Joint Adaptive Modulation and Transmit Power Control on FSS-OFDM Mobile Relay System

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Abstract This paper proposes an adaptive modulation (AM) and a transmit power control (TPC) on frequency symbol spreading (FSS) based orthogonal frequency division multiplexing (OFDM) relay system with considering the mobility of relay node. Wireless communications often suffer from large propagation loss due to shadowing and multipath fading. As a solution to this problem, relay communications, which forward data messages from a source to a destination via intermediate station(s), have been focused on. It can obtain the space diversity and expand the area coverage. In the situation where relay node has mobility, propagation channel fluctuates and communication quality is deteriorated. This paper presents a whole system design of FSS-OFDM employing AM and TPC. Exploiting a good match of AM and FSS, throughput performance can be significantly improved even in high mobility environment. In addition to this, utilizing TPC, the most suitable AM is enabled and leads to a further performance enhancement. Computer simulation verifies its effectiveness and reveals the proposed system is the most valuable means which realizes the flexible relay node deployment.

Keywords: frequency symbol spreading, relay communications, adaptive modulation, transmit power control

1. Introduction

Persistent development of mobile communication systems has been realized high date rate, high capacity and high quality communication. This triggered explosive diffusion of smart phones and tablets accessing to the Internet. Wireless communications often suffer from its propagation characteristics such as shadowing and multipath fading. Relaying, forwarding data messages from a source to a destination via intermediate station(s), has been widely investigated as one of the attracting solutions to overcome the above drawback [1]–[3]. It offers a stable transmission to the destination terminals particularly in a poor channel condition or in a place far-off from the serving base station (BS). Thus it is effective in coverage expansion. Relay communications can be classified into two schemes: amplify-and-forward (AF) and decode-and-forward (DF). AF is that the relay node forwards the incoming signal only by amplifying in the analog domain, so that forwarding delay is relatively low while additive noise effect may be enhanced [4][5]. In DF, the relay node once demodulates and decodes the source message and transmits the re-encoded message [6][7]. Although DF incurs oppressed computation complexity and delay, it can provide better communication quality than AF. Another issue on relaying is practical and efficient deployment of relay nodes. Additional deployment of fixed relay nodes increases extra cost, especially in power supply installation [8]. A possible solution is to install the relaying function on user equipment or moving vehicles as illustrated in Fig. 1. This structure could flexibly expand communication coverage and be one of the most promising means for wireless access. Such concept is now emerging as cell-less communication [9], adaptive movable access points [10], or autonomous base stations [11] In this case, the system should be designed with considering their mobility unlike the fixed relay node deployment scenario.

Adaptive modulation (AM) is capable of tracking to mobility by adequately setting modulation scheme according to the link quality [12]–[15]. It is especially effective even in orthogonal frequency division multiplexing (OFDM) where modulation scheme can be optimally determined per frequency component, i.e. subcarrier or subchannel. Meanwhile, it requires feedback information (FBI) including modulation level for all frequency components. To reduce such overhead, frequency symbol spreading (FSS) has been proposed [16]–[19]. FSS is originally inspired by multicarrier code division multiple access (MC-CDMA) [20], the difference being that FSS diffuses symbols in frequency (subcarrier) domain within the same band and has the purpose of mitigating the effect of frequency selective fa-

Fig. 1 System model: mobile relay communication
ing. With FSS-OFDM, the transmission symbols of each subcarrier are spread to all frequency components by orthogonal spreading code. Power density of each symbol originally mapped to the corresponding subcarrier is unified even though they go through a frequency selective fading channel. It means that FSS virtually provides additive white Gaussian noise (AWGN) channel and the detected symbols have the equal signal-to-noise power ratio (SNR) at the receiver. Therefore, the same modulation level can be assigned for all transmission subcarriers and it can improve bit error rate (BER) performance [18]. FSS can also reduce FBI overhead thanks to the equalized link quality nature; one piece of FBI is sufficient. Therefore, FSS has high affinity with adaptive modulation where the optimal modulation order is determined based on link quality. In the frequency selective channel, however, FSS suffers from determining the most suitable AM parameter due to the irregularity of subcarrier power densities. To solve this problem, we additionally employ a transmit power control (TPC) [21]–[24]. When the power density of subcarriers is surplus for the threshold to change the modulation level, the power is reduced to the threshold level. Conversely, the power density of subcarrier being insufficient for the required level is amplified. AM with TPC can optimize the energy and spectral efficiency. Previous work on FSS-OFDM with TPC [24] was focused on reducing superfluous transmit power consumption.

