SINR Optimization in Wideband Full-Duplex MIMO Relays under Limited Dynamic Range

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INTRODUCTION

▶ We consider a full-duplex MIMO decode-and-forward relay with:
  ▶ limited dynamic range at receive and transmit side.
  ▶ self-interference due to simultaneous reception and transmission.
▶ We propose a cancellation-suppression design that aims to:
  ▶ maximize the signal-to-interference-plus-noise ratio at the relay.
  ▶ control the distortion in the relay-destination link.

SYSTEM MODEL

\[ \begin{align*}
    r_r[n] &\rightarrow A[n] & r_r[n], \\
    r_r[n] &\rightarrow G_r[n] & r_r[n], \\
    n_r[n] &\rightarrow A[n] & r_r[n], \\
    n_r[n] &\rightarrow G_r[n] & r_r[n], \\
    H_r[n] &\rightarrow r_t[n] & r_t[n].
\end{align*} \]

Figure: System model of a relay incorporating the cancellation-suppression architecture.

▶ The link consists of a source node (S), a relay node (R), and a destination node (D) with the following characteristics:
  ▶ S has \( M_s \) transmit antennas and receives \( n_s[n] \).
  ▶ D has \( M_d \) receive antennas and receives \( d_r[n] \).
  ▶ R has \( N_r \) receive antennas and \( N_t \) transmit antennas, and transmits \( r_r[n] \) while receiving \( r_t[n] \).

▶ The received signal at \( R \) consists of the information signal \( r_r[n] = H_{rr}[n] \cdot s_r[n] \), the self-interference \( i_r[n] = H_{rr}[n] \cdot r_r[n] \) and the noise \( n_r[n] \):
  \[ n_r[n] = n_r[n] + v_r[n] + H_{rr}[n] \cdot v_r[n] \]

PROBLEM SETTING AND DESIGN

▶ The cancellation-suppression architecture consists of the \( L_d \)-th order cancellation filter \( A[n] \), the \( L_r \)-th order filter \( G_r[n] \) and the \( L_t \)-th order filter \( G_t[n] \).

▶ The signal-to-interference-plus-noise ratio after processing is defined as

\[
\text{SINR}_{c} = \frac{\mathbb{E}[\|G_r[n] \cdot r_r[n]\|^2]}{\mathbb{E}[\|G_r[n] \cdot n_r[n] + A[n] + H_{rr}[n] \cdot G_t[n] \cdot r_r[n]\|^2]} \]

▶ Filters \( A[n] \), \( G_r[n] \) and \( G_t[n] \) are designed as the solution to the problem:

\[
\begin{align*}
    \text{maximize} & \quad \text{SINR}_c, \\
    \text{subject to} & \quad \mathbb{E}[\|r_r[n]\|^2] \leq P_{\text{max}}
\end{align*}
\]

▶ The solution for \( A[n] = -H_{sr}[n] \).
▶ We decouple \( G_t[n] \) and \( G_r[n] \) by designing \( G_t[n] \) as the solution to

\[
\begin{align*}
    \text{minimize} & \quad \mathbb{E}[\|i_r[n]\|^2] + \mathbb{E}[\|H_{rr}[n] \cdot v_r[n]\|^2], \\
    \text{subject to} & \quad H_{rd}[n] \cdot G_t[n] = H_{eq}[n], \\
    \mathbb{E}[\|r_t[n]\|^2] & \leq P_{\text{max}}
\end{align*}
\]

▶ Linear constraints preclude trivial solutions and control the distortion in the relay-destination link.

DESIGN

▶ Problem (3) is equivalent to

\[
\begin{align*}
    \text{minimize} & \quad \|g_{t}^l(p_t + R_t)g_r^l\|, \\
    \text{subject to} & \quad H_{rd}[g_r^l] = h_{rd}^{eq}, \\
    \|g_{t}^lR_{g_t}\| & \leq P_{\text{max}}
\end{align*}
\]

▶ After some calculations, problem (4) can be expressed as a standard linear least squares with inequality constraints. For a feasible solution we require that \( N_t > M_s \) and \( L_t > (M_dL_r/(N_t-M_s)) \).
▶ Finally, \( G_r[n] \) is designed as the solution to

\[
\begin{align*}
    \text{maximize} & \quad \|g_{t}^lP_{g_r}g_r^l\|, \\
    \text{subject to} & \quad H_{rd}[g_r^l] = h_{rd}^{eq}
\end{align*}
\]

▶ Problem (5) is recognized as a generalized eigenvalue problem.

SIMULATIONS AND RESULTS

▶ The simulations have the following parameters:
  ▶ \( m_s = m_r = M_s = M_t = 2 \).
  ▶ 64-QAM OFDM with 8192 subcarriers, a cyclic prefix length of 1/4 and an oversampling factor of 2.
  ▶ \( H_{sr}[n], H_{rd}[n] \) and \( H_{rd}[n] \) have orders \( L_{sr} = L_{rd} = L_{rr} = 2 \) and gains of 0, 0 and 30 dB, respectively. Additionally, \( L_{sr} = L_{rd} = L_{rr} = 2 \) and \( P_{\text{max}} = 20 \) dB.

\[
H_{rd}^{eq} = \begin{cases} 
  I, & n = 0 \\
  0, & n \neq 0
\end{cases}
\]

Figure: Self-interference power isolation in terms of the noise level at the transmitter.

Figure: Additional isolation in terms of the noise level at the transmitter for different orders of \( G_r[n] \).

Figure: SINR improvement in terms of the dynamic range of the receiver.