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Time Domain Precoding for MIMO-OFDM Systems

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- Motivation
- State of the art
- Precoding for MIMO flat fading channel
- Precoding for MIMO frequency selective channel
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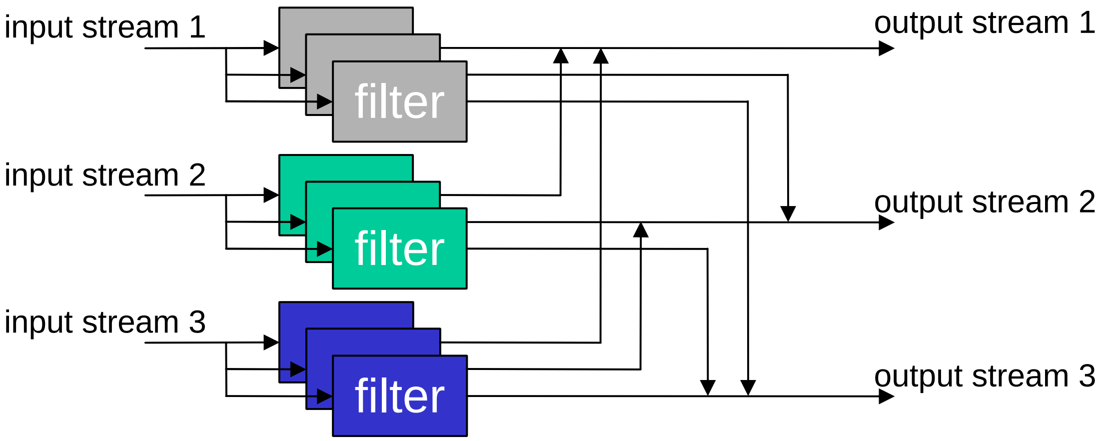
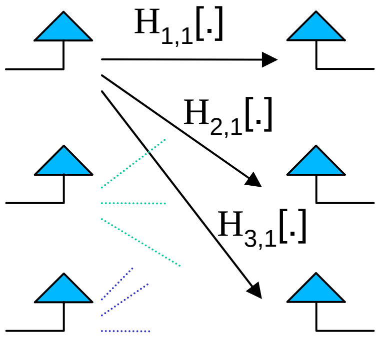
Motivation

- Square MIMO system
- Frequency selective channel



- Output streams affected by
  - ISI : inter-symbol interference (frequency selective channel)
  - MSI : multi-stream interference (multi-user system)

Problem setting

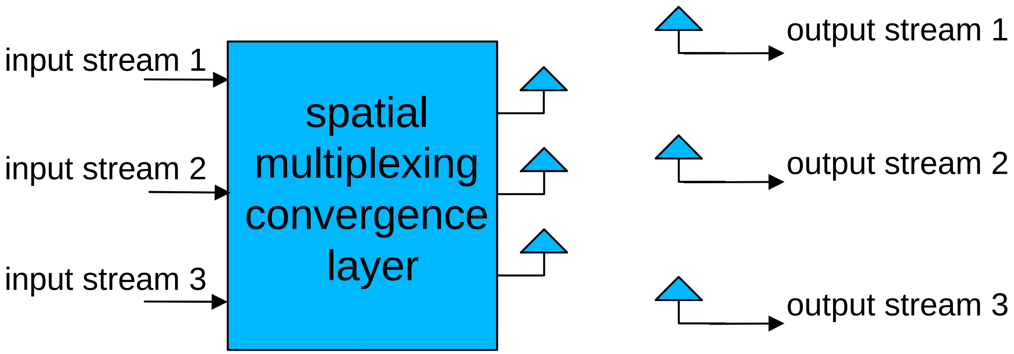


$$\mathbf{H} = \begin{bmatrix} H_{1,1}[.] & H_{1,2}[.] & H_{1,3}[.] \\ H_{2,1}[.] & H_{2,2}[.] & H_{2,3}[.] \\ H_{3,1}[.] & H_{3,2}[.] & H_{3,3}[.] \end{bmatrix}$$