In mobile relay situation, destination node should track channel variations in source–relay and relay–destination links, respectively.

The key contributions of this paper are: 1) improving overall throughput performance via jointly optimized AM and TPC; 2) verifying its effectiveness under high mobility situation on mobile relay system. Computer simulation clarifies its improved throughput performance compared to the conventional DF mobile relay. The rest of this paper is organized as follows. Sections 2. and 3. describe the channel model and system model, respectively. Section 4. presents the proposed mobile relay system incorporated with FSS-OFDM and AM-TPC. Section 5. shows the computer simulation results. Finally, the paper is concluded in Section 6.

### 2. Channel Model

This paper assumes time varying multipath fading channel which is expressed as,

$$h(t, \tau) = \sum_{j=0}^{J-1} h_j(t) \delta(\tau - \tau_j)$$

$$h_j(t) = \frac{g_j}{\sqrt{K}} \sum_{k=1}^{K} \exp[j(2\pi f_d t \cos \alpha_k + \phi_k)]$$

where $h_j$ is the complex channel coefficient and $\delta$ indicates the Dirac’s delta function. $J$ and $\tau_j$ denote the number of discrete paths and the delay time, respectively. $K$ waves arrive at the receiver at the instance $\tau_j$. $g_j$ and $\alpha_k$ and $\phi_k$ denote the $j$-th path gain, angle of arrival (AoA) of the $k$-th wave and its initial phase, respectively. $f_D$ is the Doppler frequency. Here assumes normalized path gain, i.e., \[ \sum_{j=0}^{J-1} E[|h_j|^2] = 1 \] where $E[\cdot]$ stands for the expectation (ensemble average) operation. We can then obtain the frequency response $H(f, t)$ via Fourier transform of the impulse response as,

$$H(f, t) = \int_0^\infty h(t, \tau) e^{-j2\pi f \tau} d\tau$$

$$= \sum_{j=0}^{J-1} h_j(t) e^{-j2\pi f \tau}$$

(3)

where $f$ denotes the carrier frequency. In a mobile communication environment, the frequency response is generally not flat. $J > 1$ provides frequency selective fading channel where $|H(f, t)|$ fluctuates in the transmission bandwidth. In this case, FSS can artificially mitigate the effect of frequency selective fading and improve the BER and throughput performance [15].

Path loss characteristics in this paper follow the Friis transmission equation. Let $P_t$, $G_t$, $G_r$, $\lambda$ and $d$ denote the transmission power, antenna gains of transmitter/receiver antennas, wavelength and the propagation distance, the reception power $P_r$ is given by

$$P_r = \left( \frac{\lambda}{4\pi d} \right)^2 G_t G_r P_t$$

(4)

From Eq. (4), it is obvious that the reception power mitigates according to square of the distance $d$.

### 3. System Model: FSS-OFDM Based Mobile Relay

In mobile relay communications, optimal modulation scheme should be determined with reduced FBI. We present a system design based on FSS-OFDM to improve the BER and throughput performances.

#### 3.1 Source node

Figure 2(a) shows the block diagram of the source node for FSS-OFDM based mobile relay system. The transmission signal produced by FSS-OFDM is expressed as

$$s(t) = \sum_{i=0}^{N_d+N_p-1} g(t - iT) \cdot \sqrt{\frac{2P}{N_c}} \cdot \sum_{m=0}^{N_c-1} u(m, i) \cdot \exp\{-j2\pi t - iT_m/T_i\}$$

(5)

where $N_d$, $N_p$ and $N_c$ denote the number of data symbols, pilot symbols and subcarriers, respectively. $T$ indicates the
OFDM symbol duration including guard interval (GI) and $T_s$ is the effective symbol duration without GI. In OFDM, the inter-symbol interference (ISI) caused by the multipath fading can be avoided by inserting GI. When its length is $T_g$, $T_g = T_s + T_g$ is satisfied. Subcarrier spacing is $1/T_s$.

