Massive MIMO Transmitter Design

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Motivation

- Massive MIMO provides significant advantages
  1. High spectral efficiency
  2. Relaxed Scheduling
  3. Spatial Multiplexing - Diversity - Beamforming
- Until now only small MIMO (8x8) supported in LTE

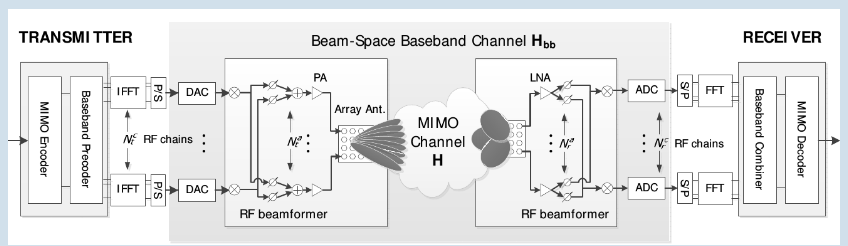
Why no massive MIMO implementation?

1. Cost
   - Each antenna requires own RF chain
2. Size
   - $\lambda/2$ distance between antennas
3. Power Consumption
   - Increases with number of RF chains

Possible Solutions

1. Hybrid Beamforming
   - Using a combination of digital and analog beamforming
2. Spatial Modulation
   - Using the antenna index for modulation
3. Parasitic Antennas
   - Only one active antenna element
4. UE RF Chain
   - Using the cost optimized RF chains of mobile phones

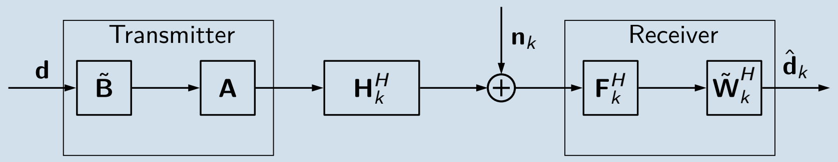
Hybrid Beamforming [1]



Basic Idea

- Use a combination of digital and analog beamforming to reduce the number of RF chains

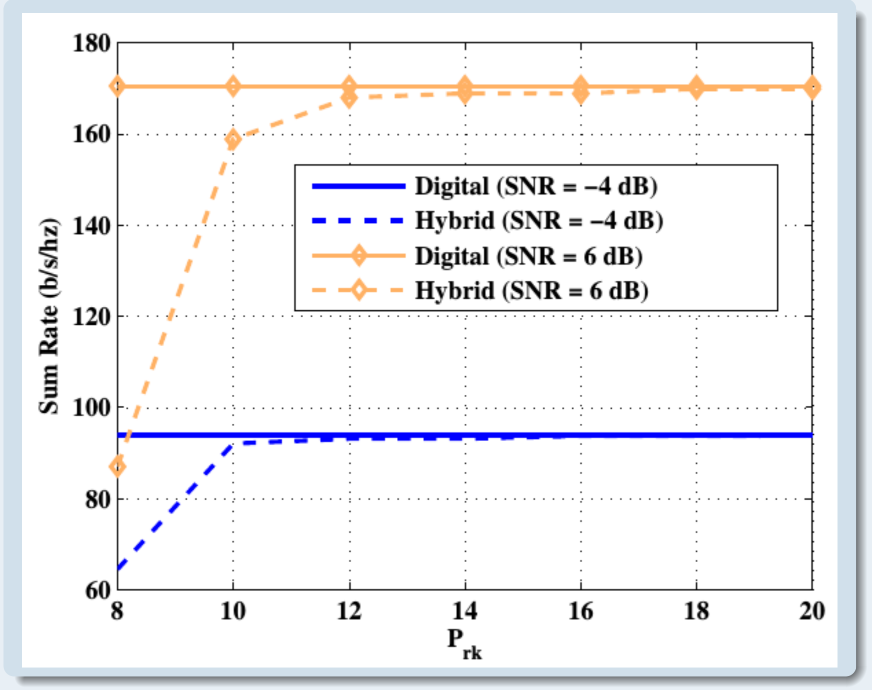
Mathematical Description



- $\tilde{\mathbf{B}} \in \mathbb{C}^{P_t \times S} = [\tilde{\mathbf{B}}_1, \ldots, \tilde{\mathbf{B}}_K]$: Digital precoding matrix for every user
- $\mathbf{A} \in \mathbb{C}^{M \times P_t}$: One analog precoding matrix (entries have constant envelope)

$$\hat{\mathbf{d}}_k = \tilde{\mathbf{W}}_k^H \mathbf{F}_k^H (\mathbf{H}_k^H \sum_{i=1}^{K} \mathbf{A}\tilde{\mathbf{B}}_i \mathbf{d}_i + \mathbf{n}_k)$$