- Matrix **H** contains the impulse answers (L taps) of the MIMO sub-channels
- The non-diagonal terms of **H** ($H_{1,2}[.]$ $H_{1,3}[.]$ …) represent MSI
- L >1 in the diagonal terms ($H_{1,1}[.]$ $H_{2,2}[.]$ $H_{3,3}[.]$ …) represents ISI

Spatial Multiplexing Convergence Layer

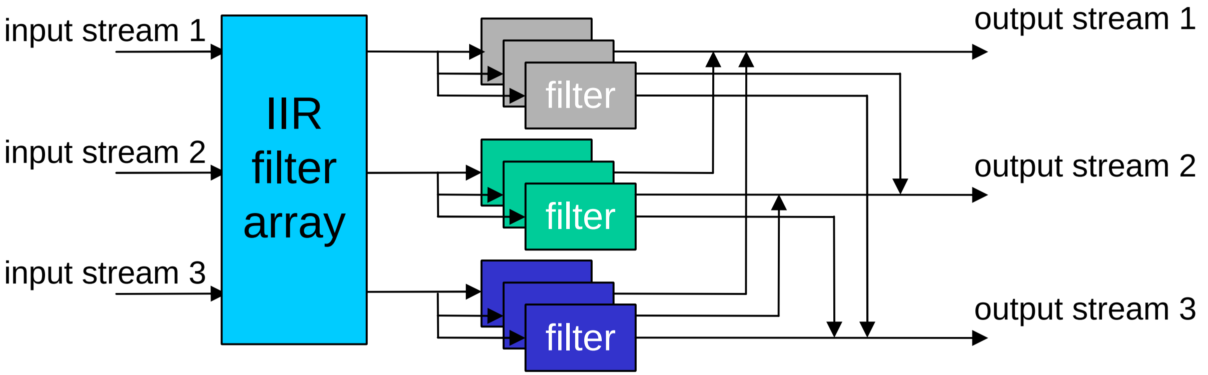
- Aim: find a linear precoding scheme to free output streams from all interferences
- Precoding to only combat MSI in [Paulraj-2003]
- Precoder-decoder pair in [Nossek-2004],[Scaglione-2002]



* A. Paulraj, R. Nabar, and D. Gore, *Introduction to Space-Time Wireless Communications*. Cambridge University Press, 2003.
* J. A. Nossek, M. Joham, and W. Utschick, “Transmit Processing in MIMO Wireless Systems,” in *Proc. IEEE 6th Symp. Circ. and Syst.*, Emerging Technologies: Frontiers of Mobile and Wireless Communication, pp. 18–23, May 2004.
* A. Scaglione, P. Stoica, S. Barbarossa, and H. Sampath, “Linear precoders and decoders designs for MIMO frequency selective channels,” in *Proc. ICASSP*, vol. 3, (Orlando, FL), pp. 2273–2276, May 13–17, 2002.

Simultaneous cancellation

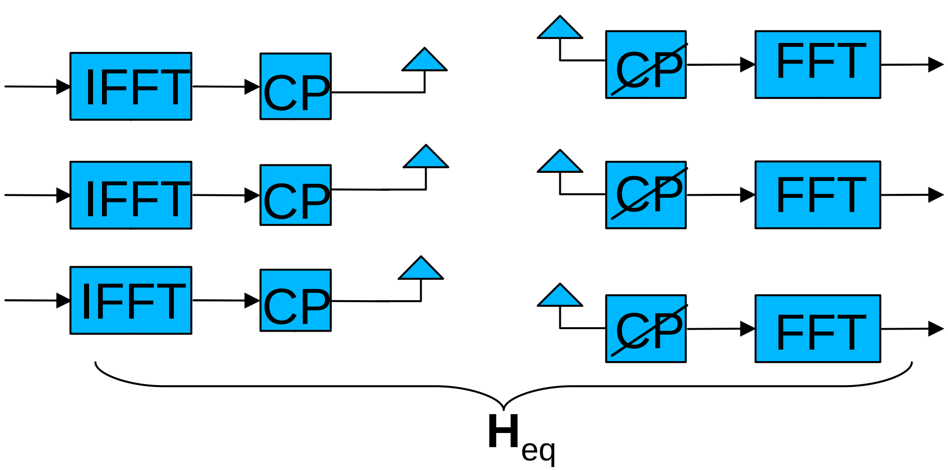
- Removing all interferences (ISI+MSI) in one step
  - at receiver side [Pohl-2002]
  - by inverting the FIR filter matrix at receiver or transmitter
  - but in a general way, inverse of FIR filter is an IIR filter (risk of unstability)



