Interference Alignment using NI FlexRIO

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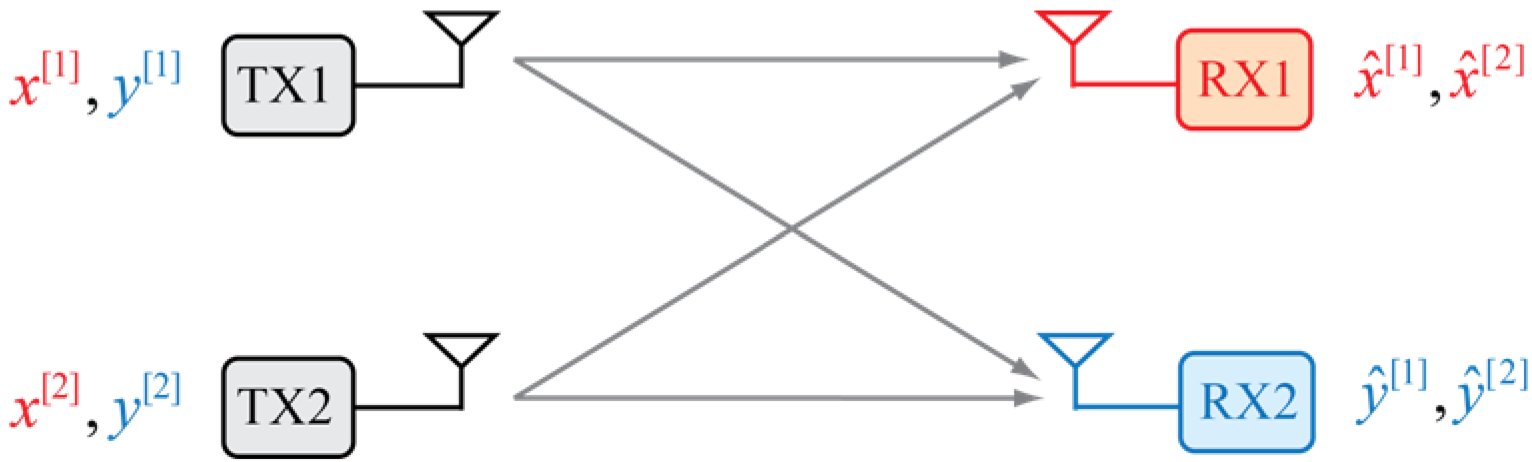
Overview

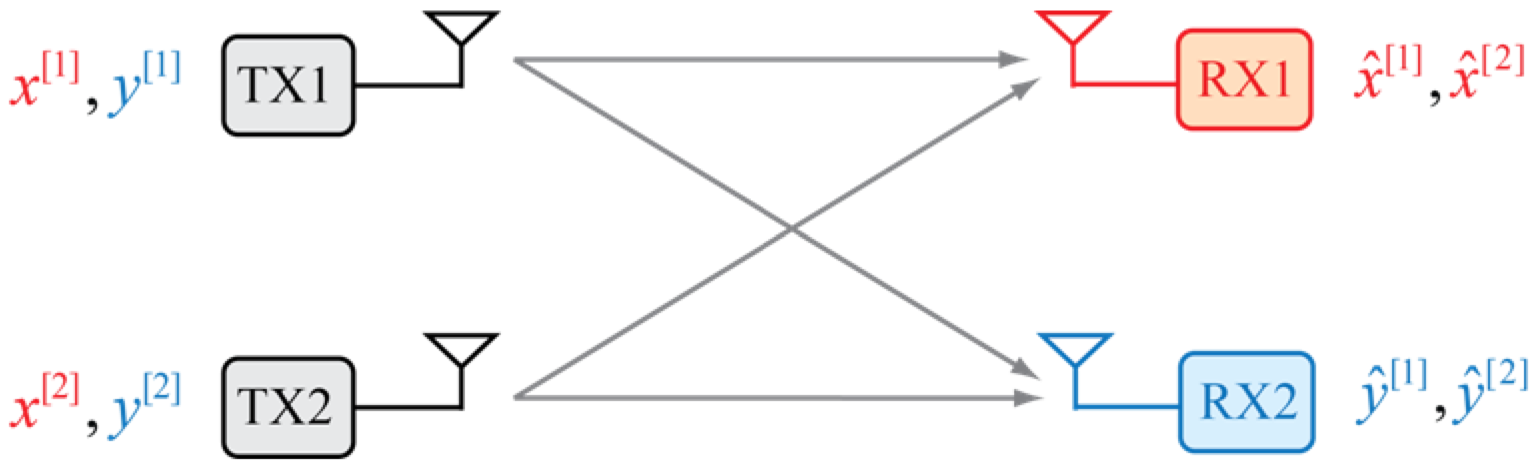
- Implementation of **Interference Alignment** on a hardware platform
- Among the first to demonstrate alignment in practice
- 2 x 2 system: A good starting point

