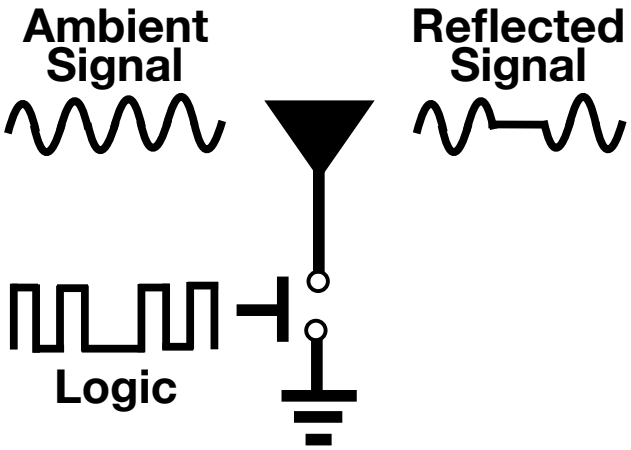
UMBC

VMscatter
A Versatile MIMO Backscatter

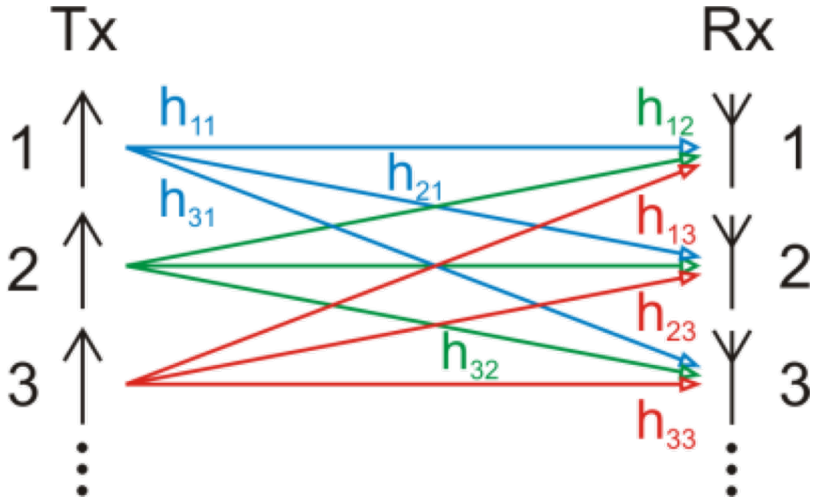
Xin Liu[*], Zicheng Chi[*], Wei Wang, Yao Yao, and Ting Zhu
University of Maryland, Baltimore County
[*] Co-primary Student Authors

Backscatter & MIMO

- Backscatter
  - Consume little energy
  - Enable lots of IOT applications

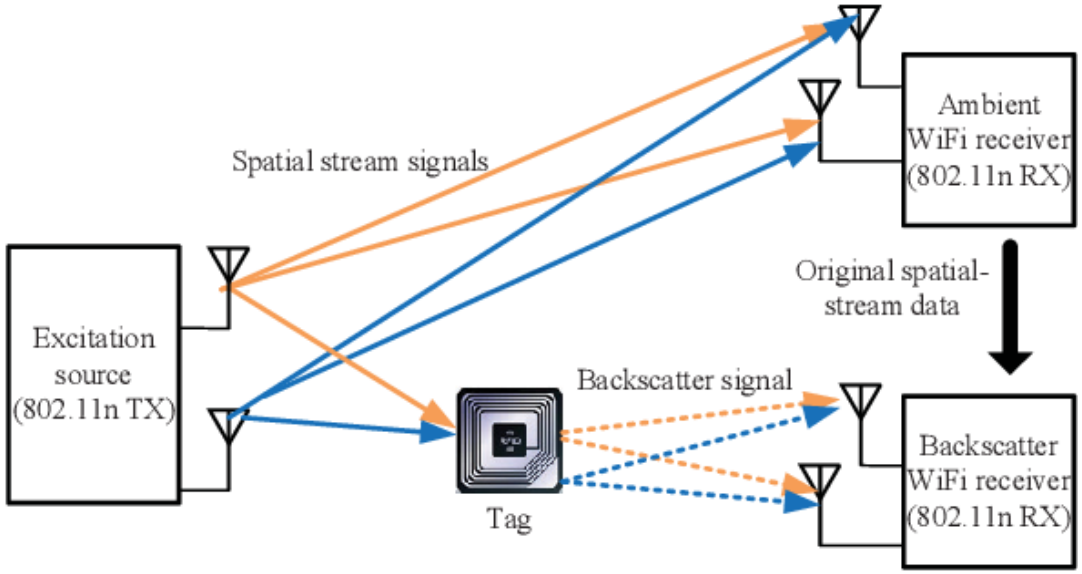


- MIMO
  - Widely used
  - More reliable and faster



Backscatter X MIMO

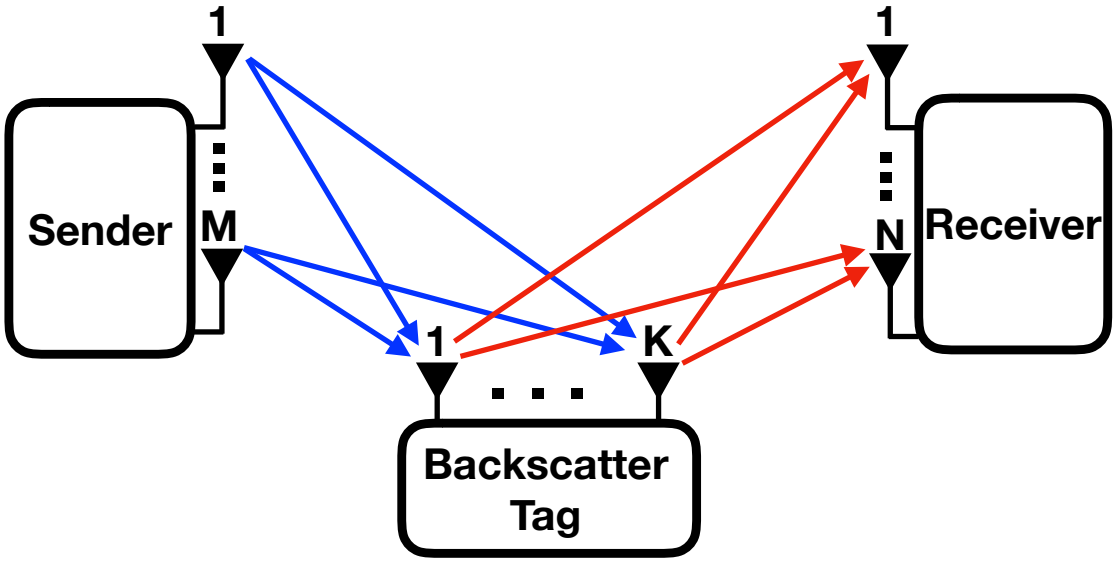
- Related work (MOXcatter [Mobisys'18])
  - Reflect MIMO signals
  - Conventional backscatter techniques



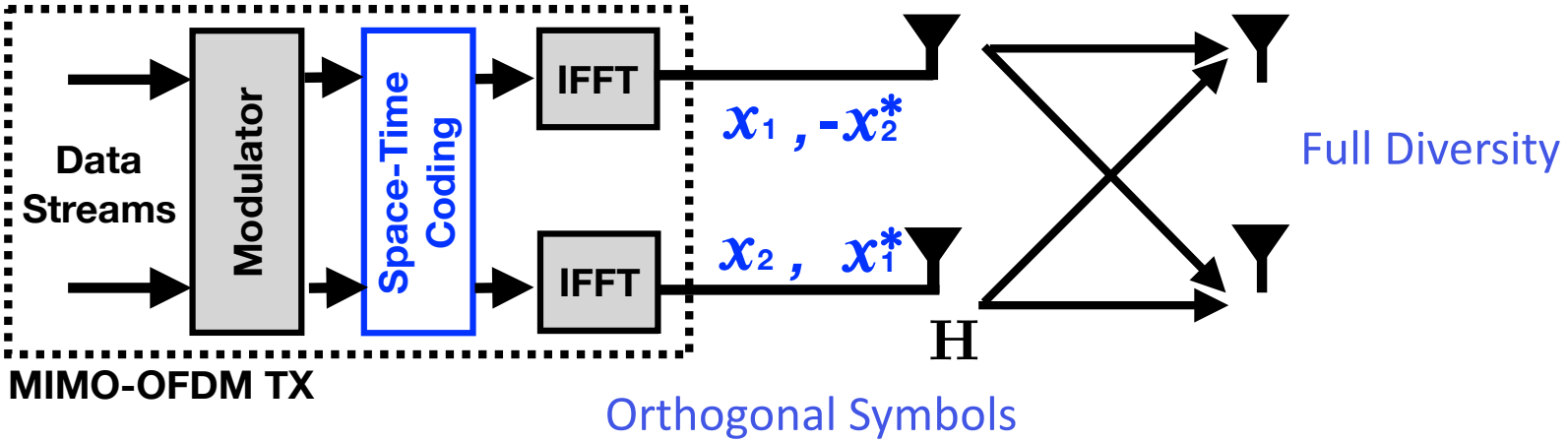
System	FreeRider	MOXcatter
	Non-MIMO	MIMO
BER	0.002	0.0095

VMscatter

- A versatile MIMO backscatter
  - Leverage MIMO technique on backscatter tags
  - Support space-time coding, spatial diversity, and generic design
  - Dramatically decrease BER (862x) and increase throughput



