Cooperative Precoding and Beamforming in Co-working OFDM WLANs

Wibowo Hardjawana, Branka Vucetic, Yonghui Li

School of Electrical and Information Engineering,
The University of Sydney, Australia

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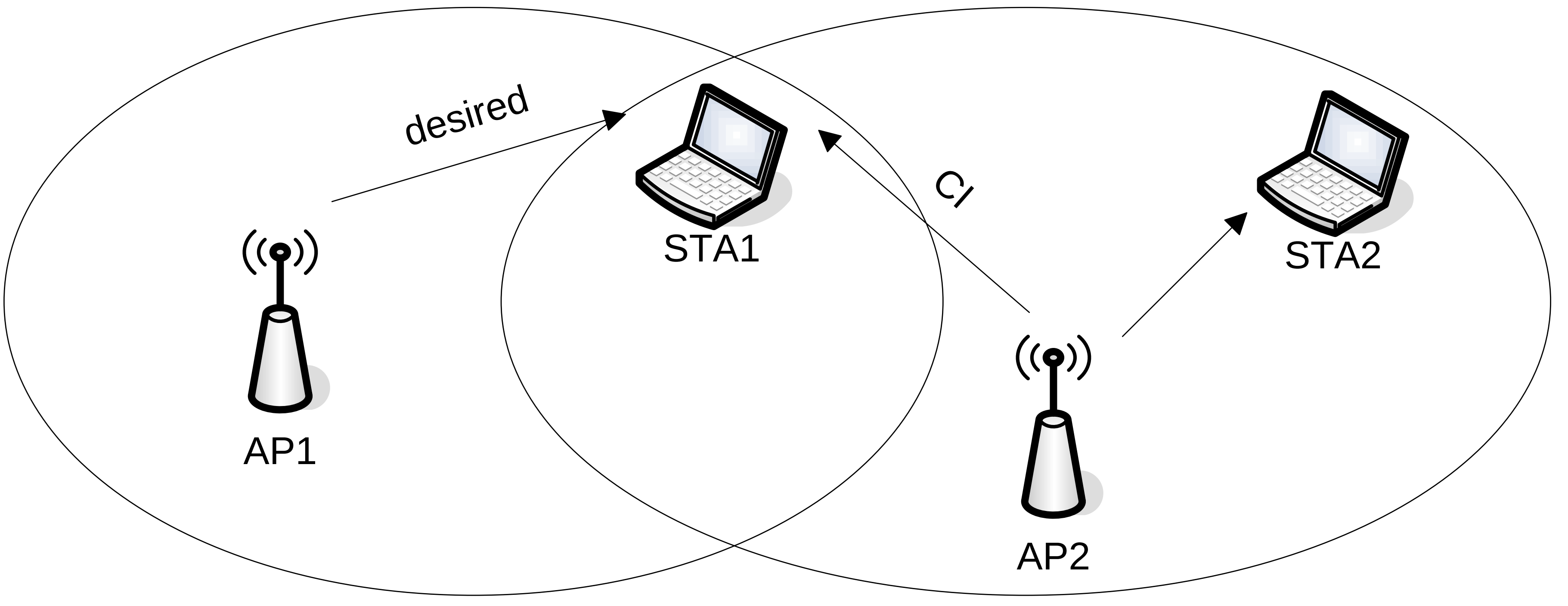
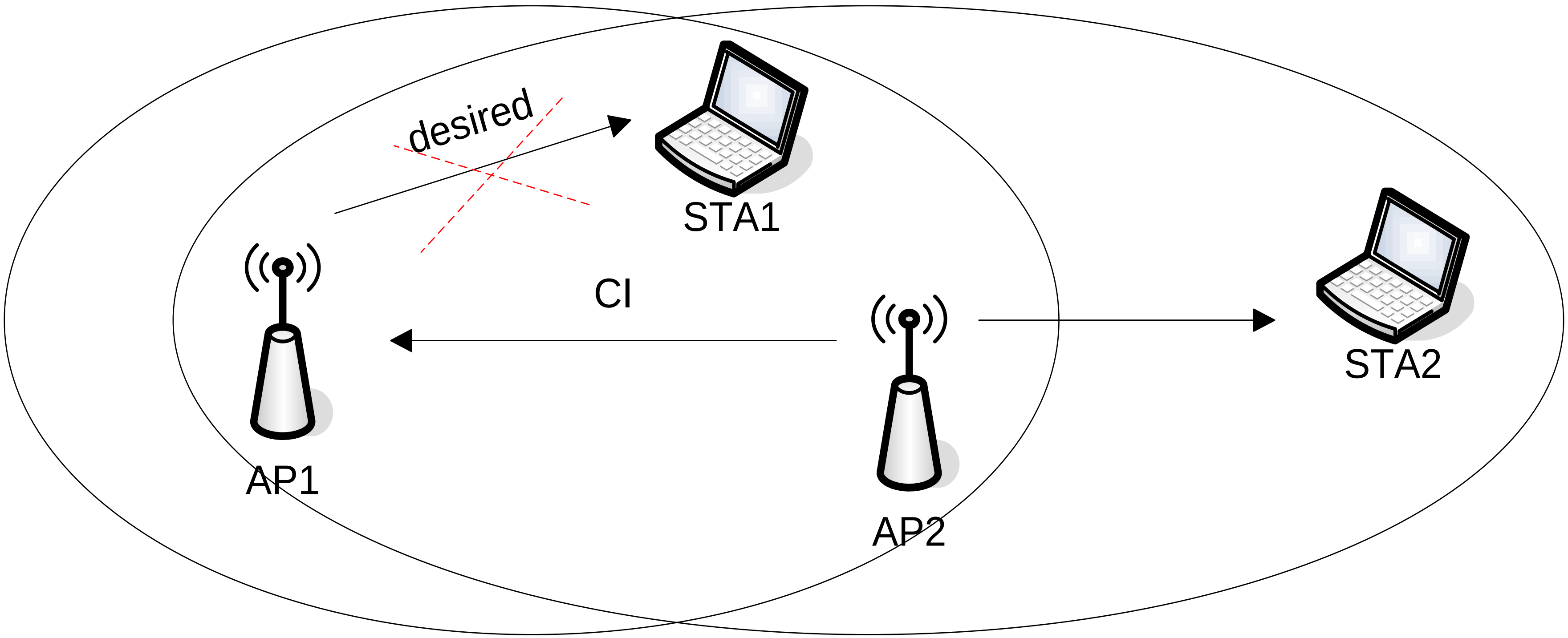
Hidden Node Problem



