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A hybrid swarm intelligence algorithm for multiuser scheduling in HSDPA

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ABSTRACT

Multiuser scheduling is an important aspect in the performance optimization of a wireless network since it allows multiple users to access a shared channel efficiently by exploiting multiuser diversity. To perform efficient scheduling, channel state information (CSI) for users is required, and is obtained via their respective feedback channels. In this paper, a more realistic imperfect CSI feedback, in the form of a finite set of Channel Quality Indicator (CQI) values, is assumed as specified in the HSDPA standard. A mathematical model of the problem is developed for use in the optimization process. A hybrid heuristic approach based on particle swarm optimization and simulated annealing is used to solve the problem. Simulation results indicate that the hybrid approach outperforms individual implementations of both simulated annealing and particle swarm optimization.

1. Introduction

An effective method to improve the spectral efficiency in a wireless communication system is the use of adaptive modulation and coding (AMC) [3,9]. A higher order modulation provides a better spectral efficiency at the expense of a worse error rate performance; a lower rate channel coding generally provides a better error rate performance at the cost of a poorer spectral efficiency. Thus, with a suitable combination of the modulation order and channel coding rate, it is possible to design a set of modulation and coding schemes (MCS), from which a selection is made in an adaptive manner in each transmission-time interval (TTI) so as to maximize system throughput under varying channel conditions. A common requirement is that the probability of erroneous decoding of a Transmission Block should not exceed some threshold value [12].

While the above adaptation is based on the selection of the best MCS, the downlink transmit power is often held constant,[1] as in the HSDPA scheme [12]. In addition, multiple orthogonal channelization codes (multicodes) can be used in transmitting data to a single user, thereby increasing the per-user bit rate and granularity of adaptation [12,11,17]. In Wideband Code-Division Multiple Access (WCDMA), such channelization codes are often referred to as Orthogonal Variable Spreading Factor (OVSF) codes; the number of OVSF codes per base station (BS) is limited due to their orthogonal property [11]. Thus, in addition to the downlink transmit power, orthogonal code channels are also a scarce resource at the BS.

In exploiting multiuser diversity, a common method employed to increase the network throughput is assigning resources to a user with the largest signal-to-noise ratio (SNR) among all backlogged users (i.e. users with data to send) at the beginning of each scheduling period. However, due to limited mobile capability [1], a user may not be able to utilize all the radio resources available at the BS. Thus, transmission to multiple users during a scheduling period could be more resource efficient. In [16], the problem of downlink multiuser scheduling subject to limited code and power constraints is addressed. It is assumed that the exact path-loss and received interference power at every TTI for each user is fed back to the BS, which would require a large bandwidth overhead.

In this paper, the problem of optimal multiuser scheduling in HSDPA is addressed. The MCSs, numbers of multicodes and power levels for all users are jointly modeled for optimization at each scheduling period, given that only limited CSI information, as specified in the HSDPA standard [1], is fed back to the BS. An integer programming model is proposed in order to provide a globally optimal solution to the multiuser scheduling problem. Due to the complexity of the method, a number of heuristic optimization algorithms, namely simulated annealing, particle swarm optimization, and a hybrid of these algorithms are subsequently proposed.

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[1] In some cases, the specification stipulates a slight power reduction for a mobile with an exceptionally good channel quality [1].

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Following the implementation of simulated annealing [15] and particle swarm optimization [5], the hybrid method is designed to take benefit of the advantages of both. The experimental results suggest that it may provide a near-optimum performance with significantly reduced practical complexity.

The following two sections describe the multiuser problem domain and a mixed integer programming model. The fourth section provides an introduction to simulated annealing and particle swarm optimization approaches, prior to the implementation of a hybrid algorithm for multiuser scheduling problem. This section is followed by experimental results and discussions of performance before the paper concludes with section six.

2. System domain

Let P_i denote the default downlink transmit power to user i from a BS, h_i denote the path gain between the BS and user i, and I_i be the total received interference and noise power at user i. The downlink received signal-to-interference ratio (SIR) for user i is given by

$$\gamma_i = \frac{h_i P_i}{I_i}, \quad i = 1, \ldots, N, \tag{2.1}$$

where

$$\sum_{i=1}^{N} P_i \leq P_T. \tag{2.2}$$

Upon receiving the SIR value, γ_i, from user i, the BS decides on the most appropriate combination of MCS and number of multicodes for user i.

If the continuous SIR value γ_i is fed back, an impractically large feedback channel bandwidth would be needed. The specification presented in [1] requires the channel quality information fed back by a mobile, also known as the *channel quality indicator* (CQI), may only be given as a finite number of non-negative integer values {0, 1, . . ., K}. The CQI is provided by the mobile via the High-Speed Dedicated Physical Control Channel (HS-DPCCH). Each CQI value maps directly to a maximum bit rate[2] that a mobile can support, based on the channel quality and mobile capability [2], while ensuring that the Block Error Rate (BLER) does not exceed 10%.

While the mapping between the CQI and the SIR is not specified in [1], this issue has been addressed in a number of proposals [18]–[14]. Recently, a mapping has been proposed in which the system throughput is maximized while the BLER constraint is relaxed [10].

