Undesired Signal Power Estimation Based on Estimated Superposed Band for Multicarrier Transmission

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***Abstract*—Superposed multicarrier transmission scheme is known to improve frequency utilization efficiency where several wireless systems share spectrum. On superposed band, log likelihood ratio (LLR) cannot be set correctly due to interference, which results in BER (Bit Error Rate) degradation. Forward error correction (FEC) metric masking is proposed to suppress the effect of interference. In this technique, LLRs corresponding to superposed band is set to zero, because received bits corresponding to superposed band is unreliable. This scheme requires superposed band detection and does not consider channel estimation error. We proposed an iterative estimation technique for undesired signal power in [6]. Although this scheme does not require superposed detection beforehand, due to the estimation error of undesired signal power, BER is degraded. In this paper, we propose an estimation technique for undesired signal power and superposed band to calculate LLR correctly. This scheme estimates the superposed band within 1 packet and based on the information about the superposed band, undesired signal power is estimated using pilot symbols. Simulation results show that as the number of pilot symbols increases, BER of our proposed scheme becomes better than that of [6] and gets closer to the BER when the estimation of undesired signal power is perfect.**

I. INTRODUCTION

Since wireless systems, such as LTE (Long term evolution) and WiMAX require broader bandwidth, deficiency of spectrum is a problem. To improve frequency utilization efficiency, superposed multicarrier transmission is proposed [1]. Superposed multicarrier transmission assumes overlap of several frequency bands without guard band as shown in Fig. 1 and requires narrower frequency band than traditional spectrum allocation. Superposed multicarrier transmission can be applied to, for example, wireless LAN where several users share the same frequency band. Although desired signal suffers from interference on superposed band, BER (Bit error rate) can be improved by setting LLR (Log likelihood ratio) corresponding to superposed band correctly [2].

Desired signal suffers from interference on superosed band from other systems. The LLRs under interference can be wrong, therefore, using wrong LLR results in degradation of BER. To mitigate the effects of interference, FEC (Forward Error Correction) metric masking is proposed in [1], which replaces LLRs of the bits that suffer from interference with zero in order not to trust the received bits. In [2] a scheme that weights LLR according to DUR (Desired to undesired signal power ratio) is proposed. However, these schemes require the information about superposed band and DUR.

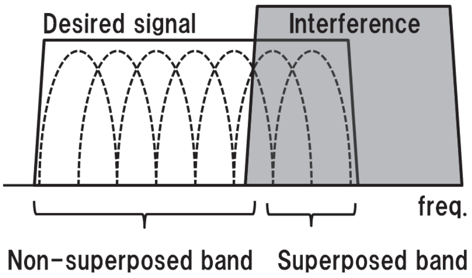


Fig. 1. Spectrum allocation for superposed multicarrier transmission

Detection techniques for superposed band and DUR are proposed in [3]– [5]. In [3], superposed band is detected by searching the FEC metric masking position that minimizes the packet error rate (PER). When interference is large, it can detect superposed band in a short time. However, this scheme requires decoding several times since it decodes the received bits after changing the FEC masking position. Thus, its computational complexity is a problem. In [4] and [5], superposed band can be detected based on residual power calculated by subtracting replica signals from received signals. The residual signal power on superposed band is larger than that on non-superposed band because of interference. After averaging the residual power over several packets, superposed band is detected by comparing the residual power with a threshold. However, this scheme cannot be applied when superposed band changes frequently since it averages residual power in time domain.

In [6], we proposed an iterative estimation technique for undesired signal power using LLR with channel estimation error. This technique estimates undesired signal power on each subcarrier based on residual power obtained by subtracting replica signal from received one, so that the superposed band detection is not needed. Although the BER is improved by the technique, because of estimation error for undesired signal power, BER is degraded greatly compared to when estimation for undesired signal power is perfect.

