Erasure decoding for LDPC-coded FH-OFDMA system in downlink cellular environments

Y.H. Kim, K.S. Kim and J.Y. Ahn

Erasure decoding methods for an LDPC-coded FH-OFDMA system to combat the intercell interference in downlink cellular environments are proposed. With the proposed methods using simple erasure detection schemes, the performance is remarkably improved in partially interfered cases with only negligible performance loss in uniformly interfered cases.

Introduction: Efficient packet based transmission with high data rate and high quality is considered as one of the requirements for future mobile communication systems [1]. In addition, a frequency reuse factor of one is preferred to make the cell planning and spectrum allocation easier. Frequency hopping orthogonal frequency division multiple access (FH-OFDMA) is among the multiple access candidates to meet such requirements owing to its capability of avoiding intracell interference and averaging the intercell interference (ICI). However, in cases of different power allocation and loading for each interferer in adjacent cells, the ICI pattern can be highly non-uniform in FH-OFDMA systems. Thus, such non-uniform ICI should be effectively managed, especially at cell boundaries, to achieve a frequency reuse factor of one. Previous work to combat interference has focused on the spread FH systems using Reed-Solomon codes with errors and erasures decoding [2, 3]. An iterative channel estimation and decoding method was also proposed for a convolutionally coded slow FH system [4], but it is desirable in the downlink with fast FH where only one or two symbols are involved in noise variance estimation. In this Letter, we employ low-density parity check (LDPC) codes [5, 6] in FH-OFDMA systems and propose simple erasure decoding methods to effectively decode the partially or uniformly interfered packet without knowing the ICI power and the location of the symbols corrupted by high power interference.

System model: In 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. 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. 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. The pilot and modulated symbols are than transmitted according to the slot configuration with OFDM modulation. At the receiver, the received symbols for the assigned data channel are given by $r_l = h_l x_l + w_l$, $0 \le l \le L$, where h_l and w_l are the complex channel gain and the additive noise of variance $\sigma^2_{w,l}$, respectively. The additive noise is composed of the background noise n_l of variance σ^2_n and the ICI I_l of variance $\sigma^2_{I,l}$. In the proposed methods, a received symbol (r_l) is replaced by an erasure (0) if it is likely to be corrupted by the high power ICI. 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 [5].

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 is given by $\Lambda(b_l) = \mathrm{Re}\{4h_l^* r_l\}/\sigma^2_{w,l}$ for BPSK, where Re{} denotes the real part. Since it is difficult to estimate $\sigma^2_{w,l}$, the average noise variance, denoted as $\sigma^2_{w,a}$, is estimated in a packet by packet manner instead. One approach is to estimate the average noise variance as $\sigma^2_{w,a} = L^{-1}\sum_{l=0}^{L-1}(|r_l|^2 - |h_l|^2)$, where h_l is estimated with pilot symbols. Then, a suboptimal decoding is to apply $\sigma^2_{w,a}$ 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. In the proposed method, such unreliable symbols are erased ($y_l = 0$) if $|r_l|^2 \ge T_l$ since the received power of the high power interfered symbols tends to be abnormally large. Otherwise, the received symbols are unchanged ($y_l = r_l$). For the threshold T_l, we utilise either $T_l = T_1|h_l|^2$ (EC1) or $T_l = |h_l|^2 + T_2\sigma^2_{w,a}$ (EC2). The EC2 method utilises the fact that the instant noise power can be estimated with $|r_l|^2 - |h_l|^2$. In the EC1 and EC2 methods, 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 $\sigma^2_{w,a}$ as the noise variance of y_l. When the ICI power is very high in partially interfered cases, $\sigma^2_{w,a}$ is an overestimate for the noise variance of the non-erased symbols. Thus, the noise variance is estimated again with the set of non-erased symbols, U, as $\sigma^2_{w,u} = |U|^{-1}\sum_{l \in U}(|r_l|^2 - |h_l|^2)$, where $|U|$ is the cardinality of U. As an option, the erasure detection can be performed again with the new threshold $T_l = |h_l|^2 + T_2\sigma^2_{w,u}$, to find the unreliable symbols undetected during the first round in the EC2 method.

