The Design of Environmentally Friendly Networks Using Coordinated Multi-Point (CoMP) Transmission

Hyoseok Yi†, Won-Yong Shin‡, and Vahid Tarokh†
†School of Engineering and Applied Sciences, Harvard University, Cambridge, MA 02138, USA
‡Computer Science and Engineering, Dankook University, Yongin 448-701, Republic of Korea
Email: hyoseok@seas.harvard.edu; wyshin@dankook.ac.kr; vahid@seas.harvard.edu

I. INTRODUCTION

Recent global concerns about greenhouse gas necessitate new approach to every element of information and communication technology. Therefore, considering a greenness as another constraint in base-station planning problem is required. There exists a large body of work on network design and base-station planning [1], but these have not taken greenness into account. In [2], the authors solved the problem of energy-efficient base-station planning in a single one-dimensional cellular network. They introduced an iterative algorithm that finds the number of base-stations and the base-station positions and in terms of maximizing energy efficiency.

In this paper, we extend the previous algorithm to a cellular network using coordinated multi-point (CoMP) transmission schemes. More specifically, a new iterative algorithm based on two types of CoMP schemes (joint processing and coordinated beamforming) is proposed under the system model, where each iteration consists of an assignment step and a positioning step. Similarly as in [2], [3], we use the energy-normalized throughput as greenness measure, defined as the ratio of the sum-rate to the total energy consumption.

II. SYSTEM AND CHANNEL MODELS

We consider a wireless cellular network serving $N$ end-users in a one-dimensional linear space whose size is given by $D \in (0, \infty)$. The location of the end-users is also given, where the users are placed at $x_n$ ($n = 1, \ldots, N$). There are two base-station types, named macro and micro base-stations which correspond to a heterogeneous network consisting of two tiers. We assume that there are $L$ macro base-stations and $M$ micro base-stations in the network. We assume that macro and micro base-stations, respectively, referred to as $b_{l,i}$ and $b_{m,j}$, are located at positions $l_i$ and $m_j$, for $i = 1, \ldots, L$ and $j = 1, \ldots, M$. The energy-normalized throughput is given by $\frac{\sum_{n=1}^{N} R_n}{\sum_{l=1}^{L} P_{l,i} + \sum_{j=1}^{M} P_{m,j}}$, where $R_n$ denotes the achievable rate of user $u_n$, which is given by $\log(1 + \text{SINR}_n)$. Here, SINR$_n$ indicates the received signal-to-interference-and-noise ratio (SINR) of end user $u_n$. $P_{l,i}$ and $P_{m,j}$ denote respectively the power consumption of macro site $b_{l,i}$ and micro site $b_{m,j}$. We group end-users into a number of disjoint sets as follows. Let $\mathcal{I}_{l,i}$ and $\mathcal{I}_{m,j}$ denote a set of users associated with macro base-station $b_{l,i}$ and micro base-station $b_{m,j}$, respectively.

III. COORDINATED MULTI-POINT TRANSMISSION (CoMP)

Downlink CoMP transmission can be classified into two general categories: joint processing and coordinated beamforming. For the joint processing case, multiple cells jointly transmit data to a given end-user using the same time and frequency radio resources. For the coordinated beamforming case, out-of-cell interference to a given end-user can be reduced via scheduling and beamforming in adjacent cells. In this paper, we compare the energy-normalized throughput for the two CoMP schemes with that of no CoMP case. Figure 1 illustrates the one-dimensional network for the two CoMP schemes.

![Fig. 1. The one dimensional scenarios using CoMP schemes.](image)

IV. MAIN ALGORITHM

Main algorithm has two major parts, namely the Assignment and Positioning Steps. We apply two different subroutines (1 and 2) for each CoMP scheme. Main algorithm is described below.

Main Algorithm

Inputs: $L$, $M$, and $x_n$ ($n = 1, \ldots, N$)
Outputs: $l_i$, $\mathcal{I}_{l,i}$ ($i = 1, \ldots, L$), $m_j$, and $\mathcal{I}_{m,j}$ ($j = 1, \ldots, M$)
1: repeat
2: Assignment Step (Subroutine 1 or 2)
3: Positioning Step (Subroutine 3)
4: until convergence is achieved (or for a fixed number

A. Assignment Step

In the Assignment Step, the spatial configuration of the base-stations is given, where in the $k$th step, the macro and micro base-stations are located at $l_i^{(k)}$ and $m_j^{(k)}$, respectively. Then, we find the sets $\mathcal{I}_{l,i}^{(k)}$ and $\mathcal{I}_{m,j}^{(k)}$ that maximize the energy-normalized throughput.

a) Joint Processing: An end-user $u_n$ belongs to two different assignment sets $\mathcal{I}_{l,i}$ and $\mathcal{I}_{m,j}$ simultaneously, because an end-user can be served by two (or more) base-stations with CoMP. Let $S(n, i_1, i_2)$, $S(n, i_1, j_2, j_1)$, and $S(n, j_1, j_2)$ denote the network throughput when user $u_n$ is associated with 1) macro base-station $b_{l,i_1}$ and macro base-station $b_{l,i_2}$, 2) macro base-station $b_{l,i_1}$ and micro base-station $b_{m,j_2}$, 3) micro base-station $b_{m,j_2}$ and macro base-station $b_{l,i_2}$, and 4) micro base-station $b_{m,j_2}$ and micro base-station $b_{m,j_1}$, respectively. We develop Subroutine 1 that iteratively finds the best assignment of users to both macro and micro base-stations which maximize the energy-normalized throughput.
Subroutine 1 Assignment Step for joint processing

