Energy Efficient Wireless Multicasting

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***Abstract*—This letter proposes an energy-efficient wireless multicasting scheme in which the base station (BS) and the mobile users cooperate to reduce the total power consumption in wireless multicasting. Minimizing the power consumption under the scheme is an NP-hard problem. The gradient guided approximation algorithm is thus proposed to achieve low computational complexity. The proposed energy-efficient wireless multicasting scheme consumes less energy than other multicasting schemes without cooperation. The energy savings are validated through well designed simulations.**

***Index Terms*—Energy efficient, cooperative communications, wireless multicasting, beamforming.**

I. Introduction

GREENING is not merely a trendy concept, but is becoming a necessity to bolster social, environmental, and economic sustainability. Naturally, green communications has received much attention recently. Wireless multicasting is the central feature of next generation cellular networks. Therefore, minimizing the energy consumption in wireless multicasting is important toward green communications. Multicast beamforming is a promising technique for wireless multicasting [1], [2]. Cooperative networking is another promising technique that potentially empowers wireless networks to reduce energy consumption [3]. In this letter, we propose a novel wireless multicasting scheme, which integrates multicast beamforming and cooperative networking. It contains two phases: in phase 1, the base station (BS) transmits the signal to the subscribers using antenna arrays with multicast beamforming; in Phase 2, the users who successfully received the signal in phase 1 forward the signal to the other users. The unsatisfied users combine the signals from the BS and from relay via maximal ratio combining (MRC). In addition, we design a low complexity gradient guided algorithm that minimizes the transmit power in the multicasting, thus reducing the energy consumption of BS [4].

II. Problem Formulation

Consider a two phase amplify-and-forward cooperative communication strategy. In phase 1, BS transmits its information to the subscribers, and the received signal at user i is y_i^b. In phase 2, user j, who successfully received the signal, forwards the signal to other users i who did not, and the received signal at user i is $y_{j,i}^r$. Here, we assume that the signal is successfully received if its SNR is larger than the user's minimum SNR requirement, and that the signal relay in phase 2 is well scheduled to avoid transmission collisions. Consider a BS with N transmit antennas, and K multicasting service subscribers with a single receive antenna. Denote h_i^b as the $N \times 1$ complex vector that models the transmit channels between the antenna array of the BS and user i, and denote w^H as the beamforming weight vector applied to the transmitting antenna array, where $(\cdot)^H$ denotes the hermitian transpose. Denote $h_{j,i}^r$ as the relay channel between user j and i. Let x be the transmit signal, and then the received signal at user i in phase 1 is

$$y_i^b = w^H h_i^b x + n_i^b. \tag{1}$$

Let $P_i^b = |w^H h_i^b|^2$, and the relay users forward the signal with the same transmit power P^r. Assume subscriber j, who successfully received the signal in phase 1, forwards the signal to user i in phase 2. The received signal at user i from relay user j is

$$y_{j,i}^r = \sqrt{\frac{P^r}{P_j^b + \mathcal{N}_0}} h_{j,i}^r y_j^b + n_{j,i}^r. \tag{2}$$

In Eqs. (1) and (2), the noise items n_i^b and $n_{j,i}^r$ are modeled as zero-mean, complex Gaussian variables with variance $\mathcal{N}_0$. Assuming the transmit signal has an average energy of 1. According to [3], the instantaneous SNR of MRC output at receiver i is

$$\gamma_i = \gamma_i^b + \gamma_{j,i}^{br}, \tag{3}$$

where, $\gamma_i^b = P_i^b / \mathcal{N}_0$, and

$$\gamma_{j,i}^{br} = \frac{\frac{P_i^b P^r |h_{j,i}^r|^2}{P_i^b + \mathcal{N}_0}}{(\frac{P^r |h_{j,i}^r|^2}{P_i^b + \mathcal{N}_0} + 1)\mathcal{N}_0}. \tag{4}$$

To satisfy the users' minimum instantaneous SNR requirement with the minimum transmit power, the multicast design problem can be cast as follows:

$$\min_{w \in \mathbb{C}^N} \quad \|w\|^2 \tag{5}$$

$$s.t.: \quad \gamma_i^b + \beta(\gamma_i^b - \rho_i^{min})(1 - \beta(\gamma_j^b - \rho_j^{min}))\gamma_{j,i}^{br} \geq \rho_i^{min}, \quad i, j \in 1, 2, \cdots, K. \tag{6}$$

Here,

$$\beta(x) = \begin{cases} 0, & \text{for } x \geq 0 \ ; \\ 1, & \text{for } x < 0 \ . \end{cases} \tag{7}$$

The above problem is NP-hard since when $\gamma_i^b \geq \rho_i^{min}$, $\beta(\gamma_i^b - \rho_i^{min})$ is 0. It is also equivalent to the transmit beamforming problem [1], which was shown to be NP-hard.