V. Pohl, V. Jungnickel, E. Jorswieck, and C. von Helmolt, “Zero Forcing Equalizing Filter for MIMO Channels with Intersymbol Interference,” in *Proc. IEEE Int. Symp. PIMRC*, vol. 3, pp. 1037–1041, Sept. 15 – Sept. 18, 2002.

Succesive equalizations

- New idea: remove ISI and MSI independently
- OFDM can cope with ISI by transmitting over frequency orthogonal flat fading sub-channels (time equalization)
- MSI remains since the equivalent channel matrix $\mathbf{H}_{eq}$ in the frequency domain is a block diagonal matrix

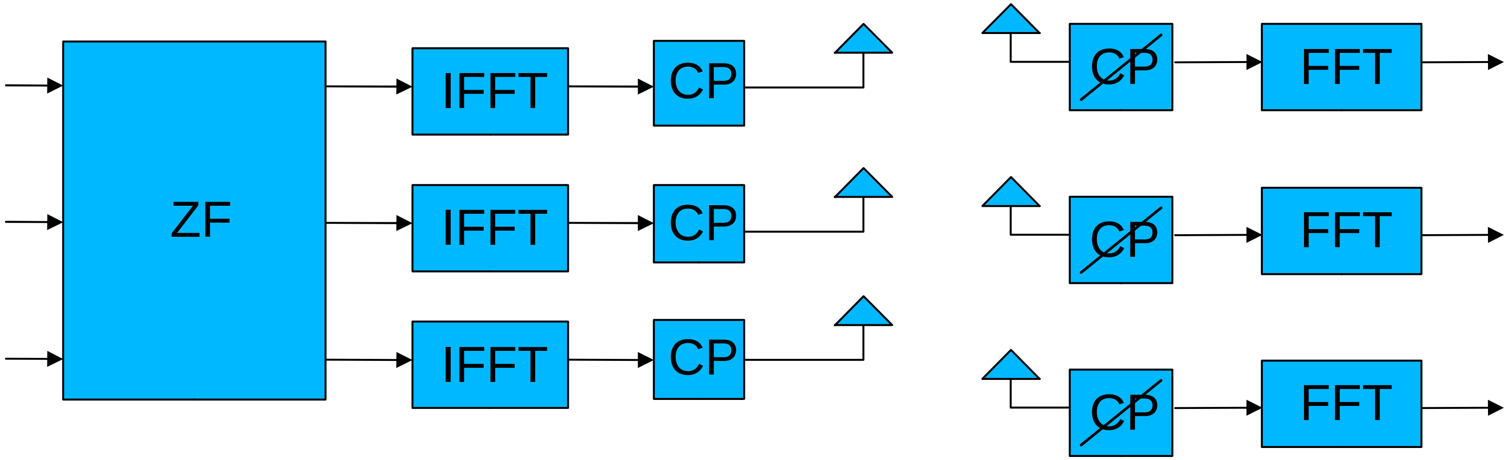


$$\mathbf{H}_{eq} = \begin{bmatrix} \mathbf{D}^{(1,1)} & \mathbf{D}^{(1,2)} & \mathbf{D}^{(1,3)} \\ \mathbf{D}^{(2,1)} & \mathbf{D}^{(2,2)} & \mathbf{D}^{(2,3)} \\ \mathbf{D}^{(3,1)} & \mathbf{D}^{(3,2)} & \mathbf{D}^{(3,3)} \end{bmatrix}$$

