A Study on Lower Layer Signal Design of LDM-BST-OFDM for the Next-Generation DTTB

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Abstract In this paper, the transmission scheme that combines LDM(Layered Division Multiplexing) with BST-OFDM(Band Segmented Transmission - Orthogonal Frequency Division Multiplexing) is proposed for the Japanese next-generation DTTB(Digital Terrestrial Television Broadcasting). The proposed LDM-BST-OFDM scheme provides a more effective frequency utilization and improvement of the performance in the stream for fixed reception. In addition, power boost of partial reception band for LDM-BST-OFDM is also studied in this paper. The performance of the proposed scheme is evaluated by computer simulations where the effectiveness of proposed scheme for fixed reception is shown.

Although LDM-BST-OFDM scheme improves the performance, dedicated receivers that can demodulate LDM multiplexed symbols are required. Therefore, LDM-BST-OFDM scheme which can decode the stream for fixed reception even if LDM multiplexed symbols are not demodulated by using conventional fixed receivers is proposed. In this paper, “LDM-BST-OFDM using frequency diversity scheme” and “LDM-BST-OFDM using extended parity in lower layer of LDM” is proposed. The reception characteristics of the proposed scheme is evaluated by computer simulations.

Key words: LDM, DTTB, UHDTV, LDM-BST-OFDM, Frequency Diversity, Extended Parity.

1. Introduction

Recently, next-generation DTTB(Digital Terrestrial Television Broadcasting) for UHDTV(Ultra-High Definition Television) is being researched and developed in the world[1,2]. The 4K terrestrial broadcasting systems are already standardized by DVB-T2(Digital Video Broadcasting - Terrestrial 2) and ATSC3.0(Advanced Television Systems Committee 3.0)[3-4]. In Japan, 4K · 8K commercial satellite broadcasting service starts in December 2018 and the 8K terrestrial broadcasting system is being researched and developed[5]. In the Japanese next-generation DTTB for UHDTV, the scheme that inherits and extends the current BST-OFDM(Band Segmented Transmission - Orthogonal Frequency Division Multiplexing) in ISDB-T(Integrated Service Digital Television Broadcasting-Terrestrial) is proposed[6]. BST-OFDM scheme is expected one of the good candidates that realize advanced and flexible broadcasting service for mobile and fixed receptions. However, it is not always possible to achieve the optimal band utilization using the BST-OFDM scheme because the fixed size segments are used.

In ATSC3.0, the non-orthogonal multiplexing scheme which is called LDM(Layered Division Multiplexing) is adopted[4]. The non-orthogonal scheme is widely known as NOMA(Non-Orthogonal Multiple Access) in the cellular multiple access schemes[7,8]. LDM can increase the transmission capacity and improve the power efficiency. Therefore, LDM-BST-OFDM scheme that combines LDM to the BST-OFDM scheme is proposed for the Japanese next-generation DTTB[9,10]. In the LDM-BST-OFDM scheme, transmitted symbols for mobile and fixed reception are multiplexed by LDM in the partial reception band. By combining the LDM scheme with the preliminary BST-OFDM scheme for UHDTV, more flexible frequency utilization can be achieved. In the next-generation DTTB for mobile reception, power boost of partial reception band is studied because it is necessary to improve robust against the time variance channel. Therefore, power boost of partial reception band for LDM-BST-OFDM is also studied in this paper. The performance of the proposed scheme is evaluated by computer simulations and the effectiveness of the proposed scheme for UHDTV fixed reception is shown.

Although LDM-BST-OFDM scheme is effective to improve the performance, dedicated receivers that can demodulate LDM multiplexed symbols are required. Therefore, LDM-BST-OFDM scheme which can decode the stream for fixed reception even if LDM multiplexed
symbols are not demodulated by using conventional fixed receivers is proposed\(^\text{11)}\). In this paper, LDM-BST-OFDM using frequency diversity scheme is shown in section 3 and LDM-BST-OFDM using extended parity in lower layer of LDM is shown in section 4. These proposed transmission scheme can decode the stream for fixed reception even in conventional fixed receivers which cannot demodulate LDM multiplexed symbols. On the other hand, the reception characteristics can be improved by using proposed fixed receivers which can demodulate LDM multiplexed symbols. In this paper, the reception characteristics of the proposed scheme is evaluated by computer simulations.