Summarizing the problems, we have two problems: The first is that superposed band detection based on residual power [4], [5] cannot be applied to a situation where interference changes quickly since the technique utilizes several packets in time domain. The second is that the BER degradation and the estimation error for undesired signal power are problems in iterative estimation for undesired signal power [6].

In this paper, to address these problems, we propose an estimation technique for undesired signal power based on estimated superposed band. This scheme estimates superposed band iteratively within 1 packet, thus it can be applied to a situation where interference changes frequently. Based on the estimated superposed band, we also estimate undesired signal power using pilot symbols since pilot symbols are known symbol, which could improve the estimation accuracy of the undesired signal power.

II. System Model

We assume an orthogonal frequency division multiplexing (OFDM) system with single transmit and single receive antennas. Each OFDM symbol, which has L subcarriers, contains FEC blocks generated by a turbo encoder. At the receiver, after the removal of the guard interval of the OFDM symbol at time t, the L' point fast Forier transform (FFT) is applied to it to obtain the $L' \times 1$ frequency domain OFDM symbol. L entries are extracted from the $L' \times 1$ vector. The received signal at subcarrier index l ($l = 0, 1, \cdots, L-1$) at time t is given by

$$y(t,l) = \begin{cases} h(t,l)x(t,l) + i(t,l) + n(t,l), & \text{for superposed band} \\ h(t,l)x(t,l) + n(t,l), & \text{for non-superposed band} \end{cases} \quad (1)$$

where $h(t,l), x(t,l), i(t,l)$ and $n(t,l)$ are channel coefficient, transmit signal, interference and noise components, respectively. Interference and noise components are white circular Gaussian random variables with probability distributions $\mathcal{CN}(0, \sigma_{if}^2)$, $\mathcal{CN}(0, \sigma_n^2)$, respectively.

As a packet structure, we assume 5 data symbols, and N pilot symbols. Since $x = 1$ is assumed to be sent as a pilot symbol, the received signals corresponding to i–th pilot signals on non-superposed band are expressed as

$$y_i(t,l) = h_i(t,l) + n_i(t,l). \quad (2)$$

On superposed band, interference $i_i(t,l)$ is added and expressed as

$$y_i(t,l) = h_i(t,l) + n_i(t,l) + i_i(t,l). \quad (3)$$

The channel is estimated by taking an average of N pilot symbols on each subcarrier.

$$\hat{h}(l) = \frac{1}{2}\sum_{i=1}^{N} y_i(t,l). \quad (4)$$

Both $y(t,l)$ and $\hat{h}(t,l)$ are given as inputs to the turbo decoder

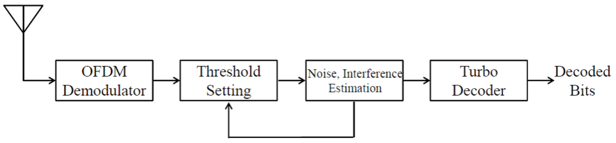


Fig. 2. The proposed receiver structure

to compute LLRs. The LLR of the m-th bit $c(t,l,m)$ of the data symbol at time t, at the l-th subcarrier is given by

$$LLR[c(t,l,m)] = \ln\left[\frac{p[c(t,l,m)] = 1}{p[c(t,l,m)] = 0}\right]. \quad (5)$$

Under Gaussian noise without any interference signals, eq. (5) is rewritten as follows.

$$LLR^{\text{Conv}}[c(t,l,m)] = \ln\left[\frac{\sum_{x\in X_1(m)} \frac{1}{\pi\sigma_n^2}\exp\left(-\frac{|y(t,l) - x(t,l)\hat{h}(t,l)|^2}{\sigma_n^2}\right)}{\sum_{x\in X_0(m)} \frac{1}{\pi\sigma_n^2}\exp\left(-\frac{|y(t,l) - x(t,l)\hat{h}(t,l)|^2}{\sigma_n^2}\right)}\right] \quad (6)$$

where $X_1(m), X_0(m)$ are element sets of Phase Shift Keying (PSK) or Quadrature Amplitude Modulation (QAM) with the m-th bit equals 1, 0, respectively.