Why VMscatter



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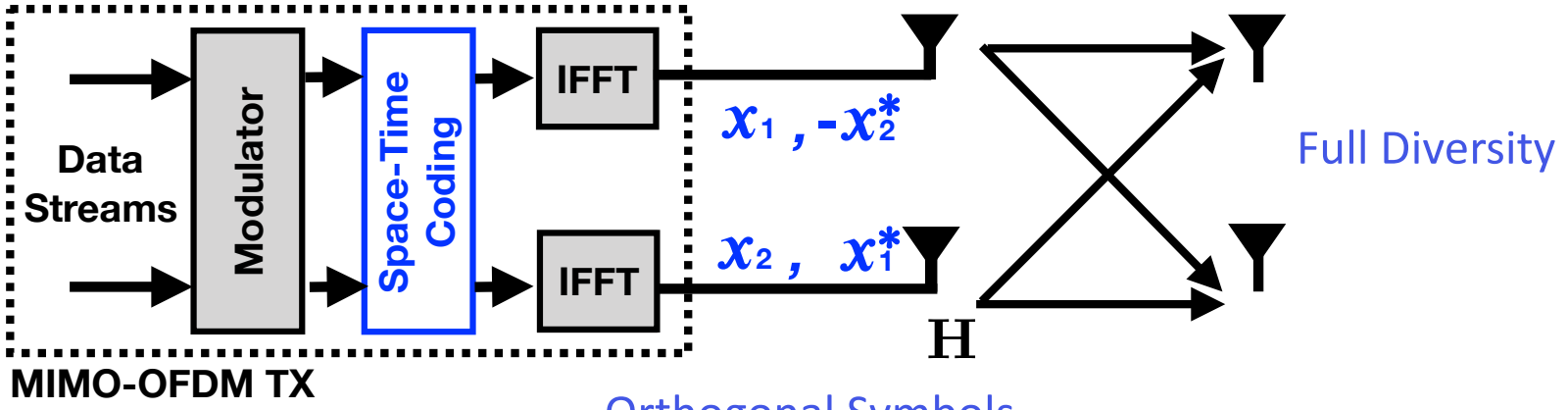
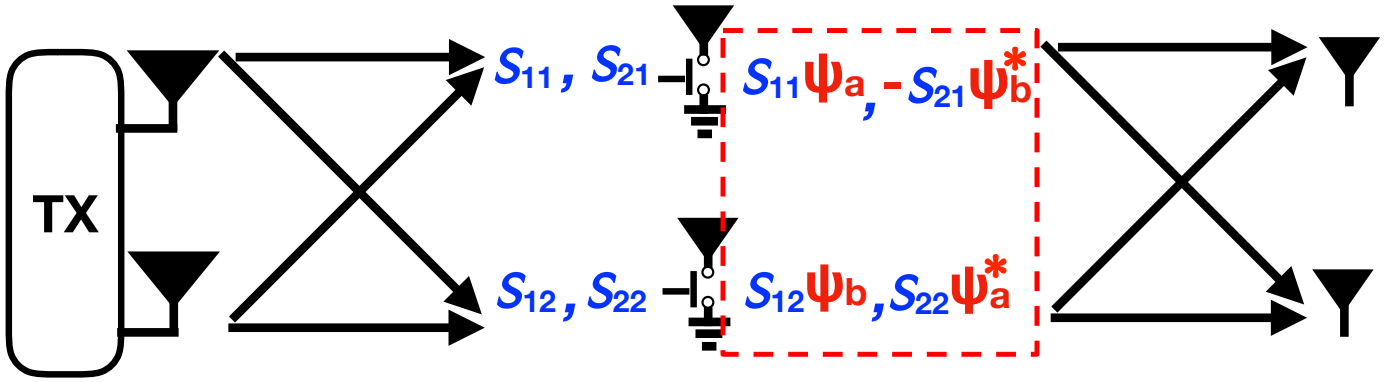
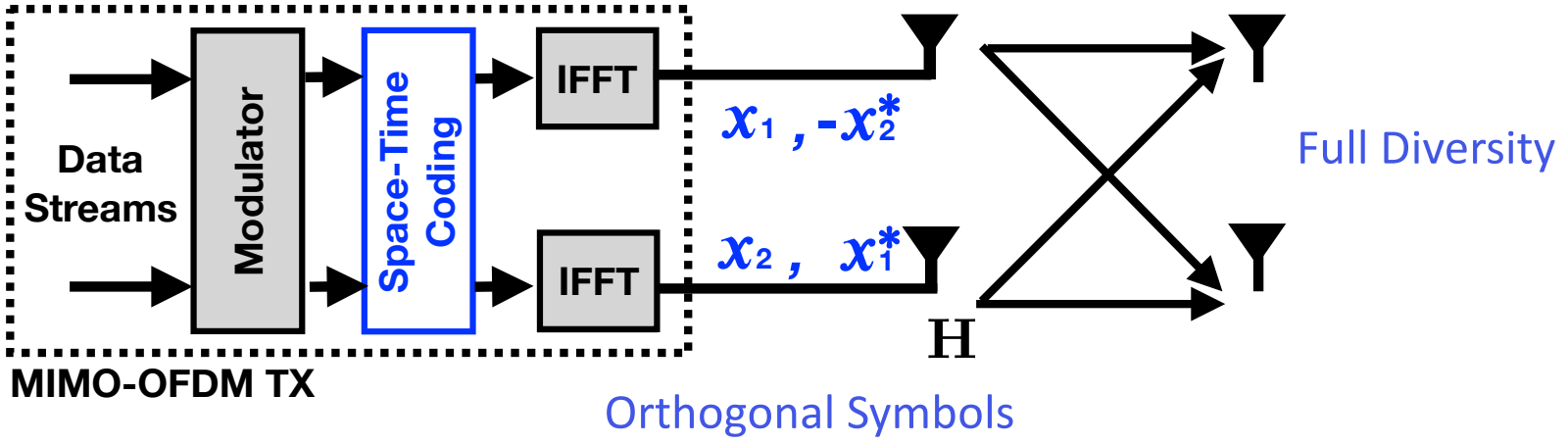
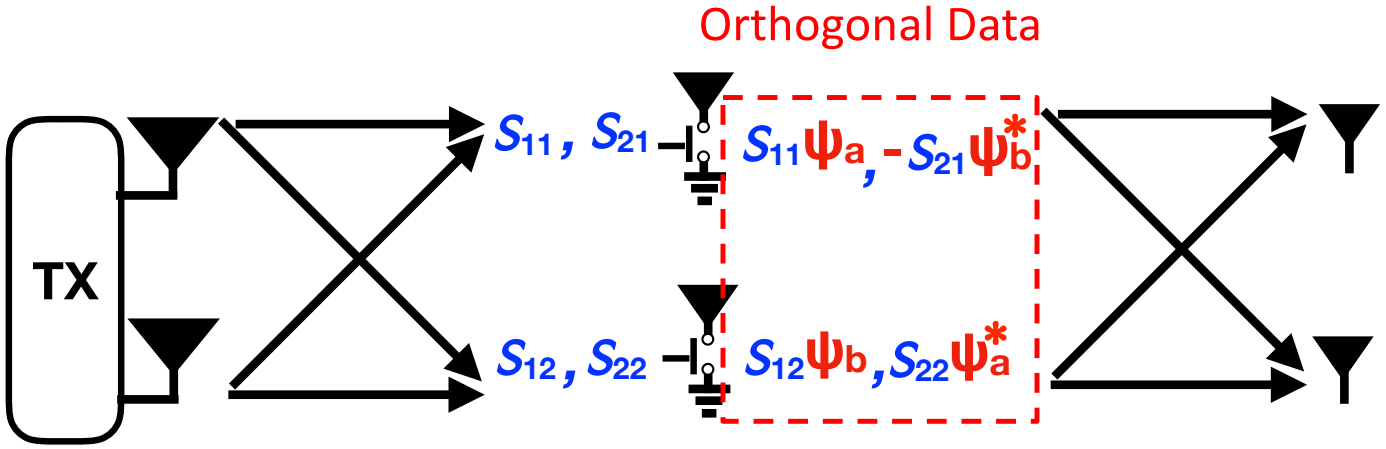


Non-orthogonal Symbols



Why VMscatter





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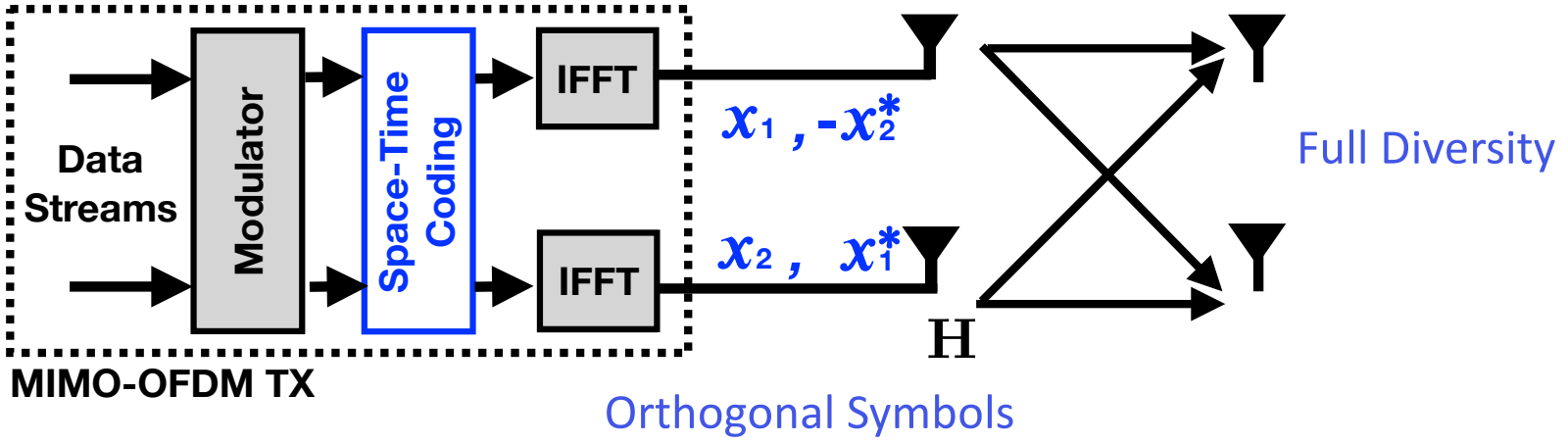
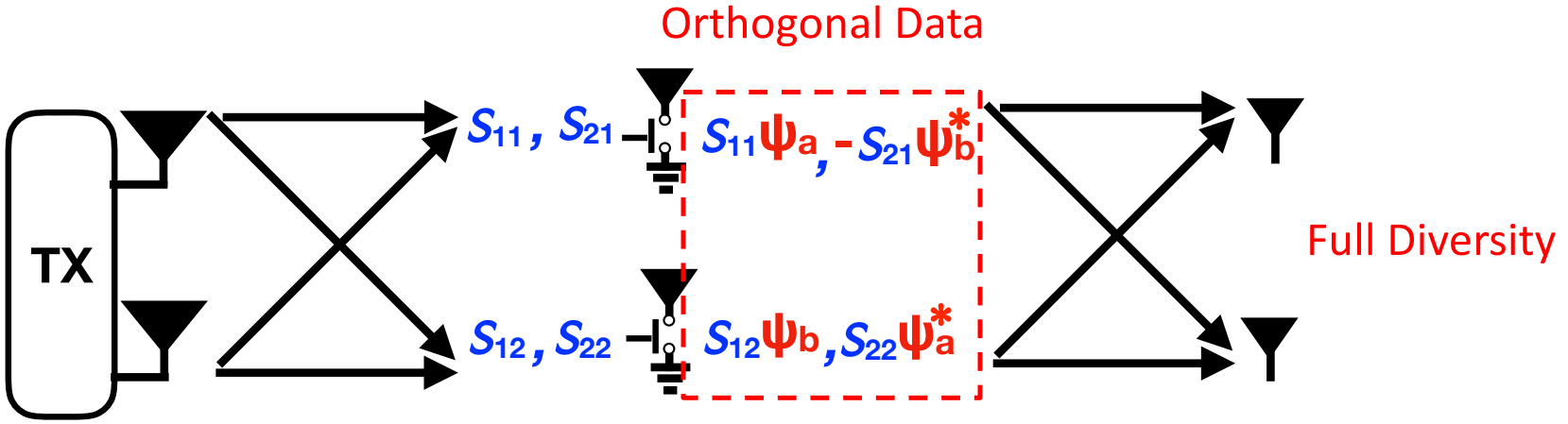
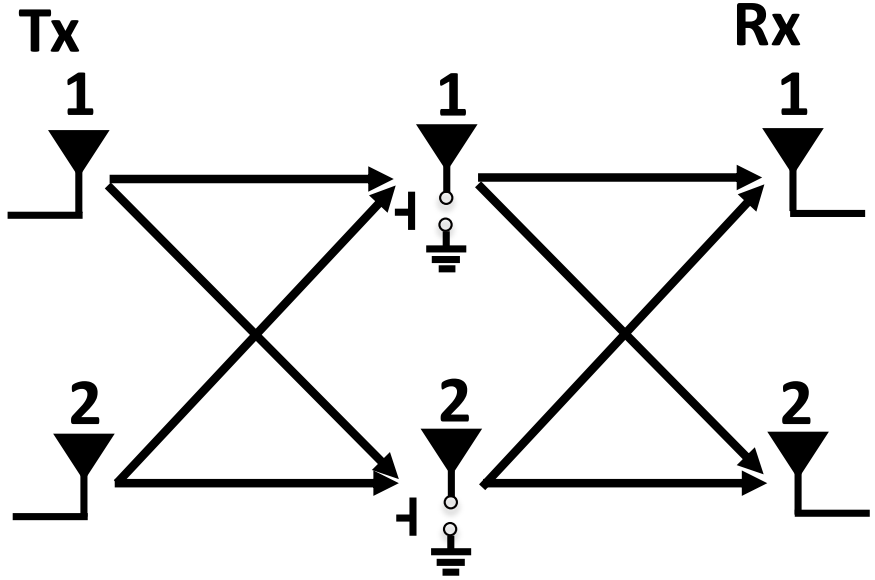




