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SNR Estimation in OFDM System by the Correlation of Decision Feedback Signal

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Abstract In the channel-varying environment, it is very important to estimate the signal to noise ratio (SNR) of received signal and to transmit the signal effectively for the modern communication system. The performance of existing non-data-aided SNR estimation methods are substantially degraded for high level modulation scheme such as M-ary amplitude and phase shift keying or quadrature amplitude modulation. In this paper, we propose a SNR estimation method which uses zero point auto-correlation of received signal per block and auto/cross-correlation of decision feedback signal in orthogonal frequency division multiplexing (OFDM) system. Proposed method can be studied into two types; Type 1 can estimate SNR by zero point auto-correlation of decision feedback signal based on the second moment property. Type 2 uses both zero point auto-correlation and cross-correlation based on the fourth moment property. In block-by-block reception of OFDM system, these two SNR estimation methods can be possible for the practical implementation due to correlation based the estimation method and they show more stable estimation performance than the previous SNR estimation methods. Also, we mathematically derive the SNR estimation expression according to computational difference of auto/cross-correlation. Finally, Monte Carlo simulations are used to verify the proposed method.

Keywords SNR estimation · OFDM · QAM · Correlation-based estimation

1 Introduction

In order to achieve optimum performance of system in channel-varying state, various receiver algorithms of modern communication systems requiresignal-to-noise ratio (SNR)

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information. Adaptive modulation and coding (AMC) technique one of smart transmission system has been adopted in digital video broadcasting-satellite second generation (DVB-S2) which is a next standards for satellite broadcasting service [1]. Control block in this system, should understand correct channel state and can allocate resources according to channel state information (CSI). Especially, SNR estimation algorithm to find out channel state is simple and correct to react quickly to rapidly changing situation first of all.

Existing SNR estimators can be classified according to a number of criteria. Data-aided (DA) estimators can be used when the receiver has knowledge of the transmitted symbols, in contrast to non-data-aided (NDA) estimators, which do not require such knowledge. Decision directed (DD) can be used by substituting the true transmitted symbols by the outputs of the decoder. Maximum likelihood estimator is one of DA estimator [2], and squared signal-to-noise variance (SNV), second and fourth order moment (M_2M_4)-based and signal-to-variance ratio (SVR) has been proposed [2–4]. Although ML estimators provide good statistical performance, they tend to be computationally intensive. Under a different classification, I/Q-based estimators make use of both the in-phase and quadrature components of the received signal, and thus require coherent detection; in contrast, envelope-based (EVB) estimators only make use of the received signal magnitude, and thus can be applied even if the carrier phase has not been completely acquired. The more signal has high modulation level, therefore, the more SNR estimation is difficult when we compare simple modulation signal such as binary phase shift keying (BPSK) with M-ary amplitude and phase shift keying (APSK) or quadrature amplitude modulation (QAM) modulation signal. Even if SNR estimation algorithm could apply efficiently to BPSK signal, there is much difficulty just as it is about high dimensional signal. Recently, Most SNR estimators focus on the single-input single-output (SISO) channel with additive white Gaussian noise (AWGN), (quasi)static flat fading static, frequency selective channel and time-varying flat fading channel cases, respectively.

Therefore, we propose a SNR estimation method based on decision feedback that amenable to practical implementation and significantly improves on previous estimation methods for high level modulation signal. Proposed method uses zero point auto-correlation of received signal per block and auto/cross-correlation of decision feedback signal in orthogonal frequency division multiplexing (OFDM) system. This method can estimate more accurate SNR using correlation value of decision feedback signal and has similar estimation ability with DA but is simpler than DA estimators. In case of SNR estimation based on decision feedback, signal before decision includes errors by effect of channel and mismatch of system. Therefore, if SNR estimation method based on correlation relation is used, system can benefit synchronization secure or offset estimation as well as SNR estimation.

Proposed method can be studied into two types; Type 1 can estimate SNR by zero point auto-correlation of decision feedback signal based on the second moment property. Type 2 uses both zero point auto-correlation and cross-correlation based on the fourth moment property. In block-by-block reception of OFDM system, these two SNR estimation methods can be possible for the practical implementation due to correlation based the estimation method and they show more stable estimation performance than the previous SNR estimation methods. Also, we mathematically derive the SNR estimation expression according to computational difference of auto/cross-correlation in case of signal generation with non-equal probability in OFDM system based on reception per block transmission. QAM signal of multilevel constellation which has various amplitude and phase is difficult to apply estimation approach based on EVB. So, estimators for QAM are requiring either more complicated algorithm, or signal processing [5–9]. But, proposed method shows good estimates performance close to CBR as well as it is simple due to estimation method by correlation relation of decision feedback signal corresponding to bit error rate.