Under a situation where interference exists, eq. (6) should be written as follows.

$$LLR[c(t,l,m)] = \ln\left[\frac{\sum_{x\in X_1(m)} \exp\left(-\frac{|y(t,l) - x(t,l)\hat{h}(t,l)|^2}{\hat{\sigma}^2(l)}\right)}{\sum_{x\in X_0(m)} \exp\left(-\frac{|y(t,l) - x(t,l)\hat{h}(t,l)|^2}{\hat{\sigma}^2(l)}\right)}\right]$$

$$\hat{\sigma}^2(l) = \begin{cases} \hat{\sigma}_n^2 + \hat{\sigma}_{if}^2, & \text{Superposed band} \\ \hat{\sigma}_n^2, & \text{Non-superposed band} \end{cases} \quad (7)$$

Since the received bits on superposed band are affected by interference, the corresponding LLRs are also supposed to be set according to $\hat{\sigma}^2(l)$ considering interference. To calculate the LLR, undesired signal power $\hat{\sigma}^2(l)$ and information about superposed band is required.

III. Proposed scheme

We propose an estimation technique for undesired signal power and superposed band to calculate the LLR in eq. (7). This technique consists of iterative superposed band detection within 1 packet and the undesired signal estimation by pilot symbols. Fig. 2 shows the proposed receiver structure. We detect superposed band within 1 packet so that it can be applied to a situation where superposed band changes frequently. Undesired signal power estimation by pilot symbol uses the information about detected superposed band, which can reduce the estimation error and achieve better BER.

Fig. 3 shows the flowchart of the undesired signal estimation. When a packet is received at the receiver, no information about the superposed band is available. Thus, we estimate

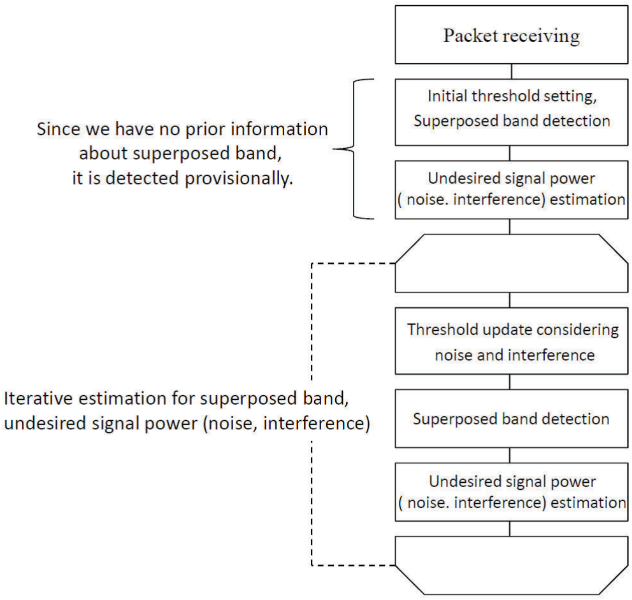


Fig. 3. Flowchart of the undesired signal power estimation

superposed band provisionally using pilot symbols. i−th pilot symbol at time t on l−th subcarrier is expressed as eq. (2) and (3). Since the pilot symbols are adjacent in time domain, we approximate $h_i \approx h_j$. On non-superposed band, noise power can be expressed by the difference of two pilot symbols as

$$\begin{aligned} |r(t,l)|^2 &= |y_i(t,l) - y_j(t,l)|^2 \qquad (8)\\ &= |h_i(t,l) - h_j(t,l) + n_i(t,l) - n_j(t,l)|^2\\ &\approx |n_i(t,l) - n_j(t,l)|^2 \qquad \text{for all } i,j,\ i \neq j. \end{aligned}$$

