MLD-based MU-MIMO Detection Scheme for LTE Downlink

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Abstract – **Currently Multi-User MIMO (MU-MIMO) attracts attention to improve frequency usage efficiency. When using Maximum Likelihood Detection (MLD) for MU-MIMO detection, we need to know the modulation type of the transmitted signals. However in 3rd Generation Partnership Project (3GPP) Long Term Evolution (LTE) system, the user to whom MU-MIMO is applied cannot be informed about the modulation type of the signals for a multiplexed interference user. Therefore, linear filters such as Zero Forcing (ZF) and Minimum Mean Square Error (MMSE) are typically applied. In this paper, we propose an MLD-based MU-MIMO detection method with modulation-type estimation. In this method, we perform MLD by assuming possible modulation types to calculate metrics, and by comparing them, we determine the modulation type of the signals for an interference user. From the computer simulation results, we find that the proposed method can obtain better performance than MMSE with a slight increase in complexity from SU-MIMO detection.**

I. Introduction

In recent years, demands on high rate wireless communication have increased. Then MIMO (Multiple-Input Multiple-Output) techniques, especially MIMO detection methods, have been studied extensively. There are many results about MIMO detection, such as ZF (Zero Forcing), MMSE (Minimum Mean Squared Error), and MLD (Maximum Likelihood Detection). MLD can achieve the best performance but needs high complexity; thus, there are many studies about the complexity reduction methods [1]. On the other hand, ZF and MMSE are attractive because of their low complexity [2].

At first, the mainstream method was the method called "SU-MIMO" in which signals for the same user are transmitted from different transmission antennas to improve the throughput. However, the effect is limited when fading correlations among antennas are high. Therefore, "MU-MIMO" techniques attract attention to improve the frequency usage efficiency. Since signals for different users are scheduled on different transmission antennas, the scheduler has the flexibility of user scheduling. In LTE (Long Term Evaluation) system whose standardization is proceeding on 3GPP (3rd Generation Partnership Project), MU-MIMO is specified in the downlink [3].

In MU-MIMO systems, generally, beamforming has been applied to the transmitted signals according to the channel state information fed back by UEs in order to reduce the interference from the multiplexed users. However, owing to the quantization error of channel state information and feedback delay, some interference will exist. MIMO detection methods are employed at the receiver to reduce the interference and improve the system performance.

In many studies about MU-MIMO, MMSE is used at the receiver because it does not need the information about the modulation type [4] [5]. Even if MLD is used in order to improve the performance, the modulation type of the signals for an interference user is assumed to be known to the receiver [6]. However, in LTE system, it will not be informed to the receiver. Therefore, MMSE have been typically assumed as a reference receiver for MU-MIMO detection [7]. When MLD is used for MU-MIMO detection, the modulation type for an interference user must be determined by some method. Although there are some research papers about modulation-type estimation method [8] [9], there are no reports that apply it to MU-MIMO.

In this paper, we propose an MLD-based MU-MIMO detection method using modulation-type estimation for interference user. Modulation-type estimation process is characterized by using MLD that assumes multiple modulation types for an interference user and estimating the optimum modulation type by using the distance obtained in each MLD process. By evaluating the throughput performance with computer simulation, we can find that the proposed method can achieve 70% throughput at 0.95–5.97 dB lower SNR than that in MMSE detection.

II. System Model

We consider systems with two transmission antennas at the base station and two different UEs (user equipments), which both have two receiving antennas. In this paper, the user to whom the desirable signals are transmitted from one transmission antenna is defined as "target user" and the one to whom undesirable signals are transmitted from the other antenna is defined as "interference user."