2. LDM-BST-OFDM Scheme

2.1 System Model

The preliminary specification of the Japanese next-generation DTTB scheme for UHDTV is proposed in the papers\(^\text{5,6)}\). In the preliminary specification, the central 9 segments can be used for partial reception and the stream for mobile reception is transmitted using the 1–9 segments out of the central 9 segments. If the number of the segments used by the stream for mobile reception is smaller than 9, the remaining segments are used for transmission of other streams such as the stream for UHDTV fixed reception. The example of typical use of the segments in the preliminary specification is shown in Fig.1. In Fig.1, the central 9 segments are used for transmission of the stream for mobile reception and the remaining 26 segments are used for transmission of the stream for UHDTV fixed reception. The number of total segments in the preliminary specification is increased as compared to current ISDB-T standard in order to realize more flexible frequency utilization. However, limitation due to the fixed size segment still exists in BST-OFDM scheme. Therefore, the aim of this paper is to increase frequency utilization and improve performances of UHDTV fixed reception by applying the LDM scheme to the central segments for partial reception. The structure of the segments of the proposed LDM-BST-OFDM scheme is shown in Fig.2. LDM-BST-OFDM scheme is based on the preliminary specification of the next-generation DTTB scheme and the part of the stream for UHDTV transmission is multiplexed to the segments that transmit the stream for mobile reception by using LDM. In the example shown in Fig.2, data symbols of the stream for mobile reception and the stream for UHDTV fixed reception are multiplexed by LDM in the central 9 segments for partial reception and the data symbols of fixed reception are also transmitted in the remaining 26 segments. In this case, the data symbols of the stream for mobile reception are assigned to the LDM upper layer and the data symbols of stream for UHDTV fixed reception are assigned to LDM lower layer. As the result, total 35 segments are used to transmit the stream for UHDTV fixed reception and increase of transmission rate or improving required CNR is expected in the transmission of the stream for UHDTV fixed reception.

\[
d_{LDM}(n) = \sqrt{1 - \alpha} d_M(n) + \sqrt{\alpha} d_F(n),
\]

where, \(n\) denotes the sub-carrier index. \(\alpha\) denotes the average LDM power ratio that is the average power of the lower layer symbols in the LDM symbols and injection level is defined as,

\[
IL = 10 \log_{10} \frac{\alpha}{1 - \alpha}.
\]

The received symbols, \(r_{LDM}(n)\), are shown as,
where, $H(n)$ and $z(n)$ denote the transfer function and additive Gaussian noise, respectively. If receivers can demodulate LDM symbols, transmitted symbols, $d_M(n)$, for the mobile reception can be demodulated by,

$$
\frac{r_{LDM}(n)}{H(n)\sqrt{1 - \alpha}} = d_M(n) + \frac{\sqrt{\alpha}}{\sqrt{1 - \alpha}} d_F(n) + \frac{z(n)}{H(n)\sqrt{1 - \alpha}}.
$$

After the demodulation of symbols for mobile reception, transmitted bit data can be obtained by decoding of coded symbols. Obtained transmitted bit data is used for generation of replica symbols. Replica symbols, $d_M'(n)$, are generated by re-coding and re-modulation of obtained bit data. In the demodulation of the symbols for fixed reception, demodulated symbols, $d_F(n)$, can be obtained by,

$$
\frac{r_{LDM}(n)}{H(n)\sqrt{1 - \alpha}} - \frac{\sqrt{1 - \alpha}}{\sqrt{\alpha}} d_M'(n) = d_F(n) + \frac{z(n)}{H(n)\sqrt{\alpha}}.
$$

After the demodulation of the symbols for fixed reception, demodulated symbols, $d_F(n)$, are decoded and transmitted bit data for fixed reception can be obtained.