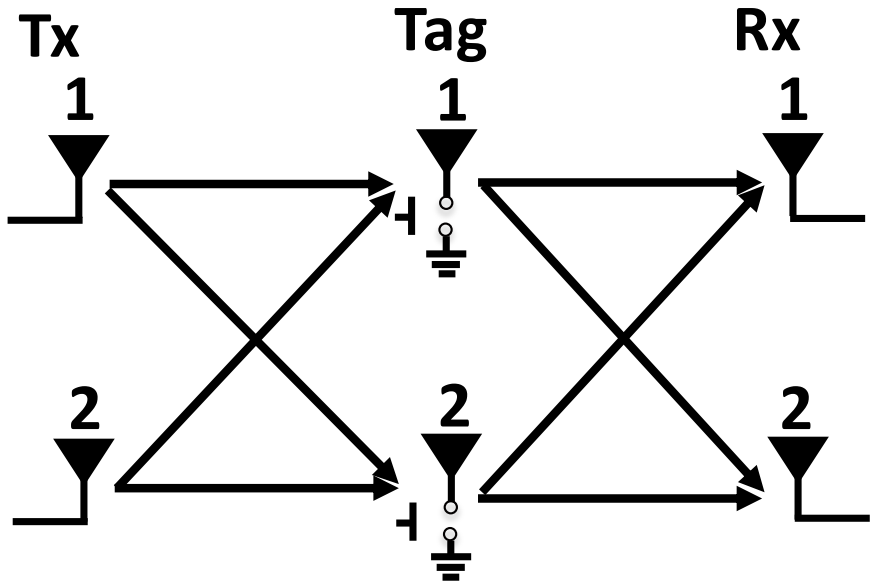
Challenges

- C1: Modulation
  - How to implement space-time coding by only turning on/off switches



Challenges

- C1: Modulation
  - How to implement space-time coding by only turning on/off switches
- C2: Demodulation
  - How to deal with pre-scatter channels and post-scatter channels



Challenges

- C1: Modulation
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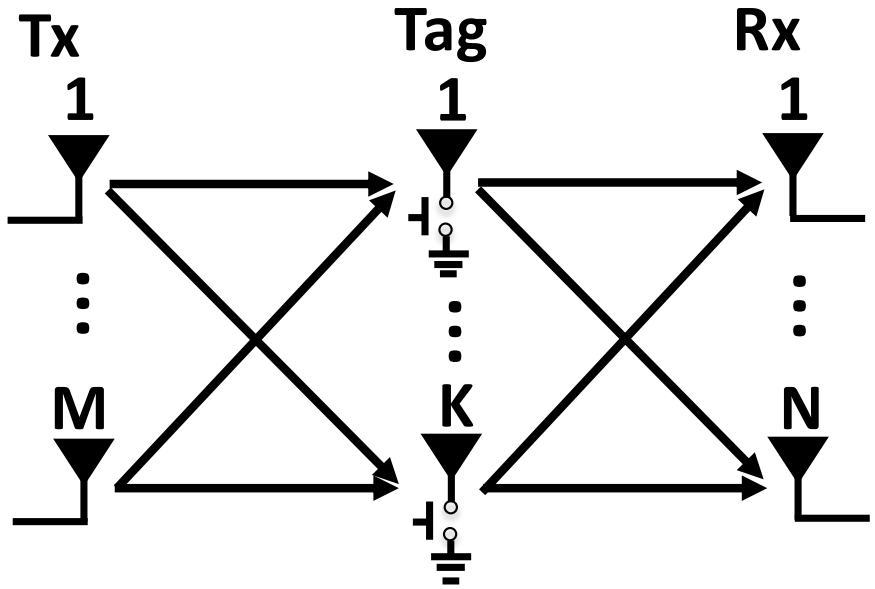
- C2: Demodulation
  - How to deal with pre-scatter channels and post-scatter channels



- C3: Extend to M×K × N
  - How to support any number of antennas on sender, tag, and receiver

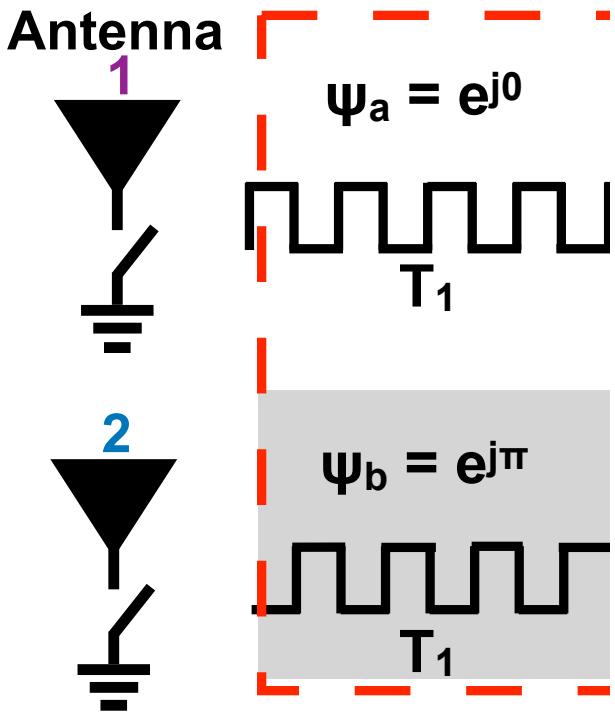
Outline

1. Modulation
2. Demodulation
3. Extend to M × K × N
4. Evaluation

Outline

1. Modulation
    1. Reducing BER
    2. Improving Throughput
2. Demodulation
3. Extend to M × K × N
4. Evaluation

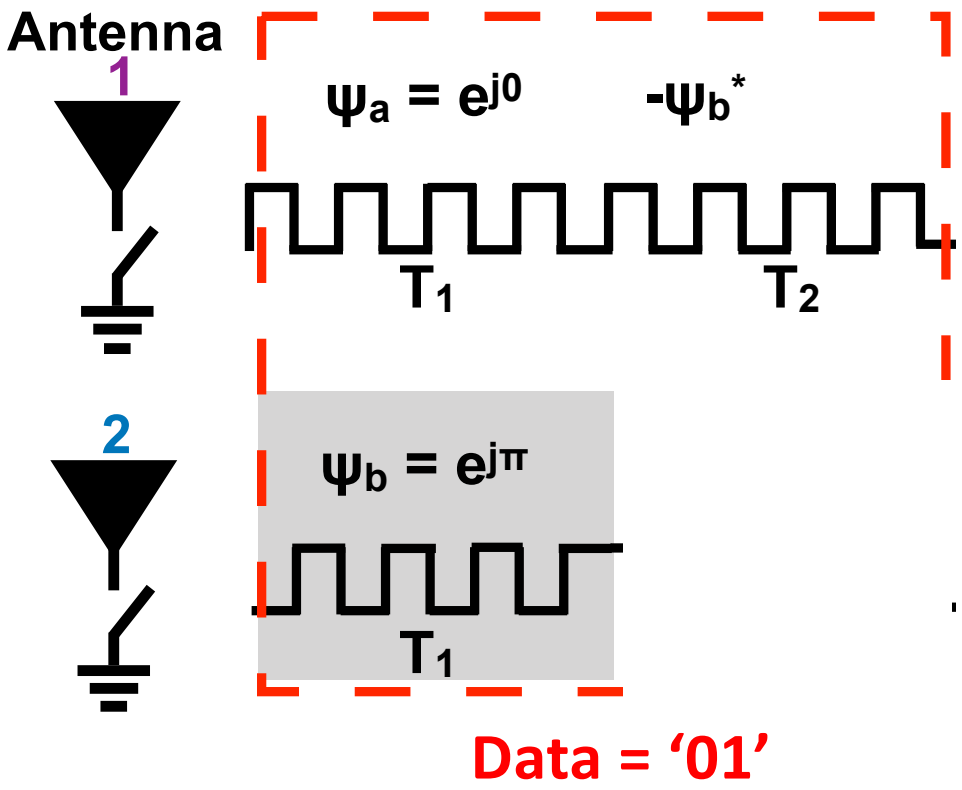
Reducing BER



Data = '01'