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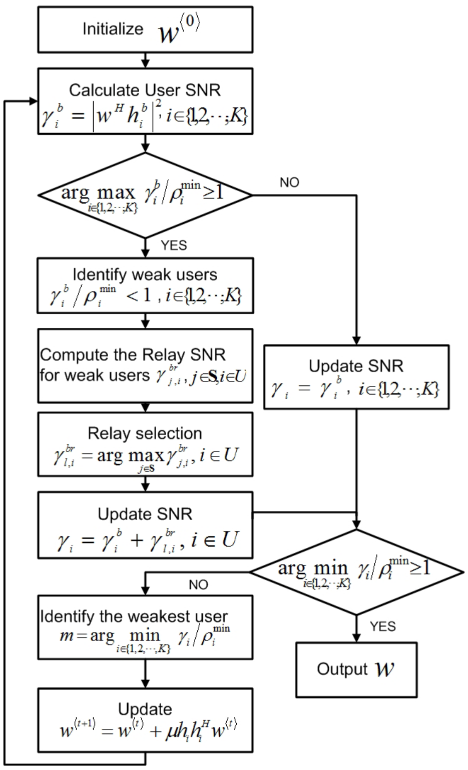

Fig. 1. Algorithm flowchart.

III. Gradient Guided Algorithm

Let $\gamma_{j,i}^r = P^r|h_{j,i}^r|^2/\mathcal{N}_0$; then, $\gamma_{j,i}^{br}$ in the constraint Eq. (6) can be expressed as

$$\gamma_{j,i}^{br} = \frac{\gamma_i^b \gamma_{j,i}^r}{\gamma_i^b + \gamma_{j,i}^r + 1}. \tag{8}$$

When $\gamma_i^b < \rho_i^{min}$ and $\gamma_j^b \geq \rho_j^{min}$, the constraint Eq. (6) becomes

$$\gamma_i^b + \frac{\gamma_j^b \gamma_{j,i}^r}{\gamma_j^b + \gamma_{j,i}^r + 1} \geq \rho_i^{min}; \tag{9}$$

otherwise, the constraint Eq. (6) is

$$\gamma_i^b \geq \rho_i^{min}. \tag{10}$$

In Eq. (9), γ_j^b is only related to the transmitting power at user j's direction and the transmit channel between BS and user j, and $\gamma_{j,i}^r$ is only related to the channel between user i and user j since all relay users use the same transmit power. Thus, increasing the power allocation at user i's direction will not reduce the relay SNR, $\gamma_{j,i}^{br}$, but will reduce the gap between γ_i and ρ_i^{min}. Therefore, the idea behind the algorithm is to increase the transmit power toward the weakest user at every iteration. The signal power at receiver i from the BS is $P_i^b = w^H h_i h_i^H w$. The gradient of the received power with respect to w is

$$\nabla_w P_i^b = h_i h_i^H w. \tag{11}$$

Let $w^{\langle t\rangle}$ be the value at iteration t; to increase the power allocation toward user i, $w^{\langle t\rangle}$ is updated as

$$w^{\langle t+1\rangle} = w^{\langle t\rangle} + \mu h_i h_i^H w^{\langle t\rangle}, \tag{12}$$

where μ is the step size of the update.

TABLE I
Simulation Parameters

Parameters	Assumption
Cellular Layout	Hexagonal grid, 3 sector per site
Inter site distance	1.8 Km
Transmit antenna gain	12 dBi
Antenna array	8 elements ULA with $d/\lambda = 0.5$
Path loss between BS and UE	128.1+37.6$\log_{10}(d)$ (d in Km)
Shadowing	log-norm 10dB std.
Path loss between UE and UE	41+22.7$\log_{10}(d)$ (d in Km)
Receiver antenna gain	0 dBi
Receiver sensitivity	-97 dB
Minimal SNR requirement	10 dB

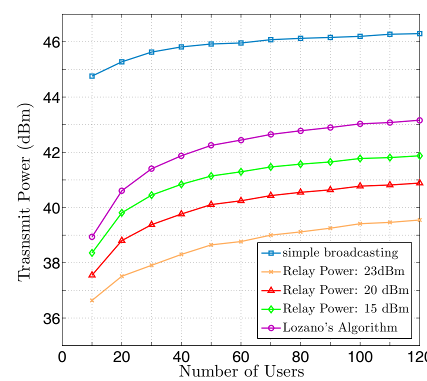

Fig. 2. Transmit power versus number of users.

The proposed algorithm is to identify the user with the smallest MRC output SNR, and then to increase the power allocation toward him/her at every iteration. The algorithm continues until all the subscribers' minimal SNR requirements are satisfied. It starts by initializing $w^{\langle 0\rangle}$, and the complete flowchart of the algorithm is shown in Fig. 1. Here, $\mathbf{S}$ and $\mathbf{U}$ are the sets of satisfied and unsatisfied users regarding their minimal SNR requirements, respectively.

IV. Simulations Results

Simulations are set up with parameters shown in Table I. Here, we evaluate the performance in a single sector, and assume the users are uniformly distributed in the sector. We further assume that the channel state information is perfectly estimated by both BS and users.