$P$ indicates the average transmitting power. $g(t)$ is the transmission pulse which is given by

$$g(t) = \begin{cases} 1 & -T_g \leq t \leq T_s \\ 0 & \text{otherwise} \end{cases} \quad (6)$$

Defining OFDM signal of the $i$-th symbol at the $m$-th subcarrier as $u(m, i)$, it is expressed as,

$$u(m, i) = \sum_{k=0}^{N_{SF}-1} c_k(m \mod N_{SF}) \cdot d([m/N_{SF}]N_{SF} + k, i) \quad (7)$$

where $d(m, i)$ is the $i$-th modulated symbol at the $m$-th subcarrier satisfying $E[|d(m, i)|^2] = 1$. $c_k(n)$ is the Hadamard code to perform FSS and satisfies

$$\sum_{n=0}^{N_{SF}-1} c_k(n)c_k^*(n) = \begin{cases} N_{SF} & \text{for } k = \omega \\ 0 & \text{for } k \neq \omega \end{cases} \quad (8)$$

where $|c_k(n)| = 1$ and $(\cdot)^*$ represents the complex conjugate.

A concept of FSS in terms of the power spectra is shown in Fig. 3. Each modulation symbol $d(m, i)$ is copied $N_{SF}$ times and multiplied by the orthogonal spreading code. These spread symbols are combined to the same FSS block. FSS block is defined as the group of subcarriers to apply spreading code. On that account, all data symbols in the specified FSS block are spread and superposed over the transmission bandwidth. Although the energy of each input data symbol is divided by $N_{SF}$ subcarriers, receiver can extract it by despreading in frequency domain. It indicates that the reception power (reception SNR) of each data symbol is unified by FSS. It enables for the spread data to obtain a frequency diversity without additional increase of transmission power for each subcarrier.

On the source node as illustrated in Fig. 2(a), the data stream is mapped to the $N_c$ modulation symbols by use of FBI from the relay node. Then the pilot and data signals are serially concatenated and serial-to-parallel (S/P) converted to be allocated to subcarriers. Each symbol of subcarrier is spread by the Hadamard code with length of $N_{SF}$ and is superposed. Here assumes that symbol superposition with the equal power ratio. The transmission signal in time domain is obtained via inverse fast Fourier transform (IFFT) and GI insertion. It goes through a propagation channel.

### 3.2 Relay node

Figure 2(b) shows the relay node structure which employs the DF method. DF based relay node detects the received signals $r_{sr}(m, i)$ as following manner,

$$\hat{u}(m, i) = \omega_{sr}(m, i) \cdot r_{sr}(m, i) \quad (9)$$

where $\omega(m, i)$ is the FSS combining weight which will be explained later in the next section. The detected signal
\( u(m, i) \) is re-modulated and transmitted to the destination node. Here assumes that relay node does not perform error detection. It relays received signal regardless of whether the signal contains error or not.

### 3.3 Destination node

Figure 2(c) depicts the destination node structure. The received signals are performed S/P conversion and GI removal. \( N_c \) parallel sequences are then applied fast Fourier transform (FFT). The converted signals in frequency domain is going to be despread by spreading code. However, the orthogonality among spread symbols is disordered due to the multipath fading. To restore it, we use a minimum mean square error combining (MMSEC) based frequency equalization combining.

