# Blind Joint Interference Suppression and Power Allocation with Alternating Optimization for Cooperative DS-CDMA Networks

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# Outline

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- System and Data Models
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  - Constrained Constant Modulus (CCM) Linear Receiver Design
  - Power Allocation
  - Channel Estimation
- Blind Adaptive Algorithms
- Simulations
- Conclusions

# Motivation

- Cooperative communications and relaying exploit the spatial diversity in wireless channels, combat fading and enhance the performance. (Laneman04)
- Multi-hop relaying can improve the coverage of ad hoc and sensor networks at the cost of extra delays, signalling and training overheads. Example: IEEE 802.15.4
- Ad hoc and sensor networks often employ spread spectrum techniques due to their robustness against interference and low power operation. (Long08, Vardhe08)
- Cross-layer design: can obtain significant gains in performance. (Jakllari07)

# Problems

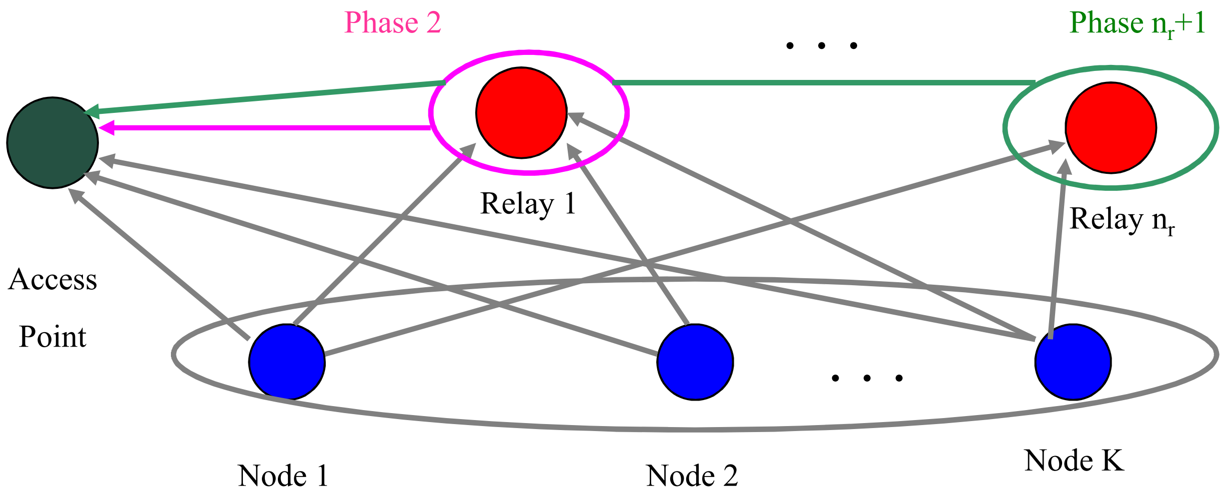
- The allocation of power levels is often done using an equal power allocation strategy -> this is suboptimal and in multi-hop systems leads to more losses.
- Multi-hop networks require a significant amount of signalling and training.
- Certain nodes in a network have poor links: improvement in coverage and performance is very important.
- Battery consumption: an optimised system can operate with lower power consumption.

# Contributions

- An optimization framework:
  - Blind joint allocation of power levels among the relays subject to group-based power constraints and the design of linear receivers -> BJPAIS-GBC.
  - Alternating adaptive algorithms with cycles between tasks.
- CCM design (de Lamare 2010b):
  - Blind CCM expressions for the power allocation and the design of linear receive filters.
  - Cooperative blind channel estimation algorithm.
- Proposed blind adaptive algorithms:
  - Selection of most important nodes in the optimisation - > a heuristic
  - Recursive alternating algorithms for blindly estimating the channels, the power allocation and the receive filters.
- A simulation study of the above techniques

# System and Data Models

- DS-CDMA network with multiple hops ($n_r$ +1 transmission phases)




- Cooperation protocols: amplify-and-forward (AF) and decode-and-forward (DF)
- Packets of P symbols
- Interference channel where synchronisation is assumed perfect and transmission is synchronous at the symbol level (Venturino06)

