Time-Efficient Resource Allocation Algorithm over HSDPA in Femtocell Networks

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Abstract— **This paper presents a time-efficient optimal resource allocation algorithm aiming to maximize the system throughput of the single-user High Speed Downlink Packet Access (HSDPA) deployed in femtocell base station. The system throughput maximization with constrained total power is first formulated as a constrained integer programming problem. We first prove that a two-group bit and energy allocation provides the global optimum solution in the system without multipath. We then focus on the use of the two-group allocation method over frequency selective channels. A pre-processing method was used to systematically cluster and remove channels to stop using energies over severely degraded channels with the two-group allocation approach. This improves the system throughput whilst greatly reducing the computation complexity. The proposed two-group approach with channel removal is suitable for femtocell base station with limited signal processing capability.**

I. Introduction

This paper develops the optimal radio resource allocation for single-user High Speed Downlink Packet Access (HSDPA) applications deployed in femtocell base stations. The HSDPA application is equipped with the adaptive modulation and coding technique and multicode transmission to offer much higher data rate services than previous Wideband Code Division Multiple Access (WCDMA) standards [1]. The femtocell network concept further enhances the HSDPA's system throughput by providing Signal to Interference plus Noise Ratios (SINRs) higher than micro/macro-cell networks for users in the proximity of the base stations [2]. The femtocell base stations have limited signal processing capability as they are low-cost and low-power wireless access points. Due to their limited capability, they require much simpler resource scheduling algorithms to be implemented. This paper aims to develop a time-efficient radio resource allocation method which can achieve a superior performance when the HSDPA operates with a higher received power, whilst keeping the computational complexity low. The wireless linkage from a femtocell base station to each user is modelled as a frequency selective channel which is the typical propagation environment in urban areas.

The HSDPA system equally allocates the bit rate and power to each transmission channel. By adapting the number of used channels to channel conditions, the equally allocated bit rate is selected to enable the worst channel to be able to transmit [1]. Equal rate and energy allocation scheme is inefficient in power utilization since a considerable portion of allocated power in each channel cannot increase the bit rate. The higher SNIR channels cannot transmit higher bit rates when each channel encounters a different inter-channel interference and inter-symbol interference (ISI).

The two-group allocation approach presented in [3] greatly enhances the efficiency and the system throughput, by adjusting the transmitted energies to eliminate the wasted energies by allowing some promising channels to transmit at a higher bit rate. A more general signal receiving model, a window-extended receiving model is then integrated with the two-group approach for better ISI suppression, thus further improving the throughput [4]. The above two-group allocation approaches use an iterative channel ordering scheme to determine the optimum numbers of high-rate channels. Such an iterative channel ordering scheme requires to traverse all low-rate channels each time it identifies a new high-rate channel, thus having excessive computational complexity when implemented in femtocell base stations. Further, the two implementations are constrained to allocate at least a lower bit rate to all channels, thus the lower bit rate is subject to the worst channel. In cases where a few channels have much lower gains than other channels, the performance of the two-group approach is considerably reduced when using a reduced lower rate.

We first prove that the two-group allocation approach is the global optimal solution for the discrete bit and power loading problem when the single-user downlink transmission operates over channels with a uniform channel gain. We then examine the two-group allocation method with a channel removal scheme prior to running the resource allocation method when considering a frequency selective propagation environment, so as to concentrate the limited resources on those promising channels and to avoid the highly complicated channel ordering scheme. This provides a higher system throughput whilst requiring lower computation workload.

II. Related Work

When the real systems use finite modulation and coding formats in each channel, the optimal resource allocation methods should be developed based on a finite set of discrete bit rate values. In addition to the HSDPA system, the equal rate and power allocation with adapted number of active channels is also used for throughput maximization in [5] due to its simple implementation. This method, however, is inefficient in power utilization.

When the allocated power in each channel is adjusted to exactly meet the SINR requirement to transmit the allocated bits, the optimal discrete bit and power loading problem can be solved by being formulated as a knapsack problem. Some heuristic-based approximate techniques, such as integer programming [6], simulated annealing method [7] and dynamic programming [8], are examined to find the sub-optimal solutions. However using more complicated system models, requires more complicated complexities since the power adjustment should be adjusted iteratively.

