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Interference Management in Future Wireless Networks for High Throughput, High Fairness and Low Energy Consumption

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Report on the Interference Management in Future Wireless Networks： Distributed Coordinated of Multi-point (COMP)

outline

- *Adaptive Bit partition in multi-user cooperative DAS*
- Minimum SER-based power allocation in D-MIMO
- Adaptive RRU cluster selection in MU-DAS

Adaptive bit partition:

- **Two kinds of interferences in Multi-user cooperative DAS: Multi-user interference (MUI) in local cell and inter-cell interference (ICI) from *s* adjacent cells.**
- **Use feedback bits to quantize the above two channels respectively.**
- **Adaptively allocate bits between the two channels based on minimum rate loss criterion.**

Deriving of rate loss expression:

- **Received signal with quantization error**

$$y_k = P\mathbf{H}_k\hat{\mathbf{w}}_k x_k + \underbrace{P\sum_{i=1,i\neq k}^{K}\mathbf{H}_k\hat{\mathbf{w}}_i x_i}_{MUI\ within\ local\ cell} + \underbrace{P\sum_{n=1}^{N}\mathbf{G}_{k,n}\hat{\mathbf{w}}_n x_n}_{ICI\ from\ adajcent\ cells} + n_k,$$

- **Average data rate:**

$$R_k^{LF} = E\left[\log_2\left(1+P\left|\mathbf{H}_k\hat{\mathbf{w}}_k\right|^2 + P\sum_{k=1,k\neq i}^{K}\left|\mathbf{H}_k\hat{\mathbf{w}}_i\right|^2 + P\sum_{n=1}^{N}\left|\mathbf{G}_{k,n}\hat{\mathbf{w}}_n\right|^2\right)\right] - E\left[\log_2\left(1+P\sum_{k=1,k\neq i}^{K}\left|\mathbf{H}_k\hat{\mathbf{w}}_i\right|^2 + P\sum_{n=1}^{N}\left|\mathbf{G}_{k,n}\hat{\mathbf{w}}_n\right|^2\right)\right]$$

- **Average data rate with perfect CSIT:**

$$R_k^{CSIT} = E\left[\log_2\left(1+P\left|\mathbf{H}_k\mathbf{w}_k\right|^2\right)\right]$$

- **Rate loss :**

$$\Delta R = R_k^{CSIT} - R_k^{LF}$$

$$\approx E\left[\log_2\left(1+P\sum_{k=1,k\neq i}^{K}\left|\mathbf{H}_k\hat{\mathbf{w}}_i\right|^2+P\sum_{n=1}^{N}\left|\mathbf{G}_{k,n}\hat{\mathbf{w}}_n\right|^2\right)\right]$$

$$\leq \log_2\left[1+PE\left(\left\|\mathbf{H}_k\right\|^2\right)\sum_{k=1,k\neq i}^{K}E\left(\left|\tilde{\mathbf{H}}_k\hat{\mathbf{w}}_i\right|^2\right)+P\sum_{n=1}^{N}\left(E\left(\left\|\mathbf{G}_{k,n}\right\|^2\right)\square E\left(\left|\tilde{\mathbf{G}}_{k,n}\hat{\mathbf{w}}_n\right|^2\right)\right)\right]$$

$$=\log_2\left[1+P\left(\sum_{m=1}^{M}L_{k,m}\right)\sum_{k=1,k\neq i}^{K}\left(E\left(\left|\tilde{\mathbf{H}}_k\hat{\mathbf{w}}_i\right|^2\right)\right)+P\left(\sum_{n=1}^{N}\left(\sum_{m=1}^{M}L_{n,m}\right)E\left(\left|\tilde{\mathbf{G}}_{k,n}\hat{\mathbf{w}}_n\right|^2\right)\right)\right]$$

$\tilde{\mathbf{H}}_k$ **is isotropically distributed within the M-1 dimension's null space of** $\hat{\mathbf{w}}_i$

$$E\left(\left|\tilde{\mathbf{H}}_k\hat{\mathbf{w}}_i\right|^2\right)=\left[E\left(\sin^2\left(\theta_k\right)\right)\right]\cdot\left[E\left(\beta\left(1,M-2\right)\right)\right]$$

$$=\left[{(M-1)}\big/{M}\cdot 2^{\frac{-B_k}{M-1}}\right]\cdot\left[1\big/{(M-1)}\right]=2^{\frac{-B_k}{M-1}}\big/M$$