Setup: The X channel



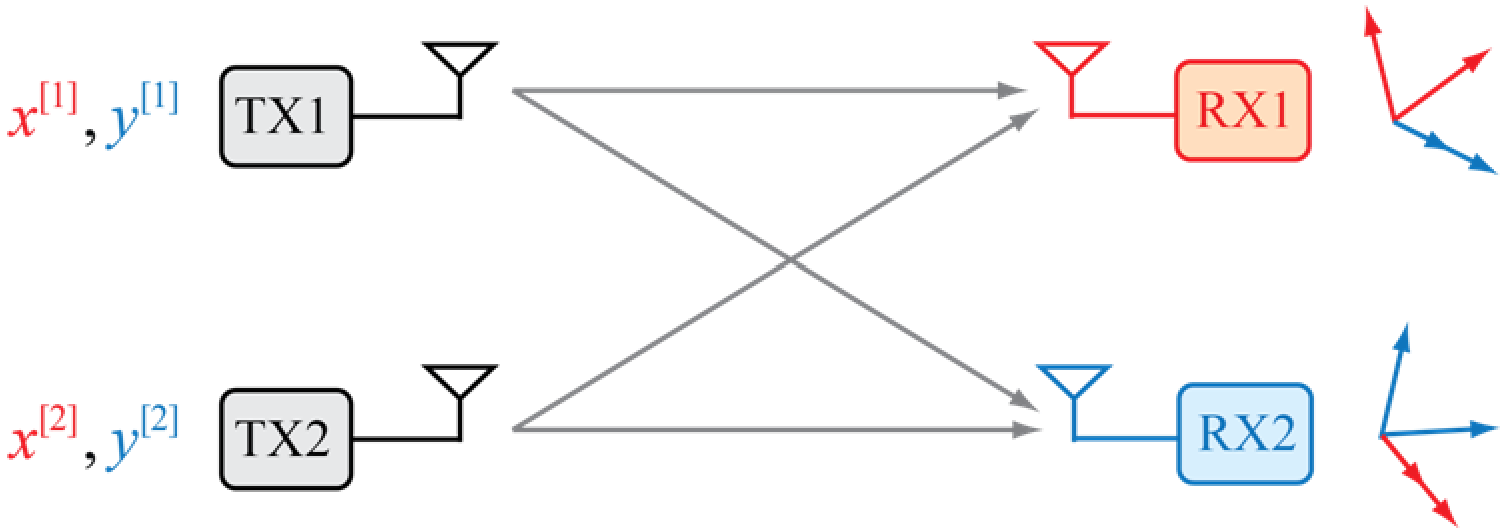
- Two transmitters, Two receivers
- Each transmitter has two distinct messages
- x destined for RX1 and y destined for RX2
- E.g., base station with two antennas transmitting to two cell phone users

Simple scheme



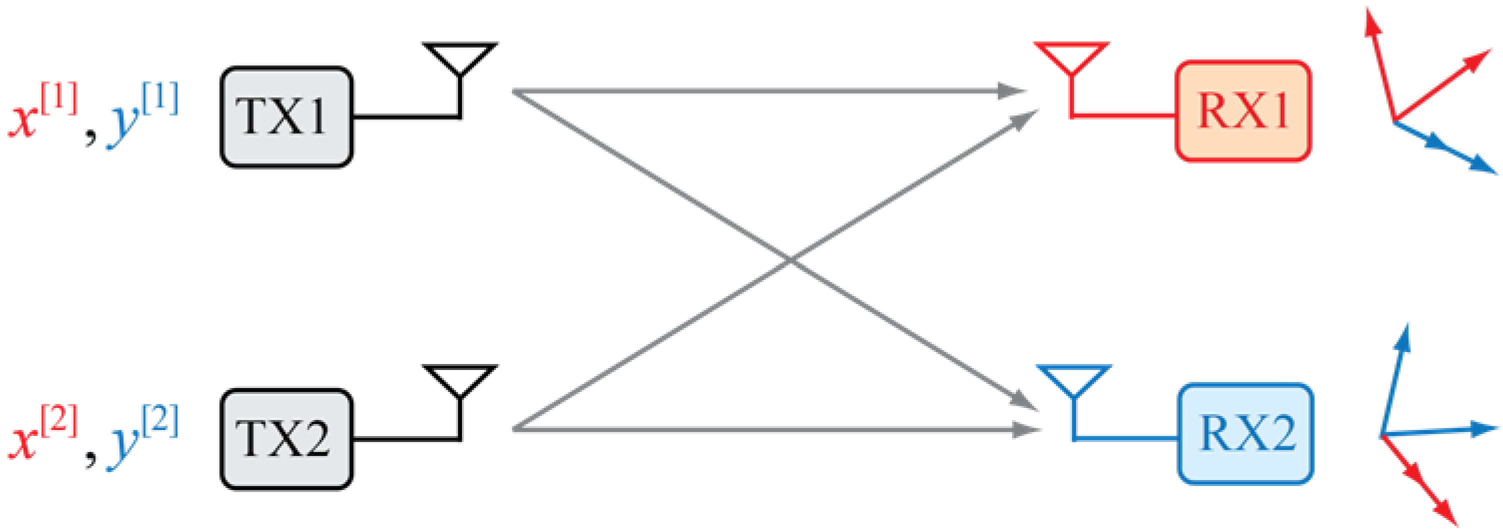
- Use **time division** with four time slots: send each message in one time slot
- Can we do better?
  YES, using Interference Alignment