The Levin Campello (LC) discrete bit loading algorithm, originally proposed in [9] and in [10] respectively, delivers the optimal bit and power allocation with polynomial computation complexity. For the multicode CDMA using random spreading codes and a linear Minimum Mean Square Error (MMSE) receiver, the bit-adding LC algorithm adapted by Imran [11] achieves optimal performances by integrating with iterative power adjustment, however it has large computational complexity. For the system operating over frequency selective channels, the two-group allocation approach is developed with the aim of approaching the optimum discrete throughput with greatly reduced complexity [3]. Further performance improvement can be achieved by developing the allocation approach based on a more general system model which incorporates ISI components, and the corresponding MMSE equalizer with improved ISI suppression [4].

This paper aims to further enhance the performance and time efficiency of the two-group approach.. The remaining part of this paper is organized as follows: the proposed two-group allocation is proved to be global optimum for the system having uniform-gain channels in Section III, Section IV presents the two-group allocation implementation over frequency selective channels, which integrates channel removal preprocessing, Section V provides the simulation results and Section VI concludes this paper.

III. Optimum Resource Allocation Over Uniform-Gain Orthogonal Channels

In this section, we solve the optimal discrete bit and power loading problem for indoor femtocell network, where the downlink channels are assumed to be orthogonal and have uniform channel gain. The optimal solution, for the two-group resource allocation is produced as the greedy solution based on an incremental energy model.

A. Problem Formulation

A multi-code CDMA system employing adaptive modulation and coding (AMC) over K parallel channels is considered, where data rates of b_p bits per symbol can be adaptively realized on each channel for $p = 1, \cdots, P$. Orthogonal spreading sequences are employed on the parallel channels, which are assumed to introduce equal channel gains to ensure that orthogonality of the spreading sequences is preserved on the receiver end. For a given total energy of E_T, this paper aims to show that the proposed two group resource allocation maximizes the total rate, R_T that can be realized over the K channels by loading b_p and b_{p+1} bits per symbol over a group of $K-m$ and another group of m channels respectively. This constrained optimization problem can then be written as follows

$$\max_{m,b_p} \left(R_T = (K-m)\, b_p + m b_{p+1} \right)$$

$$\text{st} \qquad \textstyle\sum_{k=1}^{m} E_k\left(b_{p+1}\right) + \sum_{k=m+1}^{K} E_k\left(b_p\right) - E_T \leq 0 \tag{1}$$

where $E_j\left(b_p\right)$ is the energy required to transmit b_p bits per symbol over channel j .

B. The Incremental Energy Model

In order to demonstrate the maximization achieved by the proposed two-group resource allocation scheme, the optimization problem above is formulated using an incremental energy model. An incremental energy, $e(b_i)$ is the additional amount of energy utilized to load an additional data rate of β_i to the current data rate of b_{i-1}. This additional data rate, β_i is also known as the bit granularity, which can be defined as

$$\beta_i = \begin{cases} b_i - b_{i-1}, & \text{for} \quad i = 2, \cdots, P, \\ b_1 & \text{for} \quad i = 1. \end{cases} \tag{2}$$

Likewise, the incremental energy, $e(b_i) = E\left(b_i\right) - E\left(b_{i-1}\right)$ is defined as

$$e\left(b_i\right) \triangleq \begin{cases} \frac{N_0 \Gamma \left(2^{\beta_i} - 1\right)}{h} 2^{b_{i-1}} & \text{for} \quad i = 2, \cdots, P, \\ \frac{N_0 \Gamma}{h} \left(2^{b_i} - 1\right) & \text{for} \quad i = 1, \end{cases} \tag{3}$$

where $E(b_i) = \frac{N_0 \Gamma}{h} \left(2^{b_i} - 1\right)$ is the energy required to realize b_i, h is the channel gain, Γ is the gap value, $\dfrac{N_0}{2}$ is the double sided noise power spectral density. From (3), it can be observed that the incremental energy increases exponentially with respect to the rate index, i.