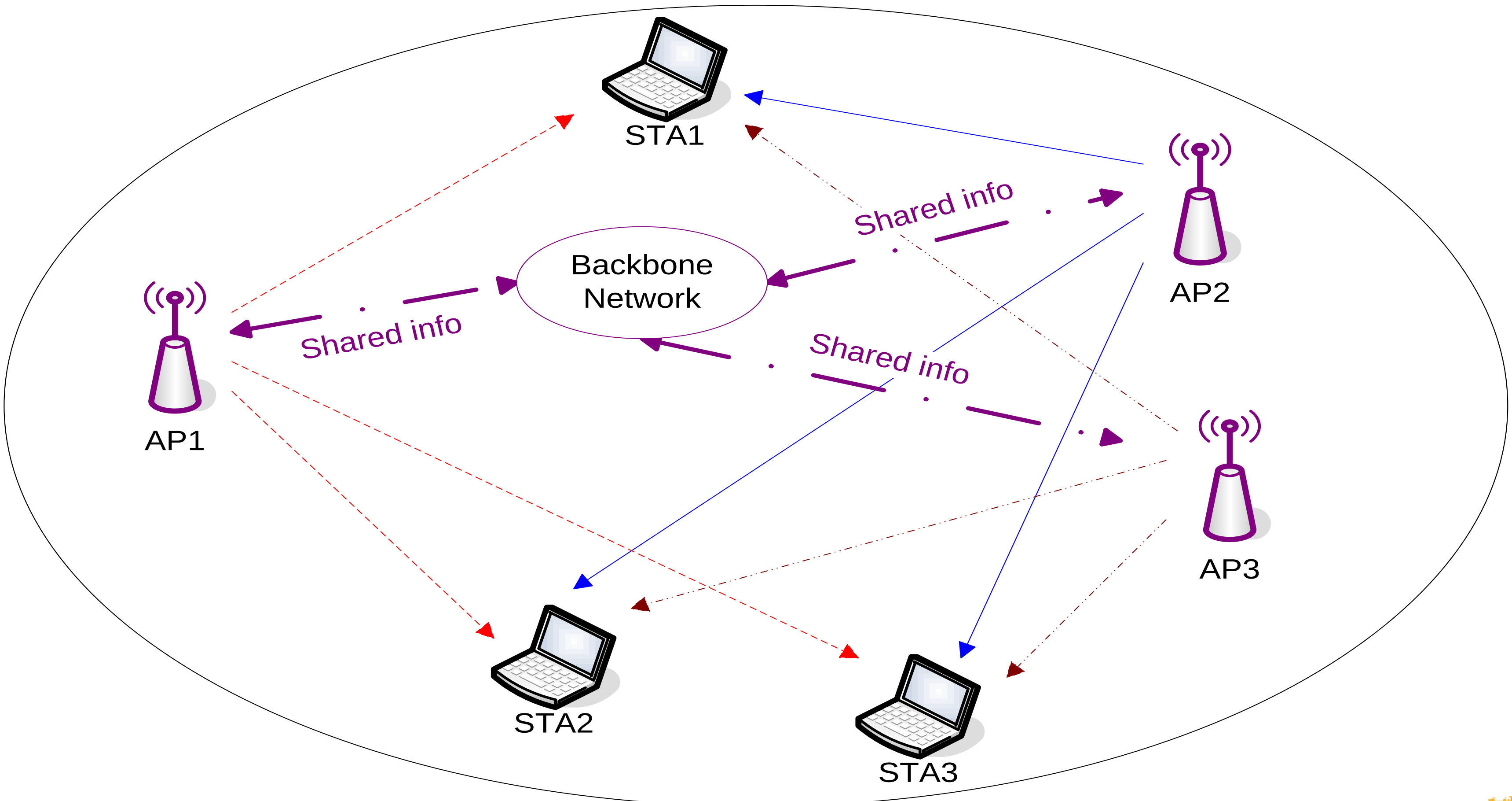
- AP2 is hidden from AP1
- STA1 gets the interference from AP2