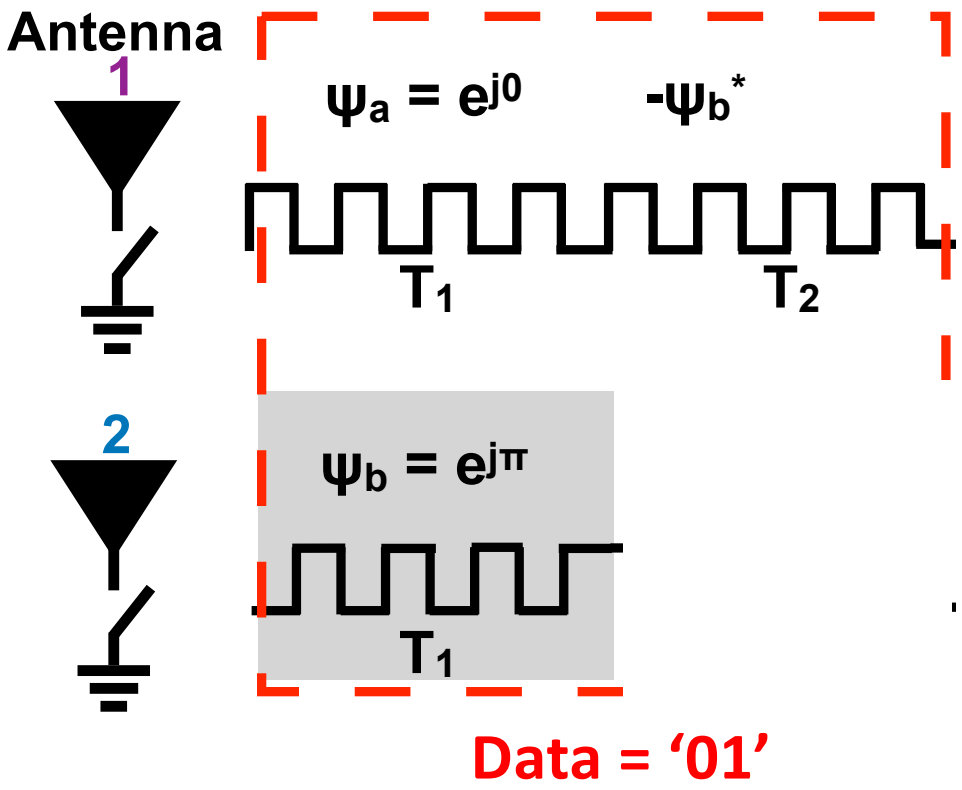
At T1, we transmit e^{ja} from antenna 1 and e^{jb} from antenna 2

Reducing BER



At T2, we transmit $-e^{-jb}$ from antenna 1 and e^{-ja} from antenna 2

Reducing BER



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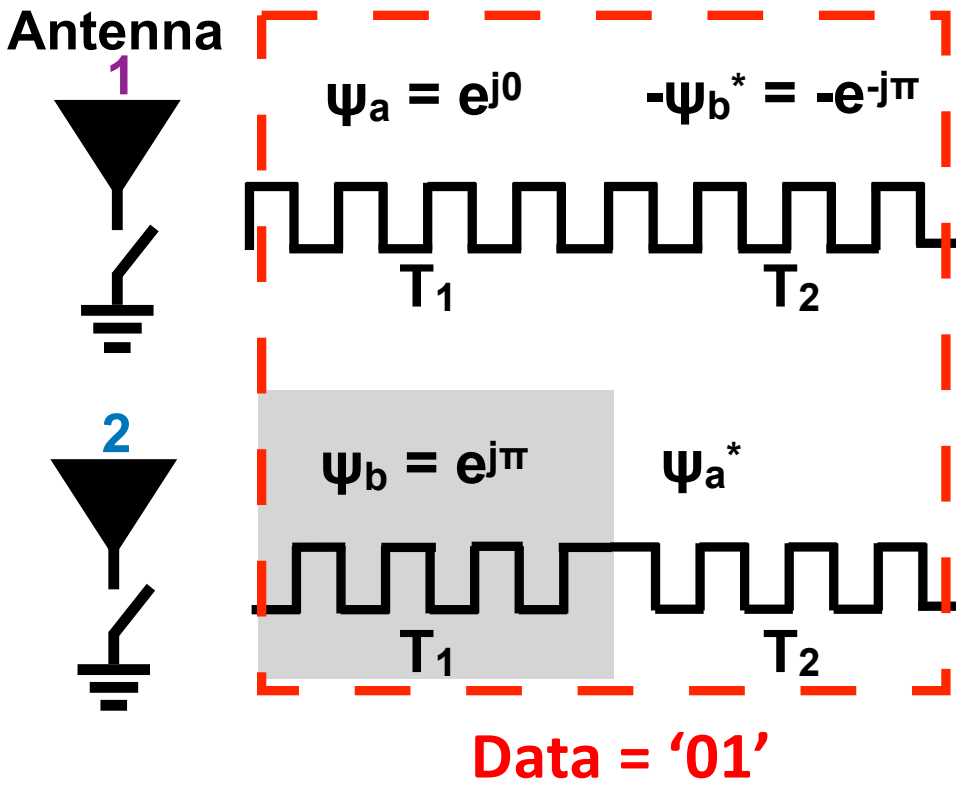
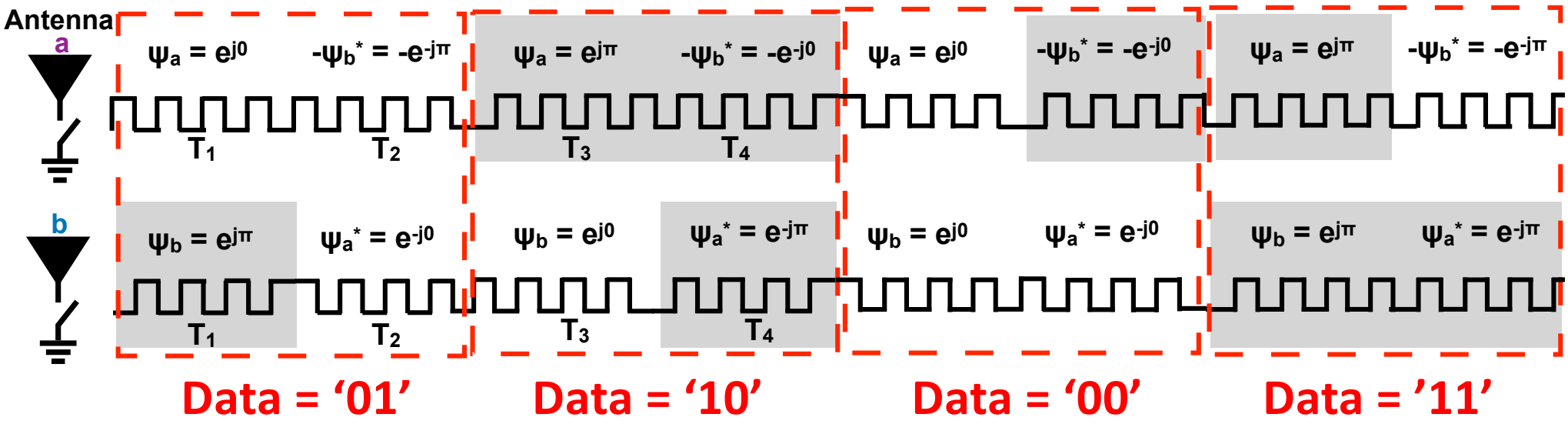
Reducing BER



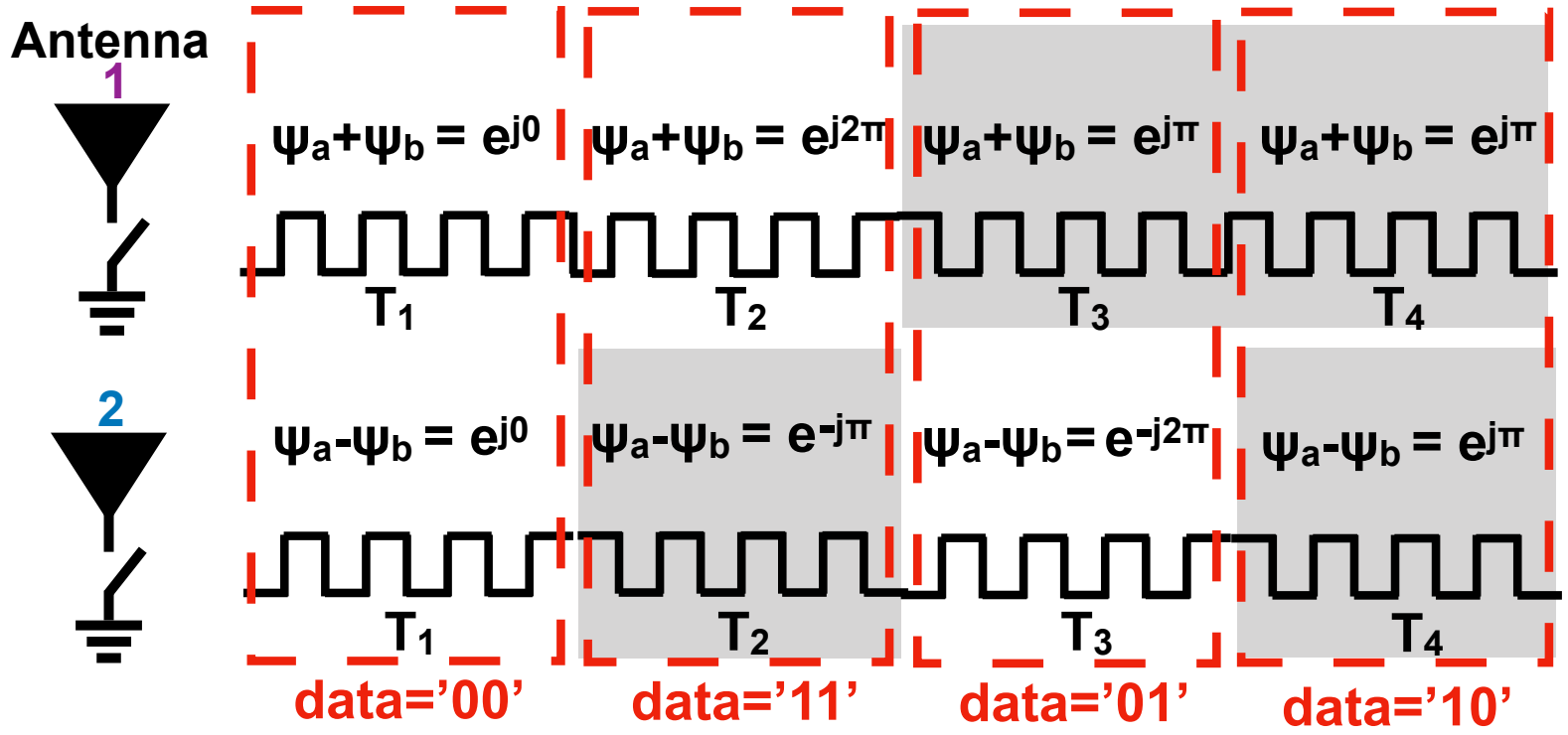
Implement the space-time coding by only using the two states of switch (on and off)