The received signal is expressed as

\[
r(t) = \int_{-\infty}^{\infty} h(\tau, t)s(t - \tau)d\tau + n(t) \tag{10}
\]

where \( n(t) \) is the AWGN with power spectral density of \( N_0 \). Resolving \( r(t) \) into \( N_c \) subcarriers via FFT, its frequency domain expression \( \hat{r}(m, i) \) is given by

\[
\hat{r}(m, i) = \frac{1}{T_s} \int_{t}^{t + T_s} r(t) \exp(-j2\pi t - mT_s)dt
\]

\[
= \sqrt{\frac{2P}{N_c}} \sum_{e=0}^{N_c-1} u(e, i) \cdot \frac{1}{T_s} \int_{0}^{T_s} \exp(j2\pi e - m)
\]

\[
\cdot t/T_s \cdot \{\int_{-\infty}^{\infty} h(\tau, t + iT)g(t - \tau)d\tau \}
\]

\[
+ n(m, i) \tag{11}
\]

where \( n(m, i) \) is AWGN component having a variance of \( 2N_0/T_s \). Assuming the maximum path delay \( \tau_{j-1} \) is smaller than the guard interval length \( T_g \), the integral with respect to \( \tau \) can be given by

\[
\sum_{e=0}^{N_c-1} \left\{ \int_{-\infty}^{\infty} h(\tau, t + iT)g(t - \tau)\exp(-j2\pi e \cdot t/T_s)dt \right\}
\]

\[
= \sum_{e=0}^{N_c-1} \int_{0}^{T_s} h(\tau, t + iT)\exp(-j2\pi e \cdot t/T_s)dt
\]

\[
= H(m/T_s, t + iT) \tag{12}
\]

Assuming the coherence time is much larger than the OFDM symbol duration \( T \), channel state can be regarded to be static within the symbol duration \( T \),

\[
H(m/T_s, t + iT) = H(m/T_s, it) \quad \text{for } 0 \leq t \leq T \tag{13}
\]

Thus, (11) can be rewritten as

\[
\hat{r}(m, i) \approx \frac{1}{T_s} \sqrt{\frac{2P}{N_c}} \sum_{e=0}^{N_c-1} u(e, i) \cdot \int_{0}^{T_s} \exp(j2\pi e - m)dt + n(m, i)
\]

\[
= \frac{1}{T_s} \sqrt{\frac{2P}{N_c}} H(m/T_s, i) \sum_{e=0}^{N_c-1} u(e, i) \cdot \int_{0}^{T_s} \exp(j2\pi e - m)dt + n(m, i)
\]

\[
= \sqrt{\frac{2P}{N_c}} H(m, i)u(m, i) + n(m, i) \tag{14}
\]

After separating pilot signals, frequency domain equalization is applied and the demodulated data symbol is expressed as

\[
d(m, i) = \sum_{k=0}^{N_SF-1} \omega(m, i) \cdot \hat{r}(m/N_SF \cdot N_SF + k, i) \cdot c_{m \mod N_SF}^k \tag{15}
\]

where \( \omega(m, i) \) is the FSS combining weight. In this paper, we use MMSEC [25] that is expressed as

\[
\omega(m, i) = \left[ \frac{\sqrt{2P}}{N_c} \cdot H(m, i) \right]^2 + 2\sigma^2 \tag{16}
\]

where \( H(m, i) \) is the channel estimate of the \( i \)-th OFDM symbol at the \( m \)-th subcarrier, \( \sigma^2 \) is the noise variance per subcarrier, which is assumed to be identically known for all subcarriers.

As explained in Sect. 3.1, each subcarrier in the FSS block holds the modulated symbols with equal power ratio. It indicates that all despread symbols exhibit the same
SNR even though they experience the frequency selective fading channel. Therefore, we can apply the same modulation scheme for each FSS block; it is enough to provide a few piece of FBI and modulation level information (MLI) to control the modulation scheme per FSS block. The proposed method can significantly reduce the overhead quantities of FBI and MLI transmission compared to the conventional scheme. From these reasons, FSS can improve BER as well as throughput performance.