Exposed Node Problem



- AP2 is exposed to AP1
- AP1 detects the transmission from AP2 (to STA2) and cannot transmit

Cooperative Transmission



- APs share information about the transmission and transmit cooperatively
- No exposed node problem in this case

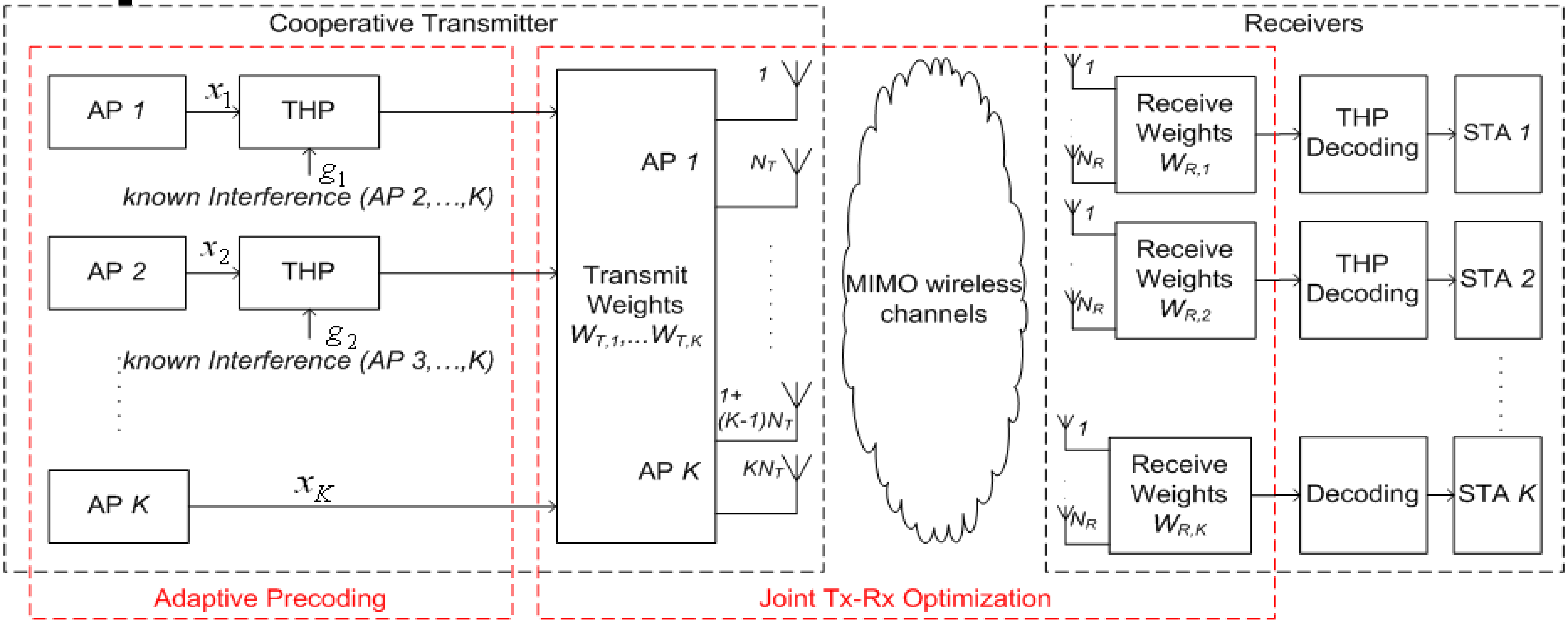
Literature Review

- *Non-cooperative* methods effective for the hidden node problem only [Hardjawana/Vucetic/Jamalipour 2006, Wong/Cheng/Letaief/Murch 2001]
- Interference *avoidance* in co-working bluetooth-WLANs [Bergkwist/Queseth 2004, Chiasserini/Rao 2003, Li/Wang/Mujtaba 2004]
- Early cooperation strategies using joint precoding and beamforming methods is applicable only to *single receive antennas* per user [Yu/Cioffi 2004, Ginis/Cioffi 2002 , Caire/Shamai 2003]
- Previous work [Foschini/Karakayali/Valenzuela 2006] used MIMO beamforming + Dirty Paper Coding [Costa 1983] (DPC) to optimize the *total capacity* → not really practical and *not align* with our objective in co-working WLANs (Fairness among operators)

System Design Criteria

- Minimize interference from other APs
- Solve the hidden node problem
- Ensure equal error performance for different operators

System Model



- APs transmit the information to its own station (STA) via KN_T antennas and gets known interference from *(K-j)* APs where *j=1,…,K*
- Interference from APs *j+1,…,K* at AP *j* are suppressed by Tomlinson-Harashima precoding (THP)
- Interference from APs 1,…,*j-1* at STA *j* are suppressed by joint Tx-Rx optimization (ZF or maximization of SINR)
- Adaptive precoding order determines the order of the links to be precoded

System Model

- Each AP transmits its signal with KN_T antennas with an adaptive precoding order
- The THP operation with known interference g_j, generates the signal $f(x_j, g_j)$ given by

$$f(x_j, g_j) = (x_j - g_j) \bmod M, \quad j = 1, \ldots, K-1$$
$$g_j = \frac{W_{R,j}^H \left\{ \sum_{i=j+1}^{K-1} H_j W_{T,i} f(x_i, g_i) + H_j W_{T,K} x_K \right\}}{W_{R,j}^H H_j W_{T,j}} \quad (1)$$

where $W_{R,j} \in C^{N_R \times 1}, H_j \in C^{N_R \times KN_T}, W_{T,j} \in C^{KN_T \times 1}$ are the receive beamforming weights vector, channel matrix, transmit beamforming weights vector at receiver *j.*

System Model

- The transmitted signal after multiplying with the respective transmit weight is given as

$$x_{T,j} = \begin{cases} W_{T,j} f(x_j, g_j), \; j = 1, \ldots K-1 \\ W_{T,j} x_j, \; j = K \end{cases} \quad (2)$$

