Differential Modulated Pilot Symbol Assisted Adaptive OFDM for Reducing the MLI with Predicted FBI

Chang-Jun AHN[†a]**, Satoshi TAKAHASHI**[†]**, *and* Hiroshi HARADA**[†]**, *Members*

SUMMARY   In an AMS/OFDM system, base station is in control of the modulation level of each subcarriers, and then, adaptive modulated packet is transmitted from the base station to the mobile station. In this case, the mobile station is required the modulation level information (MLI) to demodulate the received packet. The MLI is generally transmitted as a data symbol, therefore, the throughput is degraded. Moreover, it is necessary to have some transmission delay times and the processing time to make an adaptive modulation command (AMC) using feedback information (FBI). With the FBI delay and processing time, the system performance might be degraded. To reduce these problems, in this paper, we propose a differential modulated pilot symbol assisted adaptive OFDM for reducing the MLI with predicted FBI.

key words: AMS/OFDM, MLI, FBI

1. Introduction

Japanese government adopted the so-called E-Japan priority plan in 2001, including an explicit goal for wireless communications, to create an IPv6-based high-speed radio access environment and to enable seamless mobile communication services. The E-Japan priority plan to achieve this goal requires developing a fourth-generation mobile communication system includes ultra high-speed radio access protocol that will support a data rate as high as 100 Mbps in a vehicular environment 2005 [1]. However, in the mobile radio environment, signals are usually impaired by fading. In such channels, severe fading of the signal amplitude and inter-symbol-interference (ISI) due to the frequency selectivity of the channel cause an unacceptable degradation of the error performance. OFDM is an efficient scheme to mitigate the effect of multi-path channel, since it eliminates ISI by inserting guard interval [2], [3]. Therefore, OFDM is generally known as an effective technique for high data rate services.

In general, each modulation scheme provides a trade off between spectral efficiency and the bit error rate (BER). Choosing the highest modulation scheme that will give an acceptable BER can maximize the spectral efficiency. Therefore, an adaptive modulation scheme (AMS) is one of efficient schemes to increase the throughput [4]–[8]. In an AMS/OFDM system, base station is in control of the modulation level of each subcarriers, and then, adaptive modu-

lated packet is transmitted from the base station to the mobile station. In this case, the mobile station is required the modulation level information (MLI) to demodulate the received packet. The MLI is generally transmitted as a data symbol, therefore, the throughput is degraded in the forward link of AMS/OFDM due to the MLI transmission. To reduce this problem, sub-carrier block adaptive modulated OFDM with variable coding rates has been proposed [9]. In this scheme, adjacent sub-carriers are blocked to be assigned for the same modulation level with various coding rates for reducing the MLI transmission and the computational effort of the transmit power control. However, when the block size is large, the throughput might be degraded due to the mismatch between the block modulation level and the channel state.

Moreover, in AMS systems, feedback information (FBI) is also required. FBI is generally assumed to be infinitely precise and perfect. Previous study also did not consider the FBI. In the practical case, it is necessary to have some delay times to transmit the FBI from the mobile station to the base station. Moreover, the system requires the processing time to make an adaptive modulation command (AMC) using FBI at the base station. With the FBI delay and processing time to make an adaptive modulation, the system performance might be degraded.

To reduce these problems, in this paper, we propose a differential modulated pilot symbol assisted adaptive OFDM for reducing the MLI with the predicted FBI. MLI is taken to the mobile station as a data symbol. On the other hand, our proposed system considers the MLI as a differentially modulated pilot signal. Moreover, LMS method is used to fit a second order polynomial to each of the measured channel impulse responses to maintain the system performance [10]. This paper is organized as follows. The proposed AMS/OFDM is described in Section 2, In Section 3, we show the simulation results. Finally, the conclusion is given in Section 4.