In Fig.3, the detailed structure of the proposed LDM-BST-OFDM transmitter is shown. Before generating LDM symbols, the data symbols of the stream for mobile reception (LDM upper layer) are generated in the same manner as the preliminary specification of the Japanese next-generation DTTB scheme. In this paper, the BICM(Bit-Interleaved Coded Modulation) encoder is used to generate NU-QAM symbols. The generated data symbols in each stream are first interleaved over the corresponding number of segments wise (“Symbol Interleave 1”). In the stream for fixed reception, the output after “Symbol Interleave 1” is de-multiplexed to generate 9 segments of symbols that are transmitted in the central 9 segments and the symbols that are transmitted in the remaining 26 segments. Then, LDM symbols are generated using 9 segments from stream for fixed reception after de-multiplexing and 1~9 segments from stream for mobile reception. The symbols in the 1~9 segments in the stream for mobile reception are combined with the symbols in the first 1~9 segments from the stream for fixed reception using (1) to generated 1~9 segments that consist of LDM symbols. After generating LDM symbols, the data symbols in the central 9 segments are interleaved again (“Symbol Interleave 2”). After interleaving, central 9 segments and remaining segments are combined to generate the OFDM frame and mapped in the frequency domain using IFFT.

In Fig.4, the structure of the mobile receiver for LDM-BST-OFDM is shown. In this receiver, simple implementation is possible because the mobile receiver should only demodulate the central 9 segments without considering the multiplexed symbols from stream for fixed reception. In Fig.5, the structure of the UHDTV fixed receiver for LDM-BST-OFDM is shown. In this case, the stream for mobile reception is first decoded and the stream for fixed reception is decoded using the decoded data of the stream for mobile reception. Decoding of the stream for mobile reception is performed in the same manner as the mobile receiver case in Fig.4 and BICM encoding is re-applied against the decoded data to generate the replica symbols of stream for mobile reception (LDM upper layer symbols). Until the replica symbols are generated, LDM symbols are buffered in “Buffering1”. The generated replica symbols are subtracted from the received LDM symbols to generate the symbols of the stream for fixed reception.
Fig. 4 The structure of the mobile receiver for LDM-BST-OFDM.

Fig. 5 The structure of the UHDTV fixed receiver for LDM-BST-OFDM.

(LDM lower layer symbols). The generated symbols are then multiplexed with the other non-LDM symbols which are buffered in "Buffering2" and de-interleaving is performed over whole segments wise. Finally, the BICM decoder is applied to the de-interleaved symbols to decode the data of stream for fixed reception.

2.2 Computer Simulations

From Ref.(11), it is known that the interference of the LDM multiplexed symbols for fixed reception is approximated to Gaussian noise when the symbols for mobile reception are demodulated, and the CNR degradation of Rayleigh fading in LDM-BST-OFDM is almost equal to that in BST-OFDM from past simulations. Therefore, the performance of the proposed LDM-BST-OFDM scheme under the AWGN(Additive White Gaussian Noise) channel is evaluated by computer simulations in this paper. In the simulations, the parameters shown in Table 1 are assumed. In this paper, it is assumed that the average powers of all data carriers are equivalent to 1.0 and the average powers of scattered pilot symbols are equivalent to 4/3. In this case, layouts of the scattered pilot symbols are equivalent in stream for mobile reception and fixed reception to perform precise channel estimation against LDM symbols. The maximum number of iterations in LDPC decoding in the receivers is assumed to be 50 in this paper.

Fig.6 and Fig.7 show the comparison of the conventional BST-OFDM scheme in the preliminary specification of the Japanese next-generation DTTB scheme and the proposed LDM-BST-OFDM scheme. In Fig.6 and Fig.7, the achieved bit rates in the stream for mobile and UHDTV fixed reception respectively against the required CNR at 10^{-6} BER(Bit Error Rate) are evaluated changing the coding rate of LDPC in BICM. In the conventional BST-OFDM scheme, the stream for mobile and fixed reception are transmitted using 9 or 7 or 5 segments and remaining 26 or 28 or 30 segments respectively without performing LDM. In this paper, interleaving between streams for mobile and fixed reception in partial reception band is not adopted. In the proposed LDM-BST-OFDM scheme, against the central 9 segments that transmits the stream for mobile reception, the 9 segments of the stream for fixed reception are also LDM multiplexed in addition to the 26 segments other than the central 9 segments and

