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Joint Beam Selection and Precoding Based on Differential Evolution for Millimeter-Wave Massive MIMO Systems

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Introduction

[Why] Power consumption caused by RF chains in mmWave massive MIMO systems can be solved by beam selection. However, the spectral efficiency of traditional algorithms is unsatisfactory due to the reduction in the number of RF chains and the multiuser interference.

[What] Reduce the power consumption and the interference among each beam.

Solve the problem that the QR precoding cannot obtain the same effective channel gain.

[How] Inspired by biological evolution and differential evolution (DE) algorithm, we propose a joint DE-based beam selection and improved QR precoding algorithm.

[Goal] Improve the sum rate and BER performance. Reduce the computational complexity.

Method

A. BEAM SELECTION

Here is the specific process of the method; Roughly divided into three step

Calculate the utility function g_{nk} and the set $\mathcal{B}_k$

$$g_{nk} = \frac{|h_{nk}|^2}{1+I_{nk}}, \quad k \in \mathcal{K} \quad n \in \mathcal{N} \qquad \mathcal{B}_k = \left\{ i \in N : g_{ik} \geq \gamma_k \max_i g_{ik} \right\}$$

↓

Perform mutation,boundary detection, crossover and selection operations to obtain the approximate optimal individual U_j^{t+1}

$$V_i^{t+1} = U_{r1}^t + F \cdot \left(U_{r2}^t - U_{r3}^t \right) \qquad v_{ik}^{t+1} = \begin{cases} 1, & v_{ik}^{t+1} < 1 \\ Card(\mathcal{B}_k), & v_{ik}^{t+1} > Card(\mathcal{B}_k) \end{cases}$$

$$w_{ik}^{t+1} = \begin{cases} v_{ik}^{t+1}, & rand \leq CR \\ u_{ik}^t, & others \end{cases} \longrightarrow$$

alternative individual: $W_i^{t+1} = \left(w_{i,1}^{t+1}, w_{i,2}^{t+1}, \ldots, w_{i,K}^{t+1} \right)$

$$U_i^{t+1} = \begin{cases} W_i^{t+1}, & f(\mathcal{B}_1(w_{i1}^{t+1}), \ldots, \mathcal{B}_k(w_{ik}^{t+1})) < f(\mathcal{B}_1(u_{i1}^{t+1}), \ldots, \mathcal{B}_k(u_{ik}^{t+1})) \\ U_i^t, & others \end{cases}$$

↓

Construct a reduced-dimensional channel matrix $\mathbf{H}_b$ according to the selected beam index

$$\tilde{H}_b = H_b(m,;), m \in \{Ib_1, Ib_2, \ldots, Ib_K\}$$

Algorithm 1 DE-based Beam Selection

Require: $\mathbf{H}_b, \gamma_k, F, CR, T_{\max}$
Ensure: $\widetilde{\mathbf{H}}_b$
  Phase I: Calculate g_{nk}, using Eq. (5)
  Phase II: Find $\mathcal{B}_k$
  Phase III: Evolving
  Initialize primary population U^0
  for $t = 0 \to T_{\max}$ **do**
    for $i = 1 \to P_{size}$ **do**
      Perform mutation to generate V_i^{t+1} by Eq. (8)
      for $k = 1 \to K$ **do**
        Perform boundary detection on $v_{i,k}^{t+1}$ by Eq. (9)
        Perform crossover to generate $w_{i,k}^{t+1}$ by Eq. (10)
      end for
      Calculate the fitness function $f(\cdot)$ value
      Perform selection operation to obtain U_i^{t+1} by Eq. (11)
    end for
  end for
  Find the individual U_j^{t+1} with the smallest fitness function value from U^{t+1}
  Calculate $Ib_1, Ib_2, \ldots, Ib_K$ corresponding to U_j^{t+1} by Eq. (6)
  $\widetilde{\mathbf{H}}_b = \mathbf{H}_b(m,:), m \in \{Ib_1, Ib_2, \ldots, Ib_K\}$

B. PRECODING

In order to further improve the system performance,we propose an improved QR precoder by equalizing diagonals and using Tomlison-Harashima (TH) theory which can greatly reduce the computational complexity and improve the performance.