The transmission format of LTE downlink is described in [10]. A resource element (RE) is defined by one subcarrier in frequency domain and one OFDM symbol in time domain. One OFDM symbol consists of N_{sc} subcarriers. The subframe is defined by 14 consecutive OFDM symbols in time domain and it is equivalent to 1ms. A resource block (RB) is a set of REs in 12 consecutive subcarriers of one subframe. A reference signal (RS) is mapped in the discrete REs according to the common awareness between the base station and UEs. A control channel is mapped on the leading several OFDM symbols in the subframe and a data channel is mapped on the REs on which the RS and control channel are not mapped. The RE mapping format is shown in Fig.1.

We consider the MU-MIMO system shown in Fig.2. Assuming "A" as the transmitted signal for the target user and "B" as that for the interference user, the received signal vector $\mathbf{y}$ for the target user is given by:

$$\mathbf{y} = \mathbf{H}\mathbf{x} + \mathbf{n},$$

$$\mathbf{y} = \begin{pmatrix} y_1 \\ y_2 \end{pmatrix}, \quad \mathbf{H} = \begin{pmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{pmatrix}, \quad \mathbf{x} = \begin{pmatrix} A \\ B \end{pmatrix}, \quad \mathbf{n} = \begin{pmatrix} n_1 \\ n_2 \end{pmatrix},$$

where $\mathbf{H} \in \mathbb{C}^{2\times 2}$ is the channel matrix, $\mathbf{n} \in \mathbb{C}^2$ is the noise vector, and $\mathbf{x} \in \mathbb{C}^2$ is the transmitted signal vector, including both signals for the target and for the interference user. In the UE of the target user, the MU-MIMO detection process is performed by using the received signals and channel matrix, and then the estimated signals

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for the target user are obtained. In this paper, the channel matrix is assumed to be a priori known at the UEs.

When we use MMSE for the MU-MIMO detection, the estimated signal is obtained by multiplying the received signal vector by the weight matrix **W** for each RE as follows:

$$\mathbf{W}(l) = \mathbf{H}(l)^{\mathrm{H}}\left(\mathbf{H}(l)\mathbf{H}(l)^{\mathrm{H}} + \sigma^2\mathbf{I}\right)^{-1},$$

$$\tilde{\mathbf{x}}(l) = \mathbf{W}(l)^{\mathrm{H}}\mathbf{y}(l),$$

where l is the index of REs, σ^2 is the average noise power and $\mathbf{H}(l)^{\mathrm{H}}$ is the Hermitian transpose of $\mathbf{H}(l)$.

When we use MLD for the MU-MIMO detection, the set of signals ($A_{\min}$, $B_{\min}$) that minimizes the distance between the received signal and the replica for the set of transmitted signals (A, B) defined as

$$d(l, A, B) = \left\|\mathbf{y}(l) - \mathbf{H}(l)\mathbf{x}(l)\right\|^2$$

$$= \left|y_1 - h_{11}A - h_{12}B\right|^2 + \left|y_2 - h_{21}A - h_{22}B\right|^2$$

is searched and the minimum distance $d_{\min}(l)$ is calculated for each RE as follows:

$$(A_{\min}, B_{\min}) = \underset{A \in S_{mod1}, B \in S_{mod2}}{\arg\min}\ d(l, A, B),$$

$$d_{\min}(l) = d(l, A_{\min}, B_{\min}),$$

where *mod1* and *mod2* are the modulation types from each transmission antenna, and S_{mod1} and S_{mod2} are the sets of possible transmitted signals from each antenna. In these processes, we need to know the modulation type. However, in LTE system, the modulation type of the signals for the interference user is not informed to the receiver of the target user. Therefore we have to determine it by some method.