| Table 1 Simulation parameters |
|--------------------------------|
| Number of Carriers per Segment | 864 |
| Scattered Pilot Pattern         | 12 \times 2 |
| Number of Data Carriers per Segment | 792 |
| Number of Segments             | 35 |
| Number of Carriers              | 30241 = 864 \times 35 + 1 |
| Injection Level, IL             | -20 \sim -6 dB |
| Modulation and Coding Parameters of the Layer for Mobile Reception | |
| Number of Segments             | 5 \sim 9 |
| LDPC Code Length                | 69120 |
| LDPC Code Rate                  | 5/16 \sim 14/16 |
| Number of Iterations            | 50 |
| Modulation and Coding Parameters of the Layer for Fixed Reception | |
| Number of Segments              | 26 \sim 30, 35 |
| LDPC Code Length                | 69120 |
| LDPC Code Rate                  | 6/16 \sim 14/16 |
| Number of Iterations            | 50 |
| Symbol Modulation Scheme        | Non-Uniform |
| Scheme                          | 16QAM |
| Modulation and Coding Parameters of the Layer for Fixed Reception | |
| Number of Segments              | 26 \sim 30, 35 |
| LDPC Code Length                | 69120 |
| LDPC Code Rate                  | 6/16 \sim 14/16 |
| Number of Iterations            | 50 |
| Symbol Modulation Scheme        | Non-Uniform |
| Scheme                          | 4096QAM |
the equivalently 35 segments are used to transmit the stream for fixed reception. Although, in the case of the conventional BST-OFDM scheme (9-26seg), maximum bit rate limited to below 42.5Mbps even if the highest coding rate is used, the proposed LDM-BST-OFDM scheme can achieve maximum bit rate over 55Mbps from Fig. 7. This is considered to very advantageous in case of 8K transmission that requires high quality. Table 2 and Table 3 show the required CNR in BST-OFDM and LDM-BST-OFDM respectively if bit rate of mobile reception is achieved 2Mbps and that of fixed reception is achieved 35Mbps. In Table 2 and Table 3, “Total” denotes the required CNR of mobile reception plus that of fixed reception. From Table 2 and Table 3, total required CNR by approximately 1.7dB for LDM-BST-OFDM in which injection level is -10dB can be improved as compared to BST-OFDM (9-26seg).

Table 2 Required CNR if bit rate of mobile reception is achieved 2Mbps and that of fixed reception is achieved 35Mbps in BST-OFDM.

| Segment | Mobile CNR | Fixed CNR | Total CNR |
|---------|------------|-----------|-----------|
| 9-26seg | 3.8dB (6/16) | 28.5dB (12/16) | 32.3dB |
| 7-28seg | 6.0dB (8/16) | 26.3dB (11/16) | 32.3dB |
| 5-30seg | 8.9dB (10/16) | 24.1dB (10/16) | 33.0dB |

Table 3 Required CNR if bit rate of mobile reception is achieved 2Mbps and that of fixed reception is achieved 35Mbps in LDM-BST-OFDM.

| Injection Level | Mobile CNR | Fixed CNR | Total CNR |
|-----------------|------------|-----------|-----------|
| -10dB           | 5.4dB (6/16) | 25.2dB (9/16) | 30.6dB |
| -15dB           | 4.2dB (6/16) | 27.0dB (9/16) | 31.2dB |
| -20dB           | 4.0dB (6/16) | 29.5dB (9/16) | 33.5dB |

Fig. 8 shows the required CNR of stream for mobile and fixed reception if injection level is changed in the range of -20dB to -6dB.

Fig.8 shows the required CNR of stream for mobile and fixed reception if the injection level is changed in the range of -20dB to -6dB. The higher the injection level is, the better the performance of stream for fixed reception is. On the other hand, the performance of stream for mobile reception is degraded. Total improvement of required CNR is maximum 1.7dB if injection level is -11dB. As shown in these results, if slight degra-
dation of the required CNR in the stream for mobile reception is allowed, the proposed scheme is expected to be able to achieve more efficient transmission in the stream for UHDTV fixed reception.

