Boosting Capacity through Interference in 5G

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creating and sharing knowledge for telecommunications

RTCM'17

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Team to be credited

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Outline

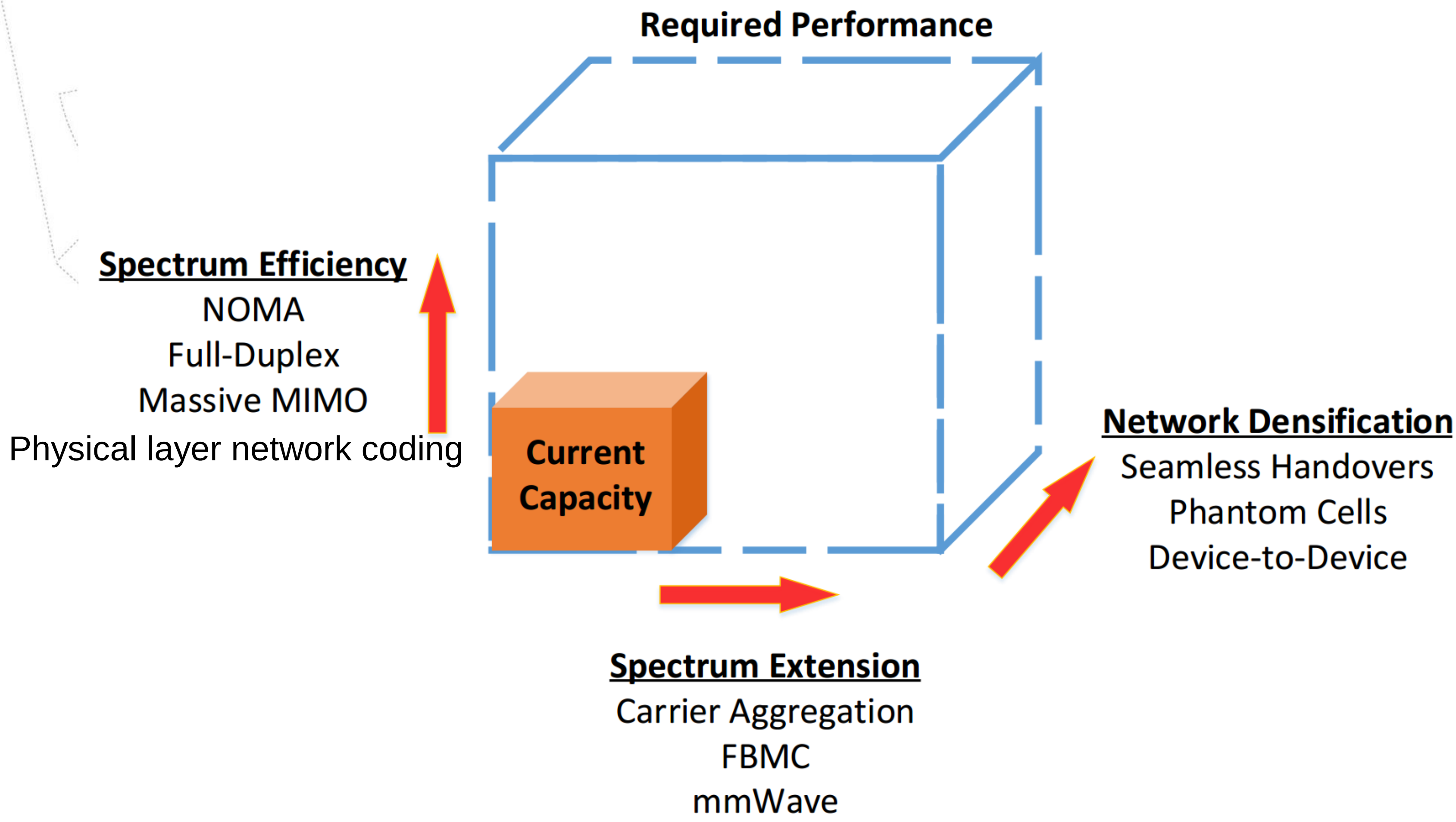
1- Context:

- Massive MIMO
- Physical Layer Network Coding (PLNC)
- In-band Full-duplex (IBFD)
- Non-orthogonal multiple access (NOMA)

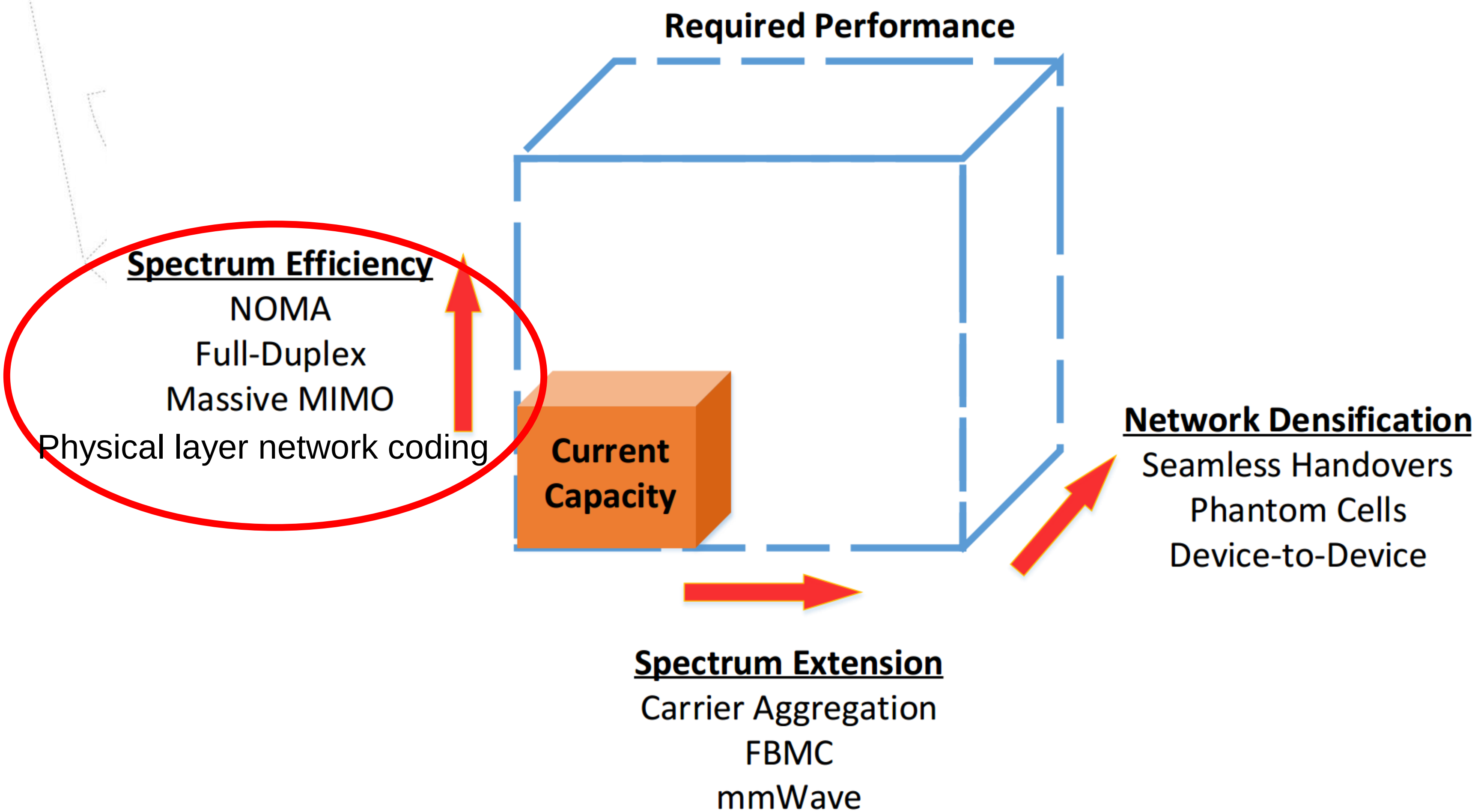
2- mMIMO+PLNC+IBFD

3- Results

How to offer more?



