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Optimized Polarization Filtering Based Self-Interference Cancellation Scheme for Full-Duplex Communication

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Outline

1. Background

In recent years, the full-duplex (FD) communication was proposed to improve spectrum utilization.

Advantage and Challenge of FD communication

Advantage	This technology has the potential to double the spectral efficiency under ideal circumstances.
Challenge	The main challenge is the strong self-interference (SI) imposed by the transmit antenna on the local transceiver.

Therefore, sufficient SI cancellation operations are required in the FD communication.

1. Background

The existing SI cancellation techniques can be classified into passive SI suppression and active SI cancellation.

- **Passive SI Suppression**

Passive SI suppression can be achieved through the signal power attenuation caused by the physical separation.

1. Antenna Placement
2. Directional Antenna
3. Antenna Polarization

- **Active SI Suppression**

Active SI cancellation relies on signal processing or filtering to mitigate the SI at the local receiver.

1. Analog SI Cancellation
2. Digital SI Cancellation

1. Background

Polarization SI Cancellation

As a new degree of freedom, polarization can also be utilized for digital SI cancellation, which increases the distinction between the desired signal and the SI.

Advantage

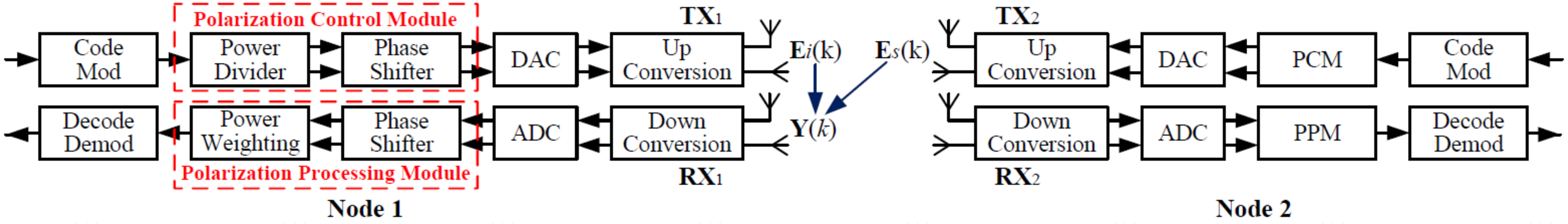
- The polarization is less affected by the phase noise and the power amplifier nonlinearity.

Main Idea

- To separate the desired signal and the SI by polarization signal processing and to eliminate the SI therein.

The existing polarization SI cancellation schemes do not guarantee that the signal to interference plus noise ratio (SINR) of output signal is maximum.

2. System Model



- Node 1 and Node 2 are communicating simultaneously on a single channel.
- Take Node 1 for example. Signal from Node 2 and Node 1 can be regarded as the desired signal and the SI respectively.

The Desired signal and the SI on the baseband $s(k)$ and $i(k)$

PSs of the desired signal and the SI $\mathbf{P}_s^t$ and $\mathbf{P}_i^t$

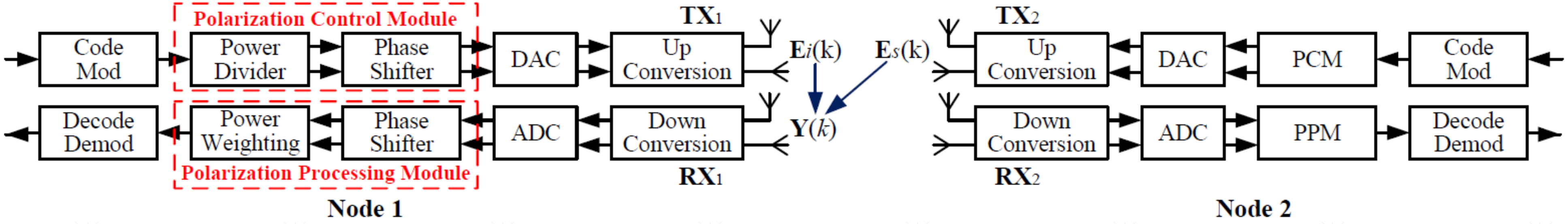
$$\mathbf{P}_s^t = \mathbf{B}_s^t \mathbf{A}_s^t = \begin{bmatrix} 1 & 0 \\ 0 & e^{j\phi_s^t} \end{bmatrix} \begin{bmatrix} \cos\gamma_s^t \\ \sin\gamma_s^t \end{bmatrix} = \begin{bmatrix} \cos\gamma_s^t \\ \sin\gamma_s^t e^{j\phi_s^t} \end{bmatrix} = \begin{bmatrix} H_s^t \\ V_s^t \end{bmatrix}$$