with $$\mathbf{D}^{(i,j)} = \begin{bmatrix} \lambda_1^{(i,j)} & 0 & 0 \\ 0 & \ddots & 0 \\ 0 & 0 & \lambda_{64}^{(i,j)} \end{bmatrix}$$

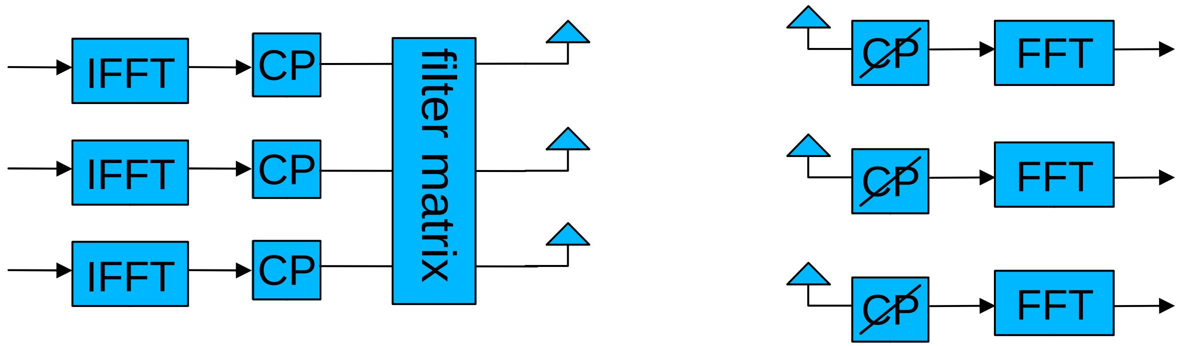
MSI removal: spatial equalization

- Can be performed in the frequency domain
  - inversion of $\mathbf{H}_{eq}$ (block diagonal matrix)
  - zero-forcing precoder



MSI removal

- Here we concentrate on <u>time domain</u> precoding (after OFDM pre-processing)
  - because frequency-domain signal may not be accessed - this is the case when 802.11a chipsets are used
  - general scheme for MSI suppression (independent of ISI suppression)



Hardware constraints

- re-use of 802.11a chips
- receiver
  - not cooperating receivers (channel estimation discarded)
  - receivers perform only standard 802.11a processing
- transmitter
  - total transmit power constraint

Statement of objective

- We look for a linear time-domain precoder that suppresses interferences in a MIMO-OFDM system with frequency selective channel

Notation

- $\mathbf{H}$: channel matrix with L taps for each sub-channel
- example 3x3 system (N=3)

$$\mathbf{H} = \mathbf{H}[.] = \begin{pmatrix} H_{11}[.] & H_{12}[.] & H_{13}[.] \\ H_{21}[.] & H_{22}[.] & H_{23}[.] \\ H_{31}[.] & H_{32}[.] & H_{33}[.] \end{pmatrix}$$

- $\mathbf{H}$ is element from set $\mathcal{R}$ (= square matrices of complex functions of a discrete variable)
- $*$ is the convolution product
- From now we work in the ring ($\mathcal{R}$,+,$*$)

Precoding in the flat fading case

- Entries of **H** have one tap

$$\mathbf{H} = \begin{pmatrix} H_{11}[.] & H_{12}[.] & H_{13}[.] \\ H_{21}[.] & H_{22}[.] & H_{23}[.] \\ H_{31}[.] & H_{32}[.] & H_{33}[.] \end{pmatrix} = \begin{pmatrix} H_{11} & H_{12} & H_{13} \\ H_{21} & H_{22} & H_{23} \\ H_{31} & H_{32} & H_{33} \end{pmatrix}$$