How to offer more?



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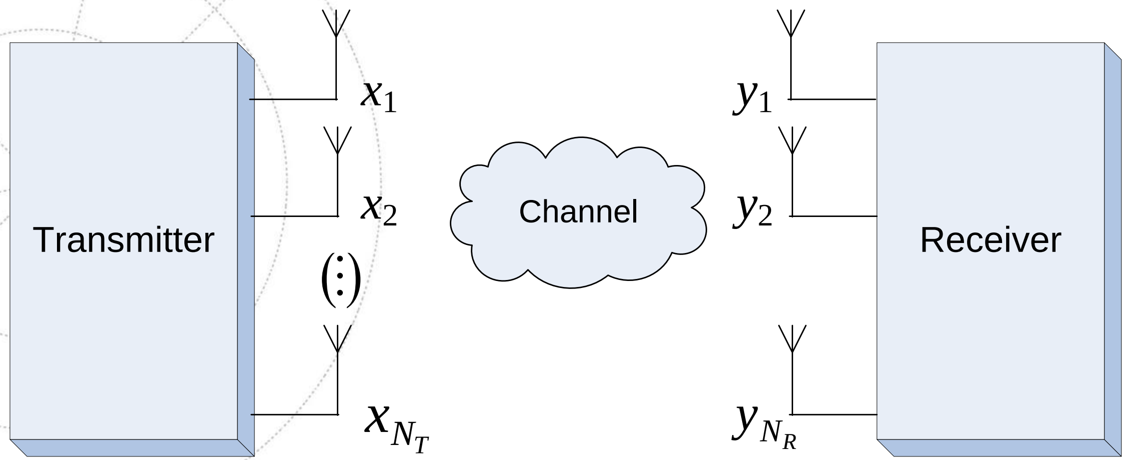
Old technology …MIMO

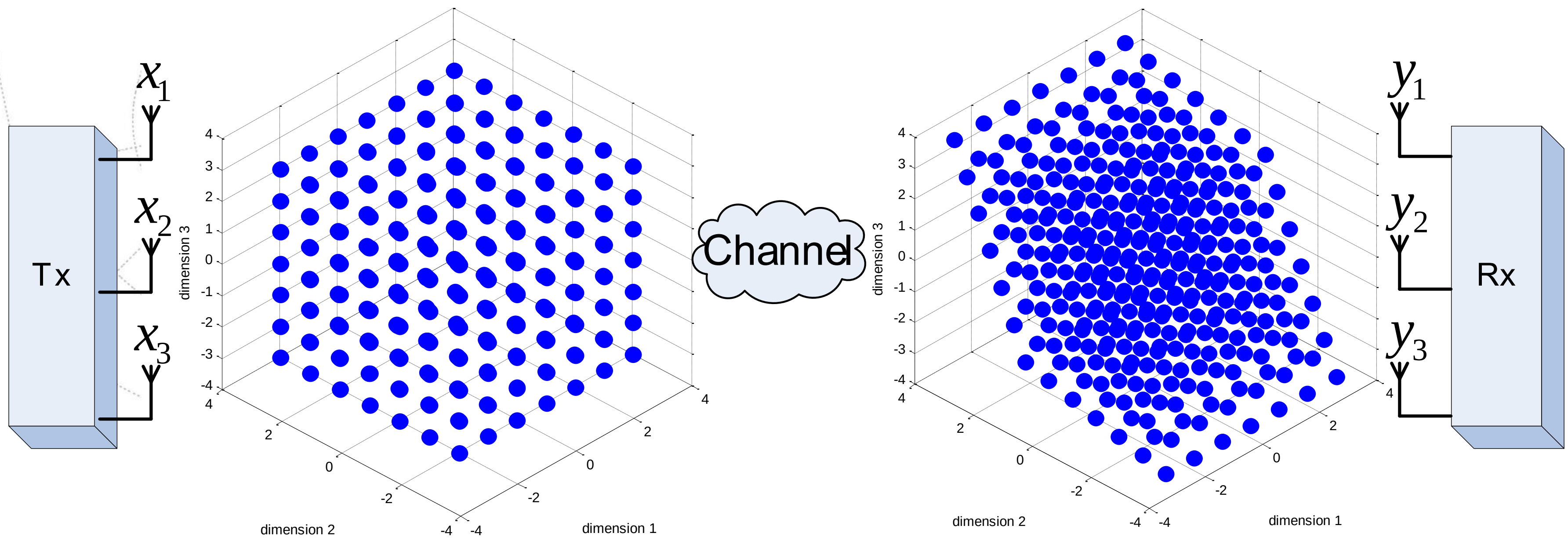


$$\begin{bmatrix} \mathbf{y}_1 \\ \mathbf{y}_2 \\ \vdots \\ \mathbf{y}_{N_R} \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1N_T} \\ h_{21} & h_{22} & \cdots & h_{2N_T} \\ \vdots & \vdots & \ddots & \vdots \\ h_{N_R 1} & h_{N_R 2} & \cdots & h_{N_R N_T} \end{bmatrix} \cdot \begin{bmatrix} \mathbf{x}_1 \\ \mathbf{x}_2 \\ \vdots \\ \mathbf{x}_{N_T} \end{bmatrix} + \begin{bmatrix} \mathbf{n}_1 \\ \mathbf{n}_2 \\ \vdots \\ \mathbf{n}_{N_R} \end{bmatrix}$$

$$\mathbf{y} = \mathbf{H}\mathbf{x} + \mathbf{n}$$

$$\hat{\mathbf{x}}_{ML} = \min_{\mathbf{x}} \left\{ \left\| \mathbf{y} - \mathbf{H}\mathbf{x} \right\|^2 \right\}$$

MIMO channel is a linear transformation



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$$\hat{\mathbf{x}}_{ML} = \min_{\mathbf{x}} \left\{ \left\| \mathbf{y} - \mathbf{H}\mathbf{x} \right\|^2 \right\}$$

Example:
3 dimensions (3 antennas using PAM).

In Massive MIMO: Linear Detection Processing suffices!