2. Proposed System

Figure 1 shows the proposed differential modulated pilot symbol assisted adaptive OFDM system for reducing the MLI with the predicted FBI.
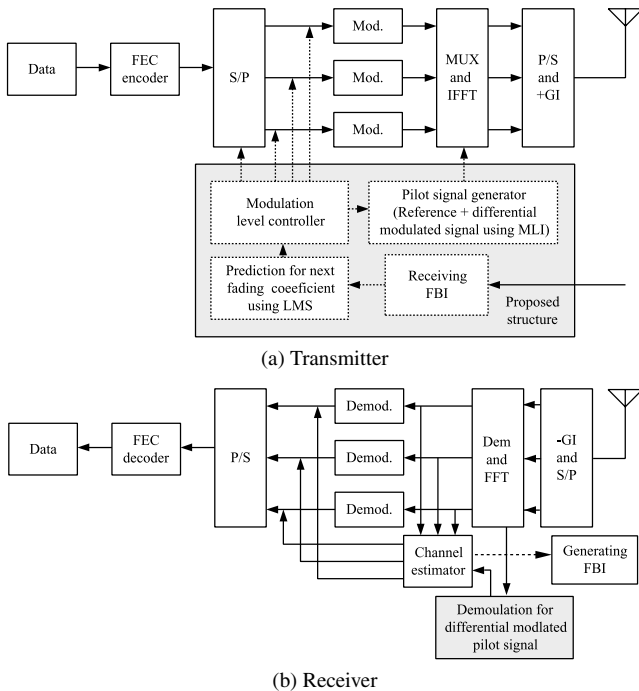
2.1 MLI

Since the MLI is transmitted on a data symbol, thus, the total

(a) Transmitter

(b) Receiver

Fig. 1   Proposed system.

Pilot signals   MLI   Adaptive modulated data

(a) Conventional adaptive OFDM packet structure

Reference signal   Differential modulated MLI   Adaptive modulated data

(b) Proposed adaptive OFDM packet structure

Fig. 2   The conventional and proposed packet structures.

(a) Schematic of differential pilot signal modulation

(b) Schematic of differential pilot signal demodulation

Fig. 3   Schematic of differential pilot signal modulation and demodulation.

transmission rate is degraded [9]. However, when we could transmit the MLI on the pilot signals, the transmission rate is not degraded since the pilot symbol does not carry any information. For the transmission of the MLI without degradation of the total transmission, we proposed the differential modulated the MLI on pilot symbols for adaptive OFDM. Differential modulation is traditionally used when the channel changes the phase of the symbol in an unknown, but consistent or continuously varying way. The data information is sent in the difference of the phases of two consecutive symbols. Under the assumption that the unknown fading coefficient changes little between two symbols, the difference in phase is preserved and can be used to carry data. Thus, we can use the pilot symbols to carry the MLI with differential modulation scheme as shown in Fig. 2. We assume a Rayleigh frequency selective fading channel where the received signals are corrupted by additional noise and fading. We use complex baseband notation at time t we transmit the ith sub-carrier pilot signal $p_{t,i}$ and we received the noisy ith sub-carrier signal $x_{t,i}$ at the receiver antenna. The action of the channel is given by

$$x_{t,i} = h_{t,i} p_{t,i} + n_{t,i}, \quad t = 1, 2, .., N_p \quad (1)$$

where $n_{t,i}$ is the additive noise which is the complex Gaussian zero-mean unit-variance distribution and N_p is the number of pilot signals. The transmitted pilot signals are normalized to have power one when averaged out over time $\mathbf{E}|p_{t,1}|^2 = 1$. For a data rate of R bits per channel use, we need $L = 2^R$ symbols. A common technique is PSK, which uses symbols that are Lth roots of unity