With β_i and $e(b_i)$, the number of bits per symbol, $b_{p+1}$and the energy, $E\left(b_{p+1}\right)$ required to transmit b_{p+1} bits can be expressed as follows

$$b_{p+1} = \sum_{i=1}^{p+1} \beta_i I_i = \sum_{i=1}^{P} \beta_i I_i \tag{4}$$

and

$$E\left(b_{p+1}\right) = \sum_{i=1}^{p+1} e\left(b_i\right) I_i = \sum_{i=1}^{P} e\left(b_i\right) I_i, \tag{5}$$

where $I_i = \begin{cases} 1 & \text{for} \qquad i \leq p+1, \\ 0 & \text{otherwise.} \end{cases}$.

In order to rewrite the constrained optimization problem given in (1) in terms of the bit granularity, β_i and the incremental energy, $e(b_i)$, variable z_i is introduced as the number of channels which incorporate the bit granularity β_i to achieve b_p bits per symbol as given in (4) for $i = 1, 2, ..., P$. With z_i, the total rate R_T and the required energy $E_{required}(b_p)$ to transmit the total rate are written as

$$R_T = \sum_{i=1}^{P} z_i I_i \beta_i \tag{6}$$

$$E_{required}(b_{p+1}) = \sum_{i=1}^{P} z_i I_i e(b_i) \tag{7}$$

Since $z_i I_i = z_i$ for $i = 1, \cdots, (p+1)$, the constrained optimization problem given in equation (1) can be written as follows

$$\begin{aligned} &\max_{z_i \text{ for } i=1,\cdots,(p+1)} \left(R_T = \textstyle\sum_{i=1}^{p+1} z_i \beta_i \right) \\ &\text{st} \qquad \textstyle\sum_{i=1}^{p+1} z_i e(b_i) - E_T \leq 0 \end{aligned} \tag{8}$$

In a more general form, this optimization problem goes as follows

$$\begin{aligned} &\max_{z_i \text{ for } i=1,\cdots,P} \left(R_T = \textstyle\sum_{i=1}^{P} z_i \beta_i \right) \\ &st \qquad \textstyle\sum_{i=1}^{P} z_i e(b_i) - E_T \leq 0 \end{aligned} \tag{9}$$

The objective of the optimization given in equation (9) is to find the maximum numbers of parallel channels z_i, which can be allocated whilst keeping the required energy, $E_{required}(b_{p+1}) = \sum_{i=1}^{P} z_i e(b_i)$, below the total available energy E_T. The following subsection gives an account of the derivation of z_i values to maximize the total rate, R_T subject to the constrained total energy, E_T using a greedy algorithm.

C. A Greedy Algorithm For Rate Maximization

The solution to the optimization problem defined by equation (9) can be found using a greedy algorithm as follows

$$z_i = \min\left(\left\lfloor \frac{E_{r,i}}{e(b_i)} \right\rfloor, K \right), \tag{10}$$

where the total residual energy $E_{r,i}$ is defined as

$$E_{r,i} = \begin{cases} E_T - \sum_{j=1}^{i-1} z_j e(b_j) & \text{for} \quad i = 2, \cdots, P \\ E_T & \text{for} \quad i = 1, \end{cases} \tag{11}$$

which decreases as a function of the rate index, i. If the channel gain is equal for all channels, the solution for (10) is given by

$$z_i = \begin{cases} K & \text{for} \quad i = 1, \ldots, p, \\ m & \text{for} \quad i = p+1, \\ 0 & \text{for} \quad i = p+2, \ldots, P. \end{cases}$$

The proof for this as follows. The residual energy $E_{r,i}$ and the incremental energy $e(b_i)$ decreases and increases respectively as the rate index i increases. From (10), this means that the number of channels z_i monotonously decreases in i for $i = 1, \cdots, P$, rendering

$$z_1 \geq z_2 \geq z_3 \geq z_4 \geq \ldots \geq z_P, \tag{12}$$

where $0 \leq z_i \leq K$ for $i = 1, \ldots, P$. If $z_{p+1} = m$ falls in the following range

$$0 \leq z_{p+1} < K, \tag{13}$$

then the maximum values of z_i that maximize the total rate, R_T must be

$$z_i = K \qquad \text{for } i = 1, \ldots, p,$$

as the channel number z_i is greater than or equal to the upper bound K for $i = 1, \ldots, p$. Furthermore, since z_{p+1} will have a value greater than that of z_i for $i = p+2, \ldots, P$, it can be concluded that

$$z_i = 0 \qquad \text{for } i = p+2, \ldots, P$$

as their values will have to be less than or equal to the minimum value of z_{p+1}, which is zero.