# System and Data Models (cont.)

- By collecting the data the from the source nodes and the relays to the destination into a $(n_r+1)M \times 1$ received vector **r**[i] we obtain

$$\begin{bmatrix} \boldsymbol{r}_{sd} \\ \boldsymbol{r}_{r_1 d} \\ \vdots \\ \boldsymbol{r}_{r_{n_r} d} \end{bmatrix} = \begin{bmatrix} \sum_{k=1}^{K} a_{sd}^{k} \boldsymbol{C}_k \boldsymbol{h}_{sd,k} b_k \\ \sum_{k=1}^{K} a_{r_1 d}^{k} \boldsymbol{C}_k \boldsymbol{h}_{r_1 d,k} \tilde{b}_k^{r_1 d} \\ \vdots \\ \sum_{k=1}^{K} a_{r_{n_r} d}^{k} \boldsymbol{C}_k \boldsymbol{h}_{r_{n_r} d,k} \tilde{b}_k^{r_{n_r} d} \end{bmatrix} + \begin{bmatrix} \boldsymbol{\eta}_{sd} \\ \boldsymbol{\eta}_{r_1 d} \\ \vdots \\ \boldsymbol{\eta}_{r_{n_r} d} \end{bmatrix} + \begin{bmatrix} \boldsymbol{n}_{sd} \\ \boldsymbol{n}_{r_1 d} \\ \vdots \\ \boldsymbol{n}_{r_{n_r} d} \end{bmatrix}.$$

- Rewriting the above signals in a compact form and using i as the symbol index in the transmitted packet, we have

$$\begin{aligned} \boldsymbol{r}[i] &= \sum_{k=1}^{K} \widetilde{\boldsymbol{B}}_k[i] \widetilde{\boldsymbol{A}}_k[i] \boldsymbol{p}_k[i] + \boldsymbol{\eta}[i] + \boldsymbol{n}[i] \\ &= \sum_{k=1}^{K} \boldsymbol{P}_k[i] \boldsymbol{B}_k[i] \boldsymbol{a}_k[i] + \boldsymbol{\eta}[i] + \boldsymbol{n}[i] \end{aligned}$$

# Linear Receiver Design and Power Allocation with a Group-Based Power Constraint: Main Idea

- Group strategy:

$$\boldsymbol{r}[i] = \boldsymbol{P}_{\mathcal{S}}[i]\boldsymbol{B}_{\mathcal{S}}[i]\boldsymbol{a}_{\mathcal{S},k}[i] + \sum_{k \neq \mathcal{S}} \boldsymbol{P}_k[i]\boldsymbol{B}_k[i]\boldsymbol{a}_k[i] + \boldsymbol{\eta}[i] + \boldsymbol{n}[i].$$

where a group of G nodes is considered in the set S.

- Linear CCM reception at the access point:

$$z_k[i] = \boldsymbol{w}_k^H[i]\boldsymbol{r}[i].$$

- Linear CCM design for power allocation and receive filter:

$$[\boldsymbol{w}_k^{\text{opt}},\ \boldsymbol{a}_{\mathcal{S},k}^{\text{opt}}] = \arg \min_{\boldsymbol{w}_k[i], \boldsymbol{a}_{\mathcal{S},k}[i]} E[(|\boldsymbol{w}_k^H[i]\boldsymbol{r}[i]|^2 - 1)^2]$$

$$\text{subject to } \boldsymbol{a}_{\mathcal{S},k}^H[i]\boldsymbol{a}_{\mathcal{S},k}[i] = P_G \text{ and } \boldsymbol{w}_k^H[i]\boldsymbol{p}_k[i] = \nu,$$

where $\nu$ is a parameter used to enforce convexity.