- We look for the precoding matrix **A** such that

$$\mathbf{H} \cdot \mathbf{A} = \mathbf{V}$$

  - with $\mathbf{V}$ any [3x3] diagonal complex matrix

- A solution is $\mathbf{A} = \frac{1}{k_{\mathrm{TD}}} \cdot \mathbf{H}^{-1}$ where k_{TD} represents the power constraint at the precoder

Equivalent channel

- In the flat fading case:

$$\mathbf{H}_{\mathrm{eq}} = \mathbf{H} \cdot \mathbf{A} = \frac{1}{k_{\mathrm{TD}}} \cdot \mathbf{I}_{3\times 3}$$

- The equivalent channel
  - is diagonal
  - all subchannels have same gain $\frac{1}{k_{\mathrm{TD}}}$
  - is a fading channel

Precoding in the frequency selective case

- All matrices are elements of $\mathcal{R}$ (= set of square matrices of complex functions of a discrete variable)
- We look again for the precoding matrix **A** such that

$$\mathbf{H} * \mathbf{A} = \mathbf{V}$$

  - with $\mathbf{V}$ any [3x3] diagonal matrix of complex functions of a discrete variable
- The inverse of $\mathbf{H}$ is no more defined

Formula derivation

- In the flat fading case, if $\mathbf{H}$ has full rank

$$\mathbf{H}^{-1} = \frac{1}{\det(\mathbf{H})} \cdot \operatorname{adj}(\mathbf{H}) \Leftrightarrow \mathbf{H} \cdot \operatorname{adj}(\mathbf{H}) = \det(\mathbf{H}) \cdot \mathbf{I}_{3\times 3}$$

  - with adj($\mathbf{H}$) the adjoint matrix of $\mathbf{H}$

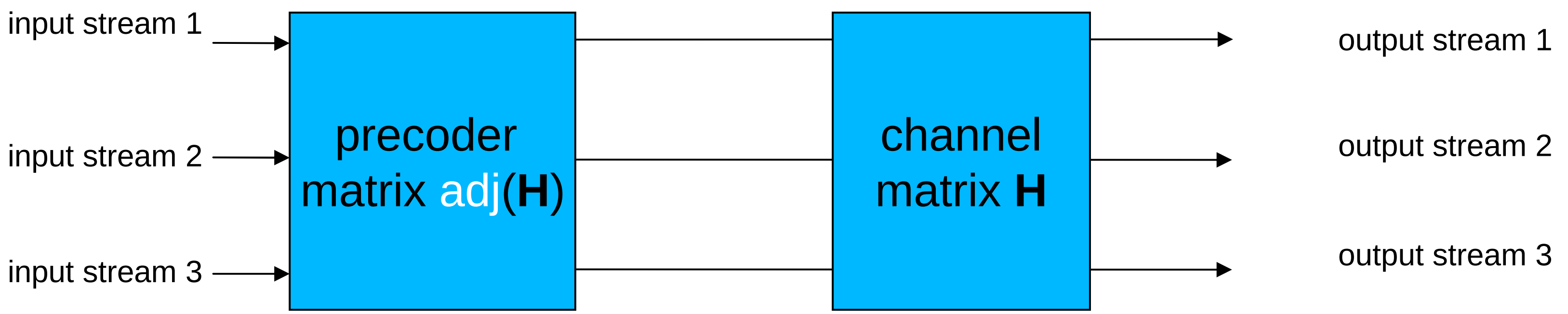
- Prerequisite for this formula is a ring structure