4. Proposal: Joint Optimization of Adaptive Modulation and Transmit Power Control for FSS-OFDM

![Flowchart of AM scheme](image)

(a) TPC Block

- Start
- Channel State Information
- Power Calculation
- Yes
- Power < TPC Threshold
  - No
  - Amplification
  - Yes
  - Power > TPC Threshold
    - No
    - No TPC
    - Reduction

(b) AM Block

- SNR Calculation
- Yes
- SNR > Target
  - 16QAM
  - No
  - Threshold Information

End

Fig. 4 Transmit power control and adaptive modulation scheme

4.1 Adaptive modulation

Flowchart of AM scheme is shown in Fig. 4 (b). In the proposed system, the adaptive modulation is performed by the source nodes using link quality fed back by the destination node. First, the destination node estimates the SNR for each FSS block as a link quality observing channel state information (CSI) from the relay node. Calculated results of SNR level is fed back to the AM decision block of the source node. The source node then chooses the modulation order referring to the threshold information which is determined based on BER achieving $10^{-3}$ [8]. Feedback delay is critical to track fast fading especially in relay systems. Tracking such small scale variation requires more frequent feedback with sophisticated adaptation control. A main objective of the adaptive modulation using feedback control is to adapt the mobility, that is, to optimize the modulation level under given Doppler frequency.

4.2 Transmit power control

![Power control scheme](image)

Although TPC [23] is effective method for AM, strict approach on TPC for multicarrier transmission system requires FBI containing reception SNR for all subcarriers. It inflates FBI amount resulting in unacceptable overhead. As explained above, FSS can reduce FBI amount to the number of FSS block and thus increment of FBI on TPC to AM is quite limited. Fig. 4 (a) and Fig. 5 provides illustrative understanding of TPC for FSS-OFDM. Transmit power of each FSS block is increased or decreased according to the relations between expected SNR and corresponding threshold for deciding modulation order. Here defines the constraint on transmission power such that its time average to be a constant within 10 frame transmissions. For example, if the reception power of FSS block1 exceeds the threshold for 16QAM, its excessive energy is saved to the threshold value. On the other hand, the reception power of FSS block2 is larger than the threshold of TPC but less than the threshold of 16QAM, it is raised so as to exceed the threshold of 16QAM. TPC is not applied if the reception power does not exceed either of two thresholds. The source node firstly perform TPC and then optimal modulation level is determined via AM function.

We assume that TPC and AM is performed only at the source node for the sake of simplification of the relay node. It is because that the transmission performance is strongly influenced by the poor channel one of the source–relay or relay-destination links. The destination node should acquire all communication quality information after all which imposes enlarged signaling overhead with complicated operation. To avoid such issue and to fully exploit advantages of FSS which substantially reduces FBI amount, we focused on only relay–destination link to perform TPC and AM. From the another viewpoint, on the FSS basis, frequency spreading effect can be kept among cascaded channels as source–relay and relay–destination. In other words, almost
frequency-flat channels are virtually created through relay communication. Therefore, focusing on joint AM/TPC operation for each FSS block is sufficient by utilizing CSI of relay–destination link. Previous work on FSS-OFDM with TPC [24] was focused on its reduced superfluous transmit power consumption effect. This paper aims to further enhance overall throughput performance via jointly optimized AM and TPC on FSS-OFDM. Use of this method enables to perform optimum adaption and maximizes the throughput performance.

5. Computer Simulation

5.1 Simulation parameter

Table 1 summarize the detailed simulation parameters.

| Transmission scheme   | FSS-OFDM |
|-----------------------|----------|
| Data Modulation       | QPSK, 16QAM |
| FFT size              | 64 |
| Number of subcarriers | 64 |
| Number of symbols     | 22 symbols ($N_p=2, N_d=20$) |
| Guard interval        | 16 |
| Doppler frequency     | 10 Hz, 200 Hz ($f_d T_s = 3.2 \times 10^{-6}, 6.4 \times 10^{-5}$) |
| Bandwidth             | 20 MHz |
| Fading                | 15 path Rayleigh fading 1 dB exponential decay |
| Path loss model       | Free space propagation |
| Transmission Power    | -40 dBm |
| Antenna gain          | Tx: 3 dB, Rx: 3 dB |
| Noise Power           | -90 dBm |
| Channel estimation    | Least square |

