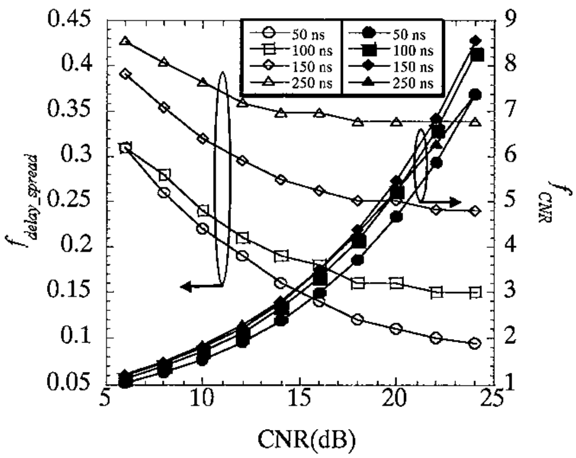

Fig.3 Link Quality Estimation Functions Characteristics

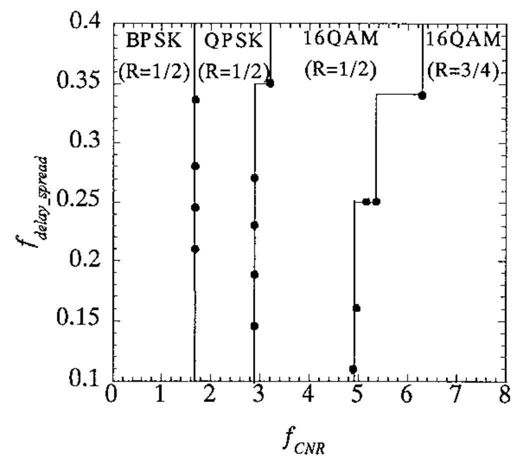

Fig.4 Modulation and Coding Rate Selection Criteria

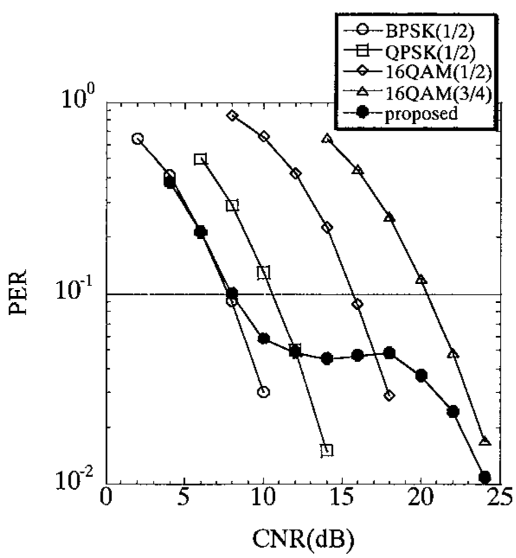

Fig.5 PER Performance (σ_τ=50ns)

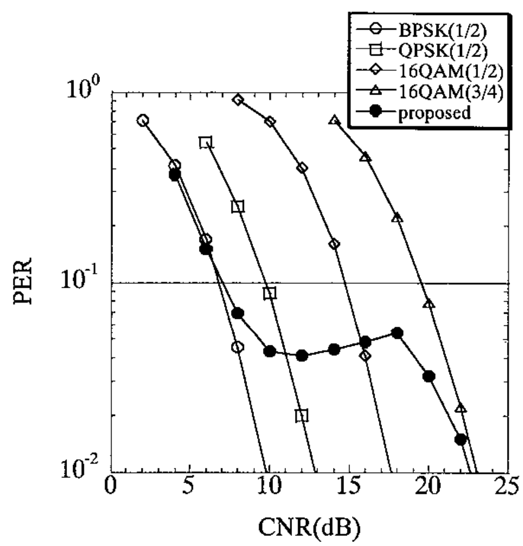

Fig.6 PER Performance (σ_τ=100ns)

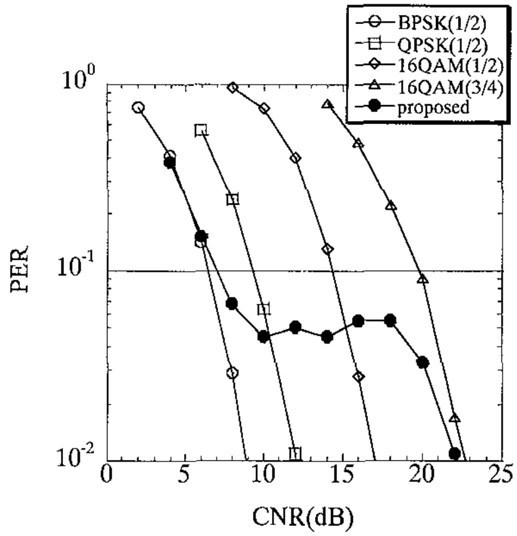

Fig.7 PER Performance (σ_τ=150ns)