Zero-forcing (or MMSE): $(\underbrace{\mathbf{H}^H\mathbf{H}}_{\mathbf{Z}})^{-1}\mathbf{H}^H\mathbf{y} = \mathbf{H}^\dagger\mathbf{y}$

Near optimal diversity [1]: $N_R - N_T + 1 \approx N_R$

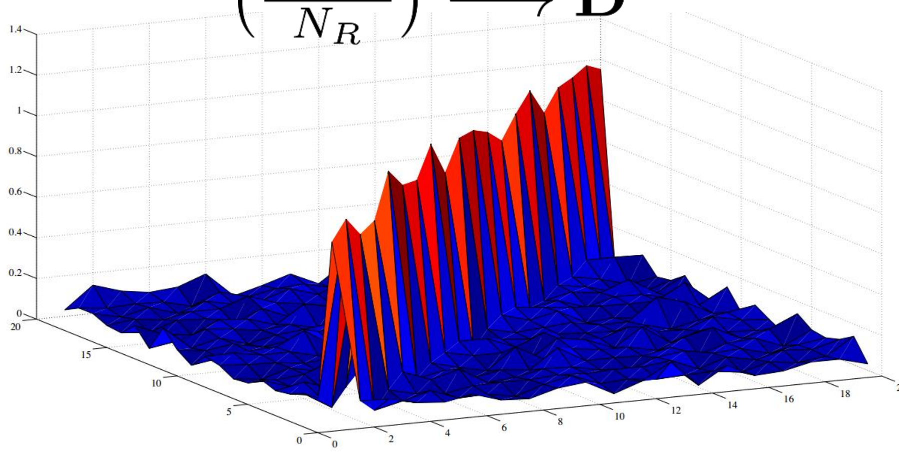
Low complexity

- But requires inverse ($\mathcal{O}(N_T^3)$!)

Exploit orthogonalization [2]:

- Neumann series
- Matrix inversion lemma

$$\left(\frac{\mathbf{H}^H\mathbf{H}}{N_R}\right) \xrightarrow{\text{a.s.}} \mathbf{D}$$



F. Rosário, F. A. Monteiro, A. Rodrigues, *"Fast Matrix Inversion Updates for Massive MIMO Detection and Precoding"*, in IEEE Signal Processing Letters, Vol. 23, No. 1, pp. 75-79, Jan. 2016.

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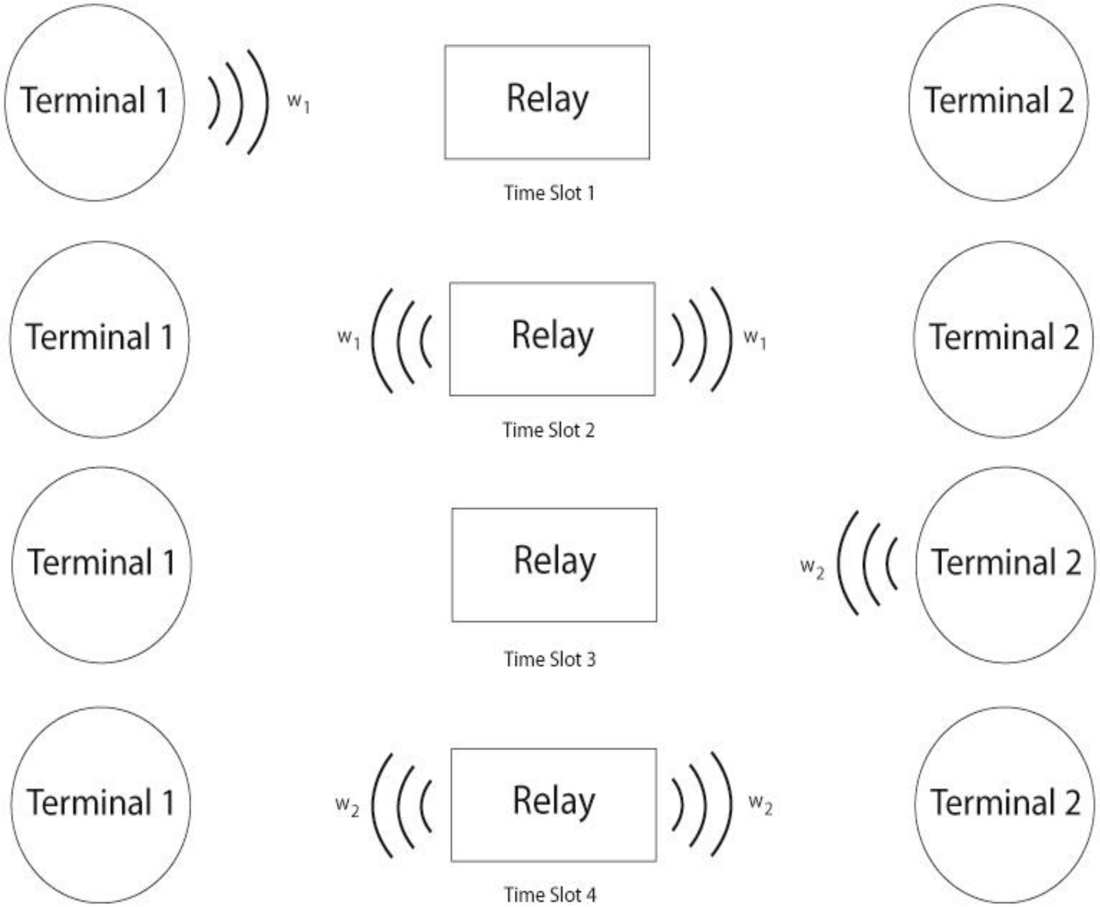
The two way relay channel

