Energy Efficiency Optimization For Two-way Relay Channels

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Introduction
Due to the global warming and the operators’ increasing operational cost, energy efficiency (EE) has drawn increasing attention and been viewed as a new optimization criterion for green wireless communication systems.

On the other hand, the wireless two-way relay channel (TWRC) is proposed to improve the system spectral efficiency (SE) as well as EE. EE optimization has been widely discussed in one-way transmissions, the basic ideas are mainly based on the convex-concave fractional programs. There are limited works considering the EE of TWRC, so this paper proposes an algorithm based on the nested optimization to solve it. Compared with optimizing by fractional programming directly, our algorithm has more insights on the relationship of the transmit power of different nodes and the constraints.

System Model
Consider a TWRC consisting of two source nodes A and B exchanging information with the assist of a relay node R. The channel capacity is:

\[ C_{A,B,R} = c_{A,B,R} = \frac{1}{2} \log_2 \left( 1 + \frac{G_{A,B}G_{R,A}G_{B,R} + 1}{N_0} \right) \]

where \( G_{A,B}, G_{R,A}, G_{B,R} \) are the channel gains from A to B, R to A, and B to R, respectively, and \( N_0 \) is the noise power.

Power consumption model:

\[ P_{c} = \sum_{i=0}^{R} P_{i} \]

where \( P_{i} \) is the power consumption of node \( i \) and \( \sum_{i=0}^{R} P_{i} \leq P_{max} \) represents the system total circuit power.

As our objective is to maximize the EE, considering with node i’s power constraint \( P_{i} \), the optimization problem can be expressed as:

\[ \max_{P} \frac{C_{A,B,R}}{P_{c}} \]

Subject to \( 0 \leq P_{i} \leq P_{max} \).

In the following, we will solve the unconstrained EE optimization at first through nested optimization, then obtain the constrained solutions based on it.

Unconstrained Optimization
Firstly, consider the unconstrained optimization problem \( \max_{P} C_{A,B,R} \). Employ the nested optimization, rewriting it as:

\[ \max \quad \sum_{k \in \{A,B,R\}} C_{k}(P_{k}, \gamma) \]

Define \( C_{k}(P_{k}, \gamma) \) as \( C_{k}(P_{k}, \gamma) = \frac{1}{2} \log_2 \left( 1 + \frac{P_{k}G_{k} + 1}{N_0} \right) \), where \( \gamma \) is the channel gain to noise ratios of the two channel from i to R.

Then we can express the unconstrained optimization problem as \( \max \sum_{k \in \{A,B,R\}} C_{k}(P_{k}, \gamma) \). We firstly try to get the close-form expressions of \( C_{k}(\gamma) \).

Lemma 1: With fixed \( \gamma \), to maximize system capacity, the optimal solution must satisfy one of the following three situations:

1. When \( P_{k}G_{k} < P_{max} \), \( P_{k}G_{k} = \sigma \), and \( P_{k}G_{k} < P_{max} \).
2. When \( P_{k}G_{k} < P_{max} \), \( P_{k}G_{k} = \sigma \), and \( P_{k}G_{k} < P_{max} \).
3. In other situation, \( P_{k}G_{k} = \sigma \).

Theorem 1: \( C_{k}(\gamma) \) can be expressed as follows upon different \( \gamma \):

1. When \( P_{k}G_{k} < P_{max} \), \( C_{k}(\gamma) = \frac{1}{2} \log_2 \left( 1 + \frac{P_{k}G_{k} + 1}{N_0} \right) \).
2. When \( P_{k}G_{k} < P_{max} \), \( C_{k}(\gamma) = \frac{1}{2} \log_2 \left( 1 + \frac{P_{k}G_{k} + 1}{N_0} \right) \).
3. In other situation, \( C_{k}(\gamma) = \frac{1}{2} \log_2 \left( 1 + \frac{P_{k}G_{k} + 1}{N_0} \right) \).

Theorem 2: \( C_{A,B,R}(\gamma) \) is a strictly quasi-concave function.

Constrained optimization
After solving the unconstrained optimal solution \( P^*, \gamma^* \), the corresponding \( \gamma^* \) can be calculated according to Lemma 2.

So \( C_{A,B,R}(\gamma) \) is first strictly increasing and then strictly decreasing as a function of \( \gamma \). the one and the only one optimal solution \( \gamma^* \) can be obtained efficiently by bisection. Then the optimal power allocation \( P^*, \gamma^* \) can be calculated according to Lemma 2.

Simulation Results
Set pathloss as 128.1 + 37.6 log_10 d(km), noise power is -100dBm, W=200KHz, \( \eta = 0.38 \). And we set three situations as follows:

1) \( k \) is a source node, consider the case \( k=A \).
2) If \( k=R \), \( k'=R \) fulfilled (3), then they are the optimal constrained solutions.
3) If (1) or (2) is fulfilled, consider the case (1). \( \gamma^* \) is optimal, and we need optimize \( P^* \) from \( \eta \).

We can conclude that:
1. Our scheme is efficiency on EE, but has a capacity loss. We should find a trade-off in practice.
2. The relay should be located closer to the node with stricter power constraint.
3. Reducing the circuit power is also an important part for the EE goal. And for these simulations above, our proposed scheme need 0.2532s on average and the convex-concave fractional programs need 0.7952s, so the complexity of the algorithm proposed by this paper is much less than the convex-concave fractional programs.