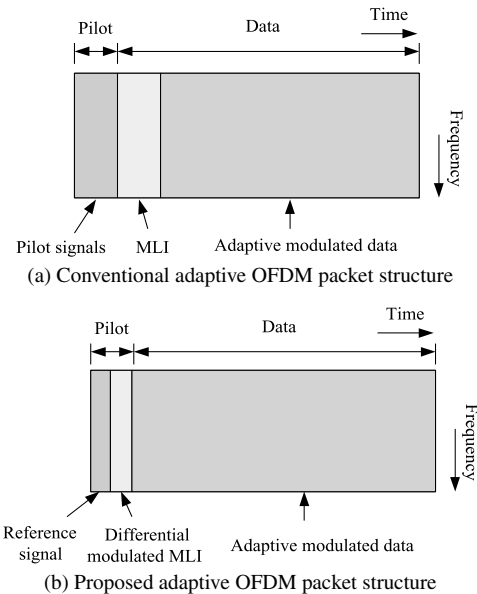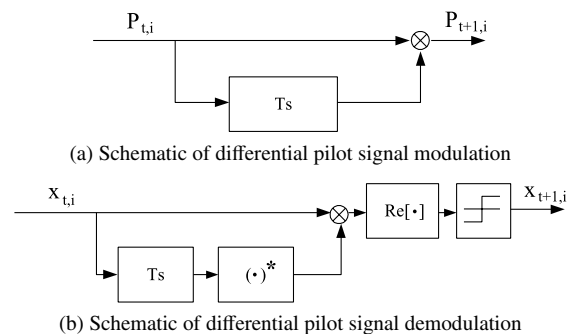$$v_l = e^{j2\pi l/L}, \quad l = 0, 1, ..., L - 1. \quad (2)$$

Figure 3 shows the schematic of differential pilot signal modulation and demodulation. Suppose we want to send a data sequence of integers $z_{1,i}, z_{2,i}, ..., z_{N_p,i}$ with $z_t \in \{0, 1, .., L - 1\}$. The transmitter sends the symbol stream $p_{1,i}, p_{2,i}, ...$ where

$$p_{t,i} = v_{z_{t,i}} p_{t-1,i}, \quad t = 1, 2, ..., N_p \quad (p_{1,i} = 1) \quad (3)$$

where the initial pilot symbol $p_{1,i} = 1$ does not carry any information and can be thought of as a reference symbol. If we assume that the fading coefficient changes slowly so that $h_{t,i} \approx h_{t-1,i}$, the ML decoder is given by

$$\hat{z}_{t,i,ML} = \arg \min |x_{t,i} - v_l x_{t-1,i}|^2. \quad (4)$$

The above expression is equal to

$$|x_{t,i}|^2 + |x_{t-1,i}|^2 - 2|x_{t,i} x_{t-1,i}| \cos(\arg x_{t-1,i} - 2\pi l/L). \quad (5)$$

This expression is minimized by minimizing the argument of the cosine. Thus, the ML decoder can be computed as

$$\hat{z}_{t,i,ML} = \lfloor \arg(x_{t,i}/x_{t-1,i}) L/(2\pi) \rceil \quad (6)$$

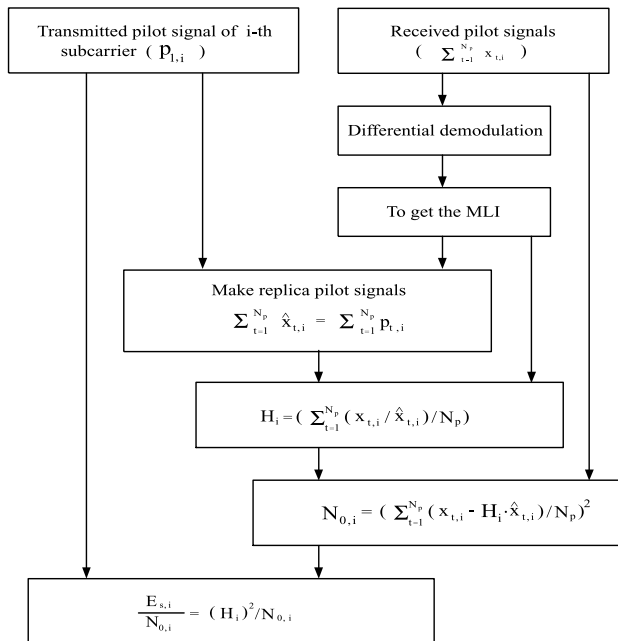where $\lfloor x \rceil$ stands for the integer closer to x. From Eq. (6), we

Fig. 4 Channel estimation algorithm.

can easily obtain the MLI using the differential modulation for pilot signals.