Interference alignment



- Extend modulated symbols to higher dimensional space
- Interfering signals are **aligned** to occupy the subspace of smallest dimension
- Desired signals are received in remaining dimensions essentially **free of interference**

Interference alignment



Previous work:

- Cadambe and Jafar (2008)
- Maddah-Ali, Motahari and Khandani (2008)
- Jafar and Shamai (2008)

Interference alignment

- **Tremendous throughput gains!**
  - 2 x 2 setup: **33%** higher
  - Total throughput **increases** with no. of terminals

    For a *M* x *K* system:

$$C(SNR) = \frac{MK}{M+K-1}\log(1+SNR) + o(\log(SNR))$$

  - 3 x 20 setup: **173%** higher

    4 x 100 setup: **288%** higher

- **Main Challenge:**

  All terminals must know **all** channel coefficients exactly

Blind interference alignment

- Proposed by Wang, Gou, Jafar (2010)

- Transmitters need **no channel information**
- Receivers need only local channel information

- What's the catch?

  - Receivers have a **reconfigurable antenna**

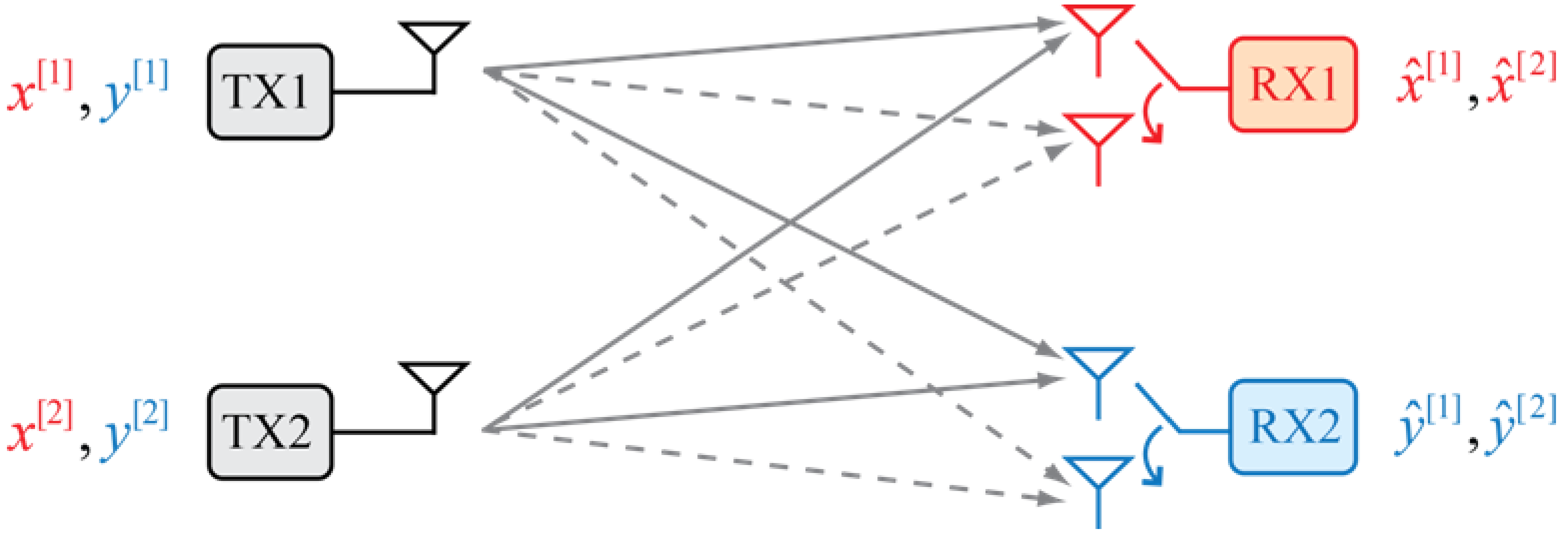
  - Two different receive modes (for 2 x 2)

