Performance of an LDPC-Coded Frequency-Hopping OFDMA System Based on Resource Allocation in the Uplink

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***Abstract*— An LDPC-coded frequency hopping OFDMA system is proposed for the uplink of the cellular systems, where the frequency hopping is based on a resource block for coherent demodulation. For the proposed system, two different resource block types are considered either for better intercell interference averaging capability or for better channel estimation performance. An iterative channel estimation and decoding method utilizing the resource block structure effectively is also proposed for the pedestrian channel environments. The performance of the proposed system with the two resource block types will be investigated both in a single cell environment and multiple cell environments to show the performance of both the interference averaging and the channel estimation.**

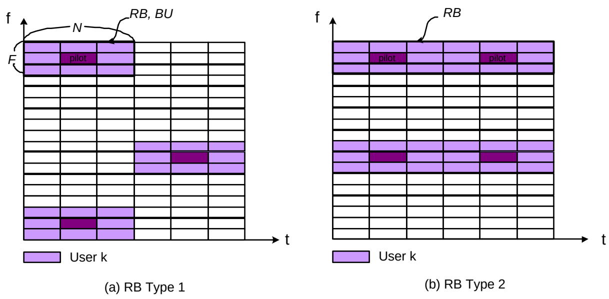

Fig. 1. The two RB types of the proposed FH-OFDMA system.

I. Introduction

In future wireless communication systems, high data rate and quality, close to the wired environments, are required to support increasing demands on various services such as video and audio streaming, file transfer, internet access, and so forth. Especially, demands on packet data service are increasing for ubiquitous internet access. Orthogonal frequency division multiplexing frequency division multiple access (OFDMA) provides us with an efficient platform for high speed packet transmission in cellular environments: high flexibility in subcarrier allocation for data rate and channel adaptation, no intracell interference, and intercell interference averaging or avoidance capability.

The OFDMA systems with sophisticatedly designed frequency hopping (FH) methods can effectively average the intercell interference together with the full exploitation of the available frequency diversity. However, the channel estimation is challenging for the FH-OFDMA systems when it is applied in the uplink since the data packets assigned in the same slot are received at the base station through different channels and hence the common pilots can not be used. In this reason, symbol-by-symbol hopping methods which can average the intercell interference better can not be applied for the frequency selective fading uplink channels. Moreover, the conventional pilot structures and the pilot estimation methods designed for the OFDM systems [1]-[3] cannot be employed for the uplink OFDMA.

In this paper, we propose a resource block (RB) based frequency hopping OFDMA system and design two different RB types considering the channel estimation and interference averaging capability. The performance of the proposed system with the two RB types will be investigated both in a single cell environment and multiple cell environments with an iterative channel estimation and decoding method utilizing the RB structure effectively to provide insight into the effect of RB structures in the overall system performance.

II. System Model

In the proposed FH-OFDMA system for the uplink, the frequency hopping is based on an RB which consists of more than one base unit (BU) composed of adjacent time and frequency resources in the time and frequency grid as illustrated in Fig. 1. The channel on the resources in the BU does not vary both in the time and frequency domains so that only one pilot symbol is inserted in the center of the basic unit to assist the channel estimation on the data fields combined with a decision-directed channel estimation method.

For the proposed system, we consider two different RB types, one of which employs one BU as in Fig. 1(a) and the other employs two BUs adjoined in time as in Fig. 1(b). The RB type 1 can provide us with better performance in the intercell interference average capability than the RB type 2 since more freedom exists in the frequency hopping. On the other hand, the RB type 2 has an advantage in the channel estimation since the received signals on double the number of resources can be utilized to refine the channel estimation for a decision-directed approach. Thus, the two RB types will show a tradeoff in their performance in various cell environments.