This paper is consisted as follows. Section 2 provides a system model and SNR estimation concept. We introduce estimation algorithm and mathematical development of proposed method for OFDM system in Sect. 3. Performance comparison are described and discussed in Sect. 4. Section 5 concludes the paper.

2 SNR Estimation Based on Correlation

2.1 System Model

In AWGN digital communication channels, we consider the received signal at the front end of receiver as

$$y(n) = x(n) + w(n) \tag{1}$$

where $x(n)$ and $y(n)$ are transmitted and received signal, respectively. $w(n)$ is additive white Gaussian noise (AWGN) with zero mean. In this case, the autocorrelation of the measured data, $y(n)$, is given as.

$$r_y(k,l) = r_x(k,l) + r_w(k,l) \tag{2}$$

Assuming $y(n)$, a wide-sense stationary random process, the autocorrelation $r_y(k,l)$ depends only on the difference, $m = k - l$. Thus, (2) may be rewritten as

$$r_y(m) = r_x(m) + r_w(m) \tag{3}$$

Because a zero-mean AGWN $w(n)$ models the nondeterministic part of (1), this process is uncorrelated with itself for all lags, except at $m = 0$, and its autocorrelation sequence (ACS) has the following form.

$$r_w(m) = \sigma^2 \delta(m). \tag{4}$$

where σ^2 is the variance of noise, and $\delta(m)$ is the discrete delta sequence. Since the autocorrelation sequence of $y(n)$ is a conjugate symmetric function of m, $r_y(m) = r_y^*(-m)$ with the amplitude upper bounded by its value at $m = 0$. The noise part of (1), which tends to affect each sample in the time domain, confines its effect to the zero-offset sample in the second order statistics domain, making it possible to reduce the problem of noise variance estimation in AWGN systems to $r_x(0)$ estimation.

Therefore, SNR of received signal is defined as

$$\rho = \frac{E[|x(n)|^2]}{\sigma^2}. \tag{5}$$

2.2 SNR Estimation Method Based on Auto-Correlation: Type I

In this paper, we propose SNR estimation method using auto-correlation based on second moment of received signal. When we consider transmission signal of random variable in set $\{+a, -a\}$ with equal probability and AWGN channel, auto-correlation values of transmit and received signal are as follows. We can be expressed as signal power S and noise power N.

$$r_x(0) = E\left[x(n)x^*(n)\right] = 2a^2 = S \tag{6}$$

$$r_y(0) = E\left[y(n)y^*(n)\right] = 2a^2 + 2\sigma^2 = S + N \tag{7}$$

where auto-correlation values of) $x(n)$ and $y(n)$ are the transmitted and received signal power, respectively. By Eqs. (3) and (4), noise power is $r_w(0) = r_y(0) - r_x(0)$. Therefore, SNR based on auto-correlation of Eq. (5) is given as

$$\hat{\rho} = \frac{S}{N} = \frac{r_x(0)}{r_y(0) - r_x(0)} \tag{8}$$

2.3 SNR Estimation Method Based on Auto/Cross-Correlation: Type II

Type II SNR estimation method estimates SNR using zero point correlation relation of received signal based on fourth moment. Equations (9) and (10) are fourth moment with square of zero point auto/cross-correlation of transmitted and received signal. Zero point auto/cross-correlations are given as

$$r_x^2(0) = E\left[x(n)x^*(n)\right]^2 = S^2. \tag{9}$$

$$r_y^2(0) = E\left[y(n)y^*(n)\right]^2 = (S+N)^2. \tag{10}$$

$$r_{xy}^2(0) = E\left[x(n)y^*(n)\right]^2 = S(S+N). \tag{11}$$

SNR based on fourth moment can calculate as auto/cross-correlation relation of transmit and receive signal, and is derived as follows.

$$\begin{aligned} \frac{r_x^2(0)}{r_y^2(0) - 2r_{xy}^2(0) + r_x^2(0)} &= \frac{S^2}{S^2 + N^2 - 2S^2 + S^2} \\ &= \left(\frac{S}{N}\right)^2. \end{aligned} \tag{12}$$

Therefore, final SNR of Type II SNR estimation method based on correlation relation can be expressed by

$$\hat{\rho} = \frac{S}{N} = \sqrt{\frac{r_x^2(0)}{r_y^2(0) - 2r_{xy}^2(0) + r_x^2(0)}}. \tag{13}$$