In the Japanese next-generation DTTB for mobile reception, power boost of partial reception band is studied because it is necessary to improve robust against the time variant channel. Therefore, power boost of partial reception band for LDM-BST-OFDM is also studied in this paper. Fig.9 and Fig.10 show the required CNR of the stream for mobile and fixed reception respectively if the boost level is changed in the range of 0dB to 5dB and injection level is changed in the range of -20dB to -6dB. In this paper, boost level is defined as the power of central 9 segments and the average power of the 35 segments is kept at 1.0. From Fig.9, required CNR of mobile reception in both BST-OFDM and LDM-BST-OFDM is improved if the higher boost level is employed. From Fig.10, required CNR of fixed reception in BST-OFDM is degraded if the higher boost level is employed. On the other hand, required CNR of fixed reception in LDM-BST-OFDM is minimized if the boost level is 1.0dB or 2.0dB because LDM multiplexed symbols for fixed reception in partial reception band is also boosted. If the partial reception band is boosted, the required CNR of LDM-BST-OFDM scheme is improved as compared to that of BST-OFDM scheme. Fig.11 shows the required CNR of the stream for mobile reception plus that of fixed reception if the boost level and injection level are changed. From Fig.11, total required CNR of BST-OFDM is 30.0dB if the boost level is 3.0dB. Total required CNR of LDM-BST-OFDM is 24.5dB if the boost level is 4.0dB and injection level is -12.0dB. From these results, total improvement of required CNR in LDM-BST-OFDM is 5.5dB as compared to BST-OFDM if the boost level is considered in the broadcasting system.
3. LDM-BST-OFDM Scheme using Frequency Diversity Scheme

3.1 Proposed Maximum Ratio Combining

Although LDM-BST-OFDM scheme is effective to improve the performance as shown in section 2, dedicated receivers that can demodulate LDM multiplexed symbols are required if the LDM scheme is applied to the broadcasting system. Therefore, LDM-BST-OFDM using frequency diversity scheme is proposed in this paper. Frequency diversity is a method for improving the reception characteristics by using multiple received symbols which are transmitted in several frequency channels. The transmitted symbols, \( d(n) \), are received as,

\[
\begin{align*}
    r(n) &= H(n)d(n) + z(n), \\
    r(n') &= H(n')d(n) + z(n'),
\end{align*}
\]

where \( n \) and \( n' \) denote the sub-carrier index. If the channel estimation is ideal, these received symbols are zero-forcing equalized as,

\[
\begin{align*}
    \frac{r(n)}{H(n)} &= d(n) + \frac{z(n)}{H(n)}, \\
    \frac{r(n')}{H(n')} &= d(n) + \frac{z(n')}{H(n')},
\end{align*}
\]

In this paper, MRC is used as a method of diversity combining. In the MRC method, each received symbol is multiplied by a weight, \( w(n) \), that maximizes the SNR(Signal to Noise Ratio) of the composite symbol, and these symbols are added together. MRC is known as optimum combiner for independent AWGN channels. The composite symbols, \( r_{mrc}(n) \), are shown as,

\[
\begin{align*}
    r_{mrc}(n) &= w(n) \frac{r(n)}{H(n)} + w(n') \frac{r(n')}{H(n')} \\
    &= w(n) \frac{r(n)}{H(n)} + \{1 - w(n)\} \frac{r(n')}{H(n')},
\end{align*}
\]

In order to maximize the SNR of the composite symbols, a weight that minimizes the power of the additive noise component is searched as follow,

\[
\begin{align*}
    w^2(n) \sigma^2_n |H(n)|^2 + (1 - w(n))^2 \sigma^2_n |H(n')|^2 \\
    = \left( \frac{\sigma^2_n}{|H(n)|^2} + \frac{\sigma^2_n}{|H(n')|^2} \right) w^2(n) \\
    - 2w(n) \sigma^2_n |H(n')|^2 + \sigma^2_n |H(n')|^2,
\end{align*}
\]

where, \( \sigma^2_n \) denotes the variances of the additive noise. From Eq.(12), an optimized weight, \( w_{opt}(n) \), is determined as,

\[
w_{opt}(n) = \frac{|H(n)|^2}{|H(n)|^2 + |H(n')|^2}, \quad (12)
\]

In addition, the power of additive noise component of composite symbols if the optimized weight is used is shown as follow,

\[
\sigma^2_{mrc}(n) = \frac{\sigma^2_n}{|H(n)|^2 + |H(n')|^2}. \quad (14)
\]