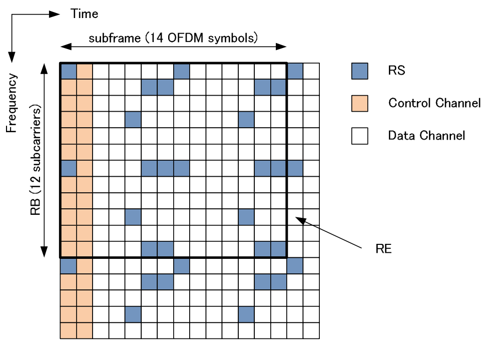

Fig.1 RE mapping format

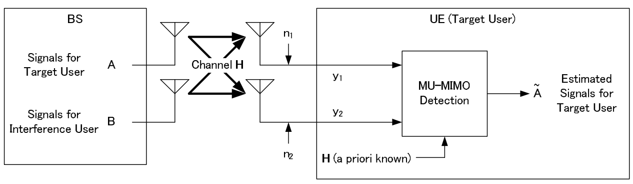

Fig.2 MU-MIMO system

III. Problem in MU-MIMO Detection with MLD

In the initial investigation, we evaluate the BER performance of the transmitted signals for the target user, in which MMSE and MLD are used for the MU-MIMO detection. The modulation type of the transmitted signals for the target user is QPSK and that for the interference user is 64QAM. When performing MLD, the modulation type for the interference user is assumed as any one of the possible modulation types (in this paper, QPSK, 16QAM, or 64QAM). The transmission format is based on LTE system [10]. The number of subcarriers (N_{sc}) and that of OFDM symbols for the control channel are assumed to be 300 and 2, respectively. Then, the number of REs for the data channel in the subframe is 3000, excepting the control channel and RS. The data channel for the target user and interference user is assigned to all RBs (25 RBs) in the subframe. The channel model is Extended Pedestrian A (EPA) model defined in [11] and the maximum Doppler frequency is 5 Hz. The simulation results are shown in Fig.3. SNR is defined as the ratio of the received signal power for the target user to the noise power in each receive antenna.

If the assumed modulation type is same as that of the transmitted signals for the interference user, the BER performance of MLD is superior to that of MMSE, as is the case with SU-MIMO. However if the assumed modulation type is wrong, the performance degrades drastically because of the difference in constellation between the assumed modulation type and the transmitted modulation type. Therefore, we consider that if we can estimate the modulation type for the interference user properly, we can obtain better performance than MMSE by using MLD with the estimated modulation type.

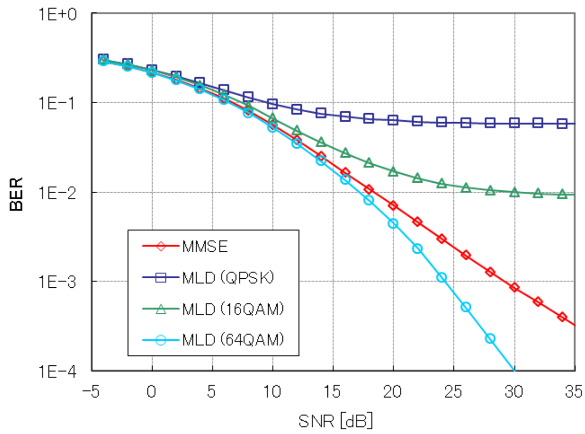

Fig.3 BER performance

IV. Modulation-Type Estimation of Interference User

In the proposed interference-user modulation-type estimation process, we perform MLD by assuming three kinds of modulation types (QPSK, 16QAM, 64QAM) as the modulation type for the interference user to calculate the metrics. When the modulation type for the target user is *mod1* and that for the interference user is assumed to be any one of the three modulation types, *mod2*, the minimum distances for each modulation type for the interference user are described as follows:

$$(A_{\min}^{(mod1,mod2)}, B_{\min}^{(mod1,mod2)}) = \underset{A \in S_{mod1}, B \in S_{mod2}}{\arg\min}\ d(l, A, B),$$

$$d_{\min}^{(mod1,mod2)}(l) = d(l, A_{\min}^{(mod1,mod2)}, B_{\min}^{(mod1,mod2)})$$

$$\text{for } mod2 = \text{QPSK, 16QAM, 64QAM.}$$

Then, the metrics for modulation-type estimation are calculated by averaging the minimum distances over N_{ave} REs and multiplying the coefficients that differ among the assumed modulation types:

$$\bar{d}_{(mod1,mod2)} = C_{mod2}\sum_{l=1}^{N_{ave}} d_{\min}^{(mod1,mod2)}(l)$$

$$\text{for } mod2 = \text{QPSK, 16QAM, 64QAM.}$$

Then, the modulation type that minimizes the metric is selected as the estimated modulation type for the interference user:

$$mod2_{est} = \underset{mod2 \in \{QPSK, 16QAM, 64QAM\}}{\arg\min} \ \bar{d}_{(mod1, mod2)}.$$