2.2 Channel Estimation

The roles of pilot symbols are to calculate the channel response vector and to compensate the faded received packet. However, the proposed system is transmitted the MLI on the pilot symbols, so the channel estimation procedure is different to compare with the conventional scheme. Here, we explain the proposed channel estimation procedure as shown in Fig. 4. The first symbol of the transmitted pilot symbols of ith subcarrier $p_{1,i}$ is already known, and its value is assumed to be $p_{1,i} = 1$. The received first pilot symbol of ith subcarrier $x_{1,i}$ includes the channel response of each subcarrier and noise term as shown

$$x_{1,i} = h_{1,i} + n_{1,i}. \tag{7}$$

Therefore, it is difficult to compensate the received data packet using the first pilot symbol. From the demodulated MLI, we can make replica pilot symbols.

$$\sum_{t=1}^{N_p} \hat{x}_{t,i} = p_{1,i} + \sum_{t=2}^{N_p} p_{t,i,MLI} \tag{8}$$

where $\sum_{t=2}^{N_p} p_{t,i,MLI}$ is the differential modulated pilot symbols using the demodulated MLI and $p_{1,i}$ is the reference symbol. The channel response of ith subcarrier is given by

$$\hat{H}_i = \left\{ \left(\sum_{t=1}^{N_p} (x_{t,i}/\hat{x}_{t,i}) \right) / N_p \right\} \tag{9}$$

where $\hat{H}_i$ is the calculated channel response on the ith subcarrier. Noise term is random signal with zero mean, so

the average channel response $\{\sum_{t=1}^{N_p}(x_{t,i}/\hat{x}_{t,i})\}/N_p$ on the ith subcarrier includes a mitigated noise. Since the noise term of replica symbols and received pilot symbols are cancelled due to its random characteristic. So the estimated channel response of ith subcarrier obtains a mitigated noise term. Therefore, noise power on the ith subcarrier is a square of difference between received pilot signals $\sum_{t=1}^{N_p} x_{t,i}$ and the multiplication of the estimated channel response of ith subcarrier and the replica pilot symbols.

$$N_{0,i} = \left\{ \left(\sum_{t=1}^{N_p} (x_{t,i} - \hat{H}_i \cdot \hat{x}_{t,i}) \right) / N_p \right\}^2 . \tag{10}$$

Finally, we can calculate the $E_{s,i}/N_{0,i}$ on the ith subcarrier

$$\frac{E_{s,i}}{N_{0,i}} = (\hat{H}_i)^2 / N_{0,i} . \tag{11}$$

From Eqs. (9) and (11), we can compensate and demodulate the received data packet for adaptive OFDM.

2.3 Prediction Based Adaptive Modulation Level Control

FBI includes an estimated channel state information such as power and noise level of individual subcarriers and the channel delay spread. In the AMS, above mentioned FBI is required. However, FBI is generally assumed to be infinitely precise and perfect. In the practical case, it is necessary to have some delay times to transmit the FBI from mobile station to base station. Moreover, the system requires the processing time to make an AMC using FBI at the base station. With the FBI delay and processing time to make an adaptive modulation, the system performance might be degraded. In the proposed system, LMS method is used to fit a second order polynomial to each of the measured channel impulse responses [10]. To maintain the system performance, we calculate the next fading for 3 packet times ($428\,\mu$sec) later using this polynomial values for increasing the accuracy of the FBI. AMC is decided by calculating the predicted SNR and presents SNR level with the threshold level information. If the predicted SNR is higher than the present SNR range to maintain the target BER, the modulation level is changed from M to $M + 1$. If the predicted SNR is lower than the present SNR, the modulation level is changed from M to $M − 1$. M is the modulation level.