- The received signal at the station (STA) *j* with N_R antennas is given as

$$y_j = W_{R,j}^H H_j x_{T,j} + \sum_{i=1}^{j-1} W_{R,j}^H H_j x_{T,i} + \sum_{i=j+1}^{K} W_{R,j}^H H_j x_{T,i} \quad (3)$$

$$+ W_{R,j}^H N_j$$

where $N_j \in C^{N_R \times 1}, P_j$ are the noise vector and transmitted power for link *j* at receiver *j.*

System Model

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Cancelled by THP

where $N_j \in C^{N_R \times 1}, P_j$ are the noise vector and transmitted power for link *j* at receiver *j.*

Joint Transmit-Receive Beamforming (ZF)

- For each station *j=1,…,K* , the desired signal coefficient $W_{R,j}^{H} H_{j} W_{T,j}$ is maximized

$$\max_{W_{R,j}, W_{T,j}} W_{R,j}^{H} H_{j} W_{T,j} \quad \textit{subject to} \ \left\| W_{T,j} \right\| = 1 \qquad (4)$$

- Select $W_{T,j}$ to be in phase with effective H_{j} , for *j=1,…,K.*
- while the total interference caused by link *j* (i.e., $W_{T,j}$) to other links, given by

$$\sum_{i=j+1}^{K} W_{R,i}^{H} H_{i} W_{T,j} \qquad (5)$$

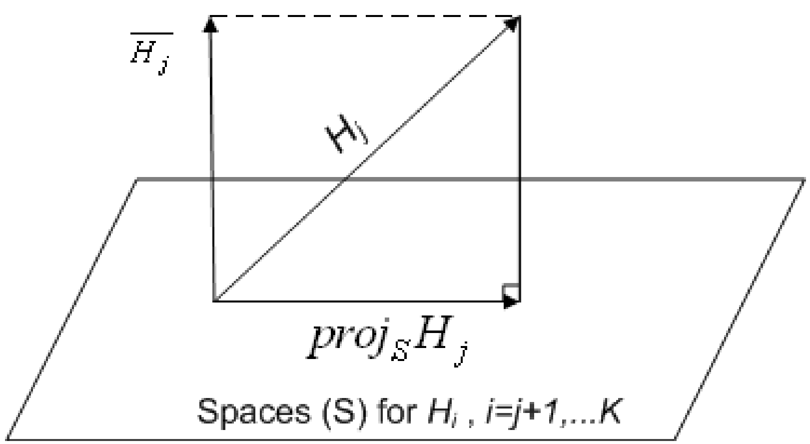
is forced to zero, giving

$$H_{i} W_{T,j} = 0 \quad \textit{for all } i = j+1, \ldots, K \qquad (6)$$

Joint Transmit-Receive Beamforming (ZF)

- By applying the Gram-Schmidt orthogonalization process, we make the effective H_j , denoted by $\overline{H_j}$, to be orthogonal to H_i

- Using the SVD, the signal is sent in the direction of the largest eigenvalue of $\overline{H_j}$



Joint Transmit-Receive Beamforming (max SINR)

- The SINR at receiver *j* is given as

$$SINR_j = \frac{W_{R,j}^H H_j W_{T,j} \left(W_{R,j}^H H_j W_{T,j} \right)^H}{\sum_{i=1}^{j-1} W_{R,j}^H H_j W_{T,i} \left(H_j W_{T,i} \right)^H W_{R,j}^H + E[W_{R,j}^H N_j N_j^H W_{R,j}]} \qquad (7)$$

where the interference matrix, $R_{N,j}$ is given by

$$R_{N,j} = \sum_{i=1}^{j-1} H_j W_{T,i} \left(H_j W_{T,i} \right)^H + E[N_j N_j^H] \qquad (8)$$

- $SINR_j$ is maximized by minimizing the denominator

$$\min_{W_{R,j}, W_{T,j}} W_{R,j}^H R_{N,j} W_{R,j}$$
$$\text{subject to } W_{R,j}^H H_j W_{T,j} = 1 \text{ and } \left\| W_{T,j} \right\| = 1 \qquad (9)$$

Joint Transmit-Receive Beamforming (max SINR)

- The receive beamforming coefficients are obtained by the standard Lagrange method

$$W_{R,j} = \frac{R_{N,j}^{-1} H_j W_{T,j}}{(H_j W_{T,j})^H R_N^{-1} H_j W_{T,j}} \quad (10)$$

- Inserting these receive weights into the SINR's expression, we obtain [Wong/Cheng/Letaief/Murch 2001]

$$SINR_j = W_{T,j}^H H_j^H R_N^{-1} H_j W_{T,j} \quad (11)$$

- $W_{T,j}$ and $W_{R,j}$ are selected to transmit the signal in the direction of the eigenvector associated with the maximum eigenvalue of $H_j^H R_N^{-1} H_j$ and satisfy (10).