In LTE system, the multiplexed interference users may differ from RB to RB. Therefore, the modulation types for the interference users should be estimated with respect to each RB.

We investigate the metrics with the simulation under the same conditions described in Section III. Since the maximum number of REs that can be assigned a data channel in one RB is 120, we assume N_{ave} = 120 in order to obtain the best performance by using the full resource. The data channel for the target user and the interference user is assigned to all RBs, and the modulation types for each RB is the same. The metrics are averaged over 1000 subframes. The coefficients C_{QPSK}, C_{16QAM} and C_{64QAM} are all set to 1.0. The average metrics are shown in Figs.4, 5, and 6. The metric is normalized by the received power of the signals for the target user.

Since the tendency of the metrics does not depend on the modulation type for the target user, we show the metrics for only the case in which the modulation type for the target user is 64QAM and that for the interference user is QPSK, 16QAM, and 64QAM. From these figures, we can find that the metric for 64QAM is relatively smaller than the other metrics at a lower SNR because of the high density of constellation. Therefore, 64QAM tends to be selected at a lower SNR while the correct modulation types are selected at a higher SNR.

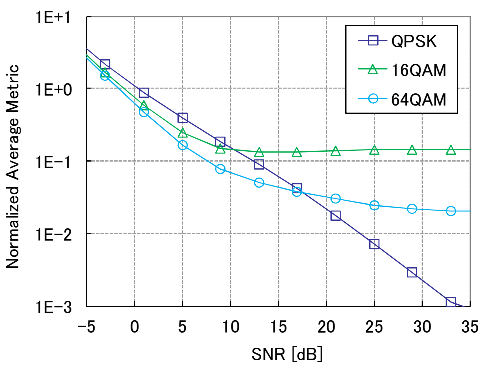

Fig.4 Average metric
(Target user: 64QAM; Interference user: QPSK)

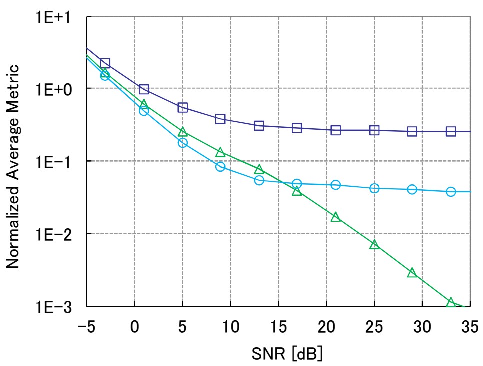

Fig.5 Average metric
(Target user: 64QAM; Interference user: 16QAM)

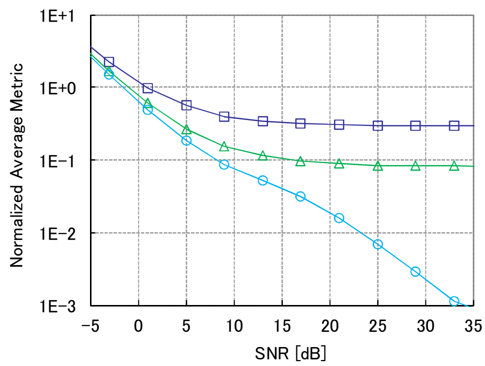

Fig.6 Average metric
(Target user: 64QAM; Interference user: 64QAM)

Next, we consider adjusting the coefficients C_{QPSK}, C_{16QAM}, and C_{64QAM} in order to improve the accuracy rates at a lower SNR. Because in the low-SNR region (lower than 5 dB), the estimation error does not affect so much on the BER performance as shown in Fig.3, we should adjust them so that the metric for the assumed modulation type becomes smaller than others in the middle-SNR region (5–20dB). Since only the ratio between the three coefficients affects the accuracy of the modulation-type estimation, we set C_{QPSK} = 1.0 and adjust C_{16QAM} and C_{64QAM}.