3. Computer Simulated Results

Figure 1 shows the simulation model for adaptive OFDM with $N_c = 1024$ subcarriers. In the transmitter side, data stream is first encoded. Here, convolutional codes (rate $R = 1/2$, constraint length $K = 7$) are used, which have turned out to be efficient for transmission of an OFDM signal over frequency selective fading channel. The coded bits are then mapped to the modulation symbols of $N_c = 1024$ subcarriers by using AMC that is calculated from the predicted channel response with LMS algorithm. Pilot symbols
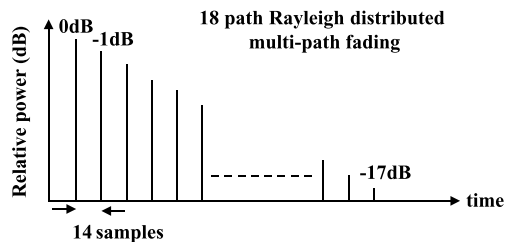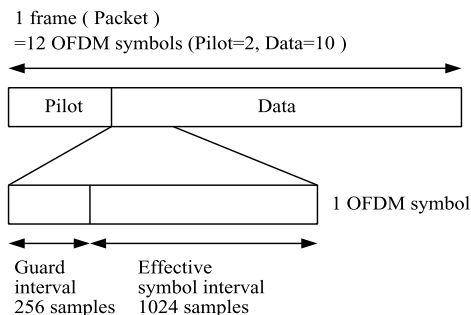
Fig. 5 Channel model.

Fig. 6 Packet structure.

Table 1 Simulation parameters.

Data modulation	QPSK,8PSK,16QAM
Pilot modulation	Differential QPSK
Data demodulation	Coherent detection
Pilot demodulation	Differential demodulation
Data rate	80 Msymbol/s
FFT size	1024
Number of carriers	1024
Guard interval	256 sample times
Frame size	12 symbols ($N_p = 2$, $N_d = 10$)
FEC	convolutional code ($R = 1/2$, $K = 7$)
Fading	18 path Rayleigh fading
Doppler frequency	10 Hz
Adaptation interval	3 packet times

Fig. 7 MSE vs. number of pilots for conventional average pilot symbols channel estimation scheme and proposed differential modulated pilot symbols based schemes at E_b/N_0=20 dB, and Doppler frequencies of 10, 200, and 500 Hz.