3 SNR Estimation by Correlation of Decision Feedback Signal

Figure 1 shows SNR estimation method in OFDM system. The input data signals are modulated by QPSK or QAM modulator (with Gray mapping). The modulated symbols are passed through a serial-to-parallel converter and inverse fast Fourier transform (IFFT) process. Then, the transmission signal of general OFDM (orthogonal frequency division multiplexing) is given by Eq. (14).

$$x(t) = \sum_{k=0}^{K-1} X_k \cdot e^{2\pi f_k t} = \sum_{k=0}^{K-1} X_k \cdot e^{\frac{2\pi}{KT_s}kt} \tag{14}$$

where K is total sub-carrier number, T_s is symbol duration, frequency of sub-carrier is $f_k = k/KT_s$, and t is $n \cdot T_s (n = 0, \ldots, K-1)$. Also, X_k is data symbol at kth sub-carrier.

Transmitted signal $x(t)$ can be expressed to discrete signal as follows.

$$x(n) = \sum_{k=0}^{K-1} X_k \cdot e^{j\frac{2\pi}{K}kn}. \tag{15}$$

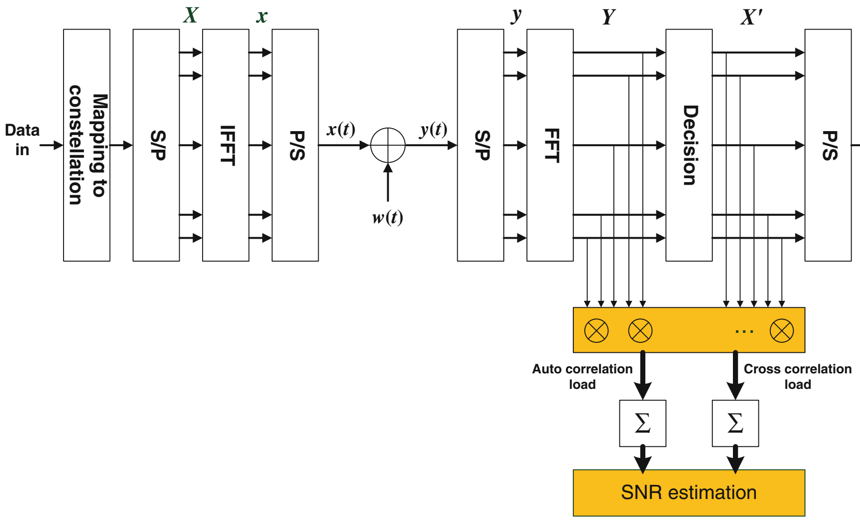

Fig. 1 SNR estimation method in OFDM system

To simplify analysis of system, communication channel is assumed to AWGN.

$$r(n) = x(n) \otimes h(n) + w(n). \tag{16}$$

where $w(n)$ is AWGN component. Considering AWGN channel to analyze mathematically, channel response $h(n)$ equals to 1 and phase synchronization supposes to be perfect. After removing cyclic prefix, after FFT, the recovered output for the kth sub-carrier is as follows (Fig. 1):

$$\begin{aligned} Y_k &= \frac{1}{\sqrt{K}} \sum_{n \in K} r[n] \cdot e^{-j\frac{2\pi}{K}kn} \\ &= X_k + N_k. \end{aligned} \tag{17}$$

3.1 Auto-Correlation of Decision Feedback Signal and SNR Estimation

SNR estimation method this paper requires zero point auto-correlation of transmitted and received signal in OFDM system. However, we don't know random symbols of transmitted signal. At the receiver side, It is difficult to find correct auto-correlation value of transmitted signal. Therefore, in this paper, we can calculate auto-correlation value of transmitted signal using decision feedback signal at the receiver.

In OFDM system, auto-correlation values of transmitted signal such as QPSK and QAM are calculated as follows.

$$r_X(0) = r_{X'}(0) = \frac{1}{K} \sum_{k=0}^{K-1} |X_k|^2 = 2, \quad \forall\ QPSK\ signal \tag{18}$$

$$\begin{aligned} r_X(0) = \frac{1}{K} \left(\sum_{n_{c_1}=1}^{N_{c_1}} |X_{n_{c1}}|^2 + \sum_{n_{c_2}=1}^{N_{c_2}} |X_{n_{c2}}|^2 + \sum_{n_{c_3}=1}^{N_{c_3}} |X_{n_{c3}}|^2 \right), \\ \forall\ 16 - QAM\ signal \end{aligned} \tag{19}$$