Adaptive Precoding Order (ZF)

- Aim to equalize SINR among users ; “worsen the lower bound and improves upper bound”
- Set link *j* to be the last link (e.g., 1) to be precoded by THP and find its SINR
- Under this configuration, link *j* needs to suppress its interference to all other (K-1) links→ worst possible SINR for link *j*
- Repeat for link *1,…,j-1,j +1,…,K*
- The link with the smallest worst SINR is the first to be precoded

Adaptive Precoding Order (max SINR)

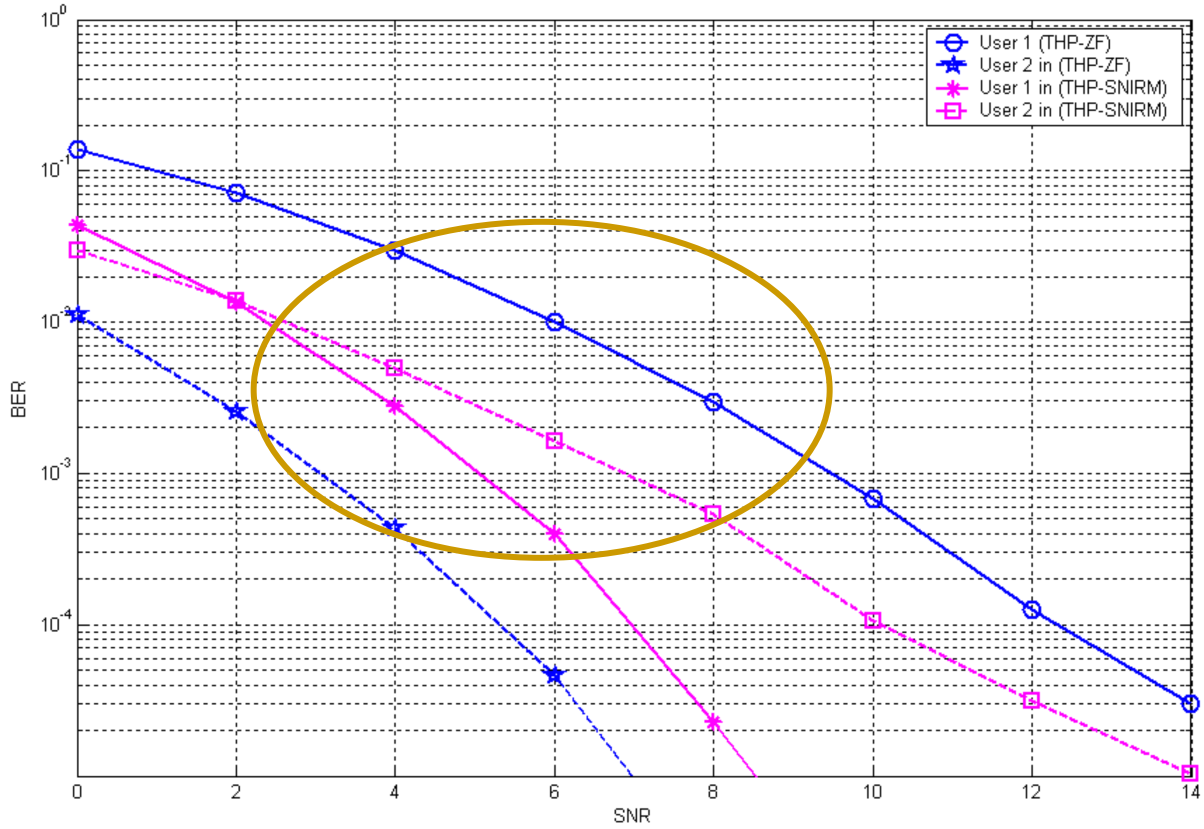
- Aim to equalize SINR among users ; "worsen the lower bound and improves upper bound"
- Set link *j* to be the first link (e.g., K) to be precoded by THP and find its (K-1)! possible SINR
- Under this configuration, link *j* needs to suppress interference from all other (K-1) links→ worst possible SINR for link *j*
- Repeat for link *1,…,j-1,j +1,…,K*
- The link with the largest worst SINR is the first to be precoded