Fig. 6 Frame structure

Simultaneous condition assumes the 15 path Rayleigh fading with exponential decay and their interval is $T_{path} = 50$ ns. This provides severe frequency selectivity. We also evaluated two cases of mobility of low and high speed; the Doppler frequencies of 10 and 200 Hz, respectively. Here assumes that the source and the destination are static, hence, the same Doppler frequency is imposed to both source–relay and relay–destination channels. Doppler frequency is assumed to be constant in the simulation period. It doubly affects the channel followability for the destination. In addition, path loss for each link is also varied depending on the position of the relay node. The path loss model follows Friis free space propagation. Fig. 6 shows the frame structure. One OFDM symbol consists of 64 subcarriers and the packet is structured by $N_p = 2$ pilot symbols and consecutive $N_d = 20$ data symbols. Channel estimation is performed by using pilot symbols and obtained CSI per pilots are averaged to suppress additive noise effect. AM in this study simply employs two settings: QPSK and 16QAM. The threshold to switch the modulation level is set by target BER: $1.0 \times 10^{-3}$. Since the number of bits is 1280 per transmission frame, satisfying this target can be regarded as error free. Table 1 summarizes the detailed simulation parameters.

The simulation topology of the mobile relay system is shown in Fig. 7. Suppose the positions of the source node and the destination node are fixed, the position of the relay node is determined at random within the circular region around the source node. The minimum distance between the relay and the destination nodes is 10 m, and maximally 200 m.

We assume that feedback can be completed so as to track the small-scale fading; the impact of feedback delay can be negligible. Main evaluation metrics are BER and throughput performances in receiver (destination) side.

### Simulation results: Adaptive modulation

Figure 8 shows the BER performances of OFDM comparing respective transmission schemes. Here plots performances of the conventional QPSK, 16QAM (fixed, without FSS), the conventional AM (without FSS), and the proposed FSS with AM (without TPC). First evaluation shows the effectiveness of AM when spreading code length $N_{SF}$ is 32 at Doppler frequencies $f_d$ of 10 and 200 Hz, respectively. SNR in the horizontal axis is defined as the averaged value observed at the destination node and it depends on
the position of the relay node. It can be confirmed that AM can contribute to improve BER performance. The proposed system achieves the best BER performance since it obtains the frequency diversity gain brought by FSS. On the other hand, as Doppler frequency rises, BER performance of both systems are deteriorated and exhibit the error floor. For this reason, the fluctuation of the channel states is too fast to track for the receiver, hence it worsen the channel estimation accuracy and distorted orthogonality between subcarriers.

Figure 9 shows the throughput performances of OFDM with fixed QPSK, 16QAM, the conventional OFDM with AM, and the proposed FSS-OFDM with AM, respectively. The proposed system significantly improves throughput performance in comparison with the case where the modulation level was fixed as well as the conventional AM scheme. Its improvement is maximally 140% compared to the conventional AM for Doppler frequency of 10 Hz at SNR of 30 dB. Furthermore, it should be noted that improvement by 110% (SNR is 30 dB here) can also be attained even in a high mobility situation such as Doppler frequency of 200 Hz. From a comparison between Figs. 8 and 9, the proposed scheme exhibits worse BER performance in the low SNR region whereas better throughput performance than the conventional schemes when $f_D = 200$ Hz. FSS is quite effective to obtain frequency diversity gain in relatively good channel condition whereas it may cause burst error in opposite condition. It can be considered that FSS polarizes the spread channel conditions to improve or degrade, resulting better throughput (packet error rate) performance and worse BER performance. This tendency becomes remarkable especially in the lower SNR region.

5.3 Simulation results: Joint adaptive modulation and transmission power control

Prior to evaluate the performance introducing TPC, we show the dependence of the spreading factor $N_{SF}$ on BER characteristic applying only AM without TPC at Doppler frequency of 10 Hz in Fig. 10. From the figure, increase of $N_{SF}$ can improve BER performance. Enlarging spreading factor can reduce frequency correlation among subcarriers and it contributes to obtaining frequency diversity gain. When spreading factor is equal to the number of subcarriers, i.e. $N_{SF} = 64$, contribution of TPC is to only reduce power consumption [24]. On the other hand, $N_{SF}$ is less than the maximum value, equivalent channel gains of FSS blocks are considered to be surplus or insufficient to the predetermined modulation order. If channel gains of subcarriers in the FSS block1 are relatively higher than that in the FSS block2, spread gain of FSS block1 is also higher than that of FSS
Throughput performance of applying TPC

Throughput performance comparison to coded OFDM ($f_D = 10$ Hz)

block2. TPC is then performed per FSS block so as to maximize energy utilization. In this case, joint optimization of AM with TPC is expected to further enhance BER or throughput performance via efficient energy utilization.