$$r_X(0) = \frac{1}{K}\left(\sum_{n_{c_1}=1}^{N_{c_1}} \left|X_{n_{c1}}\right|^2 + \sum_{n_{c_2}=1}^{N_{c_2}} \left|X_{n_{c2}}\right|^2 + \sum_{n_{c_3}=1}^{N_{c_3}} \left|X_{n_{c3}}\right|^2 + \sum_{n_{c_4}=1}^{N_{c_4}} \left|X_{n_{c4}}\right|^2 + \cdots\right), \quad \forall\ M - QAM\ signal \tag{20}$$

where N_{c1}, N_{c2}, and N_{c3} are the number of symbol of each level in QAM signal with multilevel constellation. And X_{n_c} is data symbol of each level. Auto-correlation value of QPSK signal is always 2 regardless of random variable signal, (i.e., although error of decision signal is included in receiver side). In case of M-QAM signal (M $\geq$ 8), however, if signal is generated with non-equal probability, this mapping signal has unfixed auto-correlation value because of multilevel constellation of M-QAM signal.

Therefore, auto-correlation of transmitted M-QAM signal at receiver side is impossible to predict. In this paper, we use auto-correlation value of decision feedback signal instead of transmit signal. In case SNR estimates through separated in-phase and quadrature signal, auto-correlation value of decision feedback signal with M-QAM constellation at receiver side is as follows.

$$\begin{aligned} r_{X'}(0) &= \sum \begin{pmatrix} corrected \\ decision \\ signal \end{pmatrix}^2 + \sum \begin{pmatrix} error \\ \pm 1 \to \pm 3 \end{pmatrix}^2 - \sum \begin{pmatrix} error \\ \pm 3 \to \pm 1 \end{pmatrix}^2 \\ &= \sum_{c_d=1}^{N-(E_n^{13}+E_n^{31})} \left(X'_{c_d}\right)^2 + \sum_{e=1}^{E_n^{13}} \left(X'_e\right)^2 - \sum_{e=1}^{E_n^{31}} \left(X'_e\right)^2 \quad , \quad \forall\ 16 - QAM \end{aligned} \tag{21}$$

where $r_{x'}(0)$ is auto-correlation value of decision feedback signal. Equation (21) shows case of 16-QAM. In Eq. (21), auto-correlation value $r_{x'}(0)$ of 16QAM has difference in case that ± 1 is decided to ± 3 and in case that ± 3 is decided to ± 1. Here, N is the number of sub-carrier, E_n^{13} is the number of symbols which 1 is decided to 3, and X'_e is a symbol of that time. In contrast, E_n^{31} is the number of symbols which 3 is decided to 1. Because both ± 1 and ± 3 are calculated as absolute value, error symbols which 1 becomes 3 are increased auto-correlation value and error symbols which 3 becomes 1 are decreased auto-correlation value. Therefore, difference of auto-correlation between transmit signal and decision feedback signal can be generalized as Eqs. (22) and (23).

$$\begin{aligned} \Delta r_X(0) &= r_X(0) - r_{X'}(0) \\ &= \left(\sum_{e=1}^{E_n^{13}} 3^2 - 1^2\right) + \left(\sum_{e=1}^{E_n^{31}} 1^2 - 3^2\right), \quad \forall 16 - QAM \end{aligned} \tag{22}$$

$$\begin{aligned} \Delta r_X(0) = &\sum_{i=1}^{\frac{\sqrt{M}}{2}-1} \left(E_n^{pq} \times \left\{\sum_{k=2i-1}^{\sqrt{M}/2-1} \Big(\underbrace{2k+1}_{=p}\Big)^2 - \Big(\underbrace{2i-1}_{=q}\Big)^2\right\}\right) \\ &+ \sum_{i=1}^{\frac{\sqrt{M}}{2}-1} \left(E_n^{qp} \times \left\{\sum_{k=2i-1}^{\sqrt{M}/2-1} (2i-1)^2 - (2k+1)^2\right\}\right), \quad \forall M - QAM \end{aligned} \tag{23}$$

where $p = 2k + 1$ and $q = 2i - 1$ are symbol of each level of M-QAM signal constellation, respectively and p is larger than q. M is modulation level and E_n^{pq} and E_n^{qp} are the number of symbols which $\pm p$ is decided to $\pm q$ and $\pm q$ is decided to $\pm p$, respectively. Modulation level is the higher, $\Delta r_x(0)$ is bigger and error symbol increases, simultaneously, so that estimation error of proposed method is increased.