Simulation setup

- MIMO-OFDM
- N_T=N_R=2 and K=2
- BPSK modulation
- Systems parameters:
  - 48 sub-carriers with 64-DFT
  - Symbol period = 3.2μsec
  - Guard period = 0.8μsec
- Frequency selective fading wireless channel parameters:
  - RMS delay spread = 0.16 μsec
  - Maximum channel delay = 0.8 μsec
  - 10 resolvable paths

Simulation Results

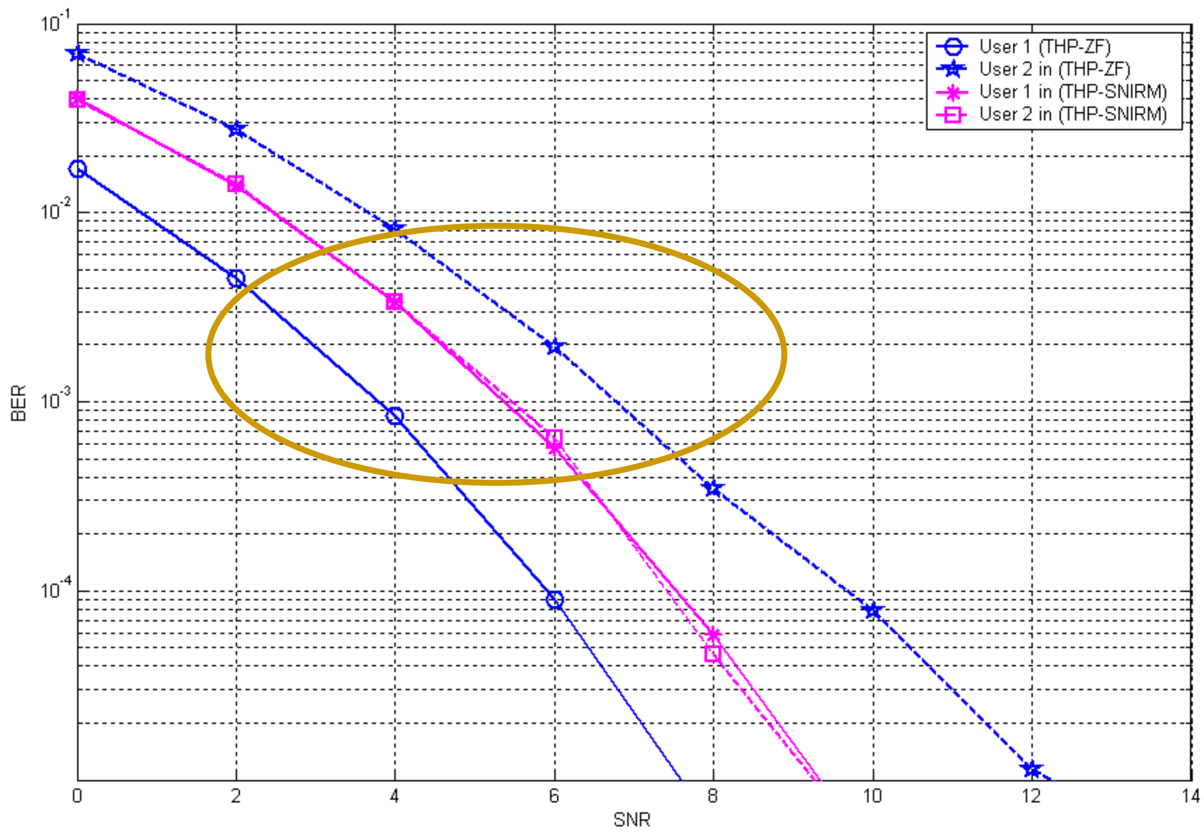
Fixed Precoding Order



- 6 dB difference among users using THP-ZF
- 2 dB difference among users using THP-SNIRM