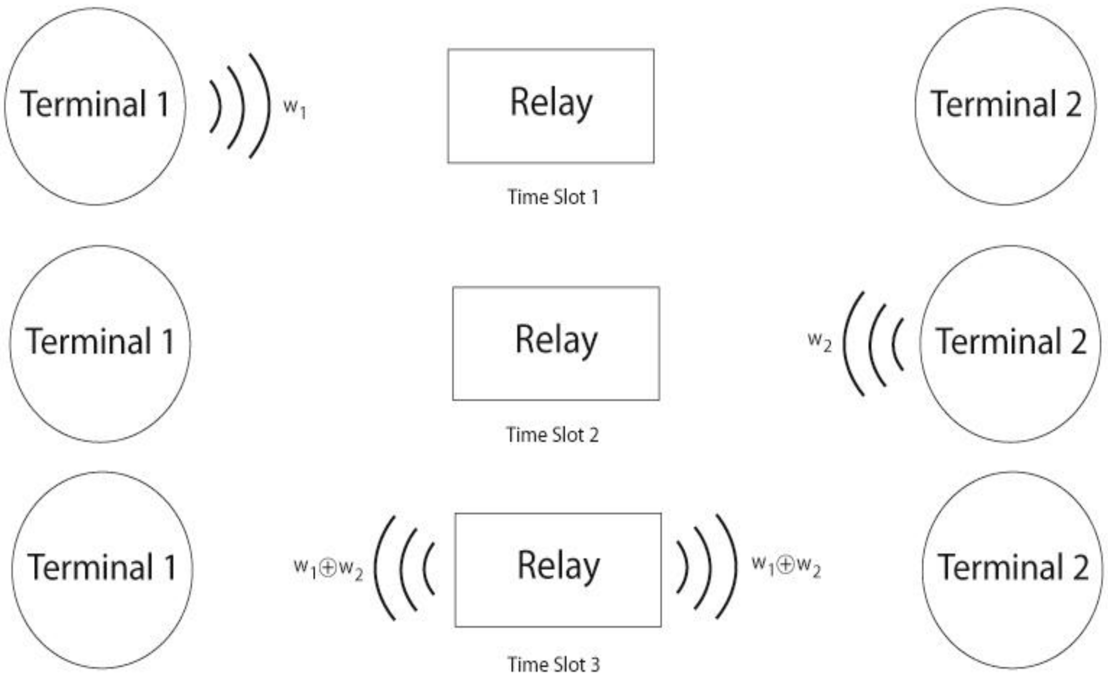
The two way relay channel

TDMA



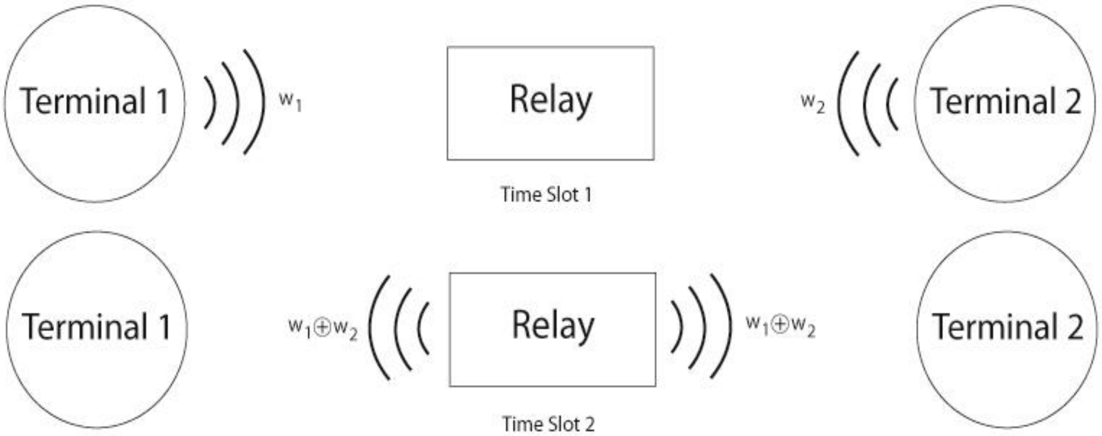
The two way relay channel

Network Coding



The two way relay channel

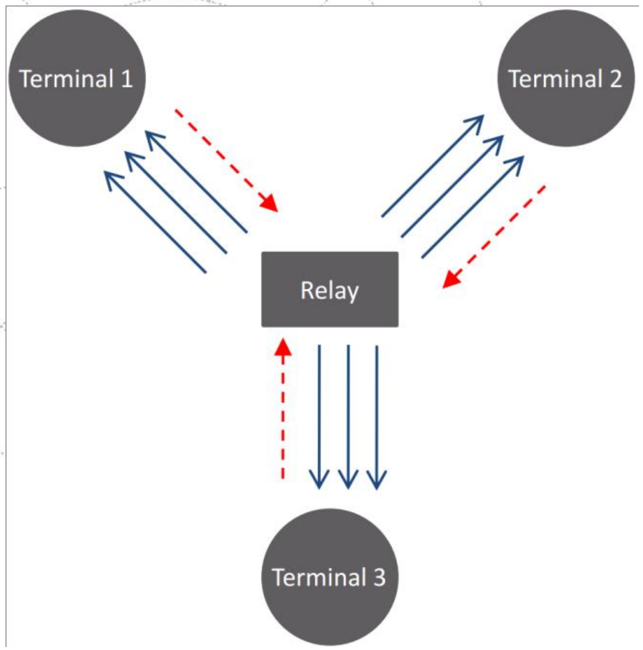
Physical layer Network Coding

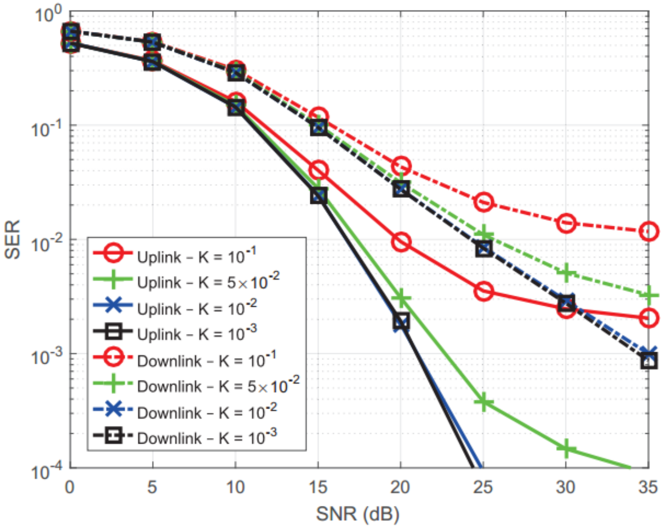


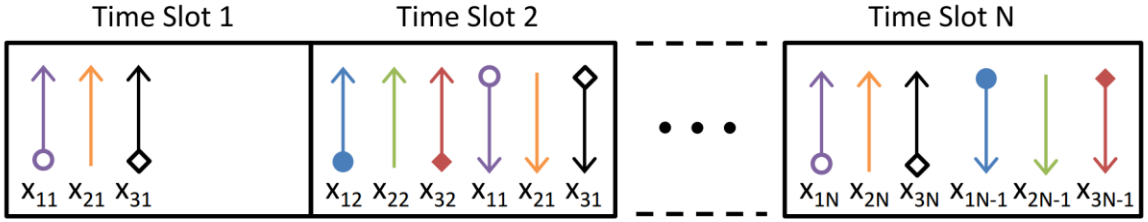
Two time-slots. Can we do better?

$\Rightarrow$ Yes: merge both stages $\Leftrightarrow$ in-band full-duplex.

The multi-way channel







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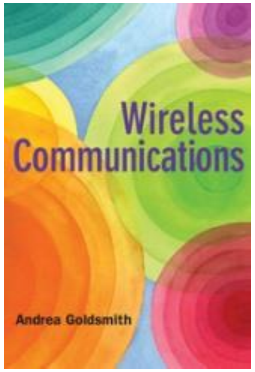
Full-duplex is changing a long-established idea

"It is generally not possible for radios to receive and transmit on the same frequency band because of the interference that results."