This indicates that the total number of channels, z_{p+1}transmitting data at the rate of b_{p+1} must satisfy

$$0 \leq z_{p+1} = m < K. \tag{14}$$

On the other hand, there are

$$z_p - z_{p+1} = K - m$$

channels transmitting at a data rate of b_p bits per symbol. The total rate is therefore given by

$$R_T = (K - m) b_p + m b_{p+1} \tag{15}$$

Hence the problem to be addressed is to find the data rate index $(p+1)$ and the number of channels m with the incremental energy $e(b_{p+1})$ to achieve the objective of the constrained optimization given in equation (9) given E_T, N_0, Γ, h, K and β_p for $p = 1, \cdots, P$.

The data rate index p is obtained by solving

$$0 \leq E_T - K E(b_p) < K e(b_{p+1}), \tag{16}$$

which yields

$$p = \min\left(\left\lfloor \frac{\log_2\left(\left(\frac{E_T}{K}\right)\left(\frac{h}{N_0 \Gamma}\right) + 1 \right)}{\beta_p} \right\rfloor, P. \right) \tag{17}$$

Note that the middle term in (16) denotes the residual energy resulted when $z_{p+1} = m$ is zero. This residual energy is upper-bounded by the total incremental energy in K channels, since $m = 0$.

The number, $z_{p+1} = m$, of channels loaded with an additional data rate $\beta_{p+1} = b_{p+1} - b_p$ bits per symbol from the chosen b_p bits per symbol is obtained by solving equation

$$0 \leq E_T - (K E(b_p) + m e(b_{p+1})) < e(b_{p+1}). \tag{18}$$

The solution to (18) can then be written as

$$m = \left\lfloor \frac{E_T - K E(b_p)}{e(b_{p+1})} \right\rfloor. \tag{19}$$

In the next section, further modification is proposed to simplify the two-group resource allocation scheme when implemented over frequency-selective channels.

IV. Simplified Two-Group Resource Allocation Over Frequency Selective Channels

The application of this two-group resource allocation scheme is proposed for the outdoor femtocell network, where the HSDPA systems are assumed to operate over frequency selective channels. We assume that with the use of advanced receivers, all channels have approximate equal channel gains, except a few channels which have lower gains when operating over frequency selective channels. The proposed simplified two-group allocation method has two stages: the channel removal pre-processing scheme which removes the obviously unpromising channels and evens out the gains of the remaining channels and the two-group allocation, which eliminates the channel ordering. Such a simplified two-group allocation method effectively overcomes the two drawbacks of the two-group allocation scheme with channel ordering to enhance the system throughput while greatly reducing the computation complexity.

A. Pre-Processing of Channel Removal

The channel removal scheme is conducted in an iterative manner in order to make the channel gains approximately uniform in the remaining channels. Starting from setting the number of active channels $\mathcal{K} = K$, the channel removal scheme iteratively updates $\mathcal{K}$ as follows. In each iteration the total available energy constraint E_T is equally allocated to all $\mathcal{K}$ active channels, then the linear MMSE equalizer is used in conjunction with the extended sampling window in [4] is used for each channel to estimate the output SINR knowing the full information of frequency selective channels. The output SINR γ_k over frequency selective channels is jointly determined by the energy allocation and signature sequence assignment over all channels for each k ($k = 1, 2, ..., K$). The calculation of γ_k can refer to [4].

