On LDPC Decoding for Frequency Hopping OFDMA Cellular Systems in the Downlink

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***Abstract*— In this paper, we consider an FH-OFDMA system with LPDC codes for the downlink of cellular systems to realize the frequency reuse factor of one. For the system, we propose simple erasure detection and LDPC decoding methods to effectively combat the highly non-uniform interference caused by the different power allocation to the data channels and frequency hopping in adjacent cells. With the proposed methods, the performance is remarkably improved in partially interfered cases without severe performance loss in uniformly interfered cases.**

I. Introduction

In future mobile communication systems, demands on packet data service with high data rate and high quality are increasing for ubiquitous internet access. In addition, the frequency reuse factor of one is preferable in the cellular environments for flexible cell planning and easy spectrum allocation. As a multiple access scheme to meet such requirements, orthogonal frequency division multiple access (OFDMA) is drawing a lot of attention due to its advantages of the robustness to multipath fading, granular resource allocation, and no intracell interference [1].

To further obtain intercell interference averaging effect, frequency hopping (FH) can be employed in OFDMA [2]. However, the intercell interference should be effectively managed at the cell boundary to achieve the frequency reuse factor of one even for FH-OFDMA systems. At the cell boundary where the interference is dominant, the downlink packets suffer from non-uniform interference since the power allocation is different among the data channels according to the location and service of the users. In such harsh environments, we generally resort to error correcting codes to recover the information reliably. However, most of the previous work on error correcting codes in non-uniform interference is based on Reed-Solomon codes in FH spread systems [3][4]. An iterative channel estimation and decoding method based on convolutional and turbo codes was also proposed to combat the partial band interference [5], but the method is not suitable for the downlink employing fast FH.

In this paper, we introduce low density parity check (LDPC) codes [6][7] to FH-OFDMA systems for a robust performance in downlink cellular environments. The problem to be solved is how to effectively decode the partially or uniformly interfered packet without knowing the interference power and the location of the symbols corrupted by high power interference. The proposed method will be shown to improve performance remarkably improved in partially interfered cases without causing severe performance loss in uniformly interfered cases.

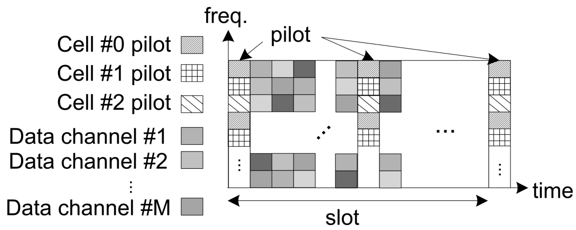

Fig. 1. The pilot and data channel structure.

II. System Description

For the downlink, a slot consists of a common pilot channel and M data channels well-distributed over the time and frequency resources in the slot as shown in Fig. 1. The FH pattern of a data channel changes in a symbol-by-symbol manner and keeps being orthogonal to the FH patterns of the other data channels in the same cell. The pilot channel may have a frequency reuse factor less than one for robust channel estimation at the cell boundary while the data channels have a frequency reuse factor of one by assigning different FH patterns to adjacent cells such that about $1/M$ of the resources in a data channel are collided with those of a data channel in adjacent cells.

The overall system model is shown in Fig. 2. For transmission over a data channel, a data packet, b_k, of size K is encoded by an (N, K) LDPC encoder. The encoder outputs c_i of length N are then mapped to the modulated symbols, x_l, of length $L = \log_Q N$, where Q is the modulation order. Then, the pilot and modulated symbols are transmitted according to the slot configuration with OFDM modulation.

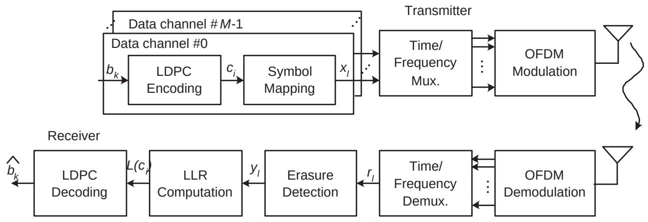

Fig. 2. System model.