- Our implementation:

  - Receiver switches between two antennas

  - But, has only one receive RF chain

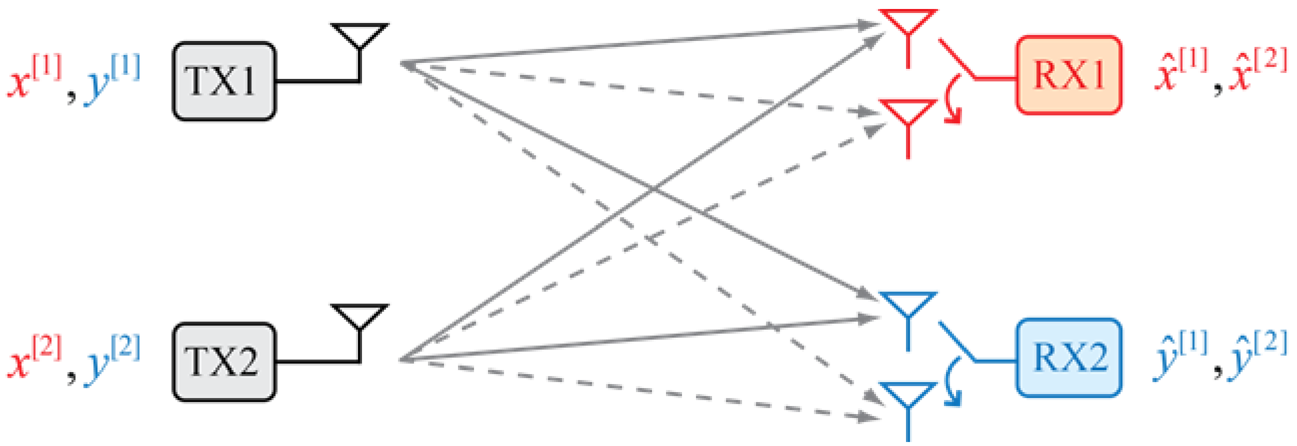
Blind interference alignment



Receiver **switches** between two antennas

- but, has only one receive RF chain

Blind IA scheme



Time Slot	1	2	3
TX1 and TX2	$x^{[i]} + y^{[i]}$	$x^{[i]}$	$y^{[i]}$
RX1	ant 1	ant 2	ant 1
RX2	ant 1	ant 1	ant 2

Recovery at the receiver

- Received signal at RX1

$$z(1) = h_{11}(x^{[1]} + y^{[1]}) + h_{21}(x^{[2]} + y^{[2]}) + n(1)$$
$$z(2) = h'_{11}x^{[1]} + h'_{21}x^{[2]} + n(2)$$
$$z(3) = h_{11}y^{[1]} + h_{21}y^{[2]} + n(3)$$

- Subtract $z(1) - z(3)$ to remove interference and recover desired messages

- Assumes channel is constant over three time slots

Practical challenges

- **Synchronization** (in time and frequency)

  - synchronize transmitters TX1 and TX2

  - synchronization of receivers with the transmitters is especially difficult due to receive antenna switching

- Constant channel over three time slots

Objectives:

- Develop a complete **hardware implementation** overcoming the practical challenges
- Compare the practical performance gains of