- **Equalizing diagonal**

Construct diagonal matrix $\mathbf{P}_b = \alpha \mathbf{Q} \mathbf{\Lambda}$

When $\mathbf{\Lambda} \in \mathbb{C}^{K \times K}$

$$\mathbf{y} = \alpha \mathbf{R}^H \mathbf{\Lambda} \mathbf{s} + \mathbf{n} = \alpha \mathbf{L} \mathbf{s} + \mathbf{n}$$

- **Tomlinson-Harashima (TH) precoding**

Perform the same modulo operation for each user

$$\mathbf{y} = \alpha \mathbf{s} + \mathbf{n}$$

Define the fitness function

$$f(\cdot) = \sum_{k=1}^{K} \left| \frac{1}{r_{kk}} \right|^2$$

Results

Optimal individual fitness value against the number of iterations

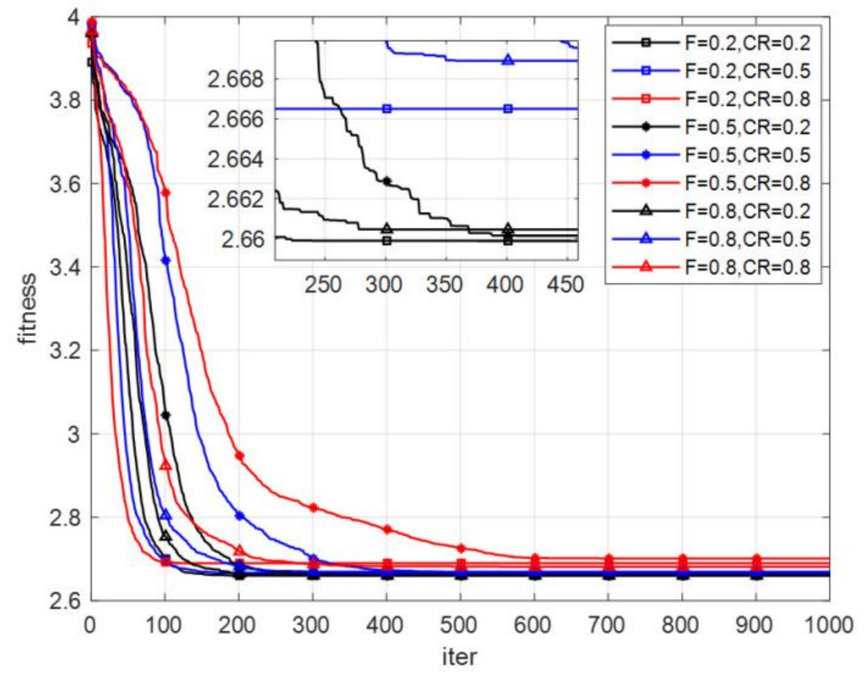

Fig.1.Fitness comparison against the number of iterations.

It is clear from Fig. 1 that the population evolves toward minimizing the fitness function $f(\cdot)$. We choose F = 0.2, CR = 0.2 to ensure that the proposed algorithm can achieve better performance.