Generally, MRC is performed on the received symbols before sub-carrier demodulation. In contrast, a method to perform MRC on the received symbols after sub-carrier demodulation is proposed in this paper. By performing MRC on the received symbols after sub-carrier demodulation, the sub-carrier modulation scheme can be changed when the transmission symbols are generated. The received symbols after zero-forcing equalization as shown in Eq.(8) and Eq.(9) are soft de-mapped and LLRs(Log-Likelihood Ratio) are obtained as,

\[
\begin{align*}
    llr(n) &= \frac{2r(n)/|H(n)|}{\sigma^2/|H(n)|} = \frac{2|H(n)|^2 r(n)}{\sigma^2 H(n)}, \quad (15)
    llr(n') &= \frac{2r(n')/|H(n')|}{\sigma^2/|H(n')|} = \frac{2|H(n')|^2 r(n')}{\sigma^2 H(n')}. \quad (16)
\end{align*}
\]

In addition, the LLR of the optimized composite symbols, \( r_{mrc}(n) \), which are obtained by substituting the Eq.(12) and Eq.(13) into Eq.(10) are determined as,

\[
\begin{align*}
    llr_{mrc}(n) &= \frac{2r_{mrc}(n)}{\sigma^2_{mrc}(n)} \sigma^2_{mrc}(n) \\
    &= \frac{2[w_{opt}(n)r(n)/H(n) + w_{opt}(n')r(n')/H(n')]}{\sigma^2_{mrc}(n)} \\
    &= \frac{2[H(n)]^2 r(n)/H(n) + [H(n')^2 r(n')/H(n')]}{\sigma^2_{mrc}(n)} \\
    &= \frac{2[H(n)]^2 r(n)}{\sigma^2 H(n)} + \frac{2[H(n')^2 r(n')}{\sigma^2 H(n')}, \quad (17)
\end{align*}
\]

From Eq.(17), LLR of the composite symbols are represented by the sum of LLRs of the received symbols
which are obtained after sub-carrier demodulation.

In this paper, the reception characteristics of proposed MRC method under AWGN channel is evaluated by computer simulations. In this section, LDPC code whose length and rate are 69120 and 10/16 respectively is used and the number of iterations is 50. The number of sub-carriers is 32K. Fig.12 shows the BER characteristics of the proposed MRC method. In Fig.12, “MRC before demodulation” denotes the BER of the conventional method where MRC is performed on the received symbols before sub-carrier demodulation. “MRC after demodulation” denotes the BER of the proposed method where MRC is performed on the received symbols after sub-carrier demodulation. From Fig.12, the required CNR at 10^{-6} BER is improved by approximately 3dB by using MRC. If the sub-carrier modulation scheme is QPSK, BER of proposed MRC method is as same as that of conventional MRC method. However, if the other sub-carrier modulation schemes are used, BER of proposed MRC method is deteriorated as compared to that of conventional MRC method.

![Fig. 12 BER characteristics of the proposed MRC method.](image1)

3.2 System Model

In the proposed MRC method that is performed on the received symbols after sub-carrier demodulation, it is not necessary to match the sub-carrier modulation scheme between multiple symbols. For example, in case that the sub-carrier modulation scheme of one symbols is NU-4096QAM, the sub-carrier modulation scheme of the other symbols can be changed to NU-1024QAM if the number of bits that can be shared in MRC is 10/12. Fig.13 shows the BER characteristics if the sub-carrier modulation scheme of one symbols is fixed at NU-4096QAM and the other sub-carrier modulation scheme is changed between QPSK and NU-4096QAM. In the frequency diversity scheme, bit rate is constant because the sub-carrier modulation scheme of one symbols is fixed. From Fig.13, if one symbols employs NU-4096QAM and the other symbols employs NU-256QAM where the number of shared bits of MRC is 8/12, the required CNR is improved by approximately 6 dB as compared to the case where both symbols employ NU-4096QAM. Therefore, the required CNR of the proposed MRC scheme can be improved maximum 9dB as compared to the case where MRC is not used. From Fig.13, it is also confirmed that the reception characteristics in the case where sub-carrier modulation scheme is QPSK to NU-64QAM deteriorate because the number of bits that can be shared is decreased.

![Fig. 13 BER characteristics of the proposed MRC method if the sub-carrier modulation scheme of one symbols is changed between QPSK and NU-4096QAM.](image2)
mitted in the upper layer. LDM multiplexed symbols are processed differently depending on the capability of the fixed receivers. The conventional fixed receivers that do not support LDM demodulation demodulate the fixed symbols without the LDM multiplexed symbols in the lower layer of the LDM band. On the other hand, the proposed receivers that support LDM demodulation demodulate LDM multiplexed symbols in partial reception band and use proposed frequency diversity. Therefore, reception characteristics of the stream for fixed reception can be improved by using proposed fixed receivers.