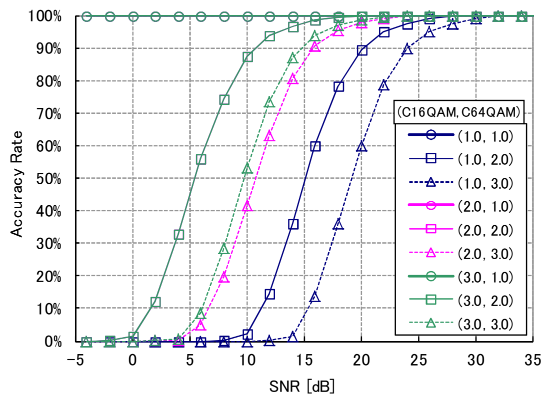

Fig.7 Accuracy rate for modulation type
(Target user: 64QAM; Interference user: QPSK)

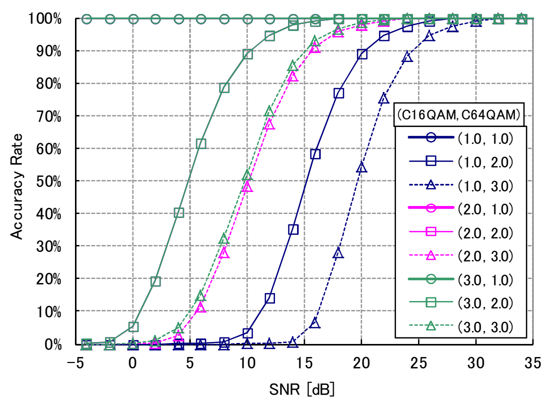

Fig.8 Accuracy rate for modulation type
(Target user: 64QAM, Interference user: 16QAM)

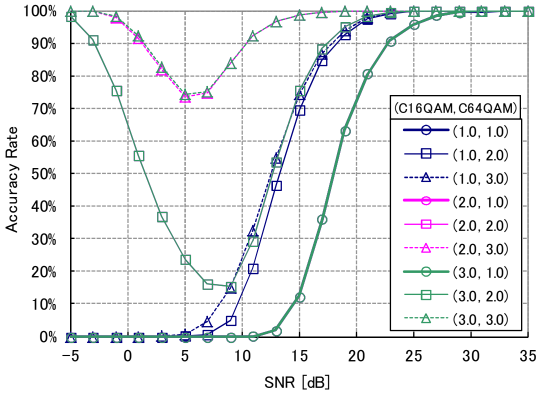

Fig.9 Accuracy rate for modulation type
(Target user: 64QAM; Interference user: 64QAM)

Figs.7, 8, and 9 show the accuracy rates for the modulation types by varying C_{16QAM} and C_{64QAM} from 1.0 to 3.0. Since the tendency of the metrics does not depend on the modulation type for the target user, we show the metrics for only the case in which the modulation type for the target user is 64QAM. From these figures, we can find that the optimum parameter set (C_{16QAM}, C_{64QAM}) is completely different, depending on the modulation type for the interference user.

Then, we evaluate the worst required SNR defined as the highest required SNR at which 90% accuracy is achieved among all pairs of the possible modulation types (target user, interference user). Fig.10 shows the worst required SNR for each pair of coefficients (C_{16QAM}, C_{64QAM}) varying from 1.0 to 3.0 in steps of 0.5. Among these parameter sets, (1.5, 2.5) minimizes the worst required SNR with 90% accuracy.