  blind IA vs. simple time-division scheme

Hardware: SDR platform from NI

Development PC
with LabVIEW

NI PXI Express Chassis
with Real-Time OS

NI FlexRIO FPGA Module

Xilinx Virtex-5 FPGA

Baseband Transceiver

A/D and D/A

Ettus XCVR2450 Transceiver

Up/down converter

System parameters

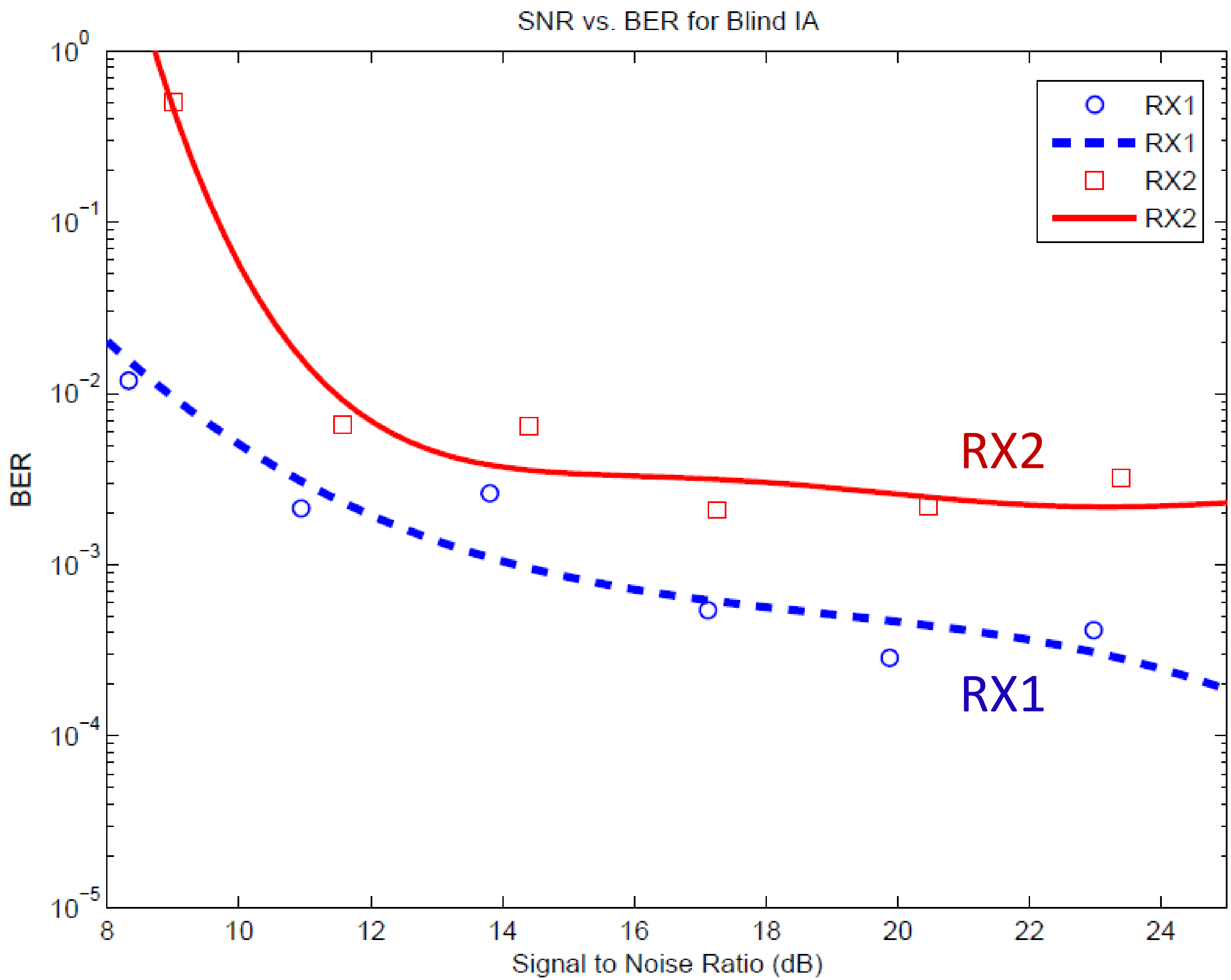
- Non-realtime implementation
- 2.4 GHz ISM band. **OFDM with QPSK signaling**
- Parameters chosen based on LTE

BW (MHz)	1.4	3	5	10	15	20
# subcarriers	72	180	300	600	900	1200
Subcarrier spacing	15 kHz					
CP length	16.67 us					
Symbol duration	1/12 ms					