### 3.3 Computer Simulations

In this section, the reception characteristics of the proposed scheme under the AWGN channel is evaluated by computer simulations. Table 4 shows simulation parameters that are used in section 3 and section 4.

| Table 4 | Simulation parameters |
|---------|-----------------------|
| Number of Carriers per Segment | 864 |
| Scattered Pilot Pattern | 12 × 2 |
| Number of Segments | 35 |
| Number of Carriers | \(30241 = 864 \times 35 + 1\) |
| Injection Level, IL | -20 ∼ -6dB |
| Modulation and Coding Parameters of the Layer for Mobile Reception | |
| Number of Segments | 9 |
| LDPC Code Length | 69120 |
| LDPC Code Rate | 6/16 |
| Symbol Modulation Scheme | Non-Uniform 64QAM |
| Number of Segments | 26 ∼ 35 |
| LDPC Code Length | 69120 |
| LDPC Code Rate | 10/16 |
| Symbol Modulation Scheme | Non-Uniform 4096QAM |
| Number of Iterations | 50 |
| Modulation Scheme for duplicated bits | 16QAM |

Fig. 15 shows BER characteristics of the stream for fixed reception under the AWGN channel. In the legend of Fig. 15, "BST-OFDM" denotes the BER characteristics under the case of using conventional fixed receivers that do not support LDM demodulation in the proposed LDM-BST-OFDM using frequency diversity scheme. This reception characteristics is as same as that of the conventional BST-OFDM scheme in which LDM is not applied. "Frequency Diversity Scheme" denotes the performances under the case of using proposed fixed receivers that support LDM demodulation in the proposed LDM-BST-OFDM using frequency diversity scheme. In the frequency diversity scheme, symbol modulation scheme for duplicated symbols in lower layer of LDM-BST-OFDM is changed. As shown in Fig. 15, the required CNR of approximately 1.2dB at fixed reception can be improved by frequency diversity scheme if injection level is -15dB and NU-16QAM is employed.

![Fig. 14](image) The structure of the proposed transmitter in the frequency diversity scheme.

![Fig. 15](image) BER characteristics of the stream for fixed reception in the frequency diversity scheme under the AWGN channel.
4. LDM-BST-OFDM using Extended Parity in Lower Layer of LDM

4.1 Extended Parity Generation

In this section, LDM-BST-OFDM using extended parity in lower layer of LDM is proposed as another LDM-BST-OFDM scheme which can decode the stream for fixed reception by using conventional fixed receivers. In this scheme for fixed reception, the parity-check matrix of LDPC code whose length is 69120 is extended\(^{13}\). The extended parity bits are generated by the extended parity-check matrix and modulated. After that, the modulated symbols are LDM multiplexed with the symbols for mobile reception. The proposed scheme can realize to decode the stream for fixed reception even if the LDM multiplexed symbols cannot be demodulated because these LDM multiplexed symbols are only extended parity bits.

In the proposed extended parity scheme, the parity-check matrix of the conventional LDPC code (type B) whose length and rate are 69120 and 10/16 respectively is extended as shown in Fig.16. In Fig.16, \(K\) denotes payload length. \(M_1\) and \(M_2\) denote parity length before extending and extended parity length, respectively. The elements of "1" in the matrix, \(A\), is scattered and the structure of parity matrix, \(B\), is staircase. The matrix, \(C\), is added to extend the conventional parity-check matrix and column weight distribution of the matrix, \(C\), is searched exhaustively for better reception characteristics. In this paper, the conventional LDPC code whose length and rate are 69120 and 10/16 respectively is extended by 4320 bits and proposed LDPC code whose length and rate are 73440 and 10/17 respectively is generated.

Fig.16 Method of extending the parity-check matrix.

The performance of the proposed LDPC code under AWGN is shown in Fig.17. In Fig.17, "Code Length = 69120" denotes the BER characteristics if the conventional LDPC code whose length and rate are 69120 and 10/16 respectively is used. "Code Length = 73440" denotes the BER characteristics if the proposed LDPC code whose length and rate are 73440 and 10/17 respectively is used. From Fig.17, the required CNR of the proposed LDPC code is improved by approximately 0.5dB as compared to the conventional LDPC code.