# MMSE Design with a Group-Based Power Constraint: Expressions

- CCM expression for the $G(n_r+1)$ parameter vector of the amplitudes:

$$\boldsymbol{a}_{\mathcal{S},k}[i] = (\boldsymbol{R}_{\mathcal{S},k}[i] + \lambda_k \boldsymbol{I})^{-1} \boldsymbol{d}_{\mathcal{S},k}[i],$$

where $\boldsymbol{R}_{\mathcal{S},k}[i] = E[|z_k[i]|^2 \boldsymbol{B}_{\mathcal{S}}^H[i] \boldsymbol{P}_{\mathcal{S}}^H[i] \boldsymbol{w}_k[i] \boldsymbol{w}_k^H[i] \boldsymbol{P}_{\mathcal{S}}[i] \boldsymbol{B}_{\mathcal{S}}[i]]$
and $\boldsymbol{d}_{\mathcal{S},k}[i] = E[z_k[i] \boldsymbol{B}_{\mathcal{S}}^H[i] \boldsymbol{P}_{\mathcal{S}}^H[i] \boldsymbol{w}_k[i]]$

- CCM expression for the receive filter:

$$\boldsymbol{w}_k[i] = \boldsymbol{R}_k^{-1}[i](\boldsymbol{d}_k[i] - \boldsymbol{p}_k[i]\gamma_k^{-1}[i](\boldsymbol{p}_k^H[i]\boldsymbol{R}_k^{-1}[i]\boldsymbol{d}_k[i] - \nu).$$

where $\gamma_k[i] = \boldsymbol{p}_k^H[i]\boldsymbol{R}_k^{-1}[i]\boldsymbol{p}_k[i]$, $\boldsymbol{R}_k[i] = E[|z_k[i]|^2 \boldsymbol{r}[i]\boldsymbol{r}^H[i]]$
and $\boldsymbol{d}_k[i] = E[z_k[i]\boldsymbol{r}[i]]$.

- The linear MMSE channel estimator is given by:

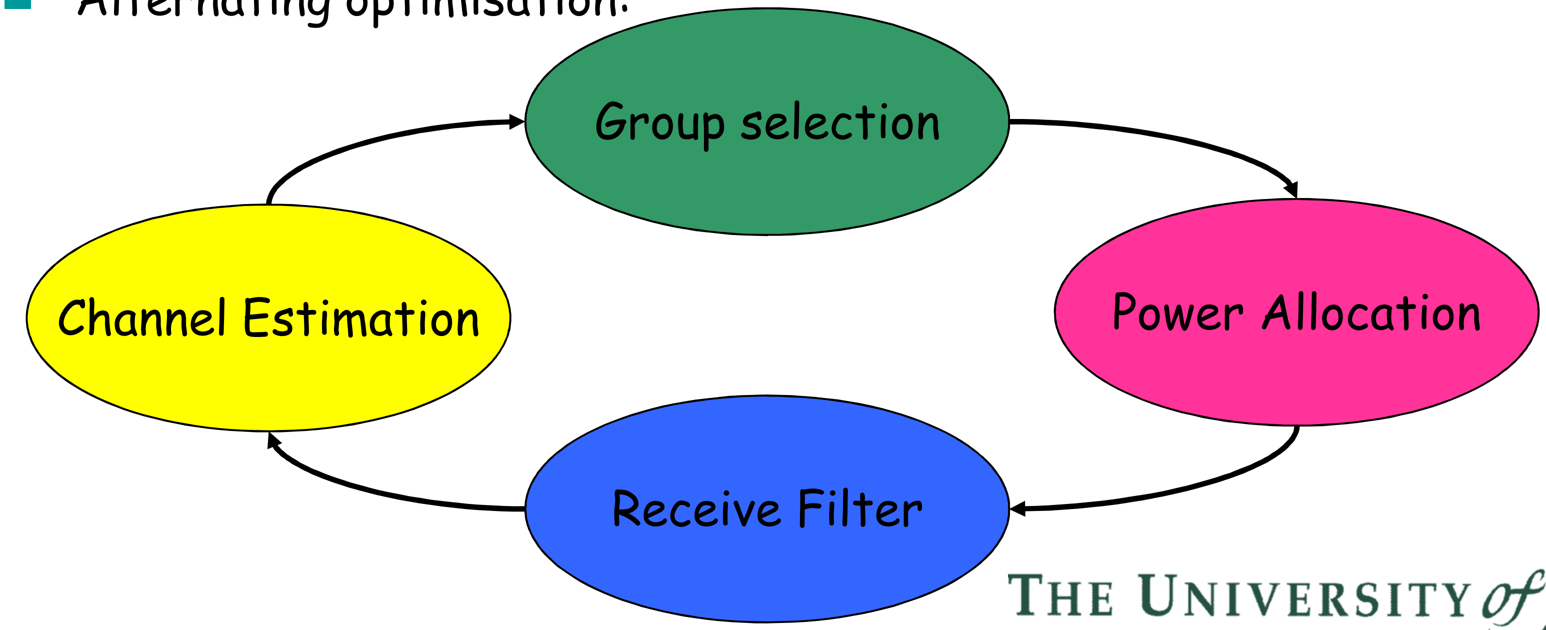
$$\hat{\boldsymbol{h}}_k[i] = \arg\min_{\boldsymbol{h}_k[i]} \boldsymbol{h}_k^H[i] \boldsymbol{\Upsilon}_k \boldsymbol{h}_k[i], \ \text{subject to} \ ||\boldsymbol{h}_k[i]|| = 1,$$