$$\mathbf{P}_i^t = \mathbf{B}_i^t \mathbf{A}_i^t = \begin{bmatrix} 1 & 0 \\ 0 & e^{j\phi_i^t} \end{bmatrix} \begin{bmatrix} \cos\gamma_i^t \\ \sin\gamma_i^t \end{bmatrix} = \begin{bmatrix} \cos\gamma_i^t \\ \sin\gamma_i^t e^{j\phi_i^t} \end{bmatrix} = \begin{bmatrix} H_i^t \\ V_i^t \end{bmatrix}$$

Power dividing matrix and phase shift matrix $\mathbf{A}_{s/i}^t$ and $\mathbf{B}_{s/i}^t$

Amplitude relationship and phase difference $\gamma_{s/i}^t$ and $\phi_{s/i}^t$

2. System Model



The desired signal after PCM processing $\mathbf{E}_s(k) = \mathbf{P}_s^t s(k)$

The SI after PCM processing $\mathbf{E}_i(k) = \mathbf{P}_i^t i(k)$

- For the receiver RX1 in Node 1, it will also receive the SI transmitted by TX1 while receiving the desired signal.

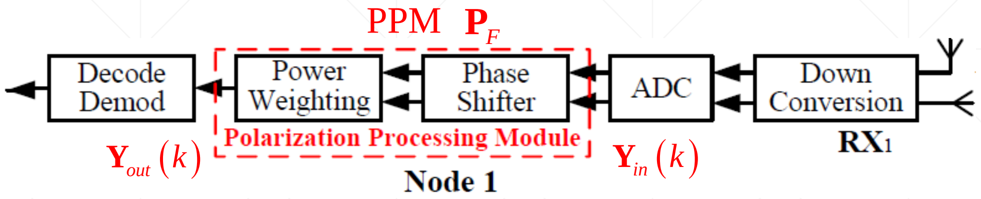
The signal received by RX1 $\mathbf{Y}(k) = \mathbf{H}_s\mathbf{E}_s(k) + \mathbf{H}_i\mathbf{E}_i(k) + \mathbf{N}(k)$

The wireless channel and the SI channel $\mathbf{H}_s$ and $\mathbf{H}_i$

The AWGN at the baseband $\mathbf{N}(k)$

3. The Proposed Scheme

The optimized polarization filtering based digital SI cancellation (OPC) scheme is introduced in this section.



For RX1, the input signal of the PPM

$$\mathbf{Y}_{in}(k) = \mathbf{H}_s \mathbf{P}_s^t s(k) + \mathbf{H}_i \mathbf{P}_i^t i(k) + \mathbf{N}(k)$$

The output signal after PPM processing

$$\mathbf{Y}_{out}(k) = \mathbf{P}_F^{\mathrm{H}} \mathbf{Y}_{in}(k) = \mathbf{P}_F^{\mathrm{H}} \mathbf{P}_s^r s(k) + \mathbf{P}_F^{\mathrm{H}} \mathbf{P}_i^r i(k) + \mathbf{P}_F^{\mathrm{H}} \mathbf{N}(k)$$

The PS of the received desired signal and SI

$\mathbf{P}_s^r$ and $\mathbf{P}_i^r$

The PS of PPM processing

$\mathbf{P}_F$

3. The Proposed Scheme

Optimized Goal

- The goal of the proposed OPC scheme is to maximize the output SINR of $\mathbf{Y}_{out}(k)$ by selecting the appropriate PS $\mathbf{P}_F$.