Fig. 2 compares the minimal transmit power of different multicasting strategies. With transmit beamforming, BS saves more than 3dBm transmit power. To identify the benefits from the cooperation, we set up three relay strategies: 1) relay with the full transmit power of user equipment that is 23dBm, 2) relay with half of the transmit power that is 20dBm, and 3) relay with the WIFI transmit power that is 15 dBm, and compare them with the Lozano's algorithm [2] that does not consider the cooperation. As the number of users increases, the performance of the proposed algorithm becomes better because there are more cooperative opportunities. When the number of users is larger than 40, the performance becomes steady, in which it uses about 3.5dBm, 2dBm, and 1dBm less

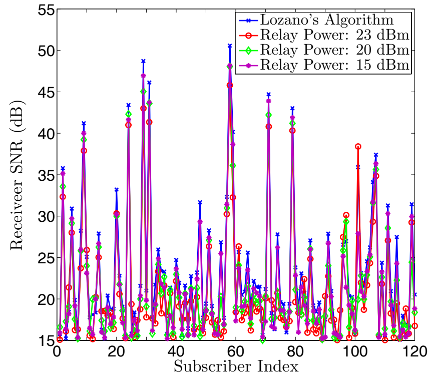

Fig. 3. User SNR. 120 users are uniformly distributed in the sector.

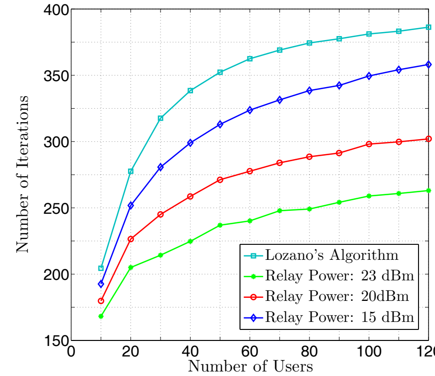

Fig. 5. Number of iterations versus number of users. μ is 0.01.

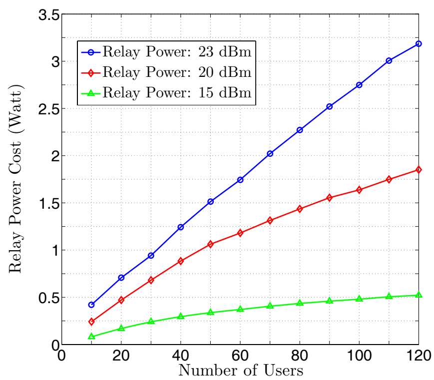

Fig. 4. Power consumed during the relay phase.

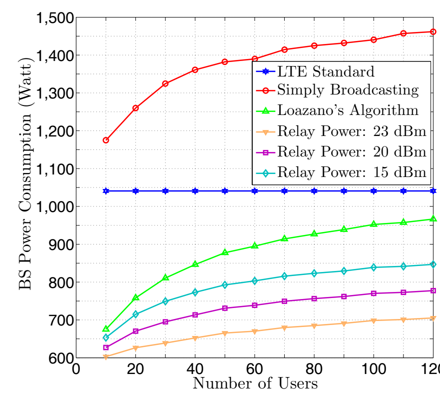

Fig. 6. BS power consumption versus number of users.

transmit power than that of Lozano's algorithm, respectively. It becomes steady because when the number of users is large enough (40 in the simulation), the cooperation gain is not limited by the cooperative opportunities, and becomes steady. In Fig. 3, the user SNRs under different multicasting strategies are compared. Both the proposed algorithm and Lozano's algorithm have almost the same performance, and all the users' minimum SNR requirements are satisfied. In Fig. 4, as the number of users increases, more power is consumed during the relay phase. When there are more users, more relay nodes are needed, and thus more relay power is consumed. Fig. 5 shows the number of iterations required to achieve the optimal transmit power of the proposed algorithm and Lozano's algorithm. When the number of user is small, our proposed algorithm is slightly better than Lozano's algorithm. However, as the number of users increases, the number of iterations of the proposed algorithm is much less than that of Lozano's algorithm. This is because there are more cooperation opportunities when the number of users is large, and thus the cooperation gain is large. With the cooperation gain, the users' minimum SNR requirements are satisfied faster because some users' SNR requirements may be satisfied during the relay phase, thus reducing the number of iterations in the beamforming process. The performance regarding the number of iterations becomes steady when the number of users is larger than 40 because the cooperation gain becomes steady. In Fig. 6, we compare the BS power consumptions under different multicasting strategies. We apply the BS power consumption model in [4] to calculate BS power consumptions regarding the transmit powers. The blue line indicates the power consumption of the standard LTE Macro BS [4], which can be considered as the power constraint of BS. Note that simply broadcasting without beamforming and cooperation cannot satisfy the users' requirement under the constraint. As compared to Lozano's multicast beamforming algorithm, our proposed algorithm can save at least 100 Watts when the number of users is larger than 60. The power savings are benefited from the cooperation between BS and users.

V. Conclusion

In this letter, we have proposed a novel energy efficient multicasting scheme, and the low complexity gradient guided algorithm to realize it.

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