Simulation results: The performance of the erasure decoding methods is investigated with QPSK modulation and a 1/6 binary irregular LDPC code of $N = 2048$ and 30 decoding iterations. There are 12 data channels in a slot, which is composed of eight OFDM symbols with 1536 used subcarriers. The ITU-R pedestrian A fading channel is used with no time variation during a slot. The ICI is generated by activating D data channels of the same power in the adjacent cell in a two cell environment, i.e. the fraction of the interfered symbols in the received data packet is given by $\rho = D/12$. We also assume perfect power control so that the SINR $(=\sum_{l=0}^{L-l}|h_l|^2/L\sigma^2_{w,a})$ is constant for every received packet.

Fig. 1 shows the packet error rates (PERs) of the EC1 method with $\sigma^2_{w,a}$ for LLR computation for various values of ρ and T_l when the SNR $(=\sum_{l=0}^{L-1}|h_l|^2/L\sigma^2_n)$ is set to 10 dB. In the case of the conventional NED method, the performance becomes worse as ρ decreases. However, with the EC1 method, a large performance gain is obtained in the partially interfered cases ($\rho = 1/6$, or $1/12$) at the cost of a slight performance loss 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.

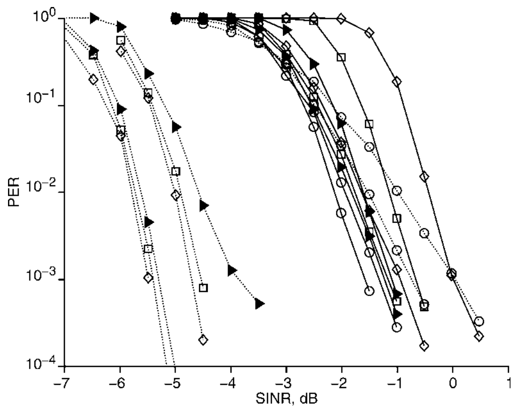

Fig. 1 *PERs of EC1 with different thresholds when SNR = 10 dB*

——— $\rho = 1$
· · · · · · $\rho = 1/2$
- · - · - · $\rho = 1/6$
- - - - - - $\rho = 1/12$
○ NED
◇ EC1$T_1 = 4$
□ EC1/$T_1 = 6$
▶ EC1/$T_1 = 9$

Fig. 2 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 $\rho = 1$. The results show that even the simplest one, method 1, provides more than 3 dB performance gain over the NED method when $\rho = 1/12$ at PER of 10^{-2}. Using $\sigma^2_{w,u}$ for LLR computation (method 2 and method 4), more gain is obtained when $\rho = 1/12$. In addition, the most complex one, method 5, which detects erasures twice in the EC2 method shows almost zero PERs when $\rho = 1/12$ (thus, the PERs are not shown in the Figure). In this way, the effect of the partial band ICI can be ignored using the proposed methods.

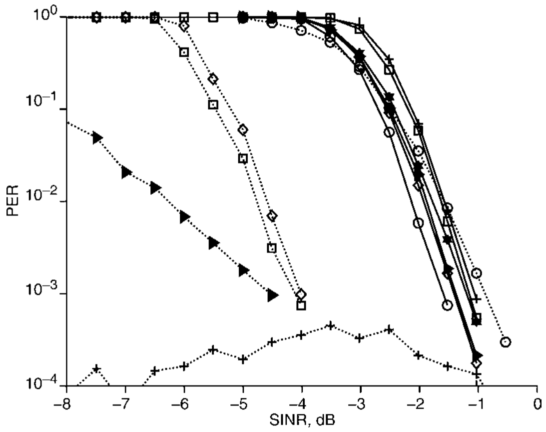

Fig. 2 *PERs of various erasure detection schemes when SNR = 2 dB*
——— $\rho = 1$
- - - - - $\rho = 1/12$
○ NED
□ method 1: EC1/$T_1 = 9/\sigma^2_{w,a}$
◇ method 3: EC2/$T_2 = 6/\sigma^2_{w,a}$
* method 5: EC2/$T_2 = 6/\sigma^2_{w,u}$/twice erasure detections
+ method 2: EC1/$T1 = 9/\sigma^2_{w,u}$
▶ method 4: EC2/$T_2 = 6/\sigma^2_{w,u}$

Conclusions: We propose erasure decoding methods for LDPC codes to mitigate the ICI for downlink FH-OFDMA systems. With the proposed methods, we can obtain a large performance gain over the conventional non-erasure decoding method in the partially interfered cases at a negligible loss in the uniformly interfered cases. The results also provide us with intuition that it is better to allocate the transmit power unevenly from the viewpoint of ICI management.

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