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Robust channel quality indicator reporting for multi-carrier and multi-user systems

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ABSTRACT

This paper considers the best-M channel-quality-indicator (CQI) reporting scheme for multi-carrier and multi-user systems. The perfect knowledge of CQIs is crucial for efficient resource allocation. Using outdated (which occurs due to feedback delay) and imperfectly estimated CQIs for resource allocation can severely degrade the system performance. The conventional approach of dealing with the imperfections in CQIs at the base station (BS) is not efficient for multi-carrier systems as the BS has a small number of CQIs and therefore, does not know the distribution of the imperfections for all subcarriers. Approaching this problem more realistically, we model the CQI variations as a discrete-time linear dynamic system where the distribution of the imperfections is unknown, and propose a novel best-M scheme that accounts for feedback delay and imperfect CQI estimation at the CQI reporting level. Instead of reporting the estimated CQIs (i.e., the conventional approach), in our scheme, each user reports so-called adapted CQIs computed by using an H^{∞}-controller based approach. Unlike the conventional approaches, the H^{∞}-controller does not require information on the probability distribution of the imperfections, and it guarantees robust performance in scenarios where the conventional approaches fail. The impact of feedback delay and imperfect CQI estimation on resource allocation is taken into account in the computation of adapted CQIs. That is adapted CQIs are computed such that if they are used for resource allocation, the deviation between the allocated rate by the BS and the actual channel rate is reduced. Results show that our scheme outperforms the schemes used in the current wireless standards.

1. Introduction

Multi-carrier transmission techniques in multi-user wireless communication system significantly improve the system performance by exploiting the frequency diversity and the multi-user diversity of the system. This can be achieved by performing channel-aware resource allocation (powers, subcarriers and slots) among users based on the channel quality indicators (CQIs) reported to the transmitter/base station (BS). However, reporting the CQI on each subcarrier may lead to prohibitively high feedback overhead that may not be feasible, especially for portable devices. In addition, due to the feedback delay, CQI estimation errors, and noisy feedback channels, the CQIs available at the transmitter may not be a perfect measure of the channel quality, and their use for resource allocation may result in a huge loss of the system throughput. This necessitates the design of such efficient CQI reporting scheme that not only reduces the feedback overhead but also takes into account the possible channel imperfections.

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1.1. Related work

The efficient CQIs reporting is an active area of research and has been quite well explored [1–12]. The existing work mainly focuses on feedback overhead reduction. There are two major classes of techniques used for feedback overhead reduction.

- The first class that exploits the correlation of the CQI between adjacent subcarriers and time instants, consists in feeding back a compressed version of the CQIs of all the subcarriers by each user. This may either be CQI quantization in which the discrete quantized values of the channel state are reported (e.g., [1–3]), or a discrete cosine transform (DCT) based feedback in which the dominant terms of the DCT of the per-subcarrier signal to interference plus noise ratio (SINR) are reported to the transmitter (e.g., [4]).
- In the second class called the best-M based CQI reporting, a user reports either the full individual CQIs values or an average CQI value of its best *M* subcarriers, and an average CQI value of the remaining subcarriers.

The best-M scheme is an appropriate scheme for multi-user OFDM and multi-carrier CDMA systems [5,14]. The feedback overhead of the compressed CQIs reporting is very high compared to that of the best-M scheme when the number of CQIs is high. In addition, it is shown in [5] that as in multi-user OFDM system a user is most likely to be assigned with good channel quality subcarriers, the best-M CQIs reporting can improve the system performance. The compression of CQIs can also be introduced into the best-M scheme in order to further reduce the feedback overhead. The 3rd Generation Partnership Project for the Long Term Evolution (3GPP-LTE Advanced) systems use the best-M technique in conjunction with CQIs compression [6,7]. In [8], a delta-modulation based feedback reduction scheme for OFDMA systems is proposed that reduces the feedback information to 1 bit per sub-carrier. In [9], the authors propose a dynamic resource sub-carrier allocation scheme for OFDMA systems which has small computational complexity as well as reduces the bandwidth cost incurred due to the CQI feedback overhead. The authors in [10] reduces the feedback overhead of multi-carrier MIMO systems by first minimizing the number of feedback bits by adaptively permuting the CQI sequences of different streams and then applying DCT compression to these feedback bits. In [11], the concept of adaptive feedback reduction for OFDMA systems is introduced, which is based on feedback window adaptation for each user depending upon user's application profile. The analysis of system sum-rate for quantized as well as non-quantized CQI reporting scheme is performed in [12]. A comprehensive overview of CQI reporting and efficient feedback techniques can be found in [13].

The impact of imperfect CQI on the performance degradation of multi-carrier systems at the resource allocation level at the base station has been well studied (e.g., [15–27]). In [15], analysis of OFDMA throughput under the assumption of imperfect CQI and un-coded modulation has been performed and a close form expression for the average throughput has been derived. Throughput maximization scheduling algorithms for multi-user and multi-antenna downlink channels with limited information about channel gains and channel directions are proposed in [16]. In [17], imperfect CQIs in a multi-antenna are dealt with by designing a linear precoder that is based on minimum-mean-square-error approach. This approach has the capability to improve the system performance by predicting the future channel. The effect of feedback delay on dual-hop relay networks with single antenna relay, and multi-antenna source and destination nodes has been studied in [18] and outage probability and density function for the output signal-to-noise ratio have been derived analytically. In [19], the achievable rate region for multiple access channel with partial channel knowledge is studied. This study shows that rate regions are reduced due to partially known channel. In [20], ergodic sum-rate maximization based power and subcarrier allocation for OFDMA downlink system with partially known channel has been studied. The exclusive effects of CQI estimation error and feedback delay on optimal resource allocation in downlink OFDMA systems are studied in [21,22] respectively, whereas the combined effect of these two phenomena on OFDMA resource optimization is investigated in [23]. In [24], the authors propose a joint framework for relay selection and resource allocation for OFDMA based cooperative system that uses outdated (due to feedback delay) CQIs. A general framework for studying the impact of imperfect channel knowledge on multi-user MIMO distributed antenna system has been demonstrated in [25] whereas the comparative analysis of for distributed antenna MIMO system in the context of single-user and multi-user scenarios with limited feedback has been performed in [26]. A low computational-complexity cross-layer approach for maximizing the downlink throughput of a system with coordinating base stations and imperfect and partial feedback is proposed in [27]. However, these works assume simple imperfection models i.e., assuming some statistical distribution for channel imperfections. In addition, these works assume that the transmitter knows, at each time, the estimated CQIs and the distribution of imperfection for all subcarriers. Moreover, the distribution of imperfection is assumed to be the same for all subcarriers. This approach is unrealistic, since due to the difference in the powers transmitted on different subcarriers and the level of interferences and feedback delay experienced by them, and due the time-varying nature of these parameters, the covariances of the imperfection for different subcarriers are different as well as time-varying.

1.2. Motivation and contributions

The reporting of CQIs of all the subcarriers in a multi-user system can help to deal with the channel imperfections but it is not appropriate due to the resulting prohibitively increased overhead. On the other hand the use of the best-M scheme reduces the overhead but it makes difficult to efficiently allocate the resources and to cope with the channel imperfections at the transmitter. In a realistic scenario where the best-M reporting scheme is used, the BS/transmitter cannot know the channel statistics for all the