On superposed band, undesired signal power is expressed as $|r(t,l)|^2 = |n_i(t,l) - n_j(t,l) + i_i(t,l) - i_j(t,l)|^2$. Superposed band is detected on each subcarrier by comparing $|r(t,l)|^2$ with $|r_{th}|^2$. If $|r(t,l)|^2$ is larger than $|r_{th}|^2$, we can say interference is detected. In other words, the subcarrier is superposed. Since there is no information about interference at first, $|r_{th}|^2$ is set by taking the average of $|r(t,l)|^2$ over frequency domain and expressed as

$$|r_{th}|^2 = E\left[|r(t,l)|^2\right]_l. \qquad (9)$$

We define $e(l)$ as a difference of pilot symbols. For non-superposed band $e(l)$ is expressed as

$$\begin{aligned} e(l) &= y_i - y_j \qquad (10)\\ &= h_i - h_j + n_i - n_j \simeq n_i - n_j. \end{aligned}$$

On superposed band, it is expressed as

$$e(l) = y_i - y_j \simeq n_i - n_j + i_i - i_j. \qquad (11)$$

We define the group of $e(l)$ on non-superposed band as $\mathbf{e}'$ and the group of $e(l)$ on superposed band as $\overline{\mathbf{e}'}$. Noise power and interference power are written as follows.

$$\hat{\sigma_n}^2 = \frac{1}{2}\mathrm{var}[\mathbf{e}'] \qquad (12)$$

$$\hat{\sigma_n}^2 + \hat{\sigma_{if}}^2 = \frac{1}{2}\mathrm{var}[\overline{\mathbf{e}'}] \qquad (13)$$

Using the superposed band which is detected provisionally, undesired signal power is also estimated by eqs. (12) and (13).

Based on the estimated noise power and interference, $|r_{th}|^2$ is updated considering noise power and interference power using the equation in [5].

$$|r_{th}|^2 = \frac{\sigma_n^2}{\sigma_{if}^2}(\sigma_n^2 + \sigma_{if}^2)\left(2\ln\frac{1-\alpha}{\alpha} + \ln\frac{\sigma_n^2 + \sigma_{if}^2}{\sigma_n^2}\right). \qquad (14)$$

Here, α is the ratio of the number of superposed subcarriers to that of all subcarriers.

Using the updated threshold, superposed band is detected again, and noise power and interference power are also re-calculated by eqs. (12) and (13). This process is repeated to estimate the undesired signal power.

IV. PERFORMANCE EVALUATION

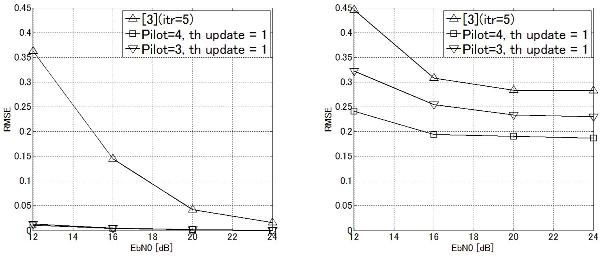
Table. I shows major simulation parameters.

TABLE I
SIMULATION PARAMETERS

Modulation	QPSK/OFDM
Number of Data Subcarriers L	62
Symbol Duration	4 μs
FEC	Turbo Code, Code Rate: 1/2
Decoding Algorithm	Linear-log-MAP
Channel Model	Multipath Rayleigh Fading
Doppler Frequency	30 Hz
Power Delay Profile	1dB Exponential Decaying Model
DUR	3, -3 dB
Superposed Rate α	10/62

A. RMSE of undesired signal power

Fig. 4 shows the RMSE of the undesired signal power for superposed band and non-superposed band, respectively. We can see that the RMSE on non-superposed band is decreased largely even for lower E_b/N_0. On superposed band, RMSE is also decreased as the number of pilot symbol increases. We can say that the RMSE is improved as a result of iterative superposed detection and undesired signal power estimation based on that.