where $\boldsymbol{\Upsilon}_k = \boldsymbol{C}_k^H \boldsymbol{B}_k^H[i] \boldsymbol{A}_k^H[i] \phi_n \phi_n^H \boldsymbol{A}_k[i] \boldsymbol{B}_k[i] \boldsymbol{C}_k$.

- Computational complexity: cubic in the number of parameters.

# Blind Adaptive Algorithms

- Main strategy:
  - Blind RALS-based algorithms -> complexity from cubic to quadratic
  - Estimate channels
  - Build the group of most relevant nodes for joint design: RAKE receiver + selection of strongest nodes.
  - Compute power allocation
  - Calculate receive filter
- Alternating optimisation:



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# Blind Adaptive Algorithms: Channel Estimation and Group Selection

- Channel estimation using an RLS-type algorithm:

$$\hat{\boldsymbol{h}}_k[i] = (\boldsymbol{I} - \tau_k[i]\hat{\boldsymbol{\Upsilon}}_k[i])\hat{\boldsymbol{h}}_k[i-1],$$

$\tau_k[i] = 1/tr[\hat{\boldsymbol{\Upsilon}}_k[i]]$ and $\hat{\boldsymbol{h}}_k[i] \leftarrow \hat{\boldsymbol{h}}_k[i]/||\hat{\boldsymbol{h}}_k[i]||$ to normalize the channel.

- The quantity $\hat{\boldsymbol{\Upsilon}}_k[i]$ is estimated by

$$\hat{\boldsymbol{\Upsilon}}_k[i] = \alpha\hat{\boldsymbol{\Upsilon}}[i-1] + \boldsymbol{C}_k^H\hat{\boldsymbol{B}}_k^H[i]\hat{\boldsymbol{A}}_k^H[i]\hat{\boldsymbol{R}}^{-p}[i]\hat{\boldsymbol{A}}_k[i]\hat{\boldsymbol{B}}_k[i]\boldsymbol{C}_k,$$

where $\alpha$ is a forgetting factor that should be close to 1 and $\hat{\boldsymbol{R}}^{-p}[i]$ is computed with the matrix inversion lemma.

- Building the group of G nodes relies on the output of the RAKE receiver:

$$z_k^{\mathsf{RAKE}}[i] = (\widetilde{\boldsymbol{C}}_k\hat{\boldsymbol{h}}_k[i])^H\boldsymbol{r}[i] = \hat{\boldsymbol{p}}_k^H[i]\boldsymbol{r}[i]$$

- Select the nodes according to:

$$\text{compute the } G \text{ largest } |z_k^{\mathsf{RAKE}}[i]|,\ k = 1, 2, \ldots, K$$