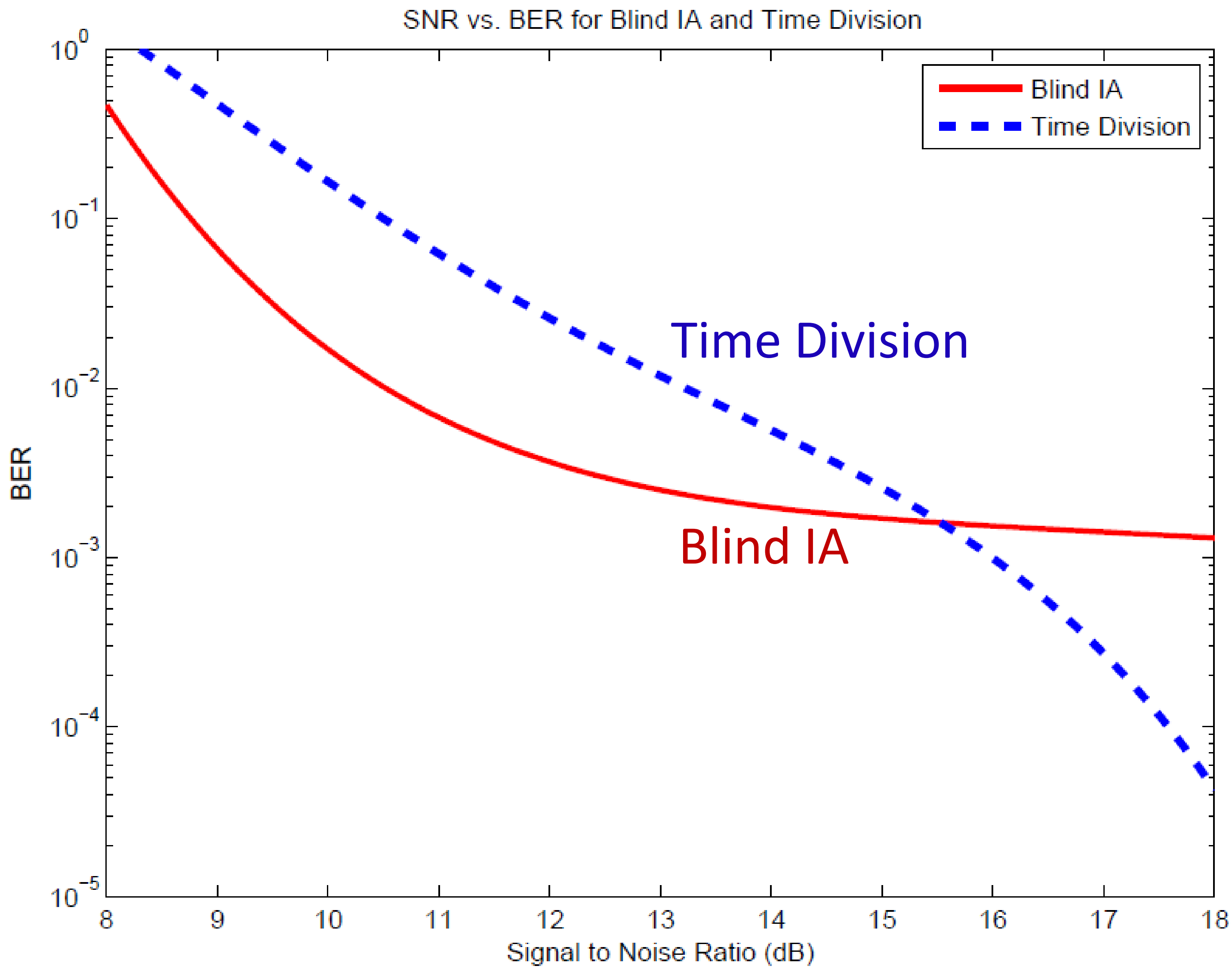
Synchronization and Switching

- TX1 and TX2 are mounted on the same PXI chassis
- Synchronize TX1 and TX2 using the
  10 MHz **backplane reference clock**
- Synchronization at receivers using **Schmidl-Cox** algorithm
- Perform antenna switching offline