Inputs: $I^{(k)}_i$ and $T^{(k)}_i$ ($i = 1, \ldots, L$), $m^{(k)}_j$, $T^{(k)}_{m,j}$ ($j = 1, \ldots, M$), and $x_n$, ($n = 1, \ldots, N$)

Outputs: $I^{(k)}_{i,j}$ ($i = 1, \ldots, L$) and $m^{(k+1)}_{n,j}$ ($j = 1, \ldots, M$)

1: $I^{(k+1)}_{i,j} \leftarrow I^{(k)}_{i,j}$ for all $i = 1, \ldots, L$, $T^{(k+1)}_{m,j} \leftarrow T^{(k)}_{m,j}$
   for all $j = 1, \ldots, M$

2: repeat
3: for all user $x_n$ do
4:   for all $I^{(k)}_i$ (or $m^{(k)}_j$) do
5:     Calculate $S(n, i_1, i_2)$ (or $S(n, i_1, j_2)$, $S(n, j_1, i_2)$ and $S(n, j_1, j_2)$)
6:   end for
7:   end for
8: end repeat
9: until convergence is achieved (or for a fixed number)

Subroutine 2 Assignment Step for coordinated beamforming

Inputs: $I^{(k)}_i$, $T^{(k)}_i$ ($i = 1, \ldots, L$), $m^{(k)}_j$, $T^{(k)}_{m,j}$ ($j = 1, \ldots, M$), $x_n$, and $P^{(k)}_n$ ($n = 1, \ldots, N$)

Outputs: $I^{(k+1)}_{i,j}$ ($i = 1, \ldots, L$), $T^{(k+1)}_{m,j}$ ($j = 1, \ldots, M$) and $P^{(k+1)}_n$ ($n = 1, \ldots, N$)

1: $I^{(k+1)}_{i,j} \leftarrow I^{(k)}_{i,j}$ for all $i = 1, \ldots, L$, $T^{(k+1)}_{m,j} \leftarrow T^{(k)}_{m,j}$ for all
   $j = 1, \ldots, M$, $P^{(k+1)}_n \leftarrow P^{(k)}_n$ for all $n = 1, \ldots, N$

2: repeat
3: for all user $x_n$ do
4:   for all base-stations $b_{i_1}$ and $b_{m,j}$ do
5:     Calculate $S(n, i_1, i_2)$ (or $S(n, i_1, j_2)$, $S(n, j_1, i_2)$ and $S(n, j_1, j_2)$)
6:     end for
7:   end for
8: end repeat
9: until convergence is achieved (or for a fixed number)

b) Coordinated Beamforming: An end-user does not experience interference from one base-station while receiving data from its home-cell base-station. The symbol $P_n^{(k)}$, $n = 1, \ldots, N$ denotes the base-station which avoids interference to user $u_n$. Let $S(n, i_1, i_2)$, $S(n, i_1, j_2)$, $S(n, j_1, i_2)$ and $S(n, j_1, j_2)$ denote the network throughput when the home-cell of user $x_n$ and $P_n$ correspond to 1) macro base-station $b_{i_1}$ and base-station $b_{i_2}$, 2) macro base-station $b_{i_1}$ and micro base-station $b_{m,j_2}$, 3) micro base-station $b_{m,j_1}$ and macro base-station $b_{m,j_2}$, and 4) micro base-station $b_{m,j_1}$ and micro base-station $b_{m,j_2}$ respectively. We develop Subroutine 2 that iteratively finds the best assignment of users to both macro and micro base-stations which maximize the energy-normalized throughput.

Subroutine 3 Positioning Step

Inputs: $I^{(k)}_i$, $T^{(k)}_i$ ($i = 1, \ldots, L$), $m^{(k)}_j$, $T^{(k)}_{m,j}$ ($j = 1, \ldots, M$), and $x_n$ ($n = 1, \ldots, N$)

Outputs: $I^{(k+1)}_i$ ($i = 1, \ldots, L$) and $m^{(k+1)}_j$ ($j = 1, \ldots, M$)

1: $I^{(k+1)}_i \leftarrow I^{(k)}_i$ for all $i = 1, \ldots, L$, $m^{(k+1)}_j \leftarrow m^{(k)}_j$ for all $j = 1, \ldots, M$

2: repeat
3: for all base-stations $b_{i_1}$ and $b_{m,j}$ do
4:   for all points picked in $[0, D]$ do
5:     Calculate $S$
6:   end for
7: end for
8: until convergence is achieved (or for a fixed number)

B. Positioning Step

The goal of the Positioning Step is to update the positions of the macro base-stations, $I_i$, and the micro base-stations, $m_j$, in the sense of maximizing the energy-normalized throughput, given a fixed assignment for the users. In the kth step, the two sets $I^{(k)}_i$ and $T^{(k)}_{m,j}$ are given. To this end, we first pick a sufficiently large number of points in $[0, D]$ for each base-station, and then update the position of each base-station in terms of maximizing the energy-normalized throughput.

V. NUMERICAL EVALUATION

As illustrated in Fig. 2, the energy-normalized throughput is evaluated via computer simulations according to the number of iterations. Our system parameters are listed in Table I, where the values for $P_r$ and $P_m$ are shown in [3]. It is shown that the energy-normalized throughput increases for each iteration, converging to a local maximum. It turns out that the coordinated beamforming scheme outperforms the other two schemes when convergence is achieved.

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