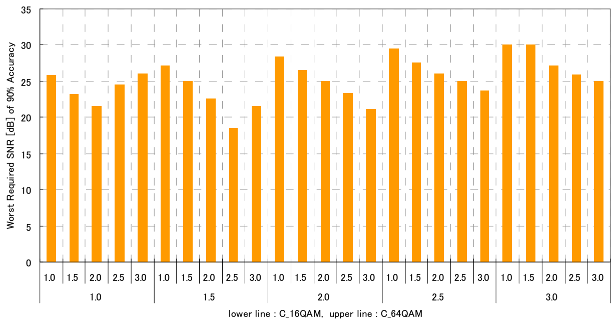

Fig.10 Worst required SNR with 90% accuracy

Fig.11 shows the BER performance using the parameter set (1.5, 2.5). "MLD (a priori known)," which is shown with the dashed line, means the BER performance of MLD in the case in which the modulation types for the interference user is a priori known to the receiver. "Proposed (N_{ave}=120)," which is shown by the solid line, means the proposed method with the metrics calculated by using all the REs in the data channel area (except the reference signal REs). "Proposed (N_{ave}=12)," which is shown by the thick line, means the proposed method with the metrics calculated by using only one leading OFDM symbol in the data channel area. The colors of the lines (green, blue and purple) correspond to the modulation type for the interference user (QPSK, 16QAM, and 64QAM). Since the MMSE performance is not affected by the modulation type for the interference user, there are only three lines for the MMSE performance that differ depending on the modulation type for the target user (shown by the red line).

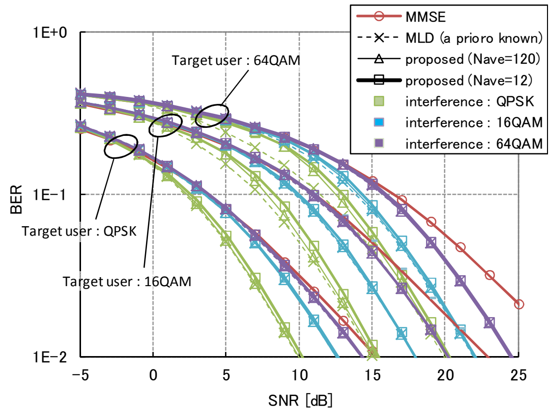

Fig.11 BER performance using parameter set (1.5, 2.5)

The BER performance of the proposed method is superior to that of MMSE, regardless of the modulation type for the target user and the interference user. In the high-SNR region, it is almost the same as that of MLD with the knowledge about the modulation type for the interference user. In spite of a low accuracy in the lower-SNR region, the BER performance is nearly equal to the performance of MMSE.

V. CONSIDERATION OF COMPLEXITY

In the proposed method, MLD for the MIMO detection process can be started after finishing the modulation-type estimation process. In the previous section, we showed that even if only one OFDM symbol is used, degradation in the accuracy is small. Therefore, we consider N_{ave} = 12 hereafter.

When we assume the number of the OFDM symbols for the control channel as two, that for the data channel in the subframe that need to perform MLD is 12. Leaving the difference in complexity caused by the modulation type out of thought, we assume the complexity for performing MLD for 12 REs as one. Then, the total complexity for one RB SU-MIMO detection (with the knowledge of the modulation type for the interference user) is 12, depending on the number of the OFDM symbols for the data channel (ignoring RS). On the other hand, when we perform the proposed MU-MIMO detection with the modulation-type estimation, we need to perform three types of MLD for the leading one OFDM symbol, and after the decision of the modulation type, we perform MLD for the other OFDM symbols to obtain the information about the distance for the calculation of LLR (log likelihood ratio). Note that we do not need to perform MLD for the leading one OFDM symbol once again because MLD has been already performed on that OFDM symbol for the modulation-type estimation and the information about the distance has been obtained. Therefore, the total complexity for one RB with the modulation-type estimation is given by $1 \times 3 + (12 - 1) = 14$. It is an increase of 16% from the SU-MIMO detection.