Figure 11 gives the throughput performance of AM based FSS applying TPC where $N_{SF} = 32$ to confirm the impact of TPC. Achievable throughput can be largely improved especially in the lower SNR region. It is remarkable that the improvement can be observed even in high Doppler frequency. For this reason, FSS has better tolerance to Doppler shift effect due to its diffusibility. Phase fluctuation due to Doppler shift is considered to be dispersed thanks to FSS. Referring back to Fig. 3, dispersed symbols experiences different Doppler effects through each subcarrier and the combined at the receiver after the channel estimation/equalization as described in (15). In this case, impact of Doppler effects, that is the residue of the frequency domain equalization, are averaged and thus mitigated. It results in throughput performance improvement brought by the proposed method. TPC can compensate required energy being insufficient for signal transmission by re-assigning surplus energy of other FSS blocks.

Finally, throughput performance of the proposed scheme and convolutionally coded OFDM with joint AM/TPC is compared when $f_D = 10$ Hz and is plotted in Fig. 12. As for the comparison scheme, coding rate of {1/2, 2/3, 3/4, 5/6} is optimally determined according to SNR conditions. Although coded OFDM can provide valuable throughput in lower SNR region, its maximal is suppressed due to coding overhead. Our proposed approach can exhibit superior throughput performance especially in the higher SNR region. It is because the FSS can obtain frequency diversity without the aid of error correction codes which causes redundancy for information transfer. Although valuable throughput cannot be obtained in the proposed system in a lower SNR region, it is significantly outperformed at SNR > 20 dB. Such superiority can be achieved notwithstanding the source node only exploits the CSI of relay–destination link. It is thanks to the notable feature of FSS which can flatten the frequency selectivity. Figure 13 shows the breakdown of selection probabilities of modulation order when $f_D = 10$ Hz. As seen by the figure, applying FSS (Figs. 13(b,c)) can select 16QAM more frequently than conventional OFDM (Fig. 13(a)) around reception SNR of 40 dB. Furthermore, joint optimization with TPC (Fig. 13(d)) raises the possibility of 16QAM in the region less than 30 dB. These observations validated the effectiveness of the proposed FSS-OFDM relay system with joint AM and TPC.

5.4 Discussion

Above results clarified preparing multiple FSS blocks can realize flexible energy utilization to raise worst-case throughput performance whereas one FSS block is sufficient in good channel condition to fully exploit frequency diversity. It leads effectiveness of an adaptive spreading factor control. Dividing FSS block is also applicable for multiuser scenario and it is expected to further enhance the system capacity via obtaining multiuser diversity. Although this paper used two modulation orders for fundamental verification of the proposal, we have disclosed throughput performance improvement especially in lower reception power situation.

From the practical implementation viewpoint, feedback error caused by SNR measurement accuracy or SNR quantization would impact to the relaying system. These degradation factors should also be considered to validate the feasibility of our proposed approach. With regard to the quantization error, reducing FBI amount brought by the FSS based proposal can be paraphrased that more quantization bits are acceptable under the same overhead constraint.
6. Conclusion

This paper proposed a joint AM and TPC on FSS-OFDM relay system where considered mobility of relay node. FSS yields the unified SNR among subcarriers by frequency spreading code. It allows to apply the same modulation level for all symbols which can reduce the controlling overhead. On the other hand, AM and TPC enables to control the modulation level optimally. Our proposal exploits good match of AM and FSS-OFDM and it could improve throughput performance of the mobile relay system. Furthermore, applying TPC can raise worst-case performance in lower reception power region. Computer simulation clarified that the proposed system improved throughput performance by 100% even in a high mobility environment where Doppler frequency is 200 Hz, compared to the conventional OFDM with AM. The proposed adaptive FSS-OFDM mobile relay system can be the most valuable solution which realizes the flexible relay node deployment.

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