The output SINR can be calculated as

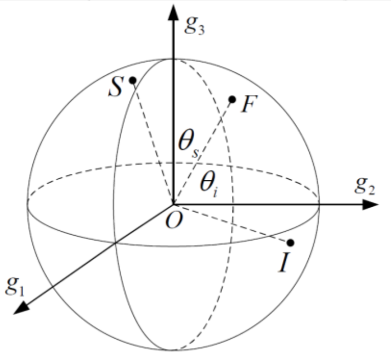
$$SINR_{out} = \frac{E\left[\left\|\mathbf{P}_F^{\mathrm{H}}\mathbf{P}_s^r s(k)\right\|^2\right]}{E\left[\left\|\mathbf{P}_F^{\mathrm{H}}\mathbf{P}_i^r i(k)\right\|^2\right] + E\left[\left\|\mathbf{P}_F^{\mathrm{H}}\mathbf{N}(k)\right\|^2\right]}$$

$$= \frac{\left\|\mathbf{P}_F^{\mathrm{H}}\mathbf{P}_s^r\right\|^2 E\left[\left\|s(k)\right\|^2\right]}{\left\|\mathbf{P}_F^{\mathrm{H}}\mathbf{P}_i^r\right\|^2 E\left[\left\|i(k)\right\|^2\right] + \sigma^2/2} = \frac{\left\|\mathbf{P}_F^{\mathrm{H}}\mathbf{P}_s^r\right\|^2 p_s}{\left\|\mathbf{P}_F^{\mathrm{H}}\mathbf{P}_i^r\right\|^2 p_i + p_n}$$

- $\left\|\mathbf{P}_F^{\mathrm{H}}\mathbf{P}_i^r\right\|^2$ and $\left\|\mathbf{P}_F^{\mathrm{H}}\mathbf{P}_s^r\right\|^2$ can be expressed as m_{Fs} and m_{Fi} , which represent the similarity of PSs $\left\langle \mathbf{P}_F, \mathbf{P}_s^r \right\rangle$ and $\left\langle \mathbf{P}_F, \mathbf{P}_i^r \right\rangle$.

- For any PS, it can be represented by a unique point on the Poincaré sphere, and any point on the Poincaré sphere corresponds to a unique PS.

3. The Proposed Scheme



(a) F, S and I on the Poincaré sphere

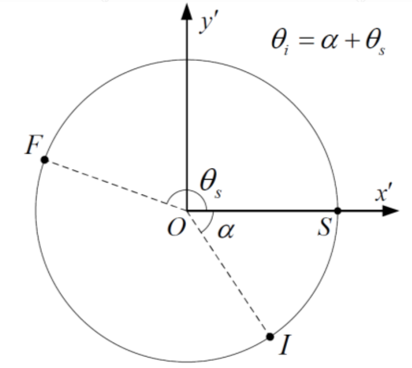
$$m_{Fs}=\left\|\mathbf{P}_F^{\mathrm{H}}\mathbf{P}_s^r\right\|^2=\cos^2\left(\theta_s/2\right)$$

$$m_{Fi}=\left\|\mathbf{P}_F^{\mathrm{H}}\mathbf{P}_i^r\right\|^2=\cos^2\left(\theta_i/2\right)$$

θ_s is the spherical angle between polarization points corresponding by $\mathbf{P}_F$ and $\mathbf{P}_s^r$, θ_i is the spherical angle between polarization points corresponding by $\mathbf{P}_F$ and $\mathbf{P}_i^r$ on the Poincaré sphere.

The output SINR can be rewritten as

$$SINR_{out}=\frac{SNR\cos^2\left(\theta_s/2\right)}{INR\cos^2\left(\theta_i/2\right)+1/2}$$



(b) The great circle polarization track

- A great circle polarization track can be constructed with the same radius as the Poincaré sphere including both S and I.
- The polarization point F that maximizes the $SINR_{out}$ must be exactly located on that great circle polarization track.

Define $\alpha=\angle SOI\in[0,\pi]$ as the spherical angle between S and I.

$$\alpha=2\arccos\left(\left\|\mathbf{P}_s^{r\mathrm{H}}\mathbf{P}_i^r\right\|\right)$$

3. The Proposed Scheme

$SINR_{out}$ can be expressed as a function of θ_s

$$f(\theta_s) = SINR_{out}(\theta_s) = \frac{SNR\cos^2(\theta_s/2)}{INR\cos^2\left[(\theta_s+\alpha)/2\right]+1/2}$$

- Since $f(\theta_s)$ is a bounded periodic function, the maximum point of $f(\theta_s)$ can be found by differentiation.