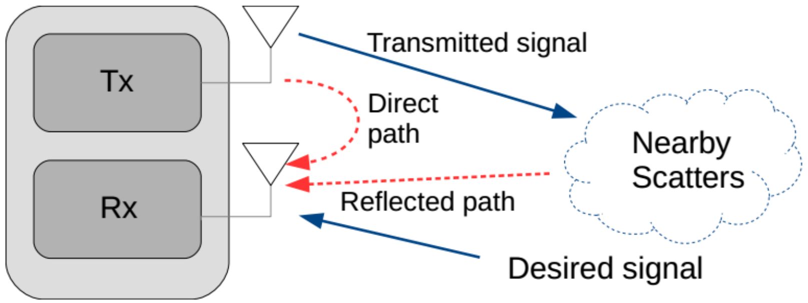
In *Wireless Communications*, Cambridge University Press, p. 454, 2003,



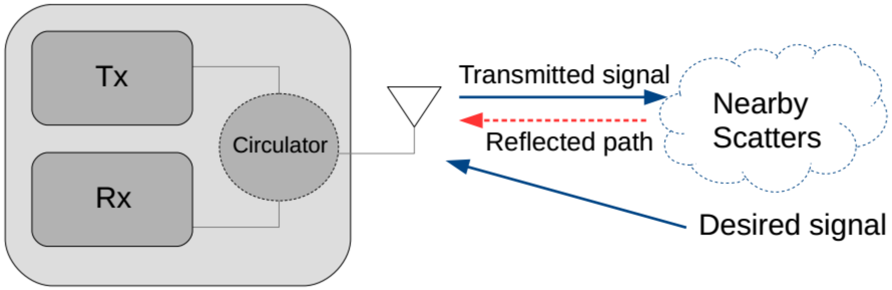
by Andrea Goldsmith

Two possible transceiver configurations with full-duplex:

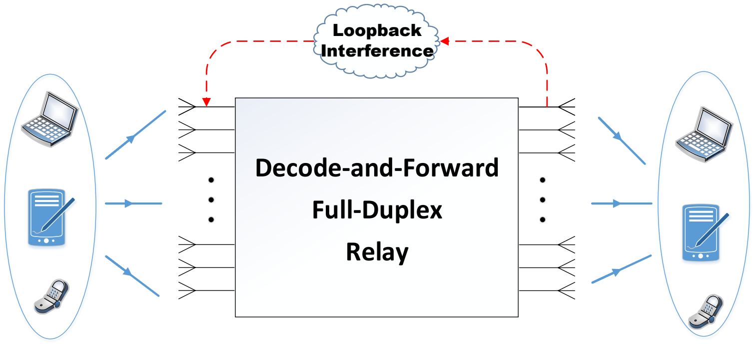
Independent Tx and Rx antennas:

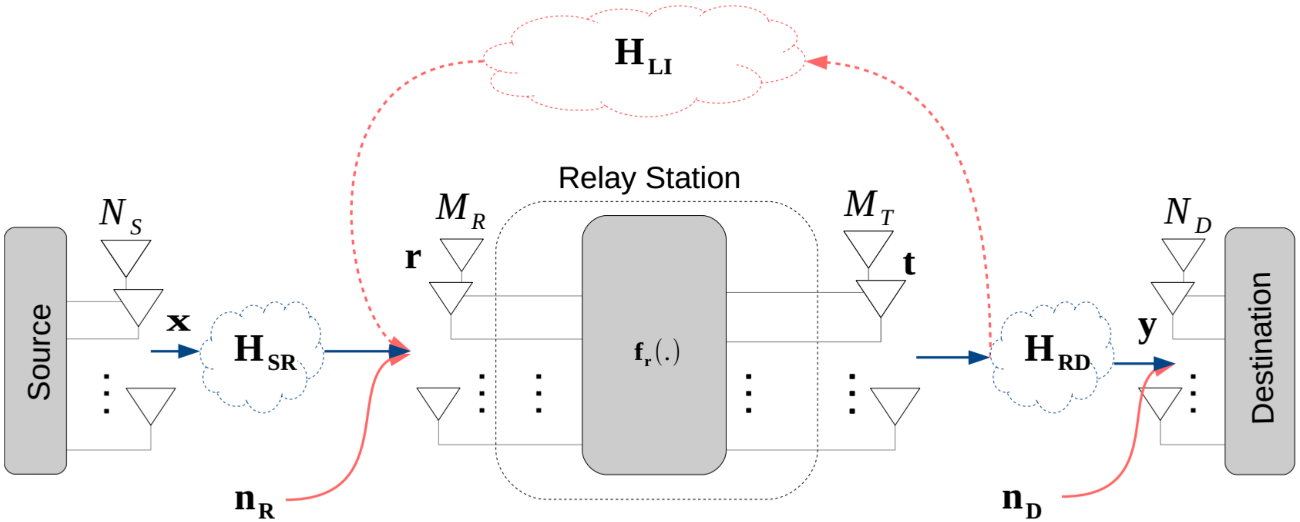


Shared antenna:



MIMO + in-band full-duplex + relay





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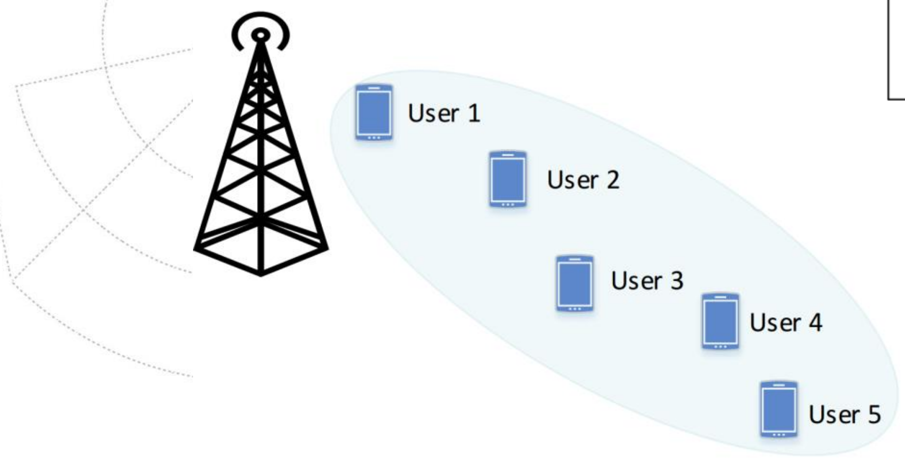
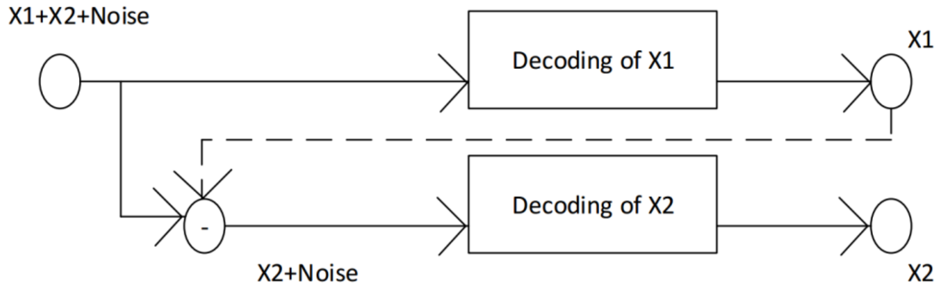
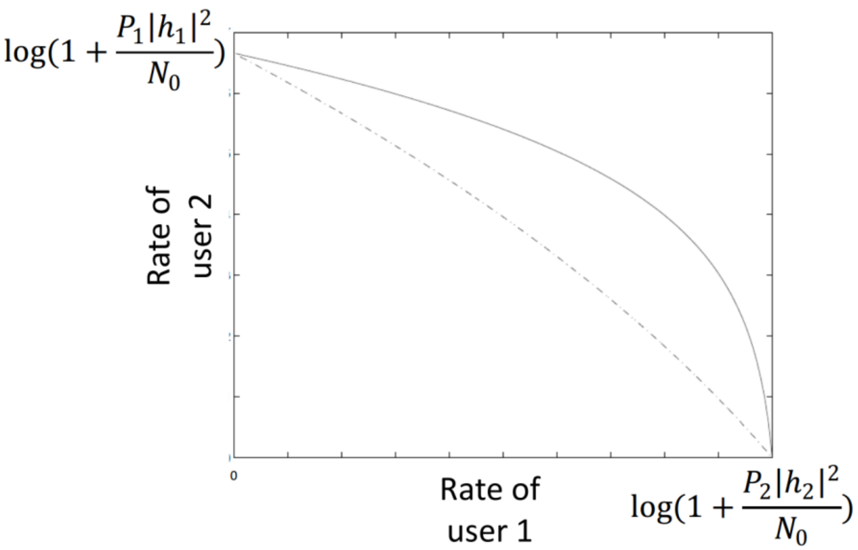
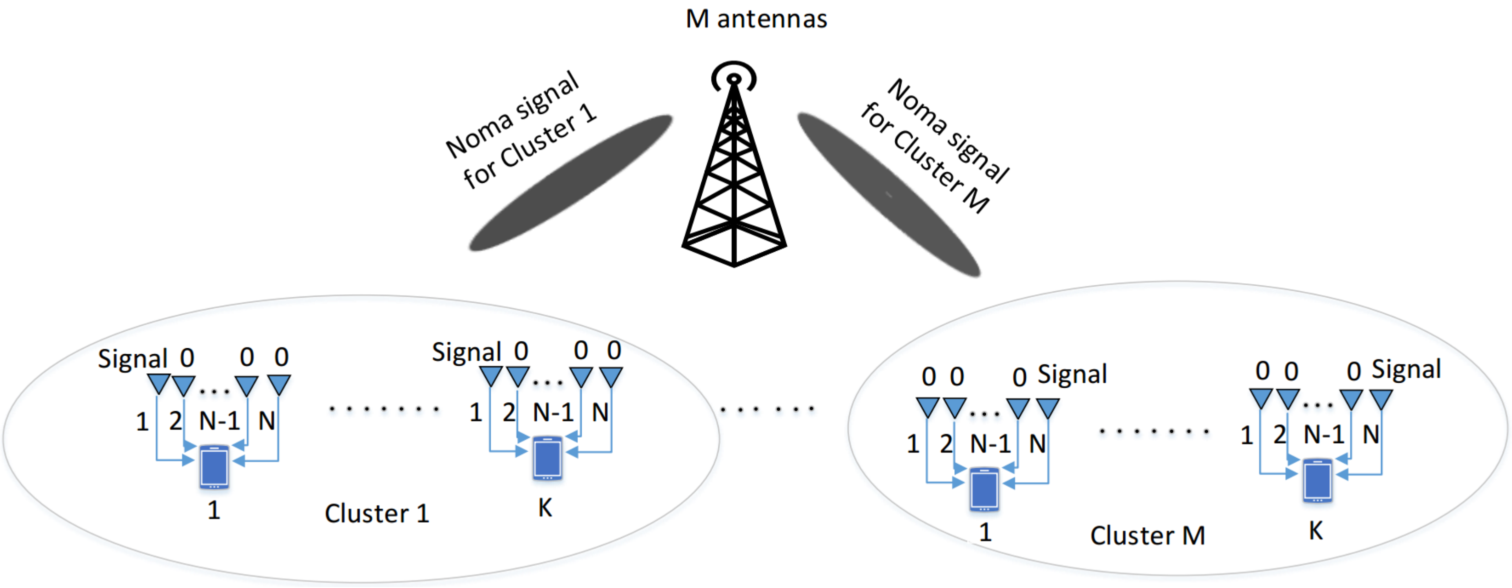
Non-orthogonal multiple access (NOMA)







MIMO-NOMA within clusters of users



R. Alberto, F. A. Monteiro, *“MIMO-NOMA with more than two users"*, submitted to ICC 2017 – Paris, France

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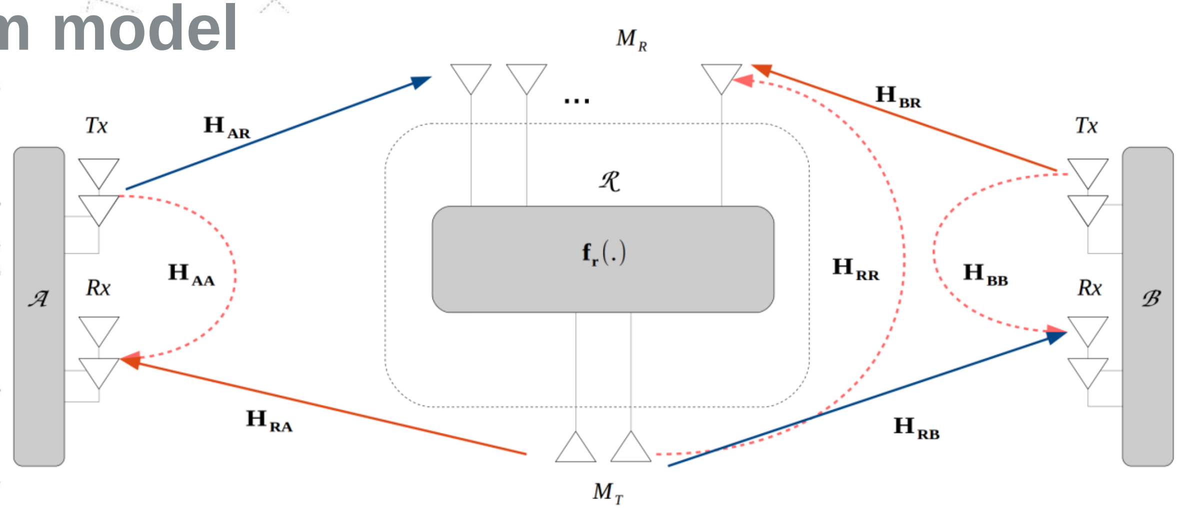
System model