Hybrid Beamforming Performance [2]



# Transmit Antennas (M)	128
#Transmit RF Chains (P_t)	$K\ P_{rk}$
# Users (K)	4
# Receive Antennas (N)	32
# Receive RF Chains (P_{rk})	≥ 8
# Streams per User (S_k)	8

Advantage

- Near full digital beamforming performance with less than 50 % RF chains depending on the SNR

Disadvantages

1. Analog Network
   - Insertion loss
   - Reproducibility
2. Many phase shifters necessary

Spatial Modulation [3]

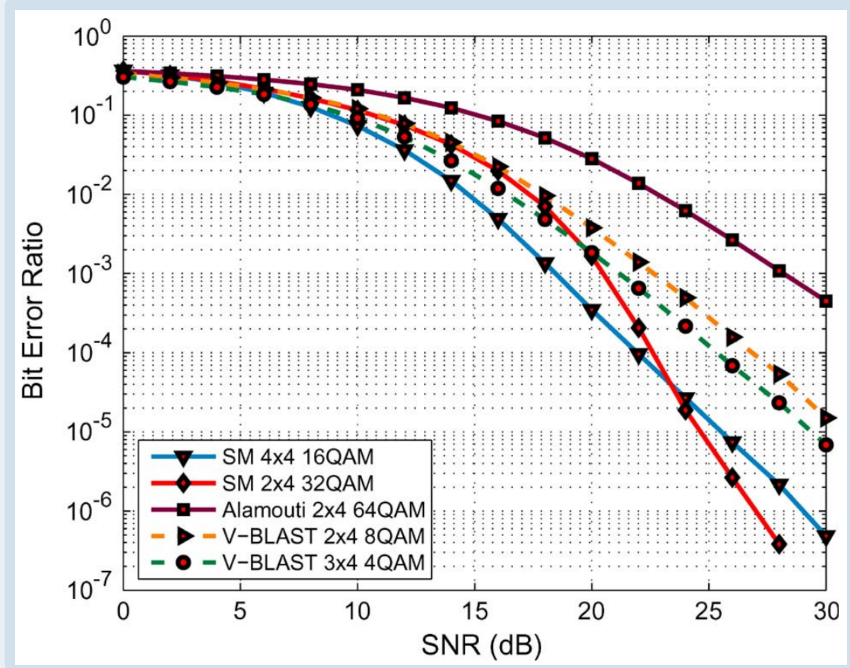
Basic Idea

- Instead of transmitting with all antennas only use one or a subset

- Spatial Modulation uses $\log(N_t) + m$ bits
- Generalized Spatial Modulation uses a subset of antennas $\Rightarrow \lfloor \log(\binom{N_t}{N_u}) \rfloor + m$ bits

Input bits	$N_t = 2,\ m = 4$		$N_t = 4,\ m = 2$	
	Antenna number	Transmit symbol	Antenna number	Transmit symbol
000	1	+1+j	1	-1
001	1	-1+j	1	+1
010	1	-1-j	2	-1
011	1	+1-j	2	+1
100	2	+1+j	3	-1
101	2	-1+j	3	+1
110	2	-1-j	4	-1
111	2	+1-j	4	+1

Spatial Modulation Performance



Advantages

- Single RF chain
- Energy efficient

Disadvantages

- Fast antenna switching
- Channel estimation
- Suboptimal spectral efficiency

Spectral Efficiency Example

- 8x8 16 QAM V-BLAST $\Rightarrow$ 32 b/s/Hz
- SM 16 QAM needs 2^{28} antennas for the same spectral efficiency $\Rightarrow$ Infeasible

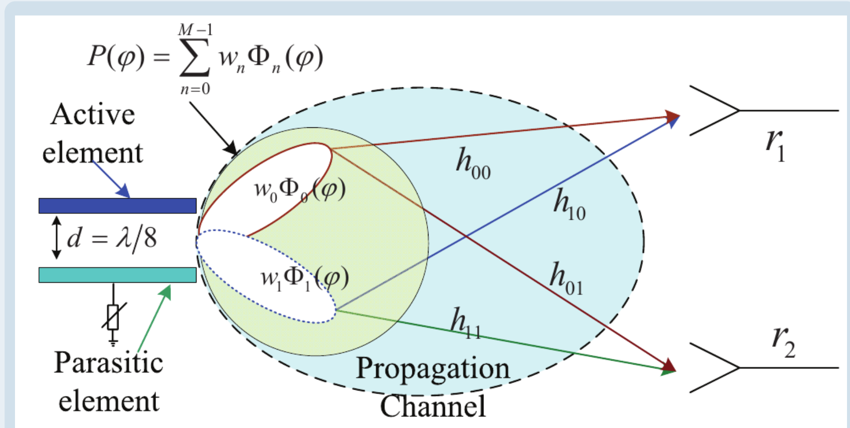
Parasitic Antennas [4]