# Blind Adaptive Algorithms: Computation of the Power Allocation

- The group-based power allocation algorithm is computed by:

$$\hat{\boldsymbol{a}}_{\mathcal{S},k}[i] = \hat{\boldsymbol{P}}_{\mathcal{S},k}[i-1]\hat{\boldsymbol{d}}_{\mathcal{S},k}[i],$$

$$\hat{\boldsymbol{d}}_{\mathcal{S},k}[i] = \alpha\hat{\boldsymbol{d}}_{\mathcal{S},k}[i] + z_k[i]\boldsymbol{v}_k[i],$$

$$\boldsymbol{k}_{\mathcal{S},k} = \frac{\alpha^{-1}\hat{\boldsymbol{P}}_{\mathcal{S},k}[i-1]z_k[i]\boldsymbol{v}_k[i]}{1+\alpha^{-1}\boldsymbol{v}_k^H[i]\hat{\boldsymbol{P}}_{\mathcal{S},k}[i-1]\boldsymbol{v}_k[i]|z_k[i]|^2},$$

$$\hat{\boldsymbol{P}}_{\mathcal{S},k}[i] = \alpha^{-1}\hat{\boldsymbol{P}}_{\mathcal{S},k}[i-1] - \alpha^{-1}z_k^*[i]\boldsymbol{k}_{\mathcal{S},k}[i]\boldsymbol{v}_k^H[i]\hat{\boldsymbol{P}}_{\mathcal{S},k}[i-1].$$

The normalization $\hat{\boldsymbol{a}}_{\mathcal{S},k}[i] \leftarrow P_G\ \hat{\boldsymbol{a}}_{\mathcal{S},k}[i]/||\hat{\boldsymbol{a}}_{\mathcal{S},k}[i]||$ is then made to ensure the power constraint.

# Blind Adaptive Algorithms: Computation of the Receive Filter

- The receive filter is computed by

$$\hat{\boldsymbol{w}}_k[i] = \boldsymbol{P}_k[i](\hat{\boldsymbol{d}}_k[i] - \hat{\boldsymbol{p}}_k[i]\hat{\gamma}_k^{-1}[i](\hat{\boldsymbol{p}}_k^H[i]\hat{\boldsymbol{P}}_k[i]\hat{\boldsymbol{d}}_k[i] - \nu),$$

where $\gamma_k^{-1}[i] = \hat{\boldsymbol{p}}_k^H[i]\hat{\boldsymbol{P}}_k[i]\hat{\boldsymbol{p}}_k[i]$ and

$$\hat{\boldsymbol{d}}_k[i] = \alpha\hat{\boldsymbol{d}}_k[i] + z_k[i]\boldsymbol{r}[i],$$

$$\boldsymbol{k} = \frac{\alpha^{-1}\hat{\boldsymbol{P}}_k[i-1]z_k[i]\boldsymbol{r}[i]}{1 + \alpha^{-1}\boldsymbol{r}^H[i]\hat{\boldsymbol{P}}_k[i-1]\boldsymbol{r}[i]|z_k[i]|^2},$$