Therefore, error symbol is related to BER performance in Eq. (24) and proposed SNR estimation method is affected by BER performance.

$$EBN(error\ bit\ number) = \log_2(M) \cdot BER \cdot Nsample = E_n^{pq} + E_n^{qp} \tag{24}$$

where N_{sample} is number of estimated sample. In OFDM system, Assuming SNR estimation of block-by-block, N_{sample} is number of sub-carriers (K).

SNR estimation method Type 1 and Type 2 based on auto-correlation of decision feedback signal can be organized as follows.

$$\tilde{\rho} = \frac{S}{N} = \frac{r_X(0) + \Delta r_X(0)}{r_y(0) - \{r_X(0) + \Delta r_X(0)\}}, \quad \text{for Type 1} \tag{25}$$

$$\tilde{\rho} = \sqrt{\frac{\{r_X(0) + \Delta r_X(0)\}^2}{r_Y^2(0) - 2r_{XY}^2(0) + \{r_X(0) + \Delta r_X(0)\}^2}}, \quad \text{for Type 2} \tag{26}$$

Type 2 method estimates SNR using cross-correlation of decision feedback signal. So, in this case, error symbol X'_k has an effect to cross-correlation value and SNR estimation performance can be changed.

3.2 Cross-Correlation of Decision Feedback Signal and SNR Estimation

In case of SNR estimation based on decision feedback, signal before decision includes errors by effect of channel and mismatch of system. Therefore, if SNR estimation method based on correlation relation is used, system can benefit synchronization secure or offset estimation as well as SNR estimation. As we show difference of auto-correlation between transmit and decision feedback signal, in previous section, cross-correlation between received and decision feedback signal can be organized as follows.

$$\begin{aligned}
r_{XY}(0) &= E\big[X(n)Y^*(n)\big] = \frac{1}{K}\sum_{k=1}^{K} X_k Y_k. \\
r_{X'Y}(0) &= E\big[X'(n)Y^*(n)\big] = \frac{1}{K}\sum_{k=1}^{K} X'_k Y_k. \\
\Delta r_{X'Y}(0) &= r_{XY}(0) - r_{X'Y}(0) \\
&= E_n^{pq}\left(\sum_{i=1}^{\frac{\sqrt{M}}{2}-1}\left\{\sum_{k=2i-1}^{\sqrt{M}/2-1}\Big((2k+1)-(2i-1)\Big)\cdot Y_e\right\}\right) \\
&\quad + E_n^{qp}\left(\sum_{i=1}^{\frac{\sqrt{M}}{2}-1}\left\{\sum_{k=2i-1}^{\sqrt{M}/2-1}\Big((2i+1)-(2k-1)\Big)\cdot Y_e\right\}\right)
\end{aligned} \tag{27}$$

where $p = 2k + 1$ and $q = 2i - 1$ are symbol of each level of M-QAM signal constellation, respectively and p is larger than q. Y_e is relevant received signal of error symbol, that is, this is received signal corresponding to error symbol of decision feedback signal in received signal Y_k before decision ($Y_e \in Y_k$).

Therefore, final SNR of Type 2 SNR estimation method based on cross-correlation including difference of decision feedback signal is given by

$$\tilde{\rho} = \sqrt{\frac{\{r_X(0) + \Delta r_X(0)\}^2}{r_Y^2(0) - 2\left\{r_{XY}(0) + \Delta r_{XY}(0)\right\}^2 + \left\{r_X(0) + \Delta r_X(0)\right\}^2}}. \tag{28}$$

4 Simulation Results and Discussion

Firstly, we use the MSE (mean squared error) to evaluate the performance of SNR estimation algorithm. The best SNR estimator is unbiased (or exhibits the smallest bias) and has the smallest variance. The statistical MSE reflects both the bias and the variance of an SNR estimate and is given by

$$MSE\left\{\hat{\rho}\right\} = E\left\{(\hat{\rho} - \rho)^2\right\}. \tag{29}$$

where $\hat{\rho}$ is estimation value of SNR, and ρ is true SNR.

In order to evaluate performance of proposed SNR estimation method, we consider simulation condition as follows. Channel is assumed to AWGN of single input and single output (SISO) and number of sub-carrier or estimated sample are 1,024 which is enough to estimate. Also, SNR of received signal for various QAM signal in wide range SNR from −10 to 30 dB is estimated. And we compare estimated performance and MSE with existing considerable NDA estimators; moment-based SNR estimation method of second and fourth moment (M_2M_4) [2–5], and six moment (M_6) [6] and linear prediction (LP)-based. These methods belong to the class of NDA envelope based (EVB) estimators, requiring neither accurate carrier recovery, nor knowledge of the transmitted symbols. This flexibility, together with implementation simplicity, makes these estimators attractive for practical applications. As well as, we compare with LP-based estimator [10]. This technique can operate on data collected at the front–end of receiver without any restriction on inter-symbol interference (ISI). This improved the SNR estimates in severe ISI channels and also helps in extending the implementation of SNR estimators in systems that require SNR estimates at the input of the receiver.