VI. THROUGHPUT PERFORMANCE

We evaluated the average achievable throughput. The throughput is given by *Throughput* = *R* (1 - *BLER*), where *R* is the bit rate. MCSs and bit rates are described in Table 1. BLER (BLock Error Rate) is defined as the rate of subframes at which all the bits are correctly received after error correcting for all the received subframes. Figs.12 and 13 show the throughput envelops that can be obtained by using ideal AMC (adaptive modulation and coding) based on the optimum switching point. While channel condition is EPA 5 Hz in Fig.12 along with the evaluations above, it is severer frequency selective channel, Extended Typical Urban (ETU) model [11] 30 Hz, in Fig.13. Table 2 shows the difference in the required SNR to achieve 70% of bit rate for the highest MCS between MMSE and the proposed method. We can find that gains from MMSE differ depending on the modulation type for the interference user. It is because noise has more influence on the MLD performance when the constellation for the interference user is denser.

Table 1 Modulation type and coding rate

Modulation Type	Coding Rate	Bit Rate [Mbps]
QPSK	0.1133	0.680
QPSK	0.3000	1.800
QPSK	0.5827	3.496
16QAM	0.3660	4.392
16QAM	0.5380	6.458
64QAM	0.4440	7.992
64QAM	0.6360	11.448
64QAM	0.7520	13.536
64QAM	0.8480	15.264

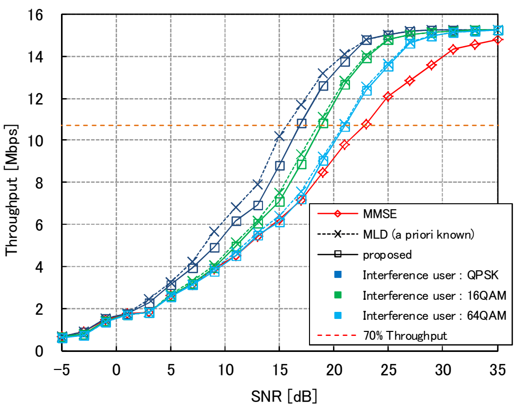

Fig.12 Throughput performance (EPA 5 Hz)

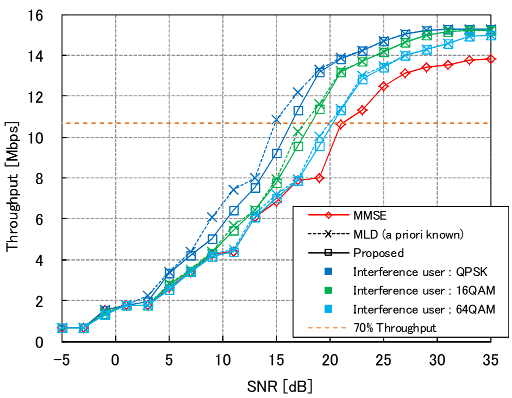

Fig.13 Throughput performance (ETU 30 Hz)

Table 2 Difference in required SNR between MMSE and proposed method

Modulation Type for Interference User	EPA 5Hz	ETU 30Hz
QPSK	5.97 dB	4.84 dB
16QAM	3.98 dB	2.98 dB
64QAM	1.79 dB	0.95 dB

VII. CONCLUSION

In this paper, we propose an MU-MIMO detection method based on MLD with modulation-type estimation. This method can improve the BER and throughput performance from MMSE with a slight increase from the SU-MIMO detection.

In this method, there is room for further research. In this paper, the coefficients are fixed regardless of SNR. Since the performance of the modulation-type estimation depends on SNR largely, we need to investigate the relation between SNR and the optimum parameters. Furthermore, we should consider the influence of realistic functions such as channel estimation on the performance of the modulation-type estimation.

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