Interference Cancellation based Cell-edge Inversion in Downlink Cellular Systems

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***Abstract*—We propose a novel method to improve the downlink data rate of cell edge users in a cellular system. The receivers are assumed to be able to cancel interference by simultaneously processing at most two codewords. The network may decide to transmit to a user from a neighboring cell. The receiver cancels the interference from its own cell, and reveices the other-cell transmission without this interference.**

I. INTRODUCTION

Interference limits the capacity of modern wireless communication systems. For example, modern cellular communication systems such as 4G LTE are designed to operate with frequency reuse 1. Allowing for hand-over margins, co-channel interference from neighboring cells may require downlink receivers at cell-edge to operate at Signal-to-Interference plus Noise Ratios (SINRs) as small as -7dB [1].

Much current research attempts to mitigate the cell-edge interference problem. Receivers may be improved by applying interference rejection and cancellation, whereas transmission technologies may be improved by attempting multipoint transmission. Multipoint transmission requires sharing accurate channel information between coordinating base stations and user data sequences may need to be transmitted from multiple points in the network. Consequently, the price of implementing multipoint transmission appears to be rather high.

As an alternative, the receivers may be improved, by using Interference Rejection Combining (IRC) receivers, or more advanced Interference Cancellation (IC) receivers. Baseline IRC has been widely studied, and it indeed provides significant gains for cell-edge users in conventional cellular settings, especially when the base stations are deployed with a single transmission antenna [1].

Extending from IRC to full-fledged IC holds much promise. The best coding strategy known for a Gaussian Interference Channel (GIC) is based on Han-Kobayashi rate splitting [2], [3], where IC receivers are combined with cooperative link adaptation by the transmitters. The transmitters split their messages into two parts, one (the public part) intended to be decodable at both receivers, the other (the private part) intended to be decodable only at the intended receiver. The receivers perform Serial Interference Cancellation (SIC), first potentially jointly decoding the public codewords [3], then canceling them before decoding their respective private codeword.

Making practical use of interference cancelation in a large wireless system is challenging, however. A viable method is opportunistic IC, where a receiver cancels interference, whenever it is possible [4]–[6]. Continuing along these lines, it was shown in [7] that in a game-theoretic setting, where Transmitter-Receiver (Tx-Rx) pairs have a strategy space consisting of power control and interference cancellation, it is sometimes beneficial for a selfish user to voluntarily reduce its transmit power.

In a cooperative setting, going past opportunism in IC is beneficial. In [8], a distributed algorithm to provide rate splitting transmissions in a cellular downlink network with SIC-capable receivers was addressed. The ensuing algorithm is complex, as the number of possible orders in which interference from multiple sources can be canceled, grows hyperexponentially in the number of interference sources.

To solve the problem of hyperexponential complexity, it was suggested in [9] to concentrate on single-stage IC, where each receiver can decode at most one interfering signal. A max-min power control problem was addressed, finding the maximum SINR that all receivers in the network of Tx-Rx pairs may enjoy. The problem was shown to be NP-hard. In [10], this approach is generalized to multistage SIC.

In this paper, we address single-stage IC receivers, i.e. the case that a receiver is capable of processing at most two codewords using SIC. This is a logical possibility different from legacy non-interference-canceling receivers, where only the intended codeword may be processed, considering all other transmissions as noise, and from receivers capable of receiving Han-Kobayashi rate-split messages, which would need to be able to deal with three codewords. We part from [4]–[10] in that we consider a downlink cellular network, and concentrate on the possibility that a receiver may receive transmissions from multiple sources, i.e. base stations. Thus we consider collaborative mutipoint transmission, or soft handover, together with IC-capable receivers in a cellular network. We assume that all transmitters in the network operate with full transmit power, and that users have been associated with particular cells. A user may receive transmissions from its own cell, as well as from a number of neighboring cells. If receiving a transmission from a neighboring cell, the transmission in its own cell is arranged so that the receiver can cancel the interference from the own-cell transmission. For such a user, the cell-edge has become inverted, so that the user is served by a base station from the other side of the cell edge.

With these assumptions, we formulate a scheduling problem, where resources are allocated to users in the cell so that a network utility is maximized. We show that this problem is convex if the utility function is concave. The problem is however of a high dimensionality, of the order of $N_c(N_u+1)!$, where N_c is the number of cells, and N_u is the number of users per cell. The problem allows for distributed formulations, where optimizations for pairs of neighbors are iterated over. However, even with such approaches, the dimensionality of the problem is high, so heuristic approaches are needed even for moderate N_u. A simple heuristic algorithm is presented.