The system model of the proposed LDPC-coded FH-OFDMA system is depicted in Fig. 2. At the transmitter of

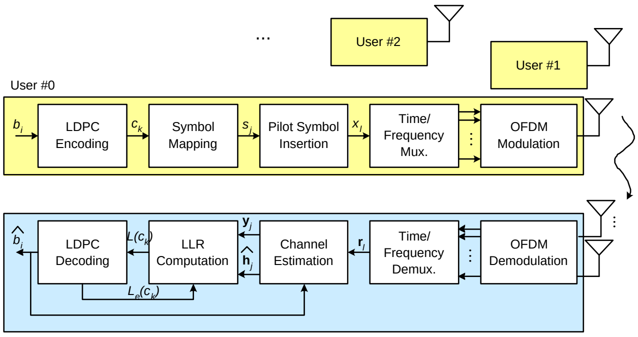

Fig. 2. The system model.

a user side, a data packet of information bits, b_i, is encoded by an LDPC encoder with a source block length K_L and a codeword length N_L. The coded bits, c_k, are then mapped to the modulated symbols, s_j, such as QPSK or QAM and the pilot symbols are inserted at the pilot locations in the modulated symbol streams. The pilot inserted symbol streams are then mapped to the pre-assigned locations of time and frequency resources according to the frame format for OFDM symbol generation.

In the proposed system, there exists no intracell interference through a timing control loop so that the received signals are synchronous. Then the received vector from the M receive antennas at the lth subcarrier of the nth OFDM symbol is given by

$$\mathbf{r}_l(n) = \mathbf{h}_l(n)x_l(n) + \mathbf{w}_l(n), \tag{1}$$

where $\mathbf{r}_l(n) = [r_{l,1}(n)r_{l,2}(n)\cdots r_{l,M}(n)]^H$ is the $M \times 1$ received vector, $\mathbf{h}_l(n) = [h_{l,1}(n)h_{l,2}(n)\cdots h_{l,M}(n)]^H$ is the $M \times 1$ channel vector, $x_l(n)$ is the modulated symbol (data or pilot), and $\mathbf{w}_l(n) = [w_{l,1}(n)w_{l,2}(n)\cdots w_{l,M}(n)]^H$ is the $M \times 1$ additive white Gaussian noise (AWGN) vector with $E\{\mathbf{w}_l(n)\mathbf{w}_l(n)^H\} = \sigma_w^2\mathbf{I}_M$. Here, the total received SNR per symbol from the M received antennas is given by $E_s/N_o = ||\mathbf{h}_l(n)||^2/\sigma_w^2$.

III. Iterative Estimation and Decoding

For the better utilization of the RB structure, we propose an iterative estimation and decoding (IED) method based on the initial pilot-aided channel estimation and the subsequent channel estimation refinement using the LDPC decoder outputs. The proposed method is more proper for the channels with low mobility.

At the first iteration prior to decoding, the channel on the data fields of the RB is estimated with the pilots in the RB such that

$$\hat{\mathbf{h}}_l^{(1)}(n) = \frac{1}{N_p}\sum_{p\in I_{T_p}} \tilde{\mathbf{h}}_{l_p}(p), (n,l) \in I_{RB}, \tag{2}$$

where $\tilde{\mathbf{h}}_{l_p}(p) = \mathbf{r}_{l_p}(p)/x_{l_p}(p)$ is the least square estimate of the channel at the pilot position of time p and frequency l_p, I_{T_p} is the time index set of pilots in the RB, and I_{RB} is set of time and frequency index pairs of the RB. For the RB type 1, no average is performed since only one pilot symbol exists in the RB.

After channel decoding, the channel estimation is refined with the decoder outputs as follows.

$$\hat{\mathbf{h}}_l^{(q)}(n) = \frac{1}{|I_{RB}|-1}\sum_{(n',l')\in I_{RB}\setminus(n,l)} \tilde{\mathbf{h}}_{l'}^{(q)}(n'), \tag{3}$$

where $|I|$ is the cardinality of a set I, $I\setminus i$ denotes the set formed from I excluding the element i, and $\tilde{\mathbf{h}}_{l'}^{(q)}(n')$ is the least square estimate from the pilot or decided symbols with decoder outputs. In (3), the channel refinement of a data field does not include the channel estimate with the decision feedback symbol of the same data field to avoid the adverse effect on the LDPC decoder.