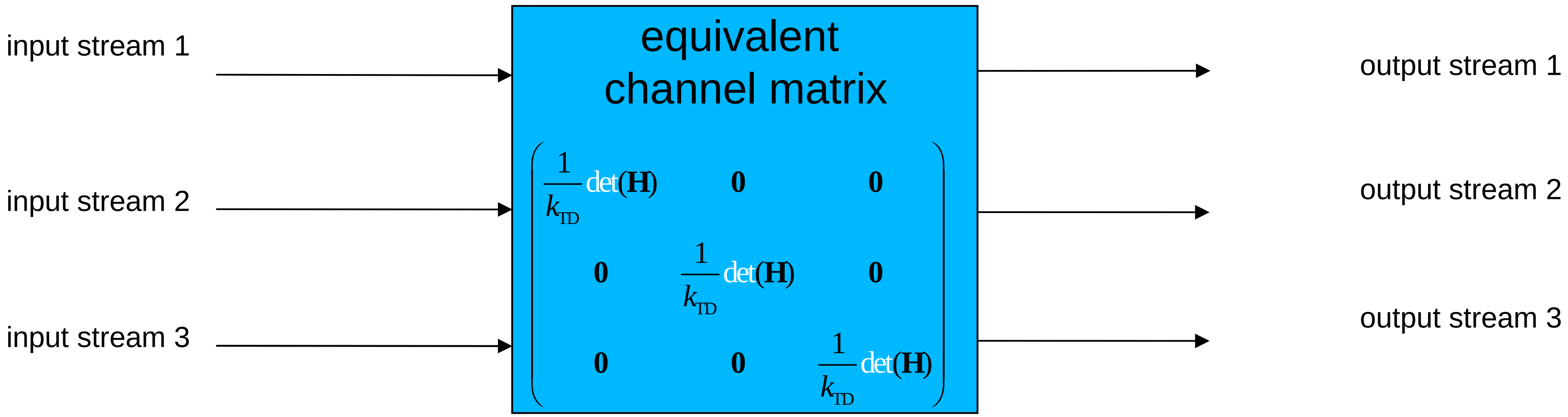
- $(\mathcal{R},+,*)$ is a ring
  - definition of det(.), adj(.)
  - term by term addition, substraction, convolution
  - no inverse must exist for convolution
  - formula $\mathbf{H} * \operatorname{adj}(\mathbf{H}) = \det(\mathbf{H}) * \mathbf{I}_{3\times 3}$ is valid

Precoder structure

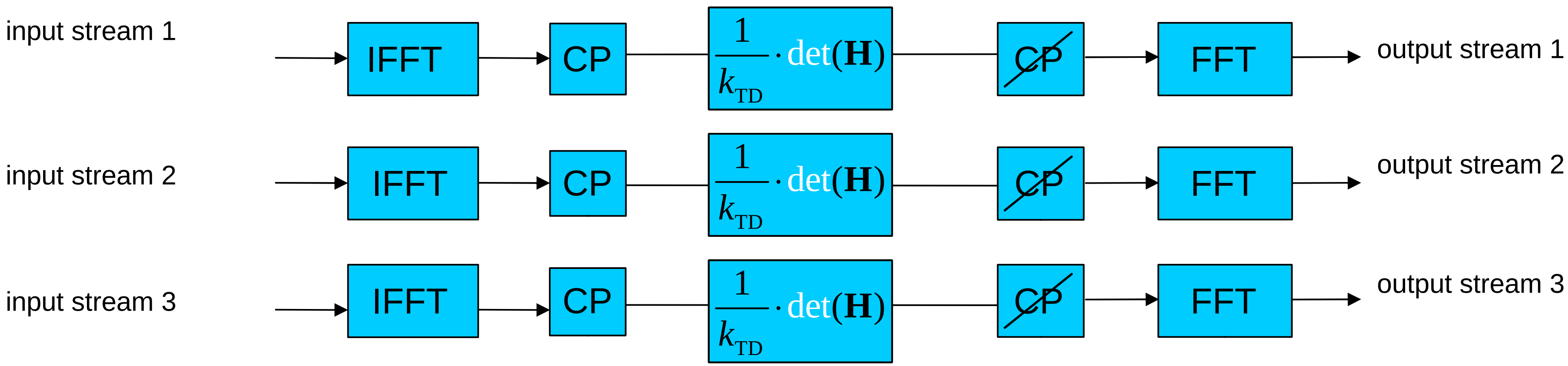
- From $\mathbf{H} * \mathrm{adj}(\mathbf{H}) = \det(\mathbf{H}) * \mathbf{I}_{3\times 3}$,
  - precoding matrix $\mathbf{A} = \frac{1}{k_{\mathrm{TD}}} \mathrm{adj}(\mathbf{H})$ is used
  - each entry of $\mathbf{A}$ has $(N-1)\cdot L-(N-2)$ taps
  - equivalent channel $\mathbf{H}_{\mathrm{eq}} = \mathbf{H} * \mathbf{A} = \frac{1}{k_{\mathrm{TD}}} \det(\mathbf{H}) * \mathbf{I}_{3\times 3}$
    - is diagonal
    - is fading
    - is frequency selective ($\det(\mathbf{H})$ is a complex function of a discrete variable)
  - equivalent channel matrix has $N\cdot L-(N-1)$ taps