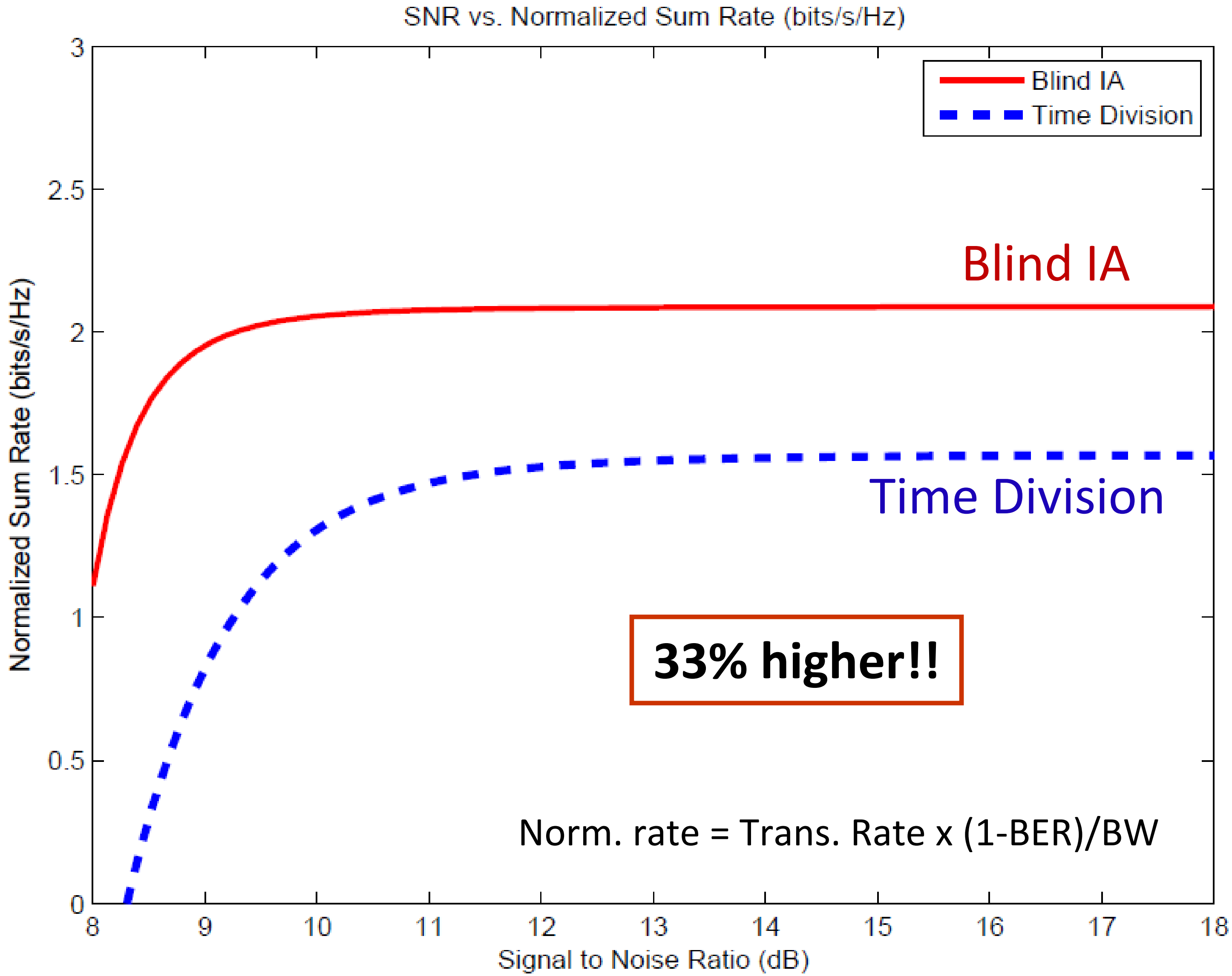
SNR vs. BER for Blind IA



SNR vs. BER for Blind IA and Time Division



SNR vs. Normalized Sum Rate (bits/s/Hz)



Conclusion

- Interference alignment:
  - Align interference to subspace of smallest dimension
  - Desired signal in remaining dimensions
- **Tremendous throughput gains!** (**33%** higher for 2 x 2)
- Challenges for future work:
  - Real-time implementation, larger systems etc.
- Major impact for current and future technologies:
  - IEEE 802.22, LTE, WiMAX, femtocells etc.

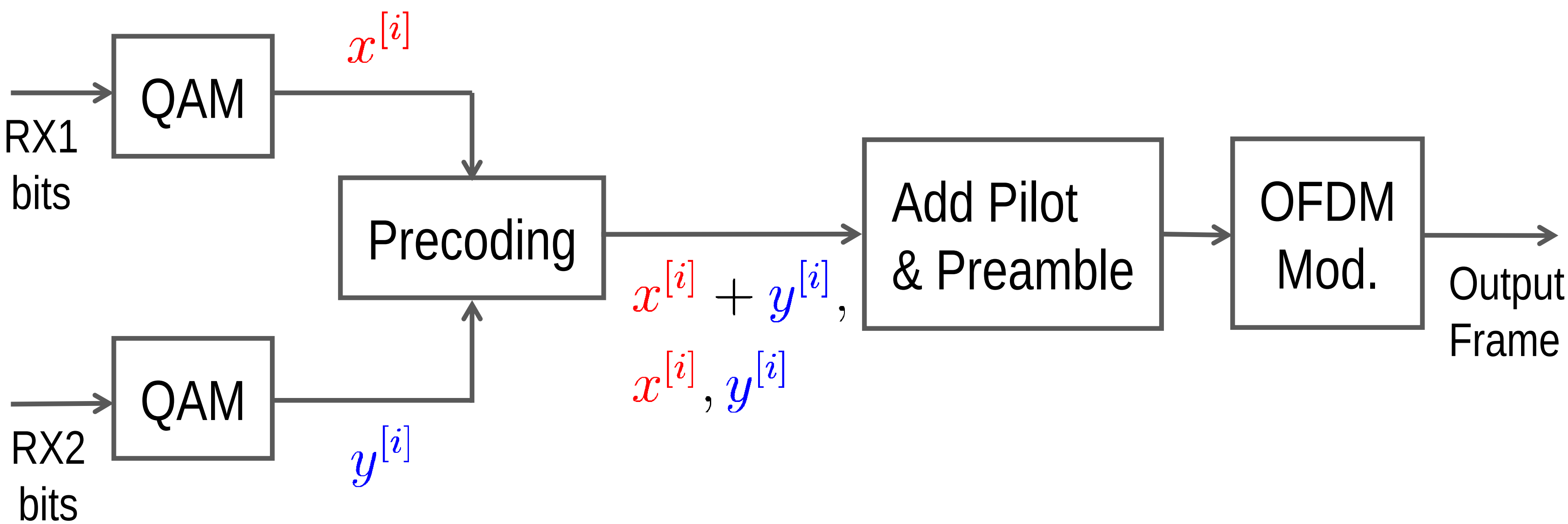
Questions?