4.2 System Model

Fig.18 shows the block diagram of the proposed transmitter in the proposed extended parity scheme. In the stream for mobile reception, the conventional LDPC code whose length and rate are 69120 and 10/16 respectively is employed. In the stream for fixed reception, the proposed LDPC code whose length and rate are 73440 and 10/17 respectively is employed. The extended parity bits which are made by proposed LDPC code are modulated by NU-QAM and these symbols are LDM multiplexed with the symbols for mobile reception. After that, the LDM multiplexed symbols are transmitted in the the partial reception band of the LDM-BST-OFDM scheme. The LDM multiplexed symbols are processed differently depending on the capability of the fixed receivers. The conventional fixed receivers that do not support LDM demodulation cannot demodulate symbols for the fixed reception in lower layer of the LDM band. Therefore, conventional LDPC decoder which can decode the LDPC code whose length and rate are 69120 and 10/16 respectively is used in this receivers. On the other hand, the proposed fixed receivers that support LDM demodulation can demodulate extended parity in lower layer of the LDM band. Therefore, proposed LDPC decoder which can decode the LDPC code whose length and rate are 73440 and 10/17 respectively is used in this receivers. Using the
proposed receiver, performance of the stream for fixed reception can be improved by LDM.

4.3 Computer Simulations

In this section, the reception characteristics of the proposed scheme under the AWGN channel is evaluated by computer simulations. The simulation parameters that are considered in this section is as same as that in section 3 which is shown in Table 4. Fig.19 shows BER characteristics of the stream for fixed reception under the AWGN channel. In this simulations, symbol modulation scheme for extended parity bits which are transmitted in lower layer of LDM is changed NU-16QAM and NU-4096QAM. If NU-4096QAM is employed as the symbol modulation scheme for extended parity bits, the extended parity bits are multiplexed by LDM within only about 2 segments of the partial reception band. On the other hand, approximately 9 segments of the partial reception band are used for LDM if NU-16QAM is employed. "BST-OFDM" denotes the BER characteristics under the case of using conventional fixed receivers that do not support LDM demodulation in the proposed LDM-BST-OFDM using extended parity in lower layer of LDM. This reception characteristics is as same as that of the conventional BST-OFDM scheme in which LDM is not applied. "Extended Parity Scheme" denotes the performances under the case of using proposed fixed receivers that support LDM demodulation in the proposed LDM-BST-OFDM scheme. As shown in Fig.19, the required CNR of approximately 1.4dB at fixed reception can be improved by extended parity scheme if injection level is -15dB and NU-16QAM is employed. The configuration of receivers in extended parity scheme is more complex than that in frequency diversity scheme. However, required CNR of extended parity scheme is improved approximately 0.2dB as compared to that of frequency diversity scheme.

Fig.20 shows the required CNR of stream for mobile reception and fixed reception under the AWGN channel if the symbol modulation scheme for extended parity bits which are transmitted in lower layer of LDM and injection level are changed. As shown in Fig.20, the required CNR of stream for fixed reception can be improved approximately by maximum 1.7dB if the deterioration of required CNR of the stream for mobile reception is allowed. Under the case that the required CNR of the stream for mobile reception is determined, it is possible to select optimal LDM parameters such as the sub-carrier modulation scheme.

Fig.21 shows the total improvement of required CNR (improvement in mobile reception + improvement in fixed reception) as compared to the BST-OFDM scheme if the symbol modulation scheme for extended parity
bits and injection level are changed. From Fig.21, total improvement of required CNR is over 0.9dB if injection level is -14.0dB and NU-16QAM is employed.

5. Conclusions

In this paper, lower layer signal design of LDM-BST-OFDM for the next-generation DTTB is studied. As the results of computer simulations, proposed LDM-BST-OFDM scheme can increase frequency utilization and improve reception characteristics of the fixed reception. In addition, it is confirmed that LDM-BST-OFDM scheme is more effective if power boost of partial reception band is considered. Furthermore, LDM-BST-OFDM scheme which can decode the stream for fixed reception even if symbols multiplexed by LDM are not demodulated is proposed. As the results of computer simulations, conventional receivers can decode the fixed symbols and proposed receivers improve the performance of the fixed reception by the proposed scheme.

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