II. SYSTEM MODEL

We assume a set of cells $\mathcal{C}$, each served by a base station. All base stations transmit with full power. For each cell $c \in \mathcal{C}$, the set of neighboring cells is $\mathcal{N}_c$, and the set users who would select c as their best cell is $\mathcal{U}_c$. With interference cancellation, each user $v \in \mathcal{U}_c$ can also receive transmission from a neighbor cell $c' \in \mathcal{N}_c$ after canceling the signal from c. Thus the network may decide that $v \in \mathcal{U}_c$, located at cell-edge in c, cancels the signal from its strongest cell c, and data to v is transmitted from the second strongest cell c' received by v, instead of conventionally receiving from strongest cell. Here this concept is called *cell-edge inversion*. We call c the primary cell of such a user v, and the other cell an inversion cell.

The transmission canceled by v needs not be intended to v, but to any user $u \in \mathcal{U}_c$. In this case it is said that the transmission to supporter u *supports* the cell-edge inversion of inverter v, which is inverting to cell c'.

Each transmission can support multiple inverting users, and each inverter could be supported by many supporters.

Each cell c has $N = |\mathcal{N}_c|$ neighbors. Resources used for transmitting to its own cell users are characterized by the intended receiver $u \in \mathcal{U}_c$, and the N-dimensional vector $\mathbf{v}$ of supported transmissions of inversions to the N neighbors. The vector $\mathbf{v}$ takes values in $(\{0\} \cup \mathcal{U}_c)^N$, where the entry $v_j = 0$ indicates that no user in c uses a transmission in this resource to support an inversion transmission from the jth neighbor of c. Since each inverting v can receive a transmission from one neighboring cell, each v may be present in $\mathbf{v}$ at most once.

Possible inversion configurations are thus characterized by the set of vectors $\mathcal{O}_c$ where the elements are ordered N-element subsets of a set consisting of $\mathcal{U}_c$ and N copies of 0. With $U = |\mathcal{U}_c|$ being the number of users in c, we have $\sum_{n=0}^{\min(N,U)} \binom{N}{n}\binom{U}{n}$ possible configurations in $\mathcal{O}_c$.

For simplicity we assume that all resources in the cell are identical. The information rate per unit resource that is used when transmitting to u a transmission which is supporting inversions $\mathbf{v}$ is thus

$$\mu_{u\mathbf{v}c} = \min_{u' \in \{u\} \cup \mathbf{v} \setminus \{0\}} \mu_{u'c} \ , \tag{1}$$

where μ_{uc} is the information rate per unit resource that user u can receive from cell c, when no IC is applied. The proportion of resources in cell c that are intended to own cell users, supporting inversions $\mathbf{v}$, is given by the scheduling weight $w_{u\mathbf{v}c}$.

When a user is receiving an inversion transmission from a cell c', the information rate per unit resource is denoted by $\mu^{\mathrm{i}}_{uc'}$. The proportion of resources given in cell c' to an inverting user u from another cell is denoted by $w^{\mathrm{i}}_{uc'}$.

The total rate of user u with primary serving cell c is thus

$$R_u = \sum_{\mathbf{v} \in \mathcal{O}_c} w_{u\mathbf{v}c}\mu_{u\mathbf{v}c} + \sum_{c' \neq c} w^{i}_{uc'}\mu^{\mathrm{i}}_{uc'} \ . \tag{2}$$

III. RESOURCE OPTIMIZATION PROBLEM

The objective of the network is to maximize system utility, which is the sum of the user utilities. The user utility is characterized by the function $U = f(R_u)$.

The optimization is over the scheduling decisions in the cells, characterized by the scheduling weights $w_{u\mathbf{v}c}$ and w^{i}_{uc}. The scheduling decisions are restricted by

- resource constraints: For each cell c, all resources are allocated once:

$$\sum_{u \in U_c} \sum_{\mathbf{v} \in \mathcal{O}_c} w_{u\mathbf{v}c} + \sum_{u \in U_{c'}, c \neq c'} w^{\mathrm{i}}_{uc} = 1 \ . \tag{3}$$

- support constraints: For each inverting user v, the resource allocated by inverting cell c_k should be overlapped with supporting resource allocated by serving cell c.

$$\sum_{u \in U_c} \sum_{\mathbf{v} \in \mathcal{O}_{c|v_k = v}} w_{u\mathbf{v}c} = w^{\mathrm{i}}_{vc_k} \ . \tag{4}$$

The optimization is convex, but with a high number of variables. Simplifying heuristics reducing the number of variables are considered.

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