Block equivalent channel





Equivalent system



- Equivalent channel has more taps than $\mathbf{H}$

$$\mathrm{length}(\det(\mathbf{H})) = L \cdot \mathrm{size}(\mathbf{H}) - (\mathrm{size}(\mathbf{H}) - 1) \geq L$$

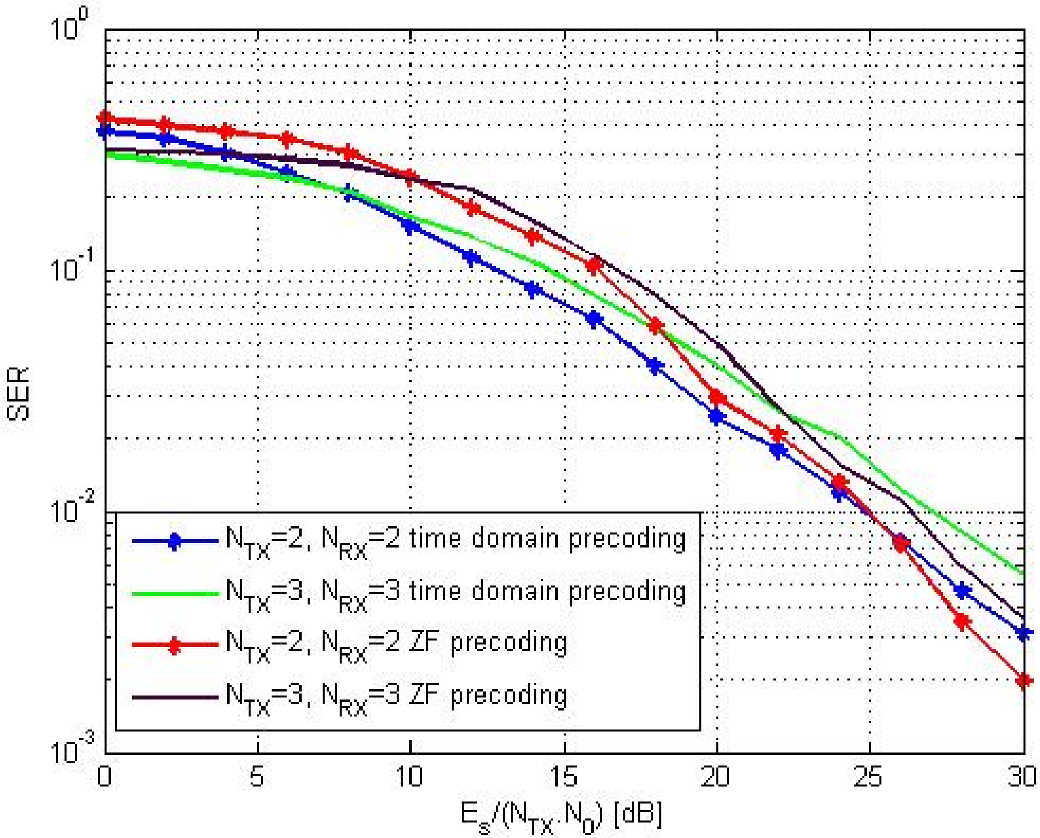
  - Check if cyclic prefix is long enough