Frame Structure

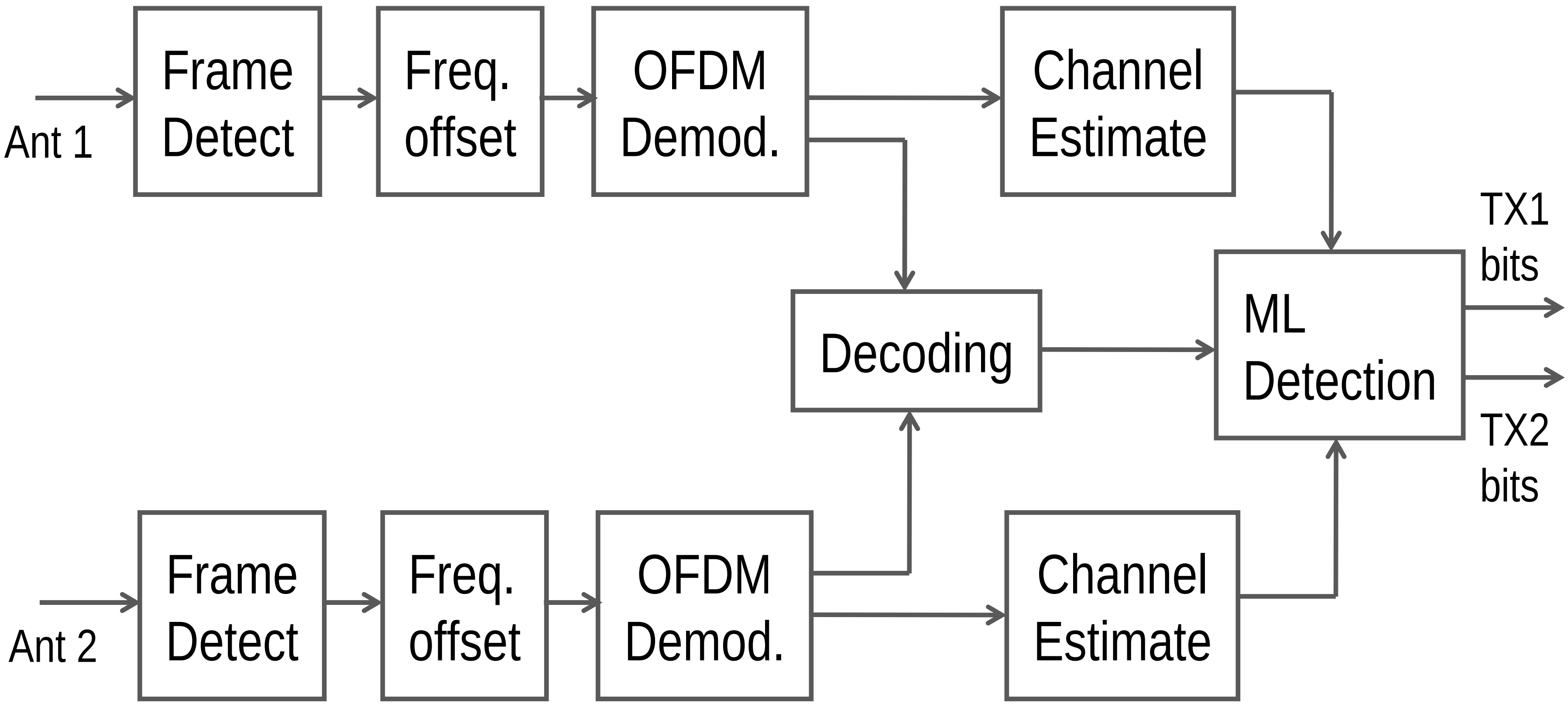
Frame length = 6 OFDM symbols = 0.5 ms

2 symbols	1 symbol	3 symbols		
Preamble	**Pilot**	**Payload**		
Frame detection, Freq. offset correction (Schmidl-Cox)	Channel estimation	$x^{[i]} + y^{[i]}$	$x^{[i]}$	$y^{[i]}$

Transmitter



Receiver



Ant 1
Frame Detect
Freq. offset
OFDM Demod.
Channel Estimate
Decoding
ML Detection
TX1 bits
TX2 bits
Ant 2
Frame Detect
Freq. offset
OFDM Demod.
Channel Estimate

SNR vs. BER for Time Division