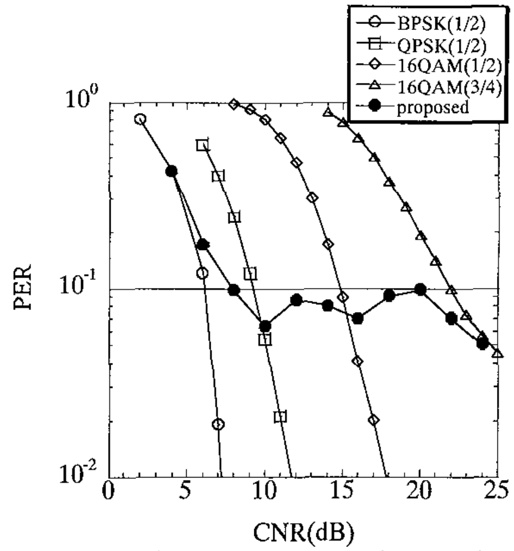

Fig.8 PER Performance (σ_τ=250ns)

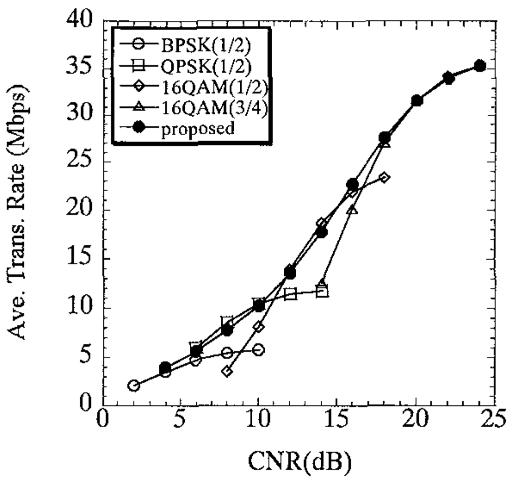

Fig.9 Average Transmission Rate (σ_τ=50ns)

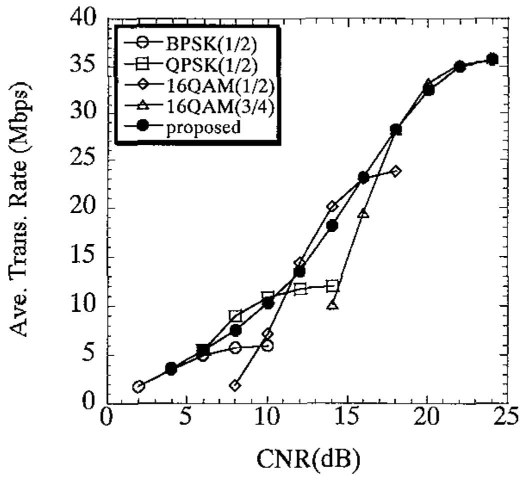

Fig.10 Average Transmission Rate (σ_τ=100ns)

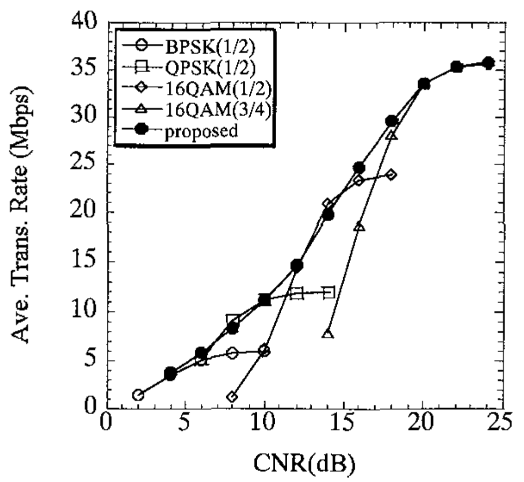

Fig.11 Average Transmission Rate (σ_τ=150ns)

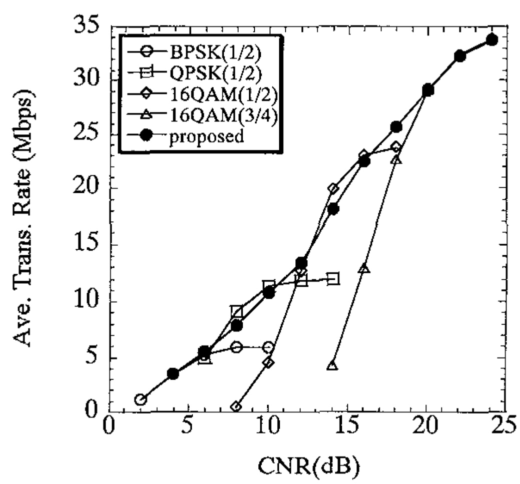

Fig.12 Average Transmission Rate (σ_τ=250ns)