The maximum point of $f(\theta_s)$

$$\theta_s' = 2\arctan\left(\frac{INR\sin\alpha}{1+INR-INR\cos\alpha}\right)$$

The $SINR_{out}$ can be calculated as

$$SINR_{out} = f\left(\theta_s'\right) = 2SNR\cdot\frac{1+2INR\sin^2(\alpha/2)}{1+2INR}$$

4. Performance Analysis

Metrics 1. The SINR Gain 2. The Achievable Rate

The polarization dissimilarity coefficient between $\langle \mathbf{P}_s^r, \mathbf{P}_i^r \rangle$	$\rho_{si} = 1 - \left\| \mathbf{P}_s^{r\mathrm{H}} \mathbf{P}_i^r \right\|^2 = \sin^2(\alpha/2)$
The SINR gain	$\eta_{OPC}(\mathrm{dB}) = 10\log_{10}\left(\frac{SINR_{out}}{SINR_{in}}\right) = 10\log_{10}\left[2 \cdot \frac{1+2\rho_{si} INR}{1+2INR} \cdot (1+INR)\right]$
The achievable rate	$R_{OPC} = 2\log_2(1+SINR_{out}) = 2\log_2\left[1+2SNR \cdot \frac{1+2\rho_{si} INR}{1+2INR}\right]$

- The SINR gain increases as the ρ_{si} decreases, when the SNR and INR of the input signal are determined.

4. Performance Analysis

$\mathbf{P}_s^r$ and $\mathbf{P}_i^r$ are identical	$\rho_{si} = 0$	SINR Gain Minimum	Effect of SIC The worst	Achievable Rate The lowest
$\mathbf{P}_s^r$ and $\mathbf{P}_i^r$ are orthogonal	$\rho_{si} = 1$	SINR Gain Maximum	Effect of SIC The best	Achievable Rate The highest

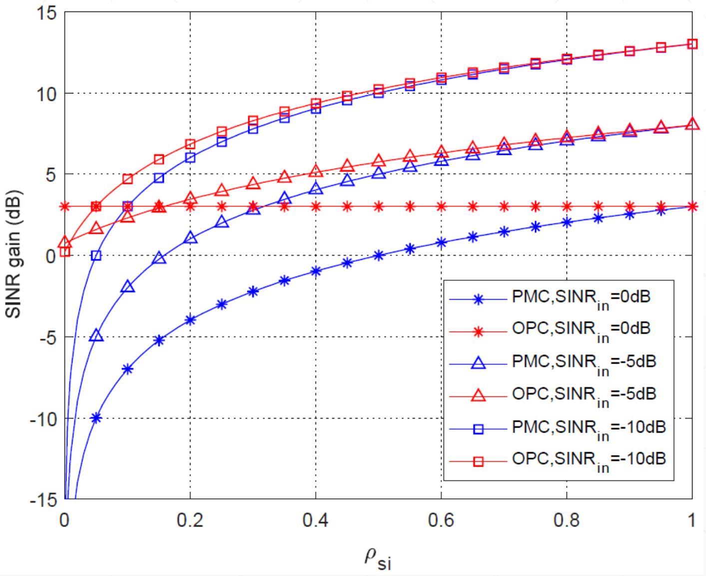
- **Compared with the existing polarization SI cancellation schemes**

1. The SINR gain of the OPC scheme is better than the existing scheme for any polarization difference coefficient.
2. The SI cancellation performance of the OPC scheme can reach the theoretical upper limit in the polarization SI cancellation schemes.
3. The SINR gain of proposed OPC scheme is always positive in the case of any polarization difference coefficient.

5. Simulation Results

The performance of the proposed OPC scheme is simulated, and it is compared to the existing polarization SI cancellation scheme based on polarization mismatch (PMC).