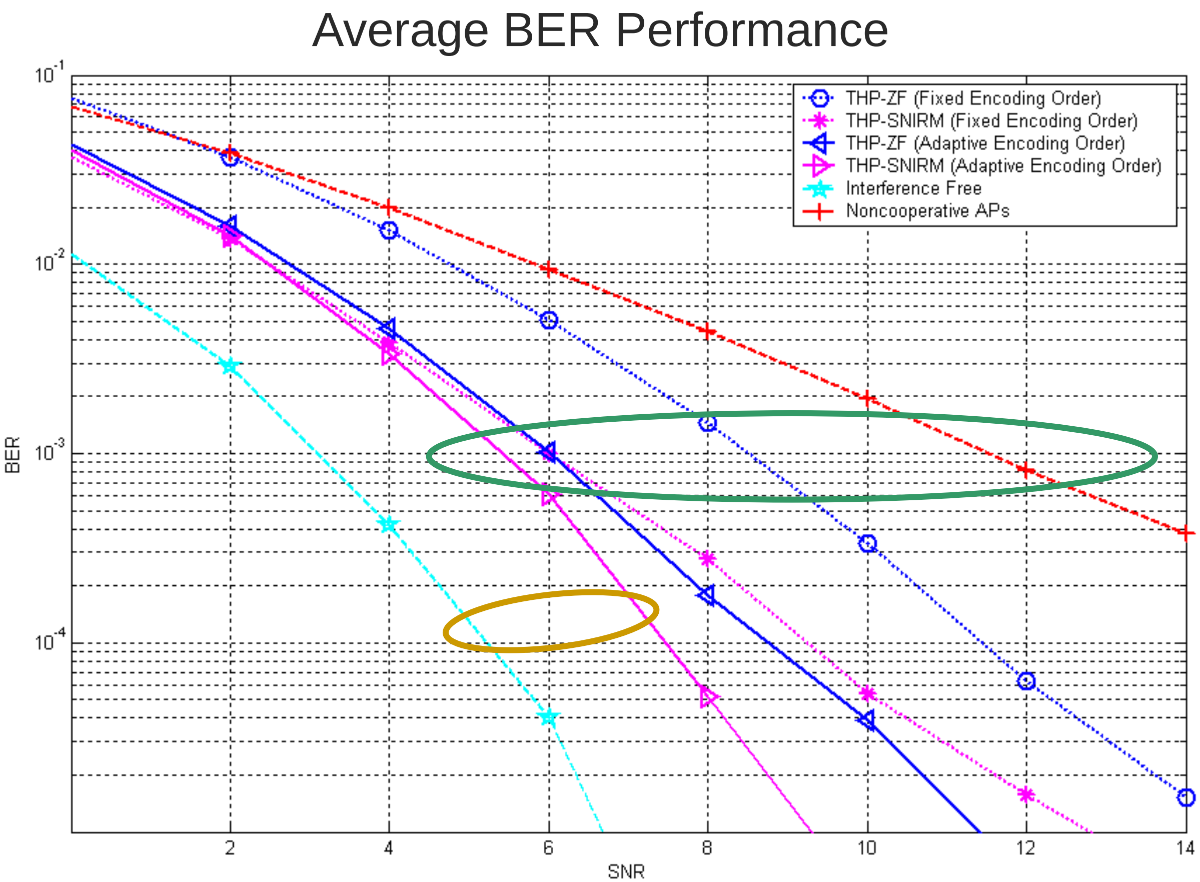
Simulation Results

Adaptive Precoding Order



- BER difference among users is reduced to 3 dB for THP-ZF
- BER difference among users is reduced to 0 dB for THP-SINRM

Simulation Results



- THP-SINRM with adaptive precoding order is the best
- 3 dB away from an interference free channel
- 7 dB better than known non-cooperative scheme (non-coop MMSE+beamforming)

Conclusions

- A cooperative transmission scheme for Co-working WLANs is presented.
- It solves the hidden node problem, the exposed node problem and removes most of the interference.
- The proposed scheme improves the error performance by 7 dB compared to non-cooperative MMSE joint transmit/receive beamforming
- It provides almost equal error performance among various operators

Questions?