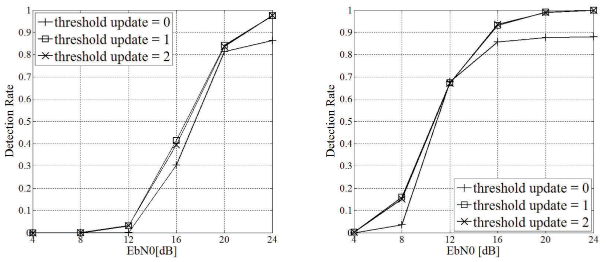


(a) RMSE for non-superposed band (b) RMSE for superposed band

Fig. 4. RMSE of undesired signal power. DUR = 0 dB, α = 10/62

B. Superposed band detection rate

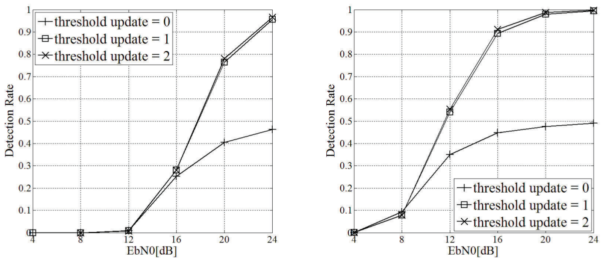
Figs. 5, 6 show superposed band detection rate when the number of pilot symbol is 4, $\alpha = 10/62$, $16/62$ and DUR = 3, -3 dB. Detection rate is a ratio of the number of packets where superposed band is detected correctly to the total number of packets. When the number of iteration is one, detection rate is improved compared to when that is zero for DUR = 3, -3 dB. In particular, detection rate becomes almost 100 % when DUR = -3 dB. However, the detection rate where the iteration number is 1 and 2 is almost the same. Therefore, we can say that one iteration is enough in this case.



(a) DUR = 3 dB

(b) DUR = -3 dB

Fig. 5. Superposed band detection rate. $\alpha = 10/62$



(a) DUR = 3 dB

(b) DUR = -3 dB

Fig. 6. Superposed band detection rate. $\alpha = 16/62$

C. BER according to the number of superposed band detection

Figs. 7, 8 show BER according to the number of superposed band detection when the number of pilot symbols is 4. In both cases where DUR = 3, -3 dB, the BER is improved when the number of superposed band detection is one compared to zero. When DUR = -3 dB, the BER improvement is larger than that of DUR = 3 dB. Furthermore, since the BER is almost the same when the number of iteration is 1 and 2, we can say that one iteration for superposed band detection is enough like superposed band detection rate.

D. BER according to the number of pilot symbol

Figs. 9, 10 show BER comparison between our proposed method and [6]. In our scheme, the number of iteration for superposed band detection is one and the number of pilot symbols is set to 3, 4 and 5. “perfect estimation” means estimation of the undesired signal is perfect.

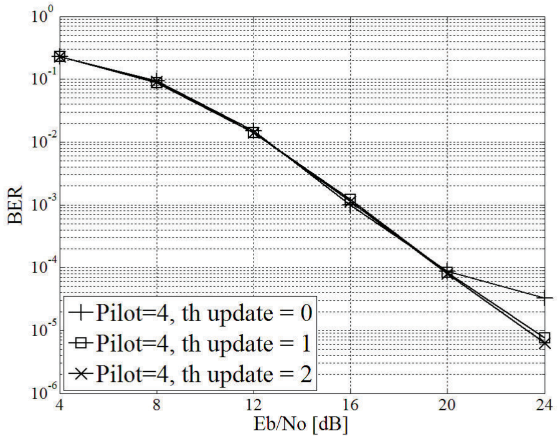


Fig. 7. BER according to the number of superposed band detection. $\alpha = 10/62$, DUR = 3 dB, pilot symbol = 4.