At T2, we transmit $-e^{-jb}$ from antenna 1 and e^{-ja} from antenna 2

Reducing BER



Improving Throughput

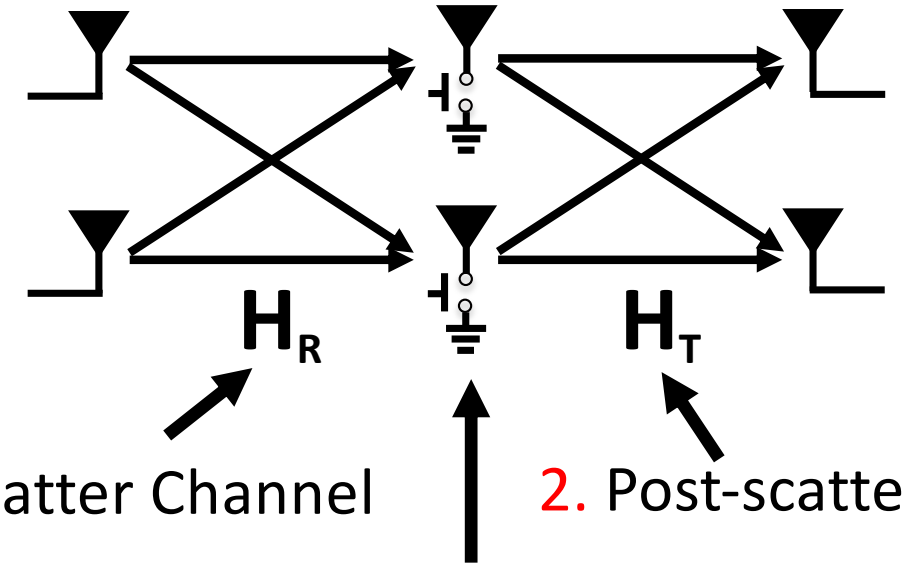


With two antennas, the throughput is doubled

Outline

1. Modulation
2. Demodulation
3. Extend to M × K × N
4. Evaluation

Demodulation



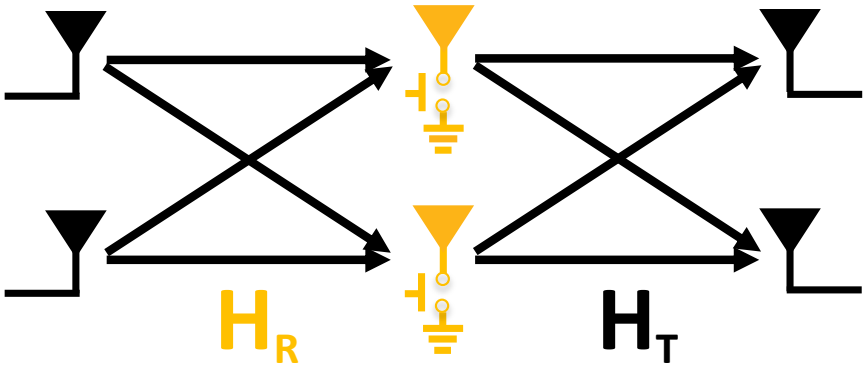
1. Pre-scatter Channel

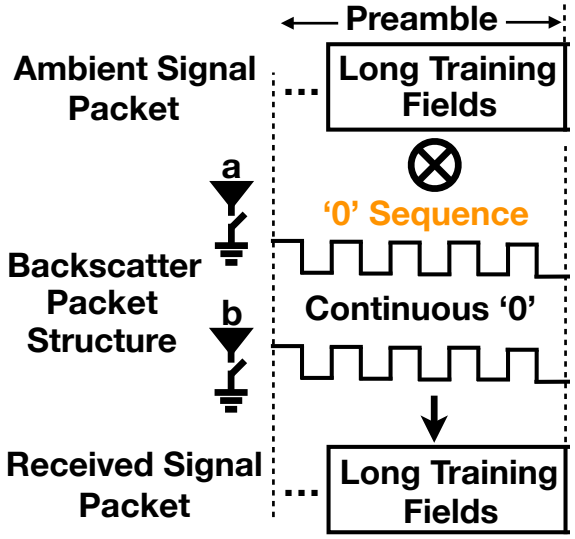
2. Post-scatter Channel

3. Backscatter

The MIMO backscatter contains three stages

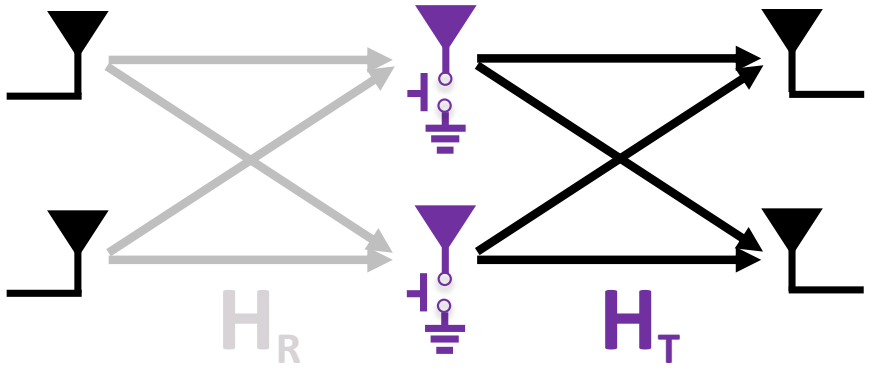
Eliminate Pre-scatter Channel

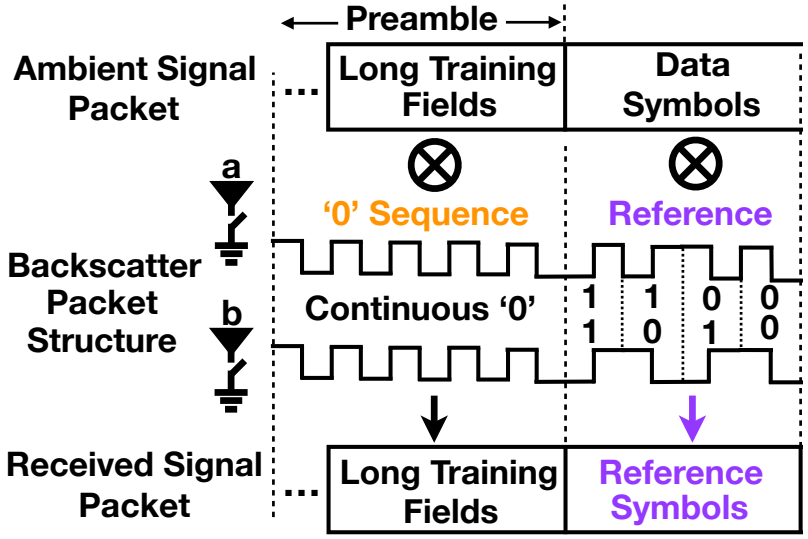




H_R can be eliminate by the existing channel estimator

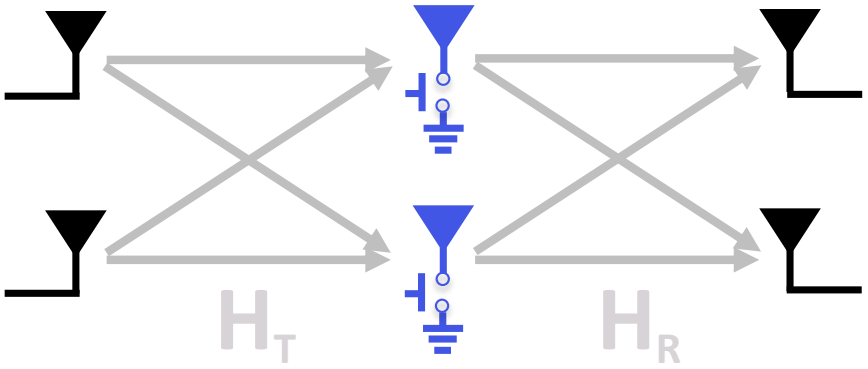
Eliminate Post-scatter Channel

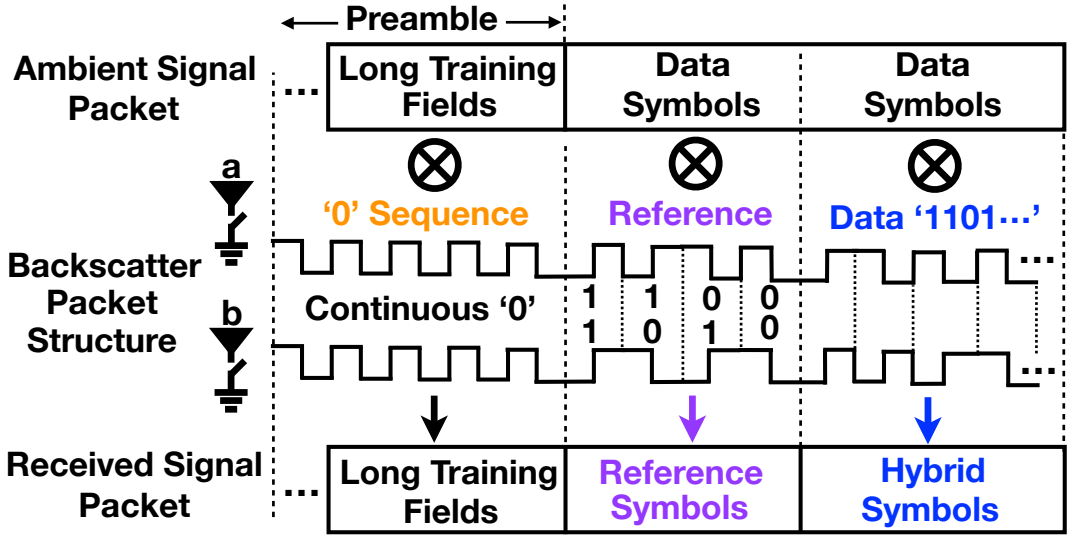




H_T can be eliminate by using reference symbols

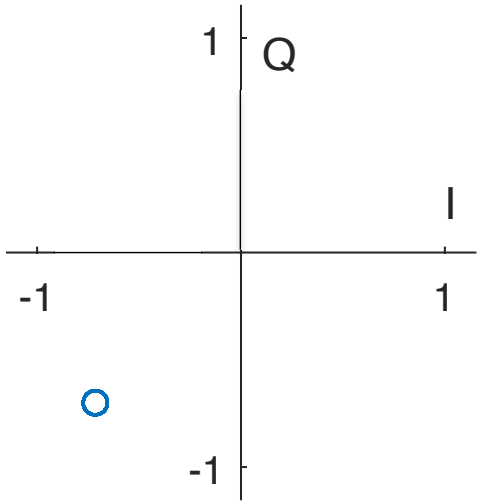
Decode Backscatter Data





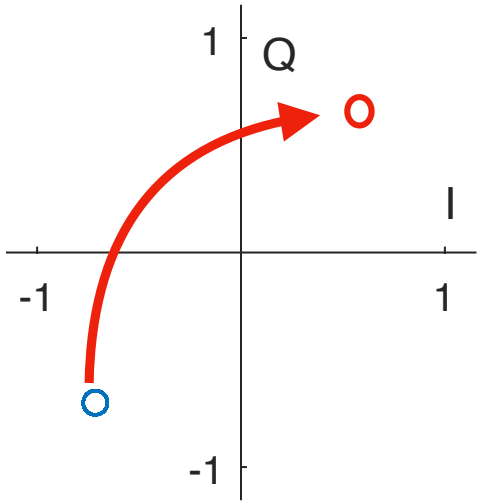
Decode by using maximum likelihood estimation