- **Cancellation performance of OPC and PMC scheme with different** $SINR_{in}$

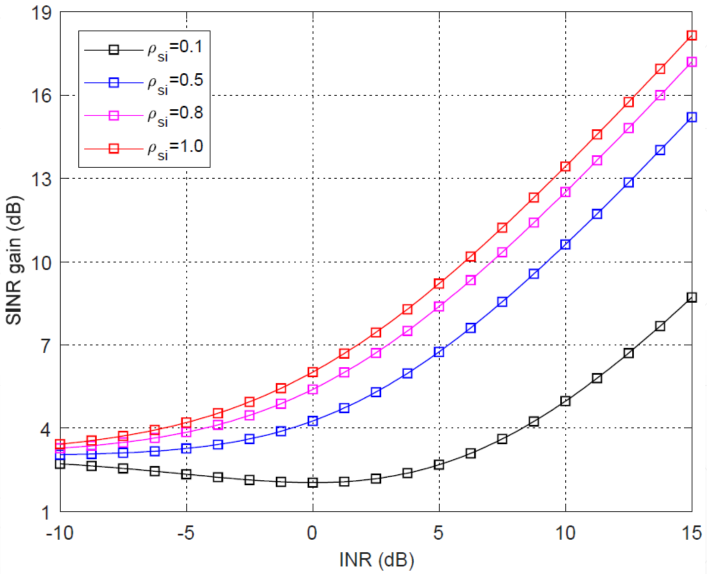


- The SINR gain of the OPC scheme is always greater than the PMC scheme under the same polarization difference coefficient.

- As ρ_{si} decreases, the performance advantages of the OPC scheme over the PMC scheme become more and more obvious.

5. Simulation Results

Cancellation performance of the OPC scheme with different ρ_{si}

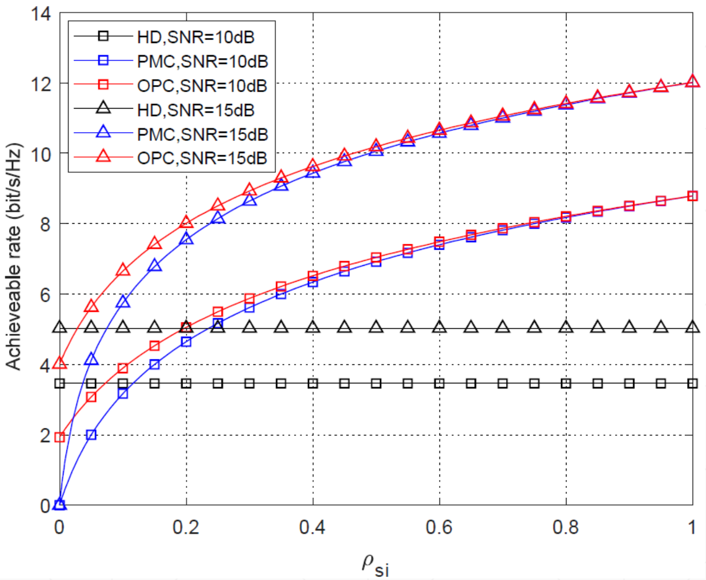


- In the case where the input INR is the same, as the polarization difference coefficient increases, the SINR gain also increases and the SI cancellation performance becomes better.

- In the actual processing of SI cancellation, the condition of $\rho_{si} \geq 0.5$ should be satisfied as much as possible.

5. Simulation Results

Achievable rate of the OPC and PMC schemes compared with HD



- The achievable rate of both the OPC and PMC schemes is increasing as the polarization difference coefficient increases from 0 to 1.

- Under the same conditions, the achievable rate of the OPC scheme is greater than or equal to the PMC scheme.

- The performance of OPC scheme is less affected by the polarization difference coefficient than the PMC scheme.

6. Conclusion

Contributions

1. We propose an SI cancellation scheme based on optimized polarization filtering.
2. Compared with the existing polarization cancellation schemes, the proposed OPC scheme can achieve an optimal trade-off between desired signal reception and SI cancellation, and ensures the maximum output SINR of the receiver.
3. The OPC scheme has better SI cancellation performance than the existing polarization cancellation schemes. The SINR gain of OPC scheme is always positive in all cases.
4. The OPC scheme has a robust performance with different polarization dissimilarity coefficient.

THANK YOU!

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