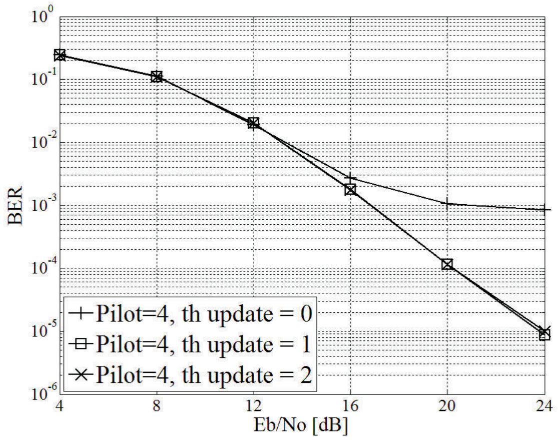


Fig. 8. BER according to the number of superposed band detection. $\alpha = 10/62$, DUR = -3 dB, pilot symbol = 4.

The results show that BER of our scheme gets better as the number of pilot symbols increases. This is because superposed band detection and RMSE of the undesired signal power are improved as shown in Figs. 4 – 6. When the number of pilot symbols is 3, BER is almost the same as that of [6] at E_b/N_0 = 24 dB. Therefore, for BER improvement, we need more than 4 pilot symbols.

V. CONCLUSION

In this paper, we propose an estimation technique for undesired signal power based on estimated superposed band. Computational complexity for superposed detection is a problem in [3], and the scheme in [4]– [5] cannot be applied when interference changes frequently since these techniques use several packets. Furthermore, estimation error for undesired signal power is a problem in [6]. For these problems, our proposed scheme is effective because it estimates superposed band within 1 packet and undesired signal power is estimated using the estimated band and pilot symbols so that RMSE of

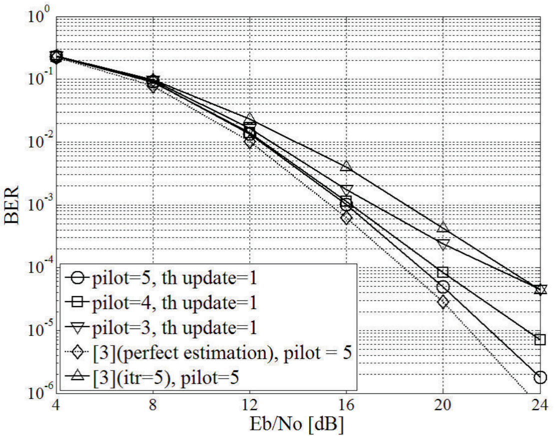


Fig. 9. BER according to the number of pilot symbol. $\alpha = 10/62$, DUR = 3 dB

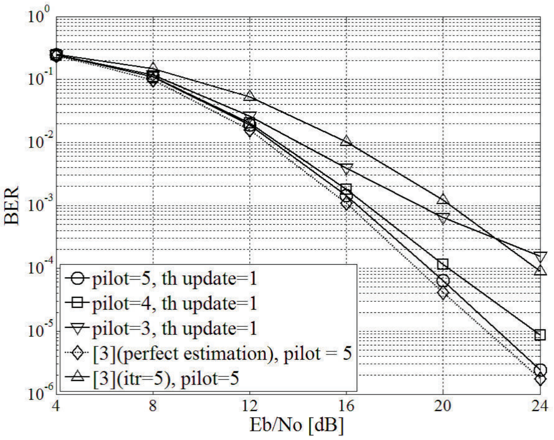


Fig. 10. BER according to the number of pilot symbol. $\alpha = 10/62$, DUR = -3 dB

undesired signal power and BER can be improved. Simulation results show that the proposed scheme decreases the RMSE for undesired signal power compared to [6] and superposed band detection rate is also improved by iterative superposed band detection. Furthermore, BER is improved compared to [6] as the number of pilot symbol increases, and gets close to the BER when the estimation of undesired signal is perfect.

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