At the receiver, the received symbols for the assigned data channel after time/frequency demultiplexing are given by

$$r_l = h_l x_l + w_l, l = 0, 1, ..., L-1, \tag{1}$$

where h_l and w_l are the complex channel gain and the additive noise in the frequency-domain, respectively. The additive noise is composed of the background noise n_l of variance σ_n^2 and the interchannel interference I_l of variance $\sigma_{I_l}^2$. In the proposed system, a received symbol, r_l, is replaced by an erasure, i.e., zero value, if it is likely to be corrupted by the high power interchannel interference through erasure detection. Finally, the log-likelihood ratios (LLRs) are computed with the erasure detector outputs, y_l, and the information bits are decoded through the sum-product algorithm at the LDPC decoder [6].

III. Erasure Decoding

For the non-uniformly interfered cases, the noise variance of each received symbol is required for optimal LLR computation. As an example, the LLR of b_l for BPSK is given by $\Lambda(b_l) = \frac{\Re\{4h_l^* r_l\}}{\sigma_{w,l}^2}$, where $\Re\{\cdot\}$ denotes the real part. Since it is difficult to estimate $\sigma_{w,l}^2$, the average noise variance, denoted as $\sigma_{w,a}^2$, is estimated in a packet by packet manner instead. One approach is to estimate the average noise variance as

$$\sigma_{w,a}^2 = \frac{1}{L}\sum_{l=0}^{L-1}(|r_l|^2 - |h_l|^2), \tag{2}$$

where h_l is estimated with pilot symbols. Then, a suboptimal decoding is to apply $\sigma_{w,a}^2$ as the uniform noise variance in LLR computation, which is called non-erasure decoding (NED) in the sequel. However, the NED method degrades the performance when the noise power is concentrated in a fraction of the received packet since the reliability of high power interfered symbols is exaggerated. To eliminate such unreliable symbols, we introduce following erasure criteria (EC) for constant modulus constellation.

EC1 - The received signal power tends to be abnormally large for the received symbols corrupted by high power interference. Thus the following criterion can be used to erase the interfered symbols.

$$y_l = \begin{cases} r_l, & \text{if } |r_l|^2 \le T_1|h_l|^2, \\ 0, & \text{if } |r_l|^2 > T_1|h_l|^2. \end{cases} \tag{3}$$

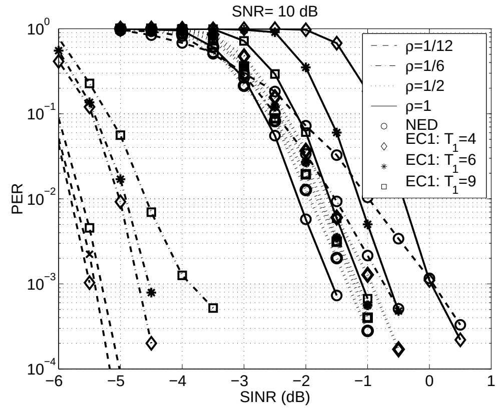

Fig. 3. Performance of *EC1* for different threshold values.

EC2 - The instant noise power can be estimated by $\hat{\sigma}_{w,l}^2 = |r_l|^2 - |h_l|^2$. Thus, the following criterion can be utilized.

$$y_l = \begin{cases} r_l, & \text{if } |r_l|^2 - |h_l|^2 \le T_2\sigma_{w,a}^2, \\ 0, & \text{if } |r_l|^2 - |h_l|^2 > T_2\sigma_{w,a}^2. \end{cases} \tag{4}$$

In (3) and (4), the threshold T_1 or T_2 should be chosen such that it does not degrade the performance in uniformly interfered or non-interfered cases, but improves the performance in partially interfered cases. After erasure detection and insertion, the LLRs are computed with y_l as the received symbols and $\sigma_{w,a}^2$ as the noise variance of y_l. When the interference power is very high in partially interfered cases, $\sigma_{w,a}^2$ is an overestimate for the noise variance of the non-erased symbols. Thus, the noise variance is estimated again with the set U of non-erased symbols as

$$\sigma_{w,u}^2 = \frac{1}{|U|}\sum_{l\in U}(|r_l|^2 - |h_l|^2) \tag{5}$$

where $|U|$ is the cardinality of U.