Let $\tilde{\gamma}_i = 10\log_{10}(\gamma_i)$ denote the received SIR value at user i in dB and q_i represent the CQI value that user i sends back to the BS via HS-DPCCH. According to [18,6,10], the mapping between q_i and $\tilde{\gamma}_i$ can generally be expressed as a piece-wise linear function

$$q_i = \begin{cases} 0 & \tilde{\gamma}_i \leq t_{i,0} \\ \lfloor c_{i,1}\tilde{\gamma}_i + c_{i,2} \rfloor & t_{i,0} < \tilde{\gamma}_i \leq t_{i,1} \\ q_{i,max} & \tilde{\gamma}_i > t_{i,1} \end{cases} \tag{2.3}$$

where $\{c_{i,1}, c_{i,2}, t_{i,0}, t_{i,1}\}$ are model and mobile capability dependent constants, and $\lfloor . \rfloor$ is the floor function. From (2.3), it is clear that $\tilde{\gamma}_i$ cannot be recovered exactly from the value of q_i alone due to the quantization. It is important to note that the region $t_{i,0} < \tilde{\gamma}_i \leq t_{i,1}$ is the operating region for the purpose of link adaptation and it should be large enough to accommodate SIR variations encountered in most practical scenarios [11]. In a well designed system, the probability that $\tilde{\gamma}_i$ lies outside this range should be small. As part of our proposed procedure, $\tilde{\gamma}_i$ can be approximated as

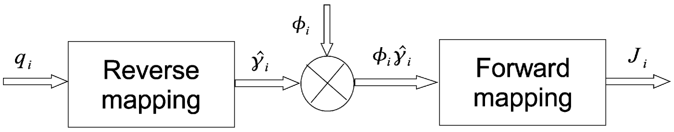

Fig. 1. The conversion process from the received CQI, q_i, from the mobile to the assigned rate index J_i at the base station.

$$\tilde{\gamma}_i^{\dagger} = \tilde{\gamma}_i^{(l)} + \left(\tilde{\gamma}_i^{(u)} - \tilde{\gamma}_i^{(l)}\right)\xi, \tag{2.4}$$

where

$$\tilde{\gamma}_i^{(l)} = \frac{q_i - c_{i,2}}{c_{i,1}}, \tag{2.5}$$

$$\tilde{\gamma}_i^{(u)} = \frac{q_i + 1 - c_{i,2}}{c_{i,1}}, \tag{2.6}$$

and ξ follows a uniform distribution, i.e. $\xi \sim U(0, 1)$. Note that this approximation assumes that $\tilde{\gamma}_i$ is uniformly distributed between $\tilde{\gamma}_i^{(l)}$ and $\tilde{\gamma}_i^{(u)}$ for a given value of q_i.

When $q_i = 0$ and $q_i = q_{i,max}$, $\tilde{\gamma}_i$ can be simply approximated as $t_{i,0}$ and $t_{i,1}$ respectively, or more generally as $t_{i,0} - \xi_{i,0}$ and $t_{i,1} + \xi_{i,1}$ respectively, with $\xi_{i,0}$ and $\xi_{i,1}$ following certain pre-defined distributions. Finally, the estimated value of γ_i is given by $\hat{\gamma}_i = 10^{\tilde{\gamma}_i^{\dagger}/10}$. We refer to the mapping from SIR to q_i in (2.3) as the *forward mapping*, and the approximation of SIR based on the received value of q_i in (2.4) as the *reverse mapping*.

3. Multiuser scheduling problem

The CQI feedback value, q_i, from user i corresponds to the rate index that the user requests from the BS, and is associated with a required number of OVSF codes (multicodes) and downlink transmit power. Since the number of multicodes and transmit power are limited, the BS may not be able to simultaneously satisfy the bit rate requests for all users as described by $\{q_i, i = 1, \ldots, N\}$. Thus, given the set $\{q_i, i = 1, \ldots, N\}$, the BS must calculate a set of *modified CQIs*, $\{J_i, i = 1, \ldots, N\}$, for all users by taking into account the power and number of multicodes constraints.

By making use of the *forward* and *reverse* mappings in (2.3) and (2.4) respectively, the set of modified CQIs, is given as

$$J_i = \min\left(\max\left(\eta_i(\tilde{\gamma}_i^{\dagger}, \phi_i), 0\right), q_{i,max}\right), \tag{3.1}$$

by assigning a power adjustment factor ϕ_i to user i, i.e. $\hat{\gamma}_i \mapsto \phi_i\hat{\gamma}_i$, where

$$\eta_i(\tilde{\gamma}_i^{\dagger}, \phi_i) = \lfloor c_{i,1}\left(\tilde{\gamma}_i^{\dagger} + 10\log_{10}\phi_i\right) + c_{i,2} \rfloor, \tag{3.2}$$

$$0 \leq \phi_i \leq 10^{\left(\frac{q_{i,max} - (c_{i,1}\tilde{\gamma}_i^{\dagger} + c_{i,2})}{10 c_{i,1}}\right)}. \tag{3.3}$$

A summary of the conversion process from the received CQI, q_i, to the final assigned rate index, J_i, is shown in Fig. 1.

The optimal scheduling problem **P1** can be expressed as

$$\mathbf{P1}: \qquad \max_{\mathbf{A}, \overline{\phi}} \sum_{i=1}^{N} \sum_{j=0}^{J_i} a_{i,j} r_{i,j} \tag{3.4}$$

subject to (3.3), where

$$\sum_{j=0}^{J_i} a_{i,j} = 1, \forall i, \tag{3.5}$$

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[2] In this paper, the bit rate refers to the transport block size, i.e. the maximum number of bits that a transport block can carry, divided by the duration of a TTI, i.e. 2 ms [11].