Energy efficiency comparison against K

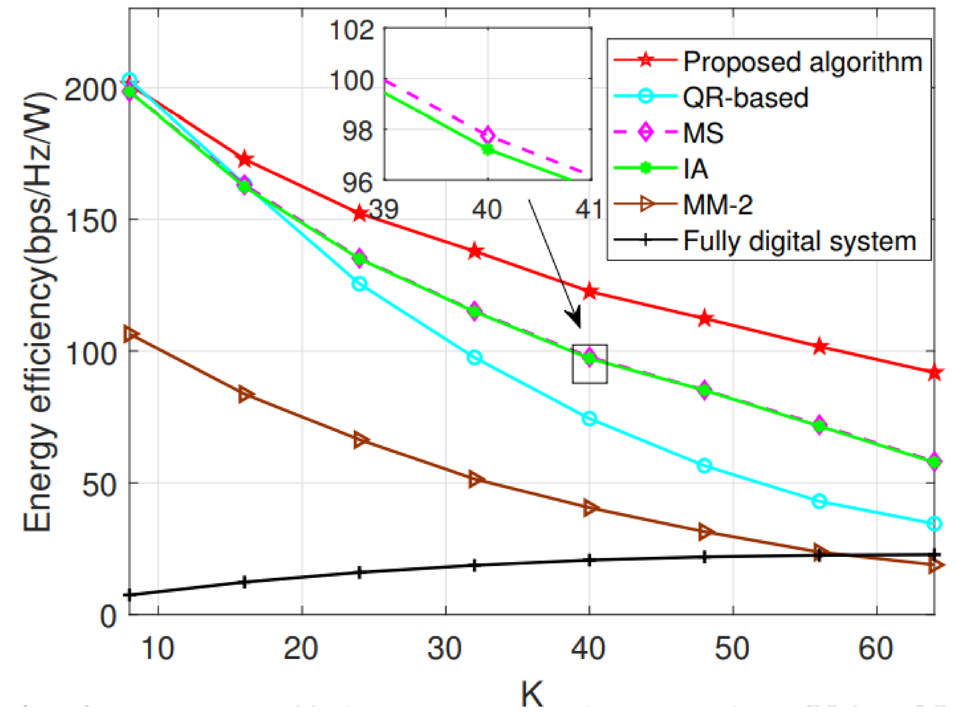

Fig.2. Energy efficiency comparison against K for N =256 and SNR=20 dB.

In Fig. 2, we observe that the proposed scheme improves the energy efficiency significantly compared with other algorithms. With the increase of K, the energy efficiency gap between the proposed algorithm and other algorithms increases.

Performance comparison against SNR

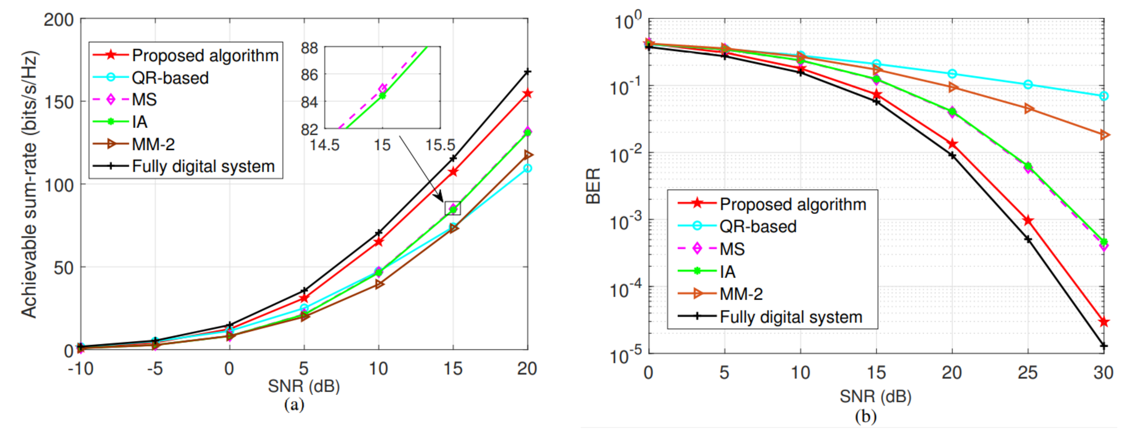

Fig.3.Performance comparison against SNR(a) Achievable sum rate; (b) BER.

It is evident from Fig. 3(a)although the achievable sum rate of all schemes improves as the SNR increases, the proposed scheme is close to that of the fully digital scheme and significantly higher than that of other schemes. And in Fig.3(b) the BER performance of the proposed scheme surpasses that of other schemes.

Conclusion

We propose a joint DE-based beam selection and improved QR precoding algorithm for mmWave massive MIMO systems. We regard beam selection as an optimization problem, and leverage the DE algorithm to seek out the optimal beam for each user, which improves the sum rate performance. Meanwhile, aiming at the poor BER problem due to different channel gains, we further propose an improved QR precoder by equalizing diagonals and using TH theory. Through the simulation, it can be proven that the proposed method is better than some other methods.

Acknowledgments

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