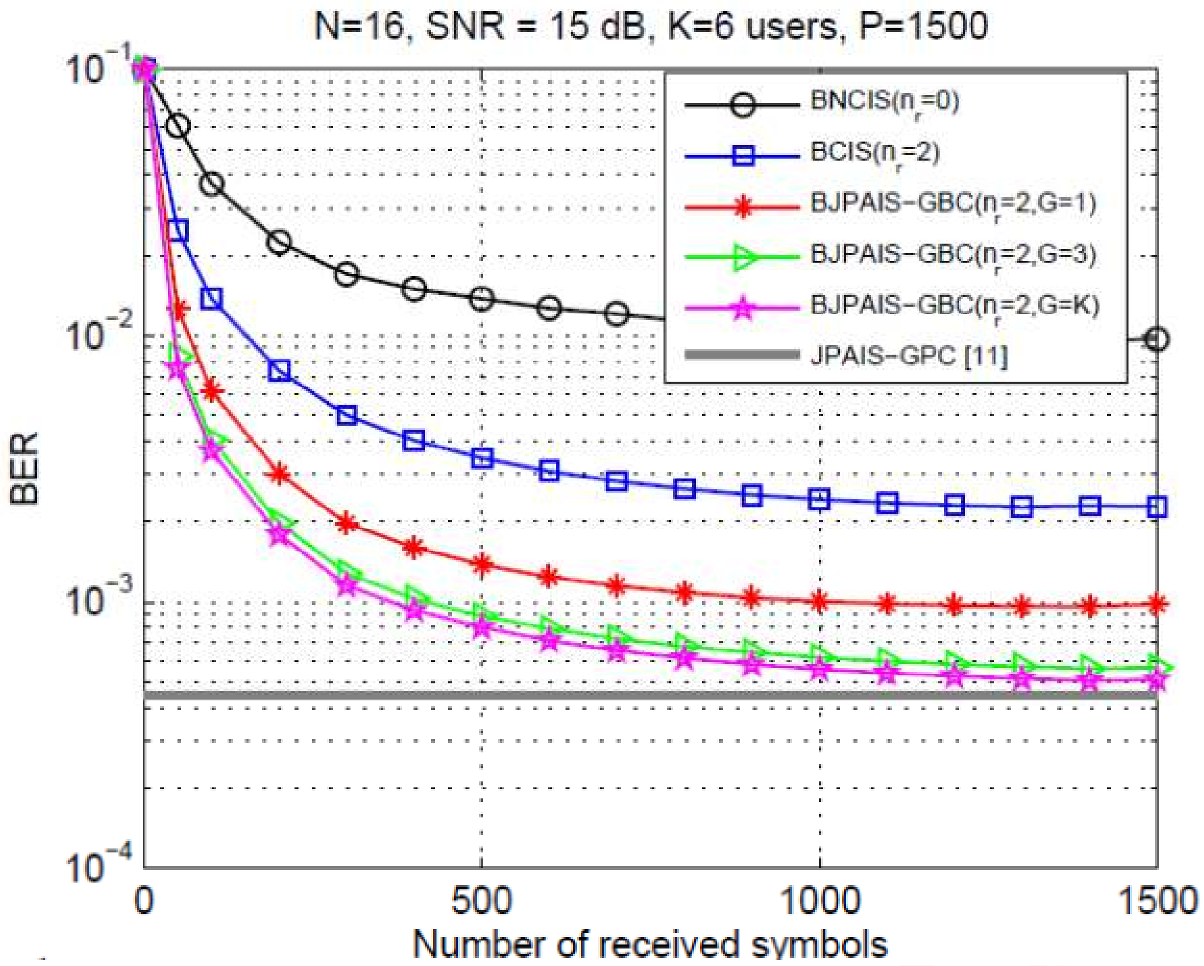
$$\hat{\boldsymbol{P}}_k[i] = \alpha^{-1}\hat{\boldsymbol{P}}_k[i-1] - \alpha^{-1}z_k^*[i]\boldsymbol{k}[i]\boldsymbol{r}^H[i]\hat{\boldsymbol{P}}_k[i-1].$$

# Simulations: Scenario and Parameters

- We assess the BER of the following algorithms:
  - Proposed BJPAIS algorithms with group-based contraints (JPAIS-GBC)
  - Cooperative blind scheme with equal power allocation (CIS) (Venturino06,Yang09)
  - Blind CCM scheme without cooperation (NCIS)
- We consider a DS-CDMA network with random spreading codes with a processing gain N=16, AF or DF protocols.
- The channels with L=5 paths have a random power delay profile with gains taken from complex Gaussian rvs with unit variance and zero mean.
- The power constraint parameter $P_{A,k}$ is set for each user so one can control the SNR and P_T= P_G + (K-G) $P_{A,k}$
- All nodes are equipped with blind linear CCM receivers which estimate the channel.
- Packets have 1500 QPSK symbols and curves are averaged over 1000 runs.
- A feedback channel, which is error free and delayless, is employed to feedback the power levels to the nodes.

