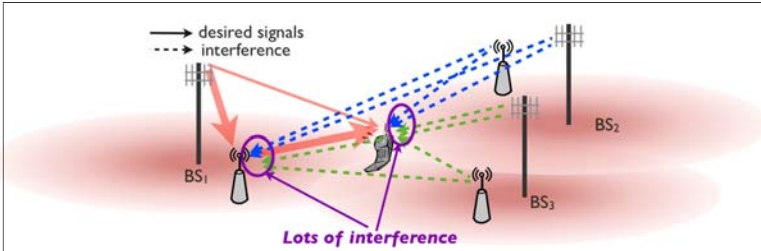
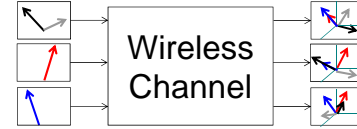


## Motivation



Degree of Freedom Optimal approach: Interference Alignment



$$DoF = \lim_{SNR \rightarrow \infty} \frac{C_{\Sigma}}{\log SNR}$$

**Need full channel state information at the transmitters (CSIT)!**

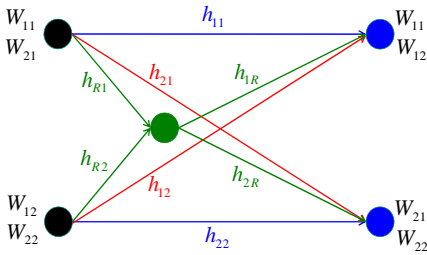
- Can relays be useful to alleviate the need for CSIT?
  - ✓ Yes! Using relays, no CSIT is needed.
  - ✓ Can achieve the optimal DoF!

- Future wireless networks expect to see a lot of interference.
- Current approach towards interference:
  - Power control (WCDMA)
  - Frequency reuse (GSM, LTE)
  - CSMA/CA (WLAN)

Far from optimal

## System Model

- 2-User X channel with a half-duplex relay:
  - **No CSIT** at the transmitters;
  - Single antenna Tx & Rx.
  - Channel is time-varying.



- When relay listens
 
$$Y_1^t = h_{11}^t X_1^t + h_{12}^t X_2^t + Z_1^t$$

$$Y_2^t = h_{21}^t X_1^t + h_{22}^t X_2^t + Z_2^t$$

$$Y_R^t = h_{R1}^t X_1^t + h_{R2}^t X_2^t + Z_R^t$$

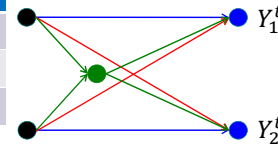
- When relay transmits
 
$$Y_1^t = h_{11}^t X_1^t + h_{12}^t X_2^t + h_{1R}^t X_R^t + Z_1^t$$

$$Y_2^t = h_{21}^t X_1^t + h_{22}^t X_2^t + h_{2R}^t X_R^t + Z_2^t$$

## Full CSI at the Relay

- Single antenna relay is sufficient to achieve the optimal DoF  $\frac{4}{3}$ .
- Relay-aided interference alignment scheme:

	Slot 1	Slot 2	Slot 3
Tx1	$d_{11}$	$d_{21}$	$d_{11}$
R			$\alpha Y_R^1 + \beta Y_R^2$
Tx2	$d_{12}$	$d_{22}$	$d_{22}$



- Signals received at Rx 1

$$\begin{bmatrix} Y_1^1 \\ Y_1^2 \\ Y_1^3 \end{bmatrix} = \begin{bmatrix} h_{11}^1 & 0 \\ 0 & h_{12}^1 \\ h_{11}^3 + \alpha h_{1R}^3 h_{R1}^1 & h_{12}^3 + \alpha h_{1R}^3 h_{R2}^1 \end{bmatrix} \begin{bmatrix} d_{11} \\ d_{12} \end{bmatrix} + \begin{bmatrix} 0 \\ h_{11}^2 \\ \beta h_{1R}^3 h_{R1}^2 \end{bmatrix} d_{21} + \begin{bmatrix} 0 \\ h_{12}^2 \\ h_{12}^3 + \beta h_{1R}^3 h_{R2}^2 \end{bmatrix} d_{22}$$

- Set

$$\frac{h_{12}^3 + \beta h_{1R}^3 h_{R2}^2}{h_{12}^2} = \frac{\beta h_{1R}^3 h_{R1}^2}{h_{11}^2}$$

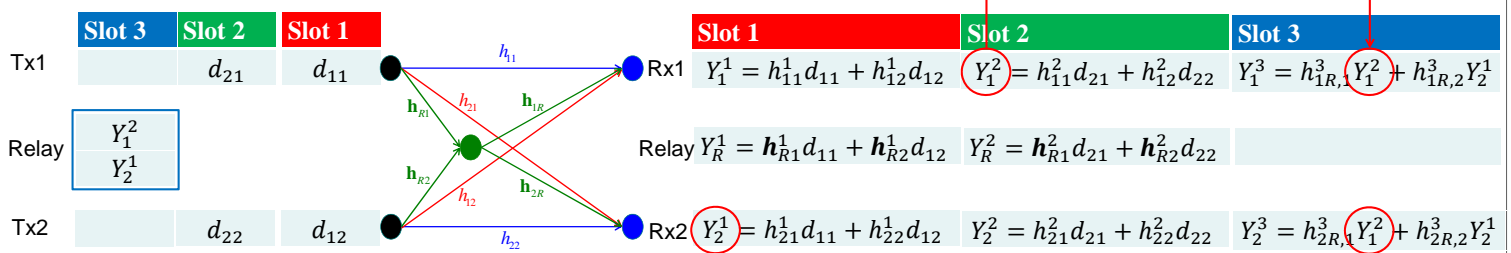
Aligned on direction  $\begin{bmatrix} 0 \\ h_{11}^2 \\ \beta h_{1R}^3 h_{R1}^2 \end{bmatrix}$

- **Joint beamforming** between the transmitters and the relay.

## Delayed CSI at the Relay

- Two-antenna relay is sufficient to achieve the optimal DoF  $\frac{4}{3}$ : **The staleness of CSI can be compensated with an additional antenna!**

- Relay-aided interference alignment scheme:



- Rx 1 can obtain  $Y_1^1 = h_{11}^1 d_{11} + h_{12}^1 d_{12}$   
 $Y_2^1 = h_{21}^1 d_{11} + h_{22}^1 d_{12}$  to decode the intended data stream  $d_{11}, d_{12}$