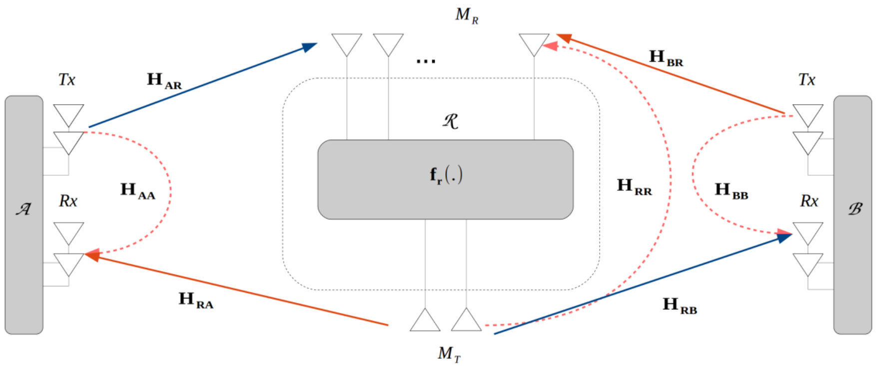
$$M_T = N_T = 2$$

$$\boxed{\begin{aligned} &\mathbf{H_{AA}x_A}(n) - \widehat{\mathbf{H}_{AA}\mathbf{x}}_A(n) := k_A\mathbf{H_{AA}x_A}(n), \\ &\mathbf{H_{BB}x_B}(n) - \widehat{\mathbf{H}_{BB}\mathbf{x}}_B(n) := k_B\mathbf{H_{BB}x_B}(n), \\ &\mathbf{H_{RR}x_R}(n) - \widehat{\mathbf{H_{RR}}\mathbf{x}}_R(n) := k_R\mathbf{H_{RR}x_A}(n), \end{aligned}}$$

$$\begin{aligned} \mathbf{y_R}(n) &= \sqrt{p_A}\mathbf{H_{AR}x_A}(n) + \sqrt{p_B}\mathbf{H_{BR}x_B}(n) + \\ &\qquad \sqrt{p_R}k_R\mathbf{H_{RR}x_R}(n) + \mathbf{n_R}(n), \\ \mathbf{y_A}(n) &= \sqrt{p_R}\mathbf{H_{RA}x_R}(n) + \\ &\qquad \sqrt{p_A}k_A\mathbf{H_{AA}x_A}(n) + \mathbf{n_A}(n), \\ \mathbf{y_B}(n) &= \sqrt{p_R}\mathbf{H_{RB}x_R}(n) + \\ &\qquad \sqrt{p_B}k_B\mathbf{H_{BB}x_B}(n) + \mathbf{n_B}(n). \end{aligned}$$

k_R, k_A, k_B SI mitigation gains

Results: how many antennas at the relay?



Target: Integer combination of messages

$$\left[\mathbf{D_A x_A}(n) + \mathbf{D_B x_B}(n)\right] \text{mod}_{\Lambda_C},$$

$$\boxed{\mathbf{D_A}, \mathbf{D_B} \in \mathbb{Z}^{N_T \times N_T}}$$

Processing: Apply zero forcing filters

$$\boxed{\mathbf{H_{BR}}^{\dagger}\mathbf{H_{AR}} \to \mathbf{0}, \mathbf{H_{AR}}^{\dagger}\mathbf{H_{BR}} \to \mathbf{0}, \text{ as } M_R \to \infty}$$

$$\begin{aligned}
\mathbf{y_P}(n) =& \mathbf{H_{AR}}^{\dagger}\mathbf{y_R}(n) + \mathbf{H_{BR}}^{\dagger}\mathbf{y_R}(n) \\
=& \left(\mathbf{H_{AR}}^{\dagger}\mathbf{H_{AR}x_A}(n) + \mathbf{H_{BR}}^{\dagger}\mathbf{H_{BR}x_B}(n)\right) + \\
& \left(\mathbf{H_{BR}}^{\dagger}\mathbf{H_{AR}x_A}(n) + \mathbf{H_{AR}}^{\dagger}\mathbf{H_{BR}x_B}(n)\right) + \\
& \left(\mathbf{H_{AR}}^{\dagger} + \mathbf{H_{BR}}^{\dagger}\right)\left(k_R\mathbf{H_{RR}x_R}(n) + \mathbf{n_R}(n)\right)
\end{aligned}$$

$$= \underbrace{\mathbf{D_A x_A}(n) + \mathbf{D_B x_B}(n)}_{\text{desired component}} + \underbrace{\tilde{\mathbf{n}}^{\star}_{\mathbf{R}}(n)}_{\text{equivalent total noise}}$$

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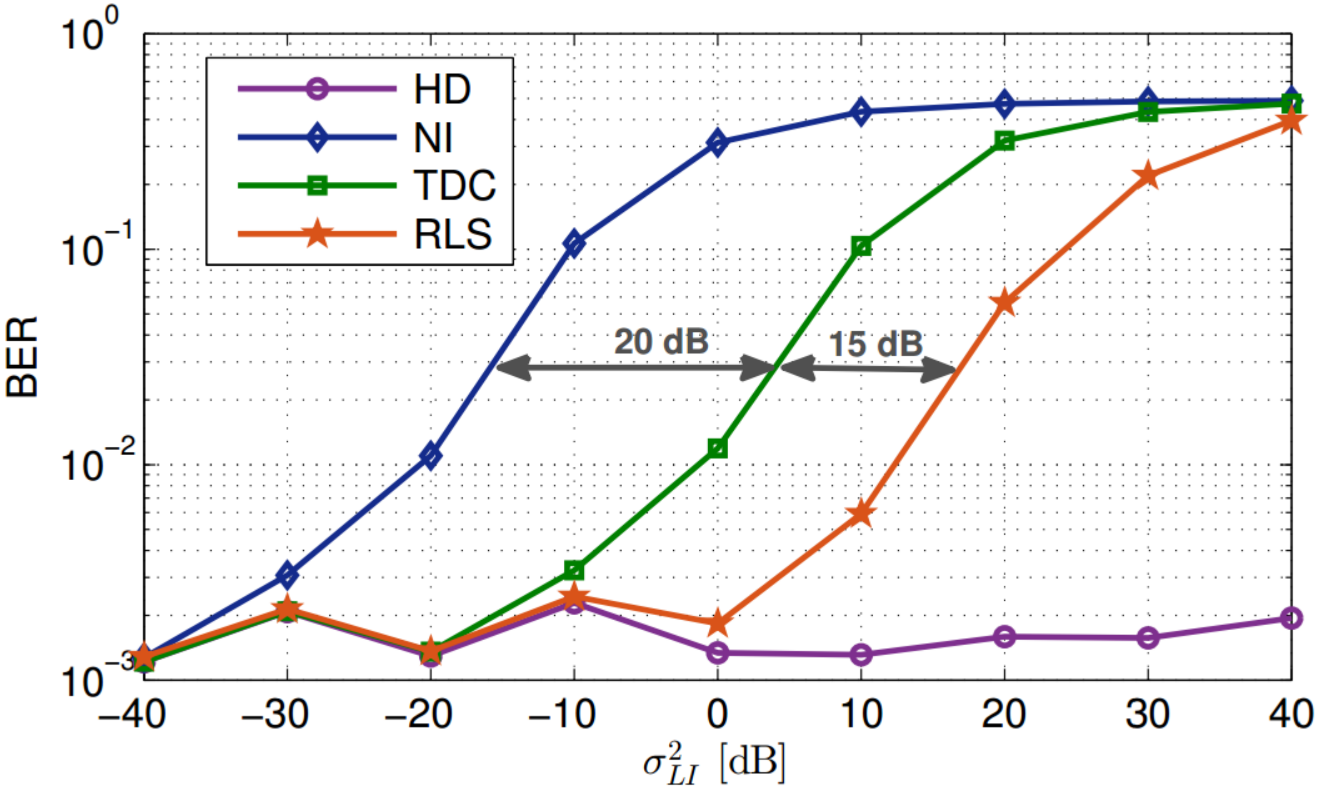
Recursive Least Squares for a MIMO relay



J. S. Lemos, F. A. Monteiro, I. Sousa, A. Rodrigues, *"Full-Duplex Relaying in MIMO-OFDM Frequency-Selective Channels with Optimal Adaptive Filtering"*, in Proceedigns of GlobalSIP- 3rd IEEE Global Conf. on Signal and Information Processing, Orlando, Florida, Dec. 2015.