# Simulations: BER X Symbols

- DF protocol



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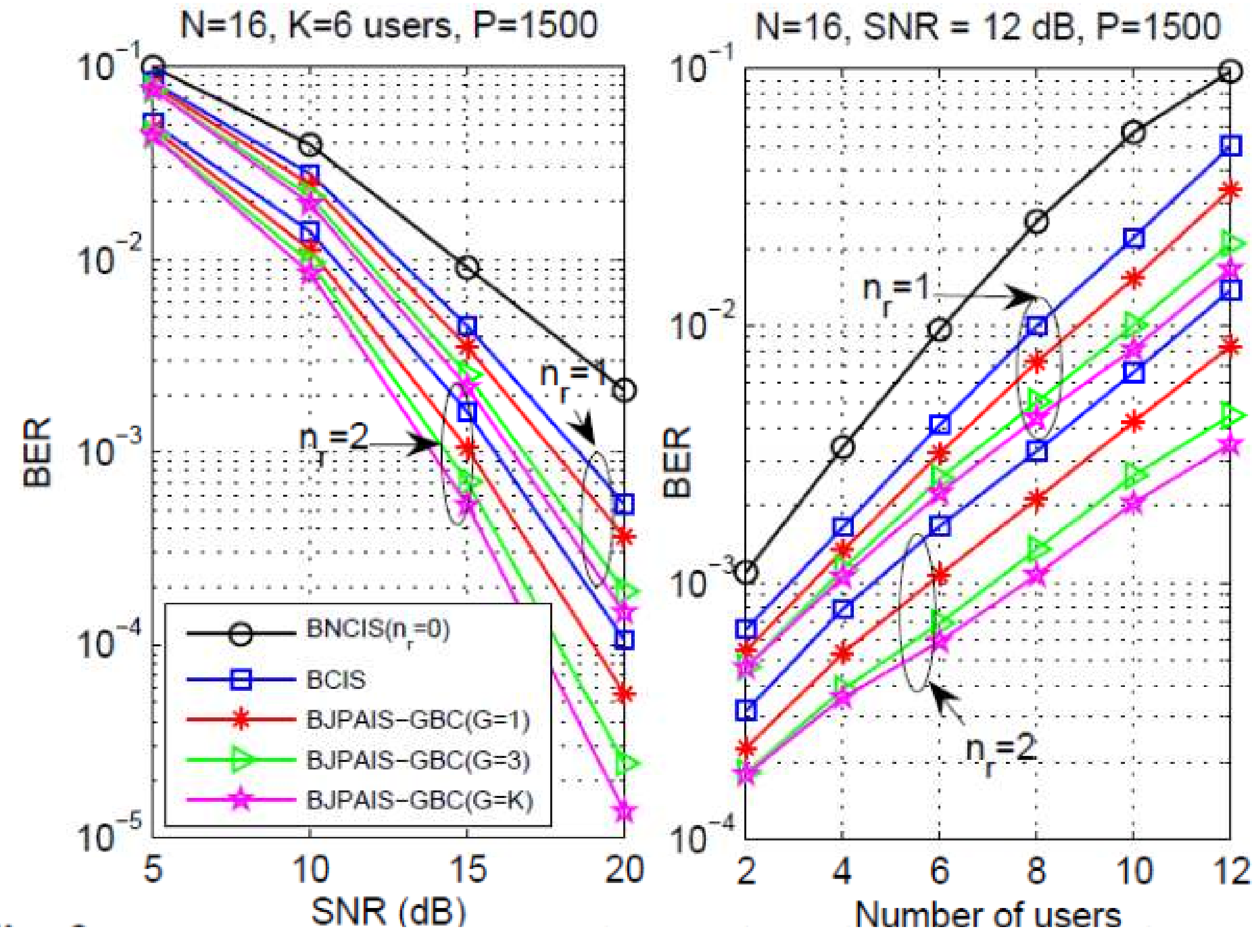
# Simulations: BER X SNR and Users

- DF protocol



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# Conclusions

- A group-based strategy (BJPAIS-GBC) that is flexible and effective for joint blind resource allocation and interference suppression has been devised.
- Blind adaptive RALS algorithms have been devised to allocate the power, estimate the channel and the receive filter.
- The application of BJPAIS-GBC with RALS to multi-hop DS-CDMA networks obtained a performance significantly better than existing techniques.
- The proposed blind techniques do not require training symbols and employ a feedback channel to provide the power allocation to the nodes.
- The proposed blind algorithms allow one to use about 20-25% more nodes for the same BER performance or to reduce the transmitted power by 3 dB.
- The complexity of the proposed algorithms is about 20% higher than cooperative blind schemes (CIS) with equal power allocation.

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