Figure 2 shows mean SNR estimate performance of ideal and experimental value for proposed SNR estimation method in 16QAM-OFDM system. In 4QAM or QPSK, proposed method has the same performance between ideal and experimental results because correlation relation of decision feedback signal doesn't change from transmitted signal's one. But the higher modulation level, estimation error is bigger. In Fig. 2, i.e. in case of 16QAM, proposed method shows about 0.5 dB difference from ideal case because of correlation value with errors of decision feedback signal.

Figures 3 and 4 are performance curve of SNR versus mean SNR estimation. Type 1 SNR estimation method is almost identical with unbiased SNR curve in QPSK signal. Type1 method has ideal SNR estimation performance because auto-correlation of decision feedback is always 2 regardless of errors of decision feedback signal. However, the impact by the error of received signal in process of cross-correlation appears at low SNR in case of proposed Type 2 method. M_2M_4 SNR estimator which is for envelope based estimation in low modulation level such as BPSK or QPSK can be estimated signal around about 0 dB SNR. LP-based shows better performance than M_2M_4, but this is more complicated by auto-correlation matrix for prediction coefficient. Comparing proposed two methods with other estimators, we know that existing estimator has estimated error under 1 dB except for Type 1 method and Type 2 method has tolerance of maximum 2 dB.

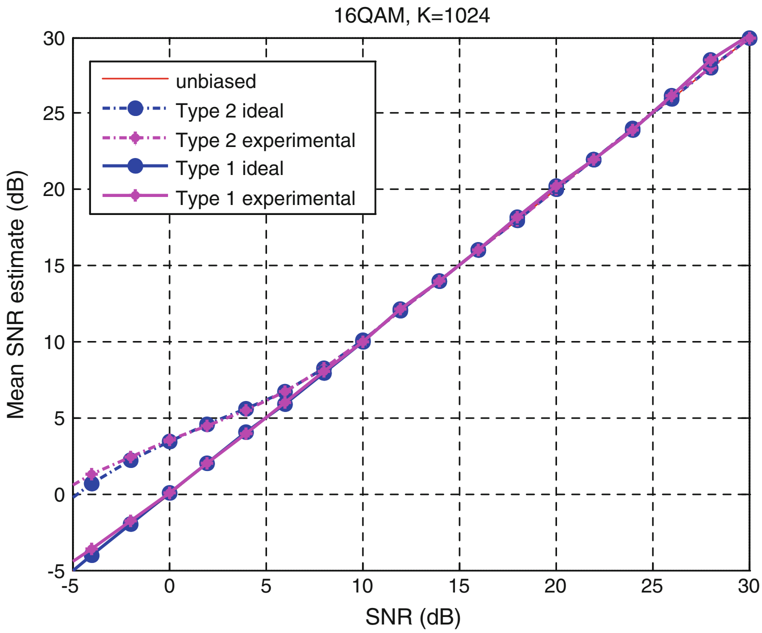

Fig. 2 Mean SNR estimation of ideal and experimental value (16QAM, $K = 1{,}024$)

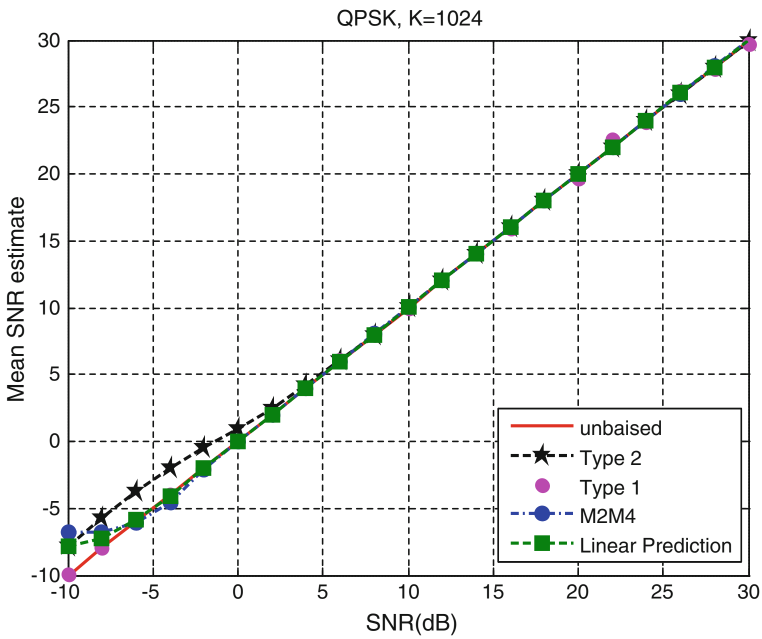

Fig. 3 Mean estimated SNR versus SNR in QPSK ($K = 1{,}024$)