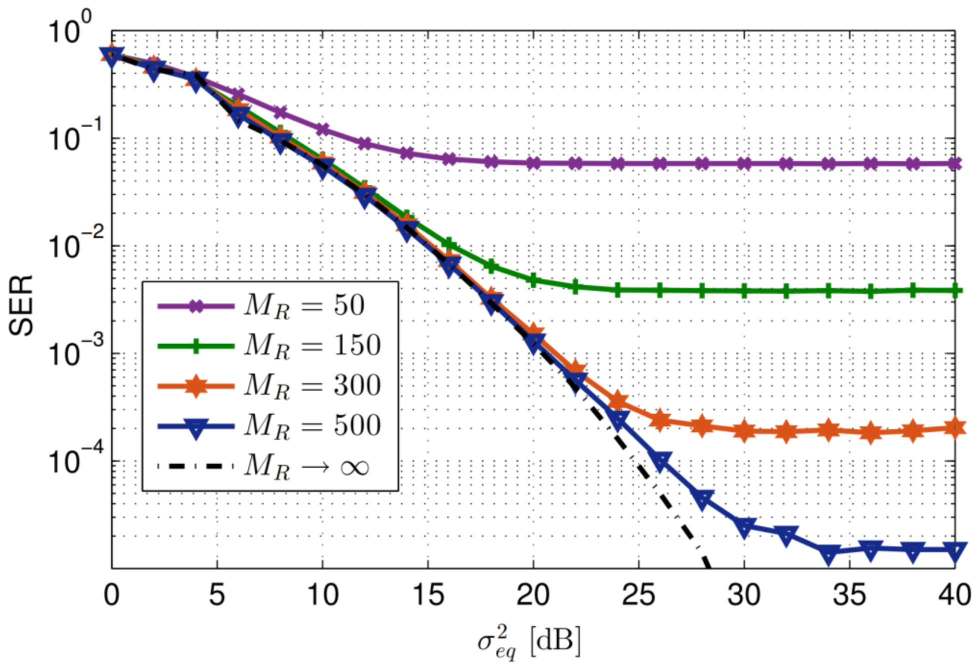
Results: how many antennas at the relay?

Massive MIMO Effect:

- SER vs equivalent interfering power ($\sigma_{eq}^2 = k + \sigma^2$)
- $N_T = M_T$, varying $M_R \to \infty$

$$k = k_A = k_B = k_R$$

$$\sigma^2 = \sigma_{\mathbf{n_A}}^2 = \sigma_{\mathbf{n_B}}^2 = \sigma_{\mathbf{n_R}}^2$$



J. S. Lemos, F. A. Monteiro, *"Full-duplex massive MIMO with physical layer network coding for the two-way relay channel"*,in Proc. Of IEEE SAM - The 9th IEEE Sensor Array and Multichannel Signal Processing Workshop, Rio de Janeiro, Brazil, July 2016

Final slide (*message to take home*)

Clever exploitations of interference offers larger sum-rates by reaching more degrees of freedom

Space domain (mMIMO)* , *power domain (NOMA), coding domain (PLNC), and full-duplex is possible (IBFD)

-Bidirectional channel with 1 time slot using MaMIMO at the relay is possible;

- The number of antennas at the relay < 300 (for SER of interest).

-Channel(s) estimation is always crucial to cancel self-interference.

Thank you!

http://iul.pt/~frmo/

Lattice-based physical-layer network coding

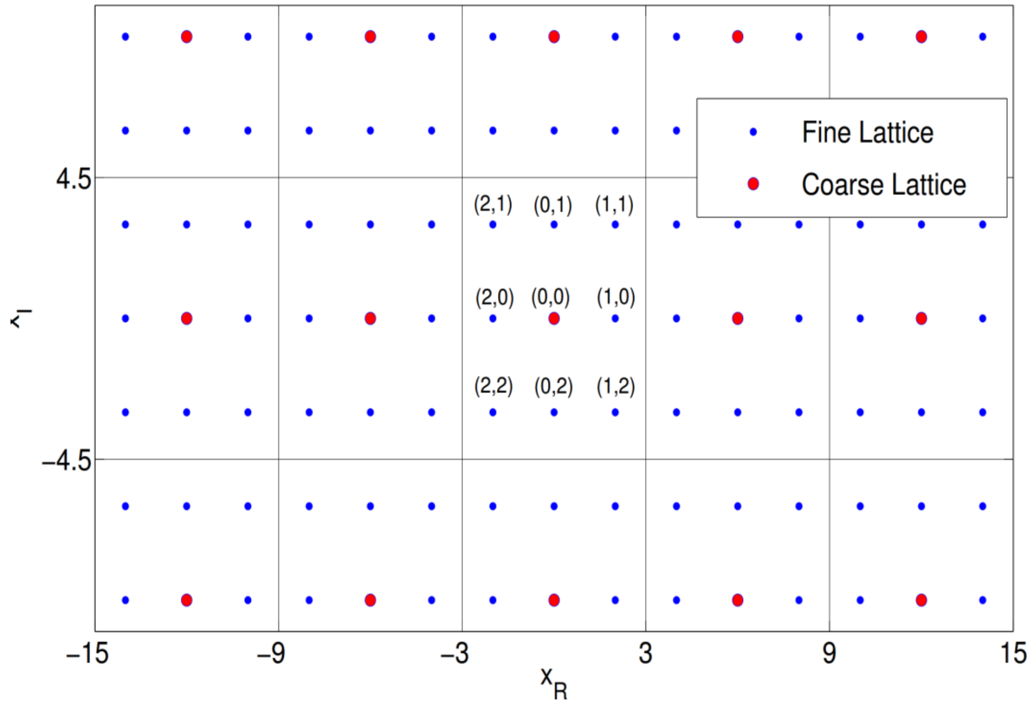
Compute-and-Forward Protocol:

- Relay forwards a linear function of received codewords
- Explore isomorphism between electromagnetic waves and codebook's additive group properties:

  Nested Lattice Codes: $\mathcal{L} = \Lambda_F \cap \mathcal{V}_{\Lambda_C} = \{\lambda = [\lambda_F]\text{mod}_{\Lambda_C}, \lambda_F \in \Lambda_F\}$

$$\phi : \mathbb{Z}_3^2 \rightarrow \mathcal{L} = \Lambda_F \cap \mathcal{V}_{\Lambda_C}(\in \mathbb{C}),$$

$$S_{A,i}, S_{B,i} \rightarrow \mathbf{x_A}, \mathbf{x_B} :$$



Results: w/ self-interference channel estimation error

Self-interference is known with some error taken from $\mathcal{CN}(0, \sigma^2_{\tilde{\mathbf{H}}})$

$$\mathbf{H} = \tilde{\mathbf{H}} + \mathcal{E}_{\mathbf{H}}$$