Example of Demodulation Stages



(a) Expected signal shifted by π

Example of Demodulation Stages



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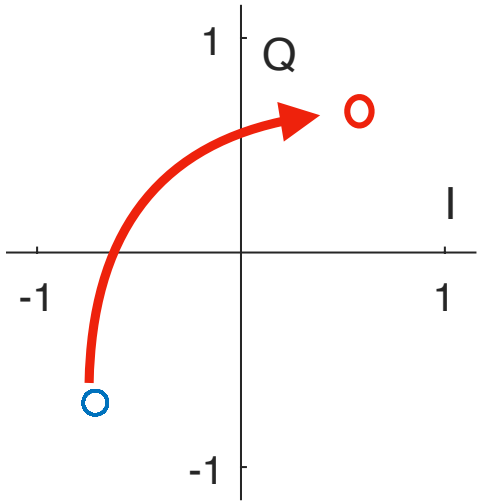
Example of Demodulation Stages



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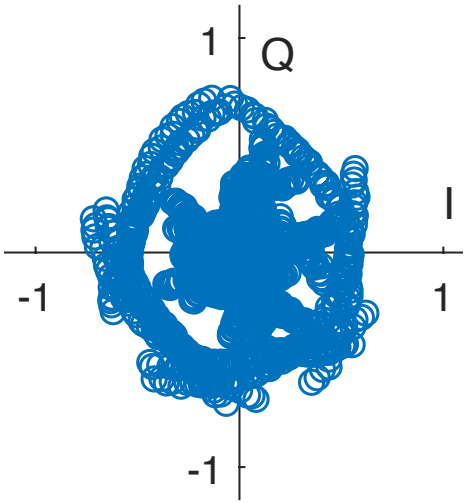
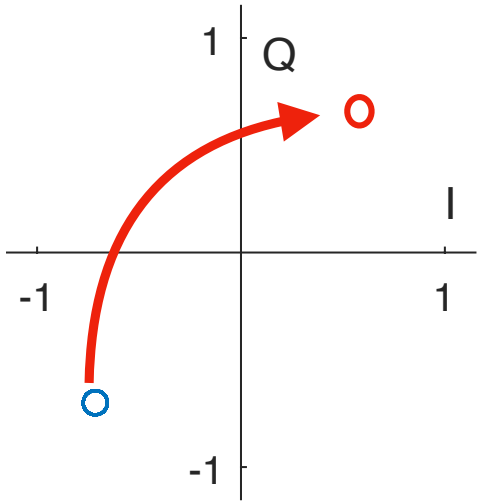


(b) Received Signal

Example of Demodulation Stages



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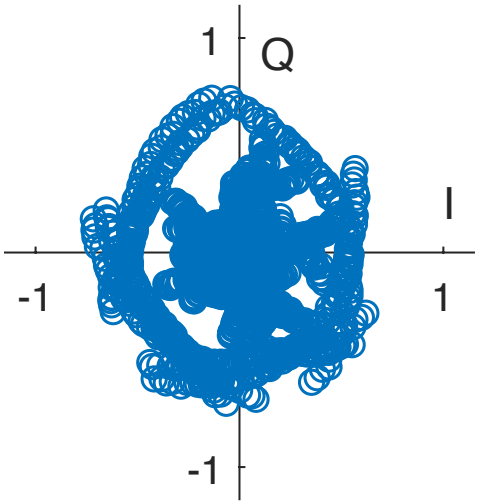
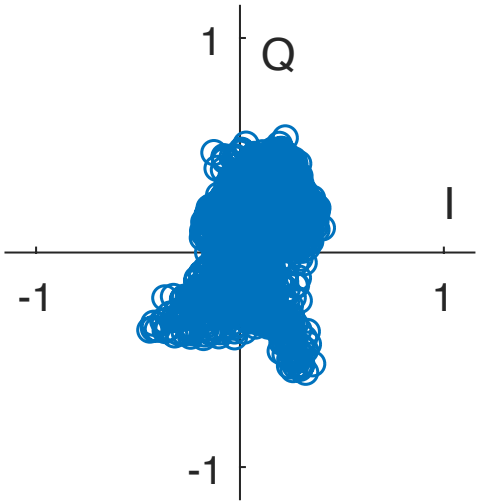
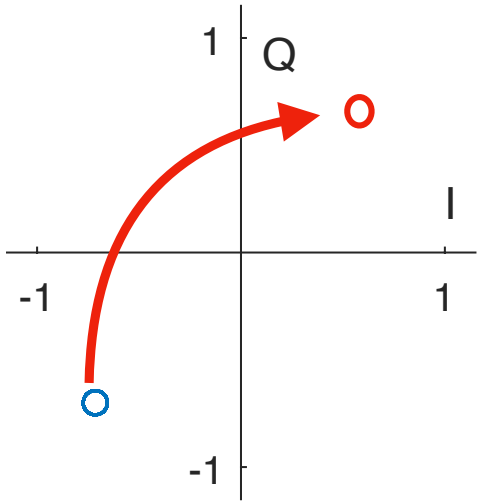


(b) Received Signal



(c) Equalized Signal (H_R Eliminated)

Example of Demodulation Stages



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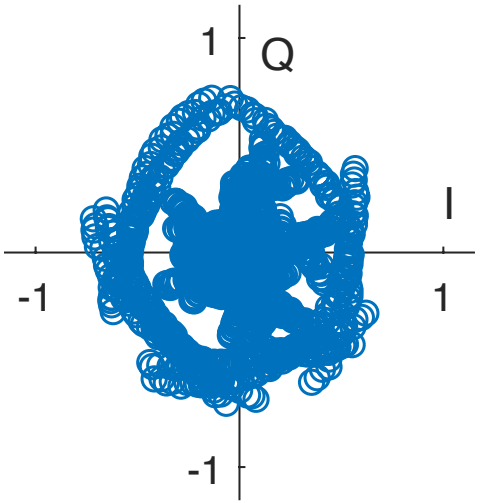
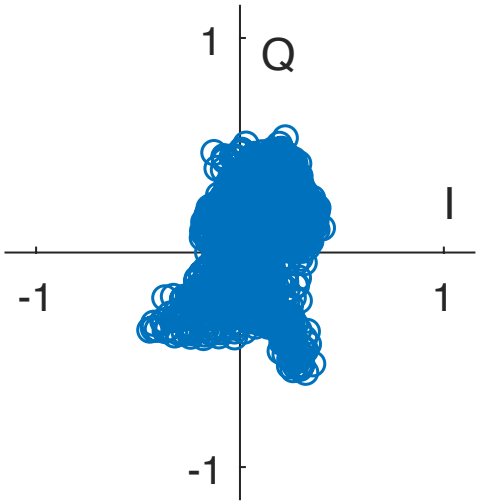
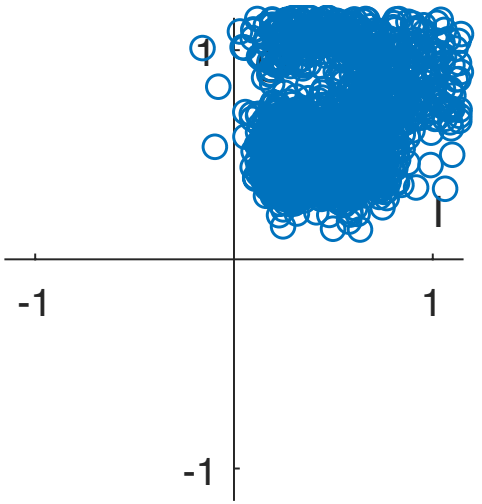


(b) Received Signal



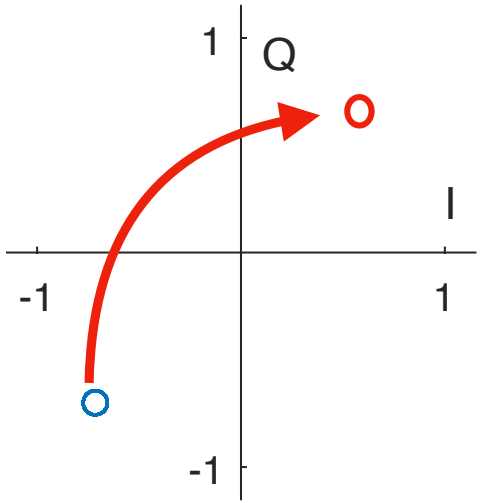
(c) Equalized Signal (H_R Eliminated)



(d) Final Signal (H'_T Eliminated)