Figure 4 shows NMSE performance. In side of NMSE, proposed Type 1 estimation method has similar performance with Cramer–Rao lower bound (CRLB) and has NMSE under 0.005 in wide SNR range of from -10 to 30 dB. In SNR over 3 dB, NMSE performance of Type

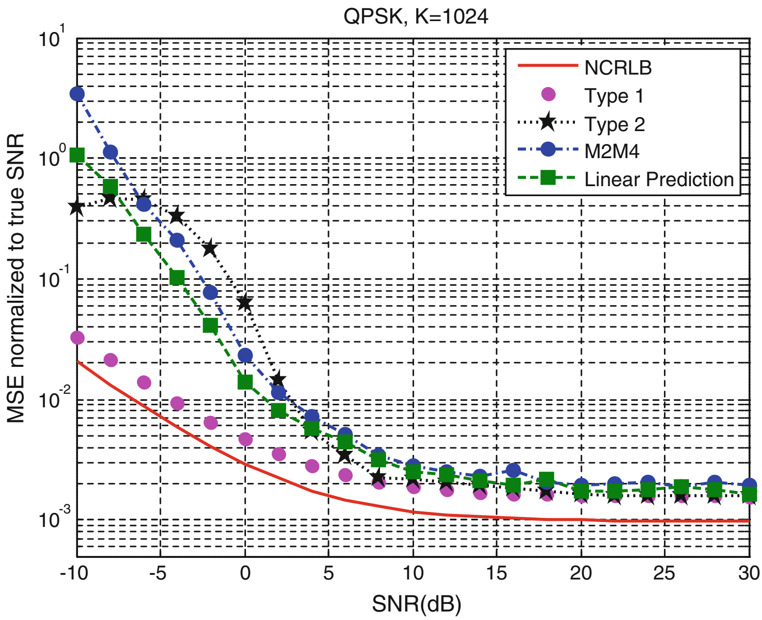

Fig. 4 NMSE versus SNR in QPSK ($K = 1{,}024$)

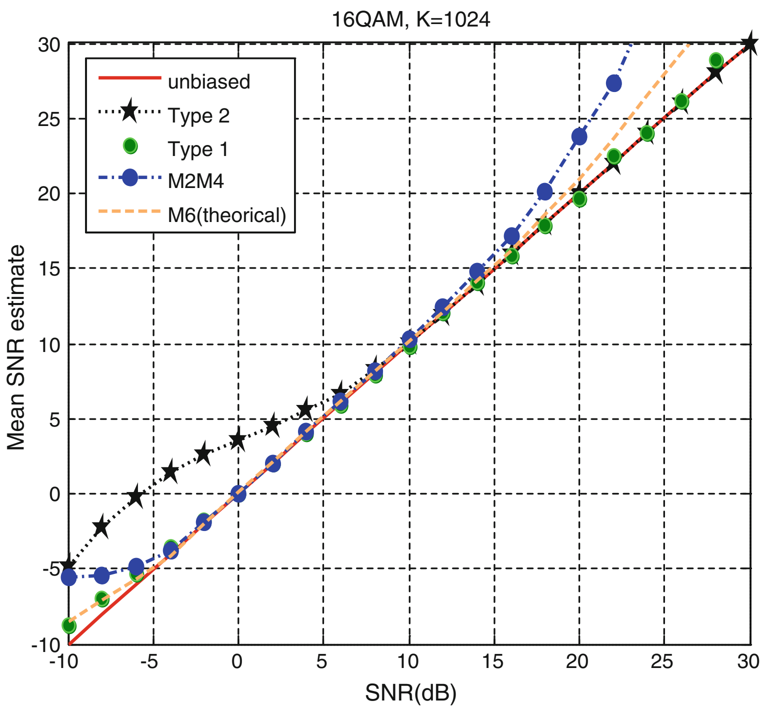

Fig. 5 Mean estimated SNR versus SNR in 16QAM ($K = 1{,}024$)