are differentially modulated by using the MLI. The OFDM time signal is generated by an inverse FFT and is transmitted over the frequency selective and time variant radio channel after the cyclic extension has been inserted. The transmitted signals are subject to broadband channel propagation as shown in Fig. 5. In this model, $L = 18$ path Rayleigh fadings have exponential shapes with path separation $T_{path} = 140$ nsec. This case causes a severe frequency selective fading. The maximum Doppler frequency is assumed to be 10 Hz. In the receiver side, the received signals are serial to parallel converted and N_c parallel sequences are passed to a FFT operator, which converts the signal back to the frequency domain. The received pilot symbols are differentially demodulated, and then, the MLI can be obtained by Eq. (6). This frequency domain signals are coherently demodulated by Eq. (9). After demodulation, the binary data is decoded by the Viterbi soft decoding algorithm. The simulation parameters are listed in Table 1. Figure 6 shows packet structure. Packet consists of 1024 subcarriers and 12 OFDM symbols (number of pilot signals:$N_p = 2$, number of data:$N_d = 10$). One OFDM symbol duration is 12.8 μsec. We consider an adaptation interval with 3 packet times in this paper, since the 3 packet times predicted FBI is the approximately same to compare with the real channel. [10]. In order to compare the performance of different channel estimations, the mean square error (MSE) between the ideal channel response, H, and the estimated channel response, $\hat{H}$, was defined as
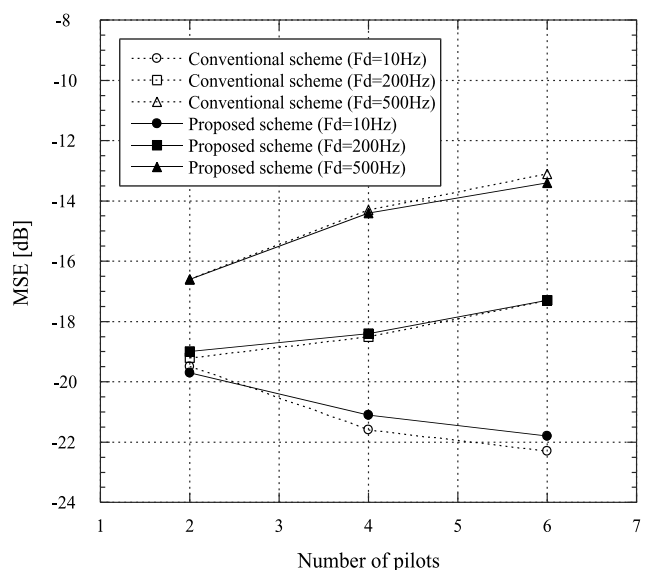
$$\text{MSE} = \mathbf{E}|H - \hat{H}|^2 / \mathbf{E}|H|^2 \qquad (12)$$

where $\hat{H}$ is $\sum_{i=1}^{N_c} \hat{H}_i$, N_c is the number of subcarriers.

Figure 7 shows MSE vs. number of pilots for conventional average pilot symbols channel estimation scheme and proposed differential modulated pilot symbols based

schemes at E_b/N_0=20 dB, and Doppler frequencies of 10, 200, and 500 Hz. It is shown that the channel estimation property is increased with increasing the number of pilot symbols at Doppler frequency of 10 Hz. On the other hands, the channel estimation property is degraded with increasing the number of pilot symbols at Doppler frequency of 200 Hz and 500 Hz. This is because the channel varying is slow in low Doppler frequency, so the channel estimation property can be increased. However, in high Doppler frequency, channel is rapidly changed, so the channel estimation property is also degraded. Moreover, the channel estimation property of the conventional scheme is better than that of the proposed scheme. With increasing Doppler frequency, the channel estimation property of the conventional and the proposed schemes shows the approximately same. This is because the differential modulated pilot symbols obtain demodulation errors and these errors are fed into the channel estimation processing in low Doppler frequency. From this
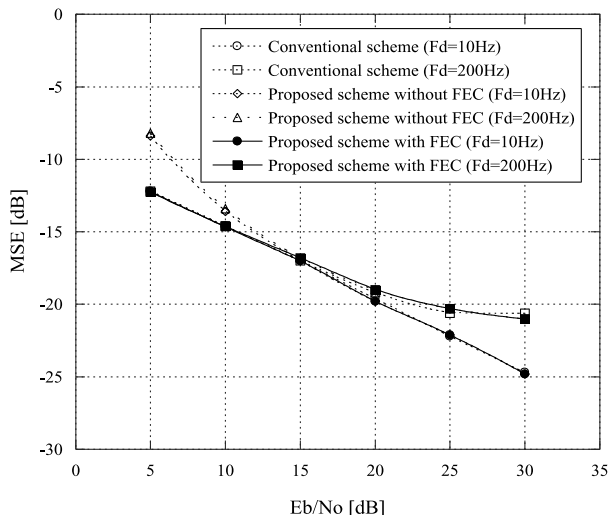
Fig. 8 MSE vs. E_b/N_0 for conventional average pilot symbols channel estimation scheme and the proposed differential modulated pilot symbols based schemes with and without FEC at Doppler frequencies of 10 Hz and 200 Hz.

reason, the proposed scheme shows worse MSE than that of the conventional scheme in low Doppler. However, in high Doppler frequency, the conventional scheme also obtain channel estimation errors due to the fast channel changing.