Example of Demodulation Stages

π is correctly demodulated



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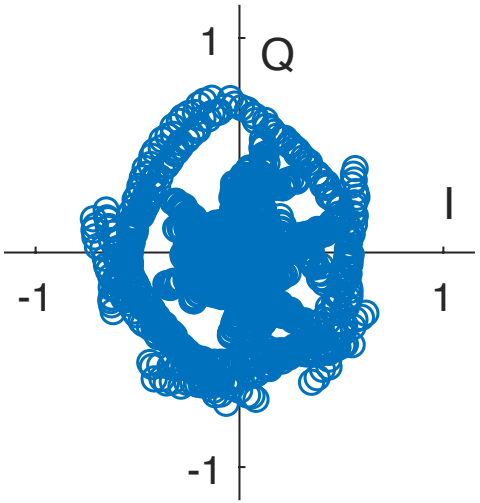
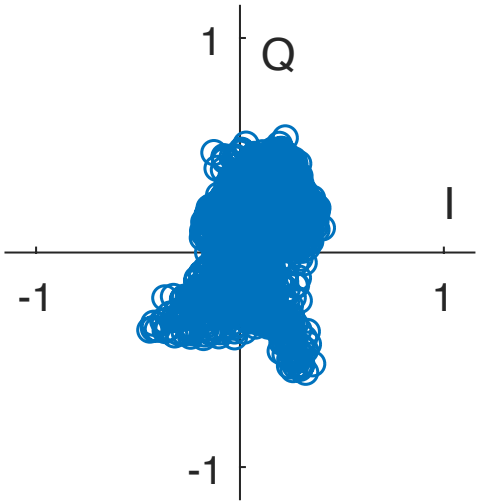
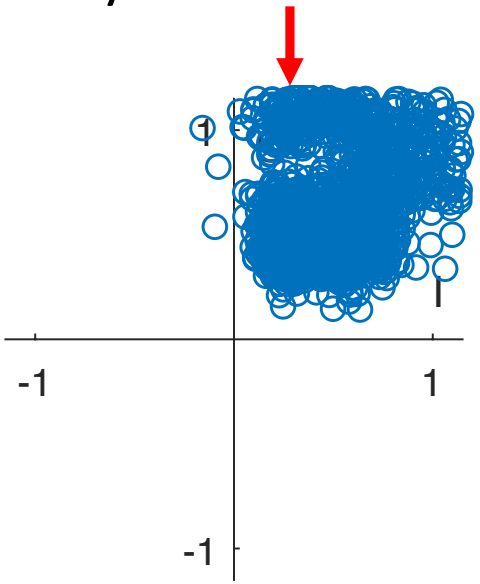


(b) Received Signal



(c) Equalized Signal (H_R Eliminated)



(d) Final Signal (H'_T Eliminated)

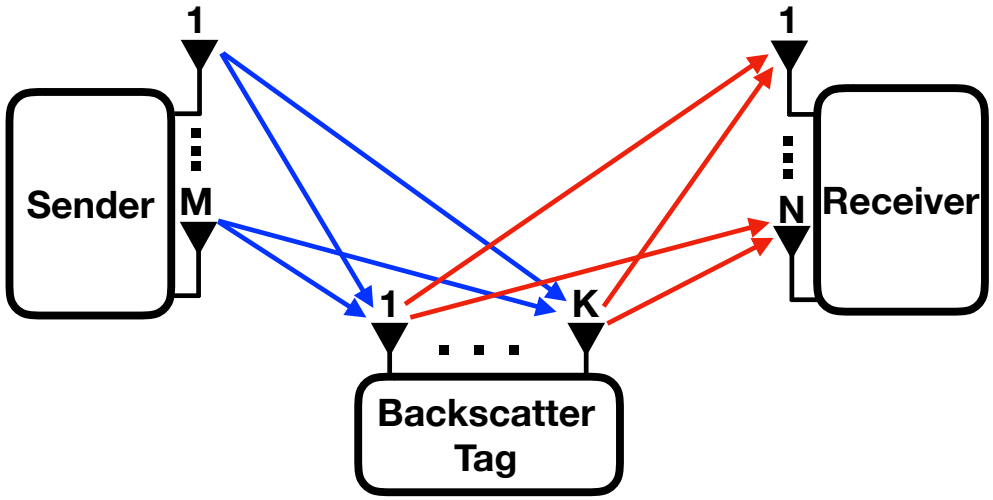
Outline

1. Modulation
2. Demodulation
3. Extend to M × K × N
4. Evaluation

Extend to M × K × N

K=2

$$\Gamma(\theta_a, \theta_b) = \begin{bmatrix} e^{j\theta_a} & e^{j\theta_b} \\ -e^{-j\theta_b} & e^{-j\theta_a} \end{bmatrix}$$



Extend to M × K × N

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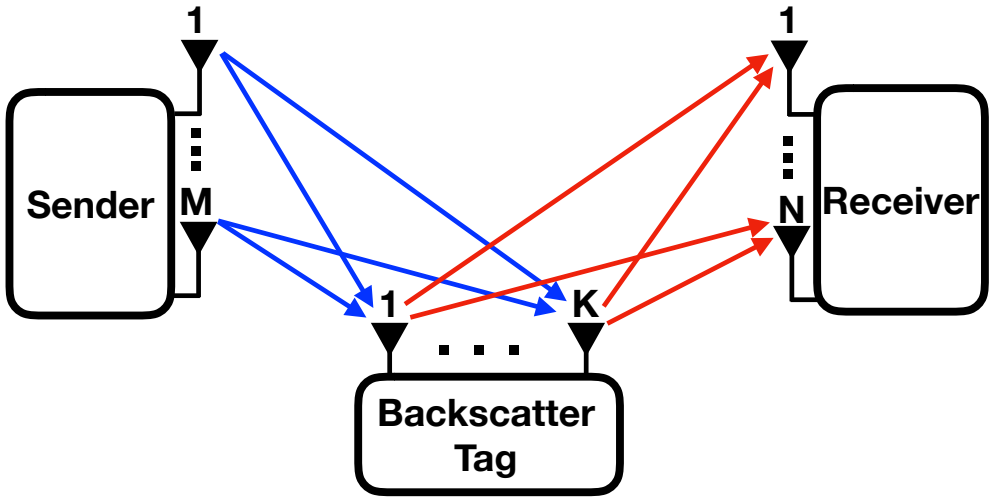
↓

K=2^2

$$\Gamma(\theta_a, \theta_b, \theta_c, \theta_d) = \begin{bmatrix} \Gamma(\theta_a, \theta_b) & \Gamma(\theta_c, \theta_d) \\ -\Gamma^*(\theta_c, \theta_d) & \Gamma^*(\theta_a, \theta_b) \end{bmatrix}$$



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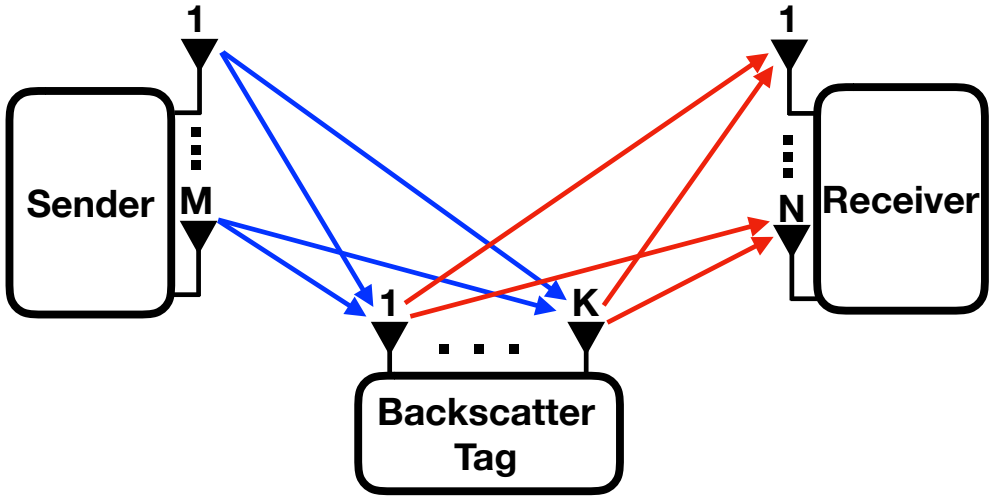
K=2^2

$$\Gamma(\theta_a, \theta_b, \theta_c, \theta_d) = \begin{bmatrix} \Gamma(\theta_a, \theta_b) & \Gamma(\theta_c, \theta_d) \\ -\Gamma^*(\theta_c, \theta_d) & \Gamma^*(\theta_a, \theta_b) \end{bmatrix}$$

K=2^n

$$\Gamma(\theta_1, \ldots, \theta_K) = \begin{bmatrix} \Gamma(\theta_1, \ldots, \theta_{\frac{K}{2}}) & \Gamma(\theta_{1+\frac{K}{2}}, \ldots, \theta_K) \\ -\Gamma^*(\theta_{1+\frac{K}{2}}, \ldots, \theta_K) & \Gamma^*(\theta_1, \ldots, \theta_{\frac{K}{2}}) \end{bmatrix}$$

Our design is generic



Outline

1. Modulation
2. Demodulation
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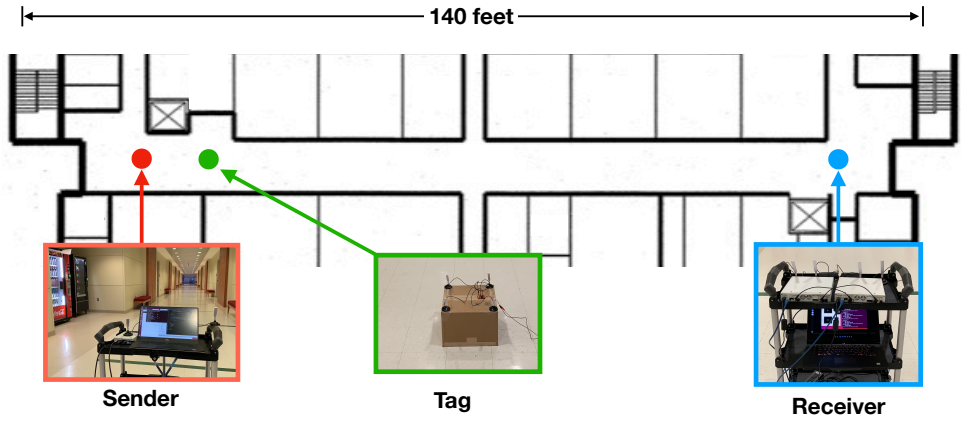
4. Evaluation