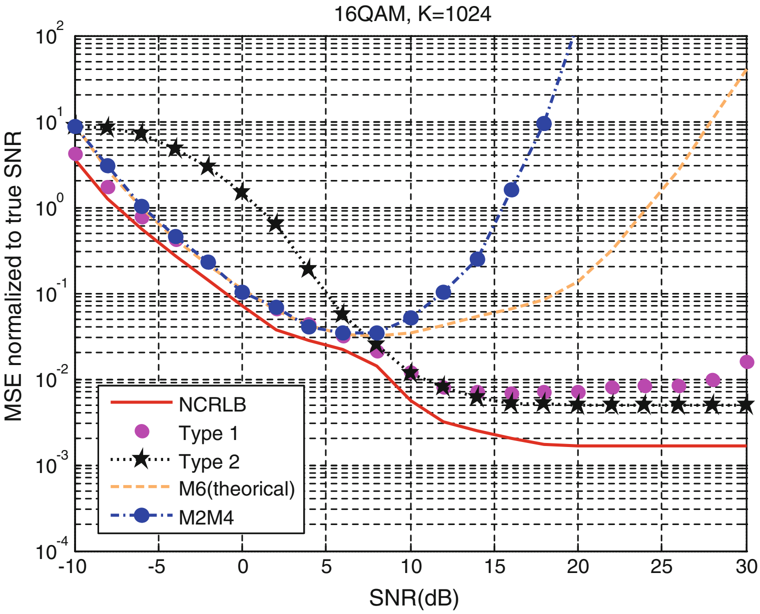

Fig. 6 NMSE versus SNR in 16QAM ($K = 1{,}024$)

2 method is better than other SNR estimators, but this method includes decision error at low SNR under 0 dB. Therefore, Type 2 method doesn't get improvement of estimation performance in low modulation level such as QPSK due to cross-correlation. As shown in next simulation, however, Type 2 method is very stable for high SNR of high modulation level.

Figure 5 and 6 illustrate performance of SNR versus mean SNR estimate and NMSE, respectively. Comparing with simulation results for QPSK signal, we know that estimation performance of M_2M_4 based on EVB method is decreased down for 16QAM signal with various envelope level and phase component. Estimation performance of LP-based estimation method is also degraded by prediction error statistic which cannot include enough prediction characteristic of high modulation signal with various envelope and phase level like QAM in a process of determining the linear prediction coefficient. In contrast to other estimators, proposed Type 1 method shows better performance even though 16QAM signal. In 16QAM signal, auto-correlation value on Type 1 method is also influenced by error of decision feedback signal corresponding to BER performance with 16QAM. But in SNR under 0 dB, number of error symbol is less than 10 ± 2 when 1,000 symbol is transmitted. Therefore, error of auto-correlation doesn't have an effect to estimation performance for whole SNR range. However, this method shows that estimation performance is slightly worse at high SNR (Fig. 6).

Estimation performance of Type 2 method is more degraded than QPSK signal at low SNR. As mentioned earlier, this method generates more estimation error in high modulation because errors of decision feedback signal have an effect to auto/cross-correlation. However, Type 2 method shows stable performance at high SNR regardless of modulation. As shown in simulation results, Type 1 method has an estimation error under 2 dB even though the signal for less than 0 dB and NMSE performance of CRLB. Type 2 method has a NSER performance under 0.005 for more than 10 dB SNR.

5 Conclusions

We propose a correlation relation-based approach that is amenable to practical implementation and significantly improves on previous estimators. Proposed method of this paper shows stable performance than previous SNR estimation method because this estimation method uses zero point auto-correlation of received signal per block and auto/cross-correlation of decision feedback signal in OFDM system. And we mathematically derived the SNR estimation expression according to computational difference of auto/cross-correlation in case of signal generation with non-equal probability in OFDM system based on block-by-block transmission. Proposed SNR estimation method had similar performance with CRLB for QPSK and QAM and had NMSE under 0.005 in wide SNR range of from -10 to 30 dB. Especially, Type 1 method had an estimation error under 2 dB even though the signal for less than 0 dB and NMSE performance of CRLB. Type 2 method has a NSER performance under 0.005 for more than 10 dB SNR. Due to its simplicity and practicality, therefore, proposed method is an attractive choice, which recently proved competitive for high level modulation. Also, SNR estimation method based on correlation relation of decision feedback signal can be brought to benefit synchronization secure or offset estimation as well as SNR estimation. However, we only consider AWGN situation in this paper and need future research about SNR estimation considering actually flat and selective fading channels with Doppler effect.

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