The inefficient channels are then identified via k-means clustering algorithms, which uses k different centroids to represent k respective clusters of the given data set, and associates each channel to one of the clusters if the channel's output SINR is closest to the cluster's centroids [12]. The clustering also proceeds in an iterative manner, where in each iteration each centroid is updated according to its resulting cluster. All the active channels are classified into 3 clusters $\mathbf{S}_i$ for $i = 1, 2, 3$, which are ordered by ascending order of their respective centroids c_i ($i = 1, 2, 3$). The clustering procedure is illustrated in Algorithm 1.

As the set $\mathbf{S}_1$ has the smallest centroid as specified above, hence the channels clustered in $\mathbf{S}_1$ have the lowest average output SINRs among all parallel channels. The set $\mathbf{S}_1$ generated by the algorithm therefore contains the unpromising channels. The $\min(|\mathbf{S}_1|, \mathcal{K} - \mathcal{K}_{\min})$ channels having the lowest output SINRs are then removed from the set of active channels, where $\mathcal{K}_{\min}$ is a parameter representing the allowable minimum number of active channels. The number of active channels is then updated as: $\mathcal{K} \leftarrow \mathcal{K} - \min(|\mathbf{S}_1|, \mathcal{K} - \mathcal{K}_{\min})$. The 3-means rather than 2-means clustering algorithm is designed aiming to isolating the outlier channels having much better channel gains among the active channels.

The channel removal procedure finishes when the condition

$$\frac{\left(\min\limits_{k=1,2,...\mathcal{K}} (\gamma_k) - \bar{\gamma}\right)^2}{\bar{\gamma}^2} \leq \Gamma \quad where \quad \bar{\gamma} = \frac{\sum_{k=1}^{\mathcal{K}} \gamma_k}{\mathcal{K}} \tag{20}$$

is satisfied, where $\Gamma < 1$ is a parameter denoting the maximum tolerable deviation of the least SINR. Satisfying condition in Eq(20) implies the most severe degradation among all channels is within the tolerable range, therefore the channel gains in all remaining channels can be considered to be approximately equal. The resulting set of active channels are then used in the two-group allocation algorithm.

Here the parameters $\mathcal{K}_{\min}$ and Γ are determined by exhaustive trials via numerical simulations and assumed to be fixed.

Algorithm 1 3-Means Clustering Algorithm

Require: $\{\gamma_1, \gamma_2, ..., \gamma_{\mathcal{K}}\}$
Ensure: $\mathbf{S}_i$ for $i = 1, 2, 3$
$\mathbf{S}_i \leftarrow \emptyset$ for $i = 1, 2, 3$
Randomly select c_i for $i = 1, 2, 3$ to have $c_1 < c_2 < c_3$
while c_1, c_2 and c_3 do not converge **do**
  for $k = 1, 2, ..., \mathcal{K}$ **do**
    $i \leftarrow argmin_{i=1,2,3} |\gamma_k - c_i|^2$
    $\mathbf{S}_i \leftarrow \mathbf{S}_i \cup \{k\}$
  end for
  for $i = 1, 2, 3$ **do**
    $c_i \leftarrow \frac{\sum_{k \in \mathbf{S}_i} \gamma_k}{|\mathbf{S}_i|}$
  end for
end while

B. Two-Group Allocation

The two-group resource allocation algorithm is then implemented to deliver the sub-optimal solution over $\mathcal{K}$ active channels after the channel removal. For an improved system performance, a linear MMSE equalizer based on the window-extended receiving model is used, therefore two-group allocation is aided by the iterative energy adjustment method in [4] in order to adjust the output SINR in each channel equal to the SINR target of the allocated bit rate within resource allocation procedure. Assuming there are m ($0 \leq m < K$) channels transmitting b_{p+1} bits, while the remaining ones transmitting b_p bits per symbol, the required transmitted energy in high-rate channel k is denoted as $E_k^{(m)}(b_{p+1})$, while the energy in low-rate channel is $E_k^{(m)}(b_p)$. For different values of m, the required energy change varies in each channel even to transmit the same bits. Mathematically, the optimal two-group allocation can be formulated as:

$$\begin{aligned} &\max_{b_p, m} \left(R_T = m b_{p+1} + (K - m) b_p\right) \\ &s.t. \sum_{k=1}^{m} E_k^{(m)}(b_{p+1}) + \sum_{k=m+1}^{K} E_k^{(m)}(b_p) \leq E_T \end{aligned} \tag{21}$$

where $K = \mathcal{K}$ for convenience, and the channel indices $1, 2, ..., m$ are re-assigned to high-rate channels. Firstly the optimal bit rate index p satisfies:

The optimal bit rate index p satisfies:

$$\sum_{k=1}^{K} E_k^{(0)}(b_p) \leq E_T < \sum_{k=1}^{K} E_k^{(0)}(b_{p+1}), \quad p = 0, 1, ..., P \tag{22}$$

when the bit rates b_p and b_{p+1} are equally allocated to all channels respectively.

The optimal m is determined in a recursive manner by allocating the higher-rate b_{p+1} to channels successively according to the ascending order of channel index. The incremental energy is re-defined to be the total energy rise by increasing the channel j's bit rate from b_p to b_{p+1}:

$$\begin{aligned} e_j(b_{p+1}) = &\left(\sum_{k=1}^{j} E_k^{(j)}(b_{p+1}) + \sum_{k=j+1}^{K} E_k^{(j)}(b_p) \right) \\ &- \left(\sum_{k=1}^{j-1} E_k^{(j-1)}(b_{p+1}) + \sum_{k=j}^{K} E_k^{(j-1)}(b_p) \right) \quad j = 1, 2, ..., K \end{aligned} \tag{23}$$

Given the total energy constraint E_T, the optimal m is proved to satisfy:

$$\sum_{j=1}^{m} e_j(b_{p+1}) \leq E_T - \sum_{k=1}^{K} E_k^{(0)}(b_p) < \sum_{j=1}^{m+1} e_j(b_{p+1}) \tag{24}$$

The optimal m is determined as follows: starting from $m = 0$, the m value increases by 1 each time by allocating the bit rate b_{p+1} to channel $(m + 1)$. Each time when m is increased, the transmitted energies over all channels are iteratively calculated for the temporary two-group bit allocation, therefore the incremental energy for the bit increment in channel $(m + 1)$ is obtained and saved. Such procedures finish when m value satisfies Eq(24), then the bit rate and the energy allocations corresponding to the optimal m are optimal two-group allocations over frequency selective channels.

V. Performance Evaluation

The parameters used in simulations are listed as follows: chip rate $B = 3.84Mcps$, spreading factor $N = 16$, number of channels $K = 15$, variance of complex Gaussian noise $N_0 = -127dBm/Hz$, gap value $\Gamma = 0dB$, and the set of discrete bit rates $\{0.5, 1, 1.5, 2, 3, 4\}$ bits per symbol. ITU Vehicular A channel model is used to model the frequency selective channels for the HSDPA system. At the transmitter, the signature sequences used for signal spreading are N-length Walsh codes, scrambled by long-period random code via elementwise multiplications, and the transmitted symbols in each channel are QAM-modulated ones with unit energy. At the receiver, the chip sampling window is extended by $\alpha = 8$ chips in each side for ISI suppressing. The total energy constraint is represented by total SNR $\left|\vec{h}\right|^2 E_T/N_0$, where $\vec{h}$ contains channel coefficients in all propagation paths. Besides the proposed simple two-group method (STG), the two-group allocation with channel ordering (o-TG), Imran's discrete bit loading method (DBL) and the HSDPA's equal-rate and power allocation (ER) are evaluated for performance comparison.

The system throughput is first examined in Figure 1, where the total bits per second C_T is given as $(B/N)R_T$, where R_T is the total bits per symbol. For the simple two-group allocation, parameters of channel removal are $\Gamma = 0.2$ and $\mathcal{K}_{\min} = 12$. For fair comparison, the HSDPA's equal rate and power scheme is evaluated integrating with the ISI-suppressing MMSE equalizer. Due to the removal of significantly unpromising channels, STG tends to concentrate the limited resources to those channels having much better conditions, so as to further improve the system throughput achieved by the two-group allocation. The channel gains of the remaining channels are also greatly evened out by the channel removal scheme therefore dropping the channel ordering does not cause performance penalty. On average, the STG outperforms the o-TG by 10%, the ER by 60%, and is only degraded by 5% compared with the throughput achieved by DBL method within the whole range of total SNR. In high SNR region ($\geq 25dB$), the STG's curve becomes flat since the channel removal scheme disables the allocation of nonzero bits to some unpromising channels even though the total available energy is sufficient.