Experiment Setup

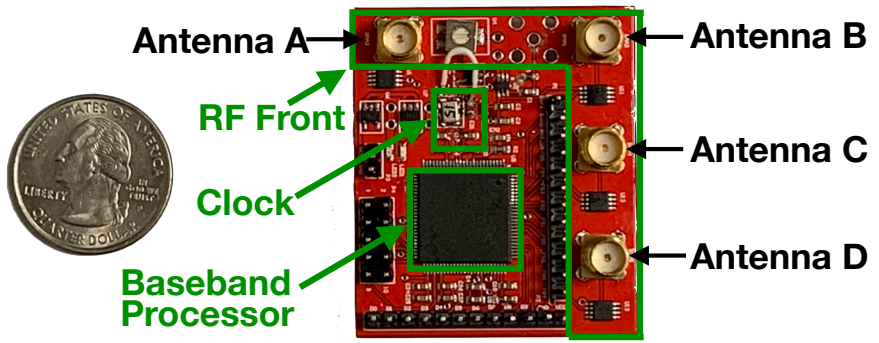
Sender: A B210 USRP + 2 Antennas
Receiver: Two X310 USRPs + 4 Antennas
Tag: Low power FPGA + 4 Antennas

Support 2×4 × 4 MIMO

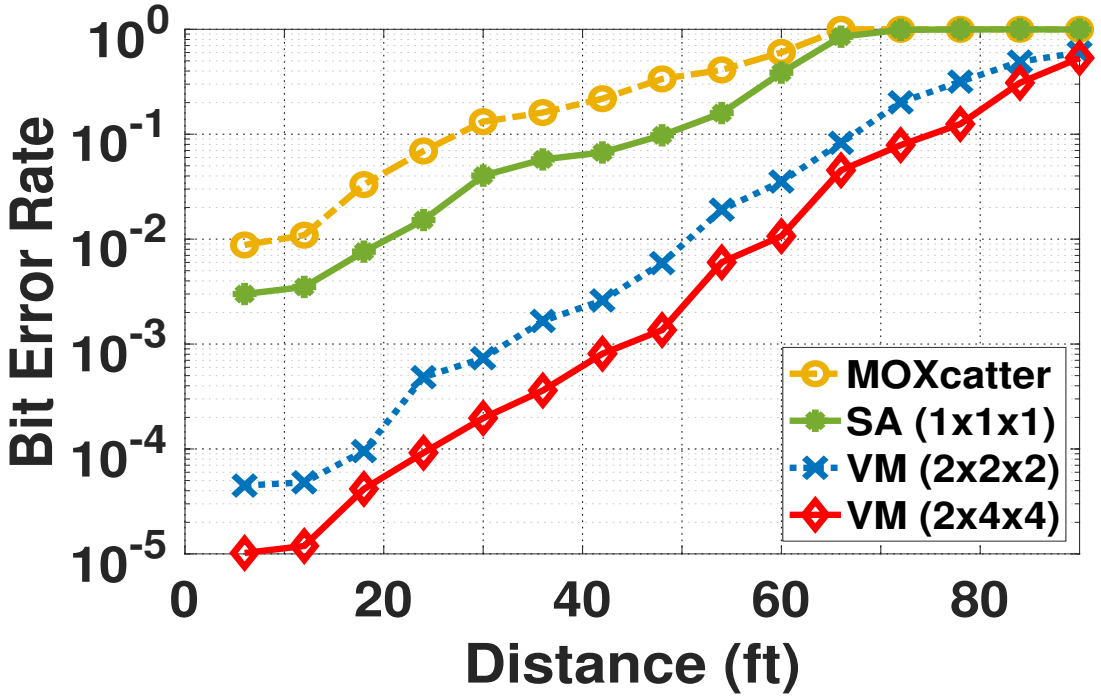


Real-world scenarios:

1. SIMO and MIMO
2. BER, PRR, and throughput
3. Sender-to-tag distance, tag-to-receiver distance, and sender-to-receiver distance
4. SNR, packet length, oscillator accuracy



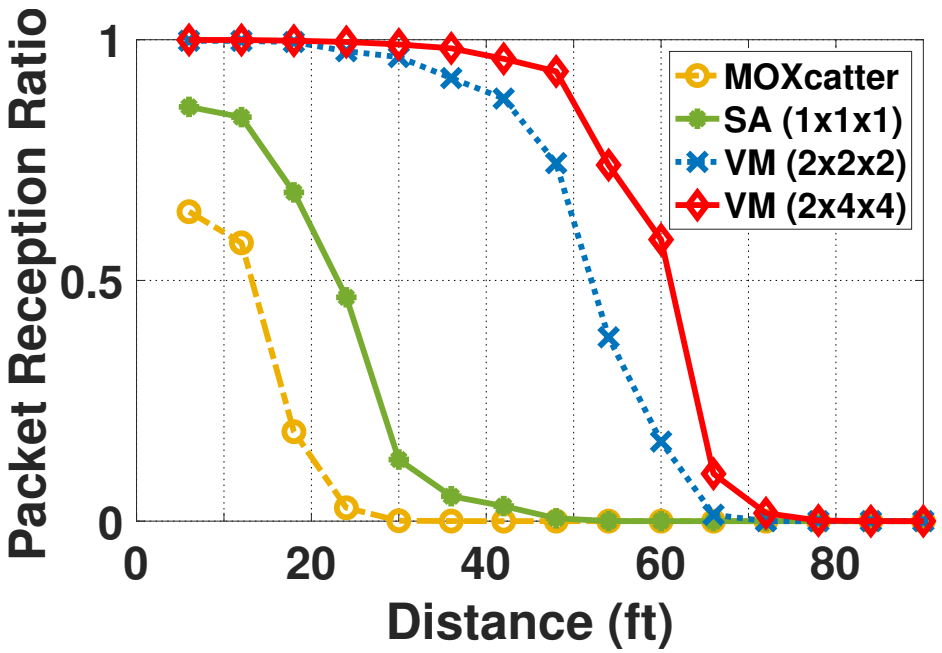
BER

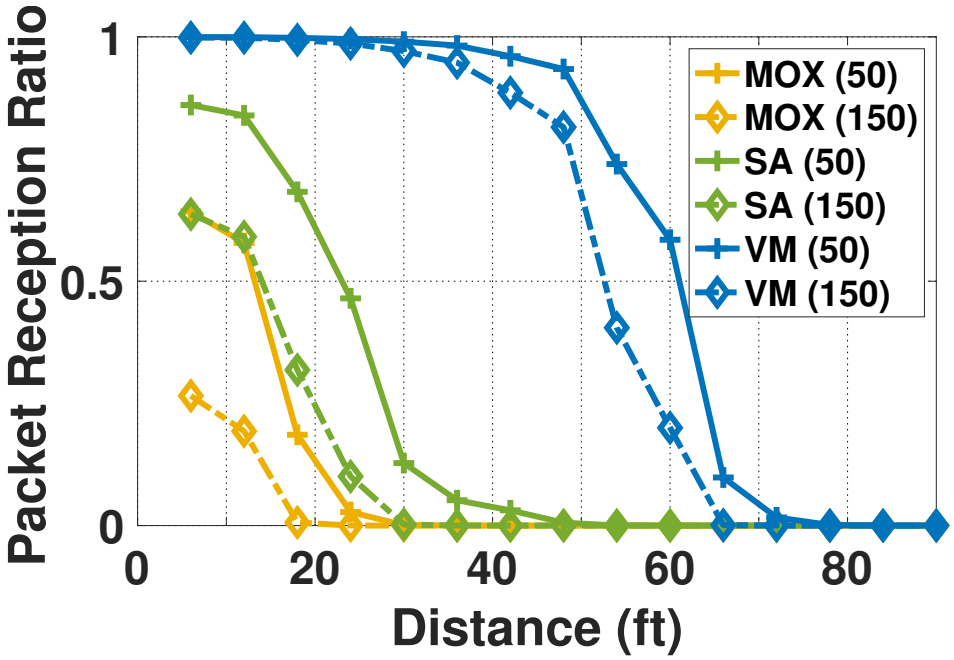


System	MOXcatter	VMscatter
	MIMO	MIMO
BER	0.0095	0.000011

BER is reduced by a factor of 862

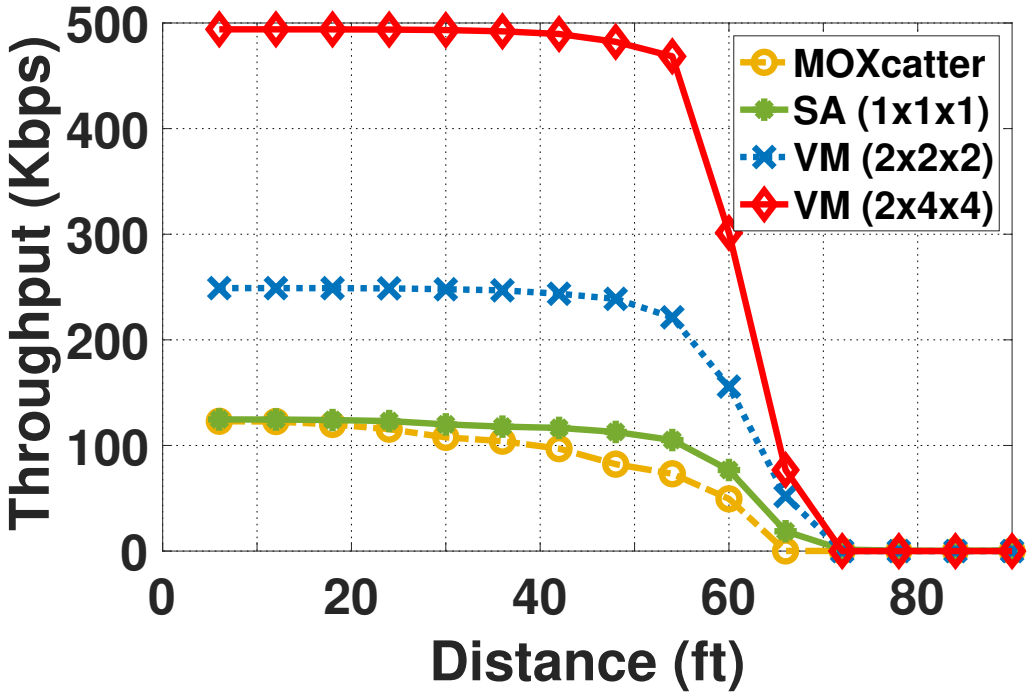
Packet Reception Ratio





VMscatter is more reliable

Throughput



The throughput of VMscatter with four antennas is around 4 times as high as that of related work

Conclusion

- The first versatile MIMO backscatter system
- Address special design challenges
- A generic design
- Build a hardware platform
- Extensively evaluated under multiple real-world scenarios