Basic Idea

- Emulate the beam pattern of a conventional MIMO system with only one active antenna element and one or more parasitic antenna elements

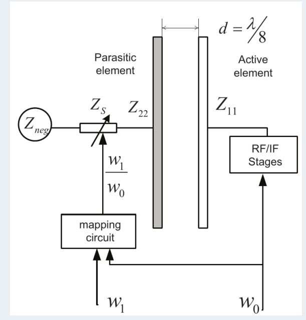
- The transmit symbols $\{\omega_n\}_{n=0}^{M-1}$ are mapped on orthonormal modes $\{\Phi_n(\phi)\}_{n=0}^{M-1}$

$$\Phi_0(\phi) = 1/k_0$$
$$\Phi_1(\phi) = [e^{jb\cos\phi} - 2\pi I_0(jb)/k_0^2]/k_1$$



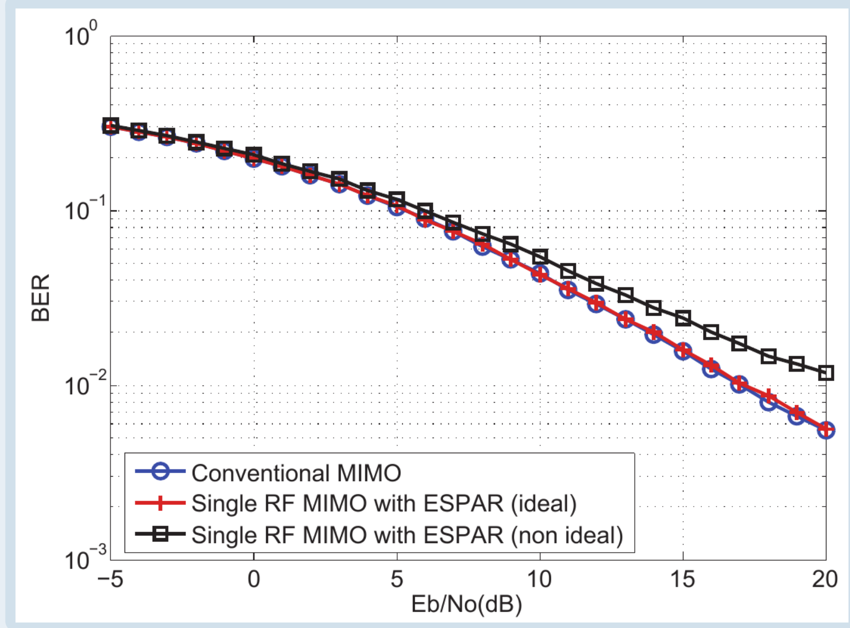
Parasitic Antenna Implementation

- Implementation with only one parasitic element
- Vector $[\omega_0\ \omega_1]^T$ emerging from a 16 QAM constellation is multiplexed over the air



- Signal ω_0 is directly driven to the sole RF chain
- Complex load is determined by the ratio of the transmitted symbols ω_1/ω_0

Parasitic Antenna Performance



- With ideal loads conventional MIMO performance can be achieved in this 2×2 16 QAM scenario

Issues

- Can we emulate patterns for a large number of antennas and high modulation?
- Analog network

UE RF Chain

- RF chains of mobile phones are already cost optimized
- Could this be the best solution for massive MIMO?

References

[1] C. Kim, J.-S. Son, T. Kim, and J.-Y. Seol, "On the hybrid beamforming with shared array antenna for mmwave mimo-ofdm systems," in *Wireless Communications and Networking Conference (WCNC), 2014 IEEE*, April 2014, pp. 335–340.

[2] T. E. Bogale and L. B. Le, "Beamforming for multiuser massive mimo systems: Digital versus hybrid analog-digital," 2014.

[3] R. Mesleh, H. Haas, S. Sinanovic, C. W. Ahn, and S. Yun, "Spatial modulation," *Vehicular Technology, IEEE Transactions on*, vol. 57, no. 4, pp. 2228–2241, July 2008.

[4] B. Han, V. Barousis, C. Papadias, A. Kalis, and R. Prasad, "Mimo over espar with 16-qam modulation," *Wireless Communications Letters, IEEE*, vol. 2, no. 6, pp. 687–690, December 2013.

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