Figure 2 depicts the numbers of channels transmitting each discrete bit rate b_p when the aforementioned resource allocation methods are used with fixed total SNR $22dB$, as the average values over 1000 realizations with different scrambling sequences. Compared with the bit rate allocation of o-TG method, the STG method greatly improves the average channel condition of active channels by deactivating only $2 - 3$ poor channels, therefore all the remaining channels can be allocated higher bit rates, so as to achieve a higher average system throughput. It is worth noting that the STG's bit rate allocation rather approximates the bit allocation of DBL method, which implies that the STG can achieve an approximate system throughput of DBL method.

We then evaluate the computation complexities of the DBL o-TG and STG methods in terms of matrix inversion numbers. Table I illustrates the matrix inversion numbers vs. the number of channels K with fixed total SNR $25dB$. The DBL method exhibits prohibitive computation complexity, and the complexity of o-TG is also unacceptable with high K value since it requires traversing the low-rate channels repeatedly when calculating the optimal m recursively. By dropping the channel ordering, the STG method has the lowest computation complexity and also the lowest increase rate with increasing K. The extra matrix inversion number brought by the channel removal scheme is independent of K, and is negligible compared with the number invoked in two-group allocation.

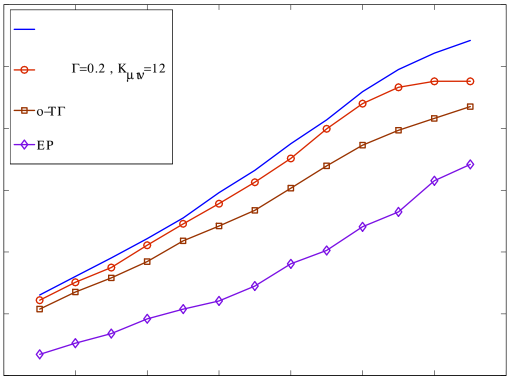

Fig. 1. System throughputs achieved by different resource allocation algorithms with varying total SNR

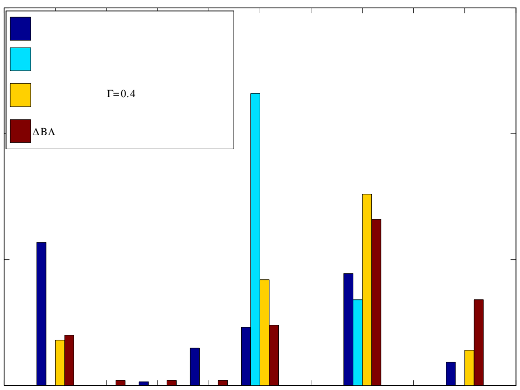

Fig. 2. Bit rate distributions achieved by different resource allocation algorithms with total SNR $22dB$.

VI. Conclusions

In this paper the optimal radio resource allocation approach is investigated for single-user HSDPA application deployed in femtocell networks, which offers higher received power but has limited signal processing capability in base stations. The two-group allocation approach previously developed in [3] and [4] is first proved to be the globally optimal solution to the discrete bit and power loading problem when operating over uniform-gain channels. The two-group allocation implementation over frequency selective channels is then enhanced by introducing a channel removal preprocessing scheme which aids the two-group allocation in eliminating the channels severely deteriorate the system performance, so as to achieve higher system throughput, while greatly reducing the computation complexity by dropping the iterative channel ordering.

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No. of Channels	8	9	11	13	15
DBL	8626	12769	23767	36095	55542
o-TG	446	556	1940	6240	14649
STG	129	155	194	181	225

TABLE I
Number of Matrix Inversions with fixed total SNR $25dB$, $\Gamma = 0.2$ and $\mathcal{K}_{min} = 12$