Once the channel estimation is performed, the LDPC decoding is performed after the log-likelihood ratio computation. The proposed IED receiver performs up to R IED iterations over the channel estimation, demodulation, and decoding and, for every IED iteration, the LDPC decoder also iterates maximum D decoding iterations until the decoded results meet a stop condition.

IV. Simulation Results

As a preliminary result, we investigate the performance of the proposed system in a single cell environment with the two RB types and the proposed IED method via Monte Carlo simulations with following parameters. A BU consists of 2 adjacent subcarriers of 3 consecutive OFDM symbols with a pilot symbol located in the first subcarrier of the second OFDM symbol in the BU. For a data packet transmission, 128 BUs each of 2 consecutive BU time durations, that is, total 256 BUs, are assigned and the RBs from any type are distributed over 20 MHz bandwidth. For the LDPC coding, a binary $(2560, 1440)$ irregular LDPC code is constructed and the sum-product decoding algorithm is employed with the stop criterion based on the syndrome check as in [4]. We assume that the transmitted power for each data packet is adjusted for the mean SNR averaged over the received packet to be a target SNR value.

Fig. 3 shows the packet error rates (PERs) of the proposed system with 2 receive antennas in the ITU-R pedestrian A channel model with the pedestrian speed of 3 km/h when the maximum numbers of IED iterations and decoding iterations are 5 and 10, respectively. In the figure, *IED 1* denotes the IED receiver applied for the RB type 1 and *IED 2* denotes that for the RB type 2. It is shown that the RB type 2 exhibits 1.5 dB performance gain over the RB type 1 with less than 2 dB performance gap over the known channel case. However, the figure does not reflect the advantage of the RB type 1 in the intercell interference average capability.

In the final paper, the performance of the two RB types in multiple cell environments will be included to show the performance tradeoff between the two RB types. In addition, the performance of the IED receivers are investigated in various conditions which includes the performance investigation

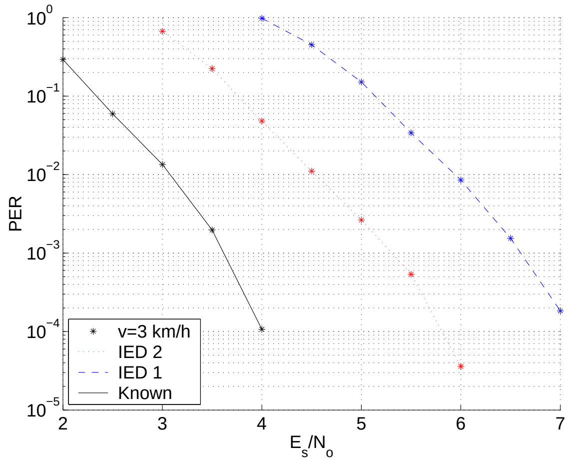

Fig. 3. The PERs of the proposed system with the two RB types for the ITU-R pedestrian A model with the pedestrian speed of 3 km/h when the maximum numbers of IED iterations and decoding iterations are 5 and 10, respectively.

with the number of maximum IED iterations and maximum decoding iterations.

V. Conclusions

We have proposed an LDPC-coded FH-OFDMA system with an RB based frequency hopping for the uplink of cellular systems. For the proposed system, we considered two different RB types considering the interference average capability and channel estimation performance. The IED receiver utilizing the RB structure effectively was also proposed and its performance was investigated as a preliminary result. In the final paper, the performance of the proposed system with the two RB types will be investigated in multiple-cell environments to incorporate both the intercell interference average capability and the IED performance.

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