Figure 8 shows MSE vs. E_b/N_0 for the conventional average pilot symbols channel estimation scheme and the proposed differential modulated pilot symbols based schemes with and without FEC at Doppler frequencies of 10 Hz and 200 Hz. In low E_b/N_0, the proposed scheme without FEC shows worse MSE than that of the conventional scheme. With increasing E_b/N_0, the channel estimation property shows the same like the conventional scheme. This is because the differential modulation is sensitive to the noise effect, so that many demodulation errors are occurred in the low E_b/N_0. Since the channel response is calculated from these demodulated MLI with errors, the channel estimation property is also worse than that of the conventional scheme. When we consider a FEC with our proposed scheme, the channel estimation property is significantly increased. Therefore, the proposed channel estimation scheme with FEC shows the same property like the conventional scheme.

In Fig. 9, the throughput of fixed modulation schemes as QPSK and 16QAM and the proposed adaptive OFDM are compared, where target BER of 10^{-5} and Doppler frequency of 10 Hz. Adaptive modulation schemes consist of QPSK, 8PSK, and 16QAM. It is shown that the proposed scheme achieves better throughput performance than the fixed modulation schemes such as QPSK, and 16QAM, since the channel capacity increases to allow the high level modulation schemes like 8PSK and 16QAM in subcarriers with increasing E_b/N_0. Therefore, the proposed scheme switches the channel modulation scheme from low level modulation scheme as QPSK to high level modulation schemes as 8PSK
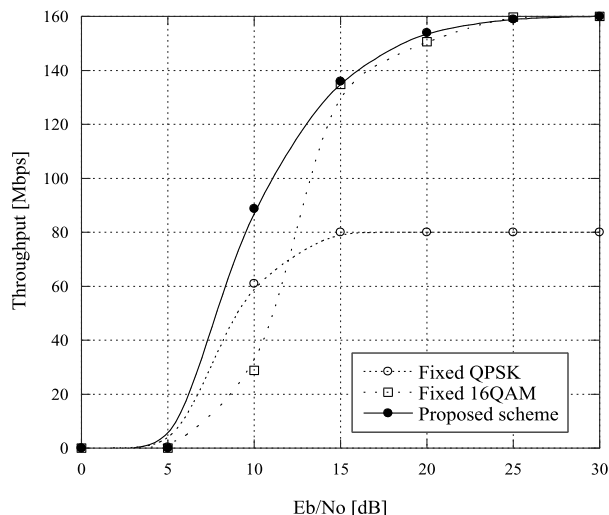

Fig. 9 Throughput of fixed modulation schemes as QPSK and 16QAM and the proposed adaptive OFDM are compared, where target BER of 10^{-5} and Doppler frequency of 10 Hz.
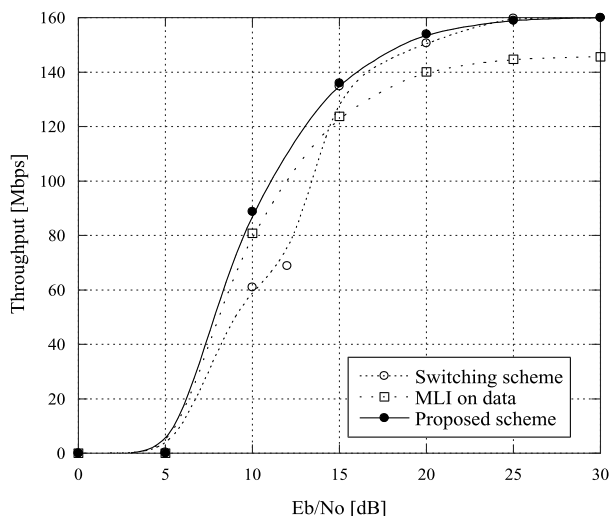