IV. Simulation Results

The performance of the erasure decoding methods is investigated at the cell boundary, where the intercell interference is dominant. Since a low order modulation and a low code rate are likely to be selected at the cell boundary, a $1/6$ binary irregular LDPC code with $N = 2048$ is used with QPSK modulation. There are 12 data channels over the slot, composed of 8 OFDM symbols with 1536 used subcarriers. For channel model, the multipath intensity profile of the ITU-R pedestrian A fading is used with no time variation during a slot. However, the fading is independent for each slot. We also assume a perfect power control so that $\sum_{l=0}^{L-1}|h_l|^2$ is remained constant in a slot at the given SINR.

Fig. 3 shows the packet error rates (PERs) of *EC1* for different threshold values when SNR=10 dB and the fraction ρ of the interfered symbols in the received data packet varies. Here, ρ can be also regarded as the ratio of the number of active data channels to the number of total data channels in the interfering cell. Here, we assume that the channel gains,

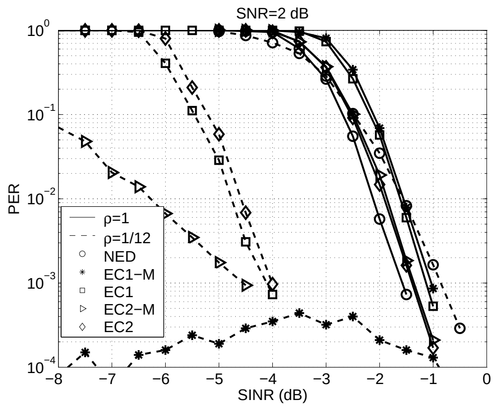

Fig. 4. Performance of various erasure decoding schemes when SNR=2 dB.

h_l, are estimated perfectly. In case of the conventional NED, the performance becomes worse as ρ decreases. On the other hand, with *EC1*, a large performance gain is obtained in the partially interfered cases ($\rho = 1/6$ or $1/12$) at the cost of a slight performance degradation in the uniformly interfered cases ($\rho = 1$). As the threshold increases, the performance gain decreases in the partially interfered cases while the performance loss decreases in the uniformly interfered cases.

Fig. 4 compares the PERs of various erasure decoding methods when the SNR is set to 2 dB. For all methods, we set a threshold to keep the loss less than 0.5 dB at the PER of 10^{-2} when $\rho = 1$: $T_1 = 9$ for *EC1* and *EC1-M*, and $T_2 = 6$ for *EC2* and *EC2-M*, respectively. The results show that even the simplest one, *EC1*, provides us with more than 3 dB performance gain over the NED method when $\rho = 1/12$ at the PER of 10^{-2}. Another observation is that, in case of $\rho = 1/12$, more gain is obtained with *EC1-M* and *EC2-M* by estimating the noise variance, $\sigma^2_{w,u}$, of the non-erased symbols and using it in LLR computation.

In the full paper, we will provide more results on the performance of various erasure decoding schemes. In addition, the effect of channel estimation using the designed pilot channel will be investigated in three cell environments for practical considerations.

V. Conclusions

In this paper, we have proposed erasure decoding methods for LDPC codes to mitigate the intercell interference for downlink FH-OFDMA systems. With the proposed methods, we can obtain a larger performance gain over the conventional non-erasure decoding method when the interference power is concentrated in a fraction of the received symbols. In addition, the performance loss is negligible by setting a proper threshold when the interference is uniformly distributed in the received symbols. The results also give us intuition that it is better to allocate the transmit power unevenly in a viewpoint of intercell interference management.

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