Channel model for simulations

- frequency selective channel (L taps)
- spatially and temporally uncorrelated channel coefficients
- channel normalization such that energy in each subchannel = 1 in average :

$$h_{i,j}[k] \sim \mathcal{CN}(0,1/L) \mid k=0\ldots L-1$$

Simulation results

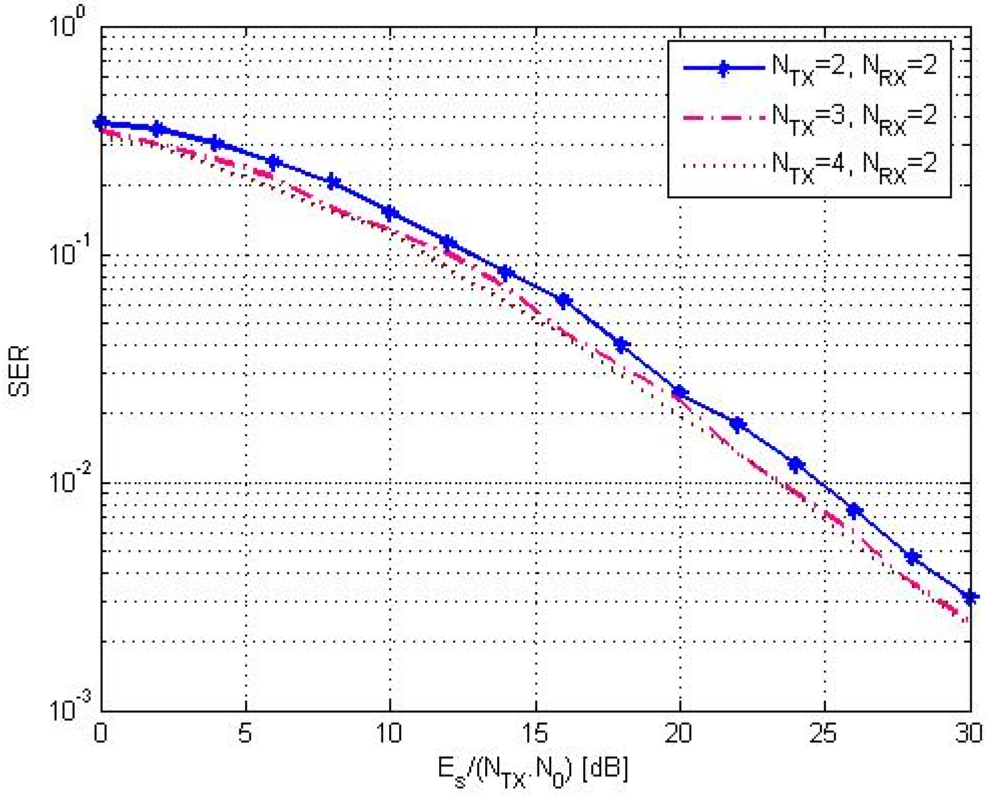


comparison of the system performance

with ZF frequency precoding

- time domain precoding performs similarly to frequency domain zero forcing precoding

Transmission antenna selection



performance with antenna selection combining

(2 data streams)

- System selects the antennas such that equivalent channel matrix has largest Frobenius norm
- Simple scheme to adapt system to changing operating conditions
- 1dB array gain

Conclusion

- Time-domain precoding for MIMO-OFDM system
- Derived a FIR filter matrix
- Precoder is independent of input streams
- Removes totally multi-user interference
- Creates virtual independent SISO links with all the same impulse response

Thank you