Fig. 10 Throughput of the conventional adaptive OFDM with MLI transmitting on data symbols, modulation switching scheme based on the estimated averaged E_b/N_0, and the proposed proposed differential modulated pilot symbols based scheme based adaptive OFDM at Doppler frequency of 10 Hz.

and 16QAM to increase the throughput performance.

Figure 10 shows the throughput of the conventional adaptive OFDM with MLI transmitting on data symbols, modulation switching scheme based on the estimated averaged E_b/N_0 and the proposed differential modulated pilot symbols based scheme at Doppler frequency of 10 Hz. Since the conventional adaptive OFDM scheme transmits the MLI on data symbols, therefore, the total transmission rate is degraded. On the other hands, the proposed scheme transmits the MLI on the pilot symbols with differential modulation. As a result, the total transmission rate is not degraded. Modulation switching scheme based on the estimated averaged E_b/N_0 shows worse throughput than those
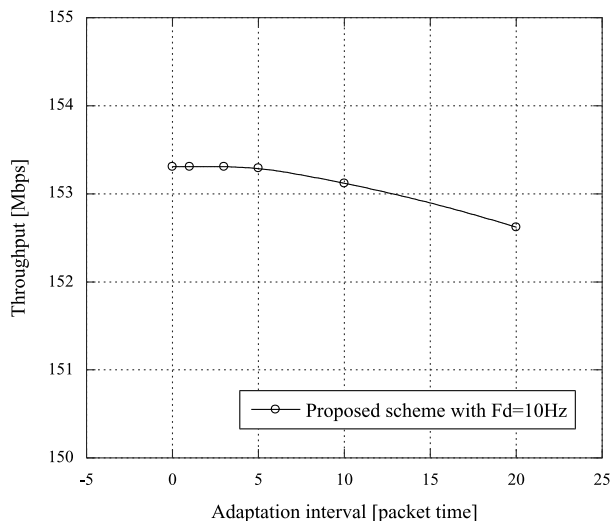
Fig. 11 The effect of various adaptation intervals on the performance of the adaptive modulation at Doppler frequency of 10 Hz.

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of the conventional and the proposed schemes until 15 dB. This is because this scheme changes a modulation level using the estimated averaged E_b/N_0. With increasing E_b/N_0, modulation switching scheme shows better throughput than that of the conventional scheme. This is because the conventional scheme transmits the MLI on data symbols, therefore, the total transmission rate is degraded. From the simulated result, the proposed adaptive OFDM scheme obtains about 10% improvement to compare with the conventional adaptive OFDM scheme.

Figure 11 shows the effect of various adaptation intervals on the performance of the adaptive modulation. In an AMS/OFDM, FBI includes the estimated channel state information (CSI) like power and noise level of individual subcarriers. However, FBI is generally assumed to be infinitely precise and perfect. In the practical case, it is necessary to have some delay times to transmit the feedback information from receiver to transmitter. Moreover, the system requires the processing time to make an AMC using FBI at the transmitter. With the FBI delay and the processing time to make an adaptive modulation, the system performance might be degraded. To maintain the system performance, it is necessary to clarify the adaptation interval as a control period using FBI. From the simulation results, we can achieve approximately same throughput performance within 5 packet times as a control period for adaptive modulation at Doppler frequency of 10 Hz.

4. Conclusion

In this paper, we proposed a differential modulated pilot symbol assisted adaptive OFDM for reducing the MLI with the predicted FBI. The proposed channel estimation scheme shows the same MSE performance over 10 dB without degradation of the throughput. As a result, the proposed system obtains about 10% improvement to compare with the conventional adaptive OFDM system.

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