Similarly: $$E\left(\left|\tilde{\mathbf{G}}_{k,n}\hat{\mathbf{w}}_n\right|^2\right)=2^{\frac{-B_{k,n}}{M-1}}\big/M$$

Upper-bound of rate loss:

$$\Delta R_{up}=\log_2\left[1+\frac{P(K-1)}{M}\left(\sum_{m=1}^{M}L_{k,m}\right)2^{\frac{-B_k}{M-1}}+\frac{P}{M}\sum_{n=1}^{N}\left(\left(\sum_{m=1}^{M}L_{n,m}\right)2^{\frac{-B_{k,n}}{M-1}}\right)\right]$$

To minimum rate loss, the optimization is divided into two steps

Where: $\mathbf{H}_k = \left[\sqrt{L_{k,1}} h_{k,1}, \cdots, \sqrt{L_{k,m}} h_{k,m}, \cdots, \sqrt{L_{k,M}} h_{k,M} \right] (1 \le m \le M)$

$\mathbf{H}_k = \frac{\mathbf{H}_k}{\|\mathbf{H}_k\|_2}$ - normalized H

$L_{k,m}$ - large scale fading

$h_{k,m} \sim CN(0,1)$ - small scale fading

$\hat{\mathbf{w}}_i$ - precoding vector

$n_k \sim CN(0,1)$ - normalized AWGN

P - transmit power constraint

M - Number of RRUs in each cell

K -Number of users

N -Number of interference cells

B_k -bits to quantize local channel

$B_{k,n}$ -bits to quantize ICI channel

$$B_k + \sum_{n=1}^{N} B_{k,n} = B_{tot}$$

First step optimization:

$$\min_{\{B_{k,n}\}_{n=1}^{N}} \frac{P}{M}\sum_{n=1}^{N}\left(\left(\sum_{m=1}^{M} L_{n,m}\right)2^{\frac{-B_{k,n}}{M-1}}\right)$$

$$s.t.\ \sum_{n=1}^{N} B_{k,n} = B_i, and\ B_{k,n} \geq 0$$

Applying the arithmetic mean-geometric mean inequality we get:

$$\frac{P}{M}\sum_{n=1}^{N}\left(\left(\sum_{m=1}^{M} L_{n,m}\right)2^{\frac{-B_{k,n}}{M-1}}\right) \geq \frac{PN}{M}\left(\prod_{n=1}^{N}\left(\sum_{m=1}^{M} L_{n,m}\right)2^{\frac{-B_{k,n}}{M-1}}\right)^{1/N}$$

Where the equality holds for: $\left(\sum_{m=1}^{M} L_{n,m}\right)2^{\frac{-B_{k,n}}{M-1}} = \left(\sum_{m=1}^{M} L_{j,m}\right)2^{\frac{-B_{k,j}}{M-1}} \quad n \neq j$

First step result: $$B_{k,n}^{opt} = \frac{B_i}{N} + (M-1)\log_2\left(\sum_{m=1}^{M} L_{n,m} \Big/ \prod_{j=1}^{N}\left(\sum_{m=1}^{M} L_{j,m}\right)^{1/N}\right)$$

upper-bound of the rate loss can be rewritten as:

$$\Delta R^{opt} = \log_2\left[1 + \frac{P(K-1)}{M} C_1 2^{\frac{-B_k}{M-1}} + \frac{P|\eta|}{M} C_2 2^{\frac{-(B_{tot}-B_k)}{|\eta|(M-1)}}\right]$$

Where $C_1 = \left(\sum_{m=1}^{M} L_{k,m}\right)$ **and** $C_2 = \prod_{n=1}^{|\eta|}\left(\sum_{m=1}^{M} L_{n,m}\right)^{1/|\eta|}$

Second step optimization:

differentiate the objective function with respect to B_k

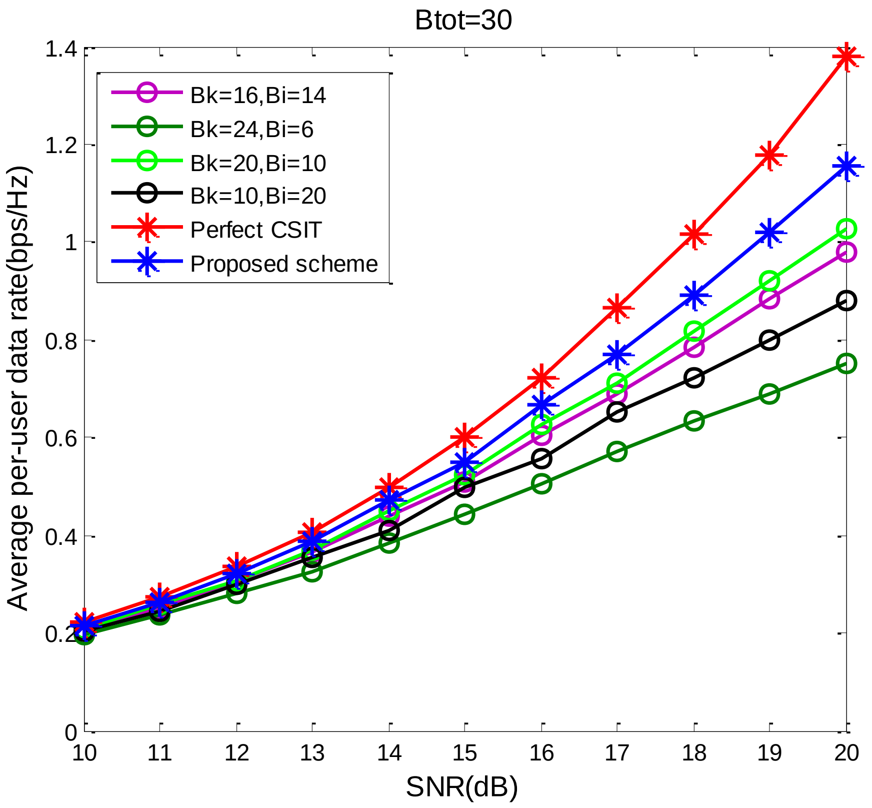
$$\ln 2 \times \left[-\frac{P(K-1)C_1}{M(M-1)} 2^{\frac{-B_k}{M-1}} + \frac{PC_2}{M(M-1)} 2^{\frac{-(B_{tot}-B_k)}{|\eta|(M-1)}} \right]$$

Set differential function to zero, we get optimum number of B_k

$$B_k^{opt} = \frac{|\eta|(M-1)\log_2\left(\frac{(K-1)C_1}{C_2}\right) + B_{tot}}{|\eta|+1}$$

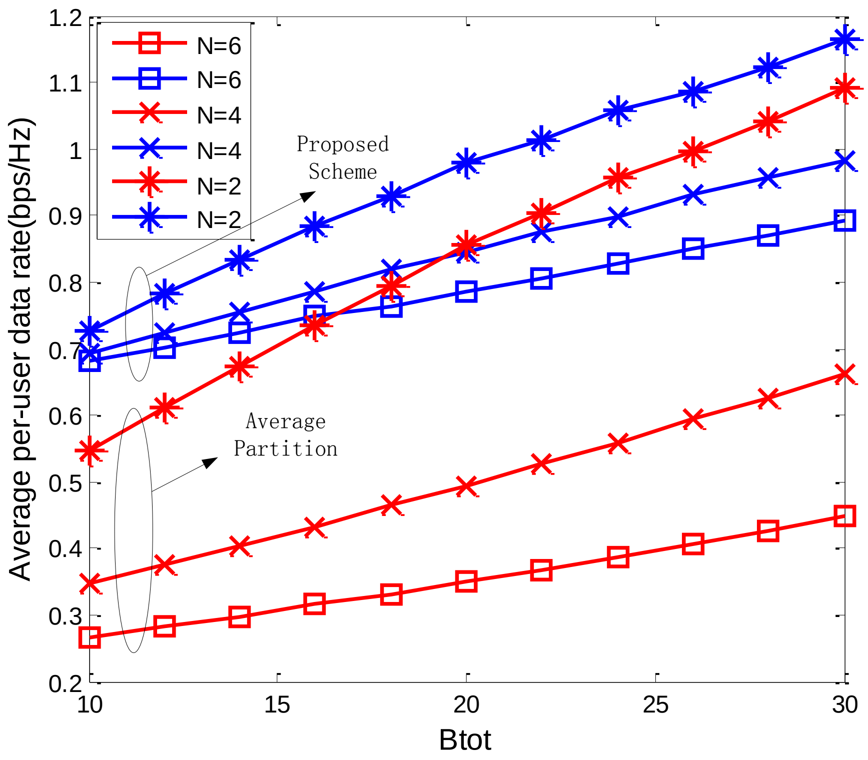
Simulation parameters
N=2, Btot=30
K=3,M=4.
cell radius: 100 meters
path loss exponent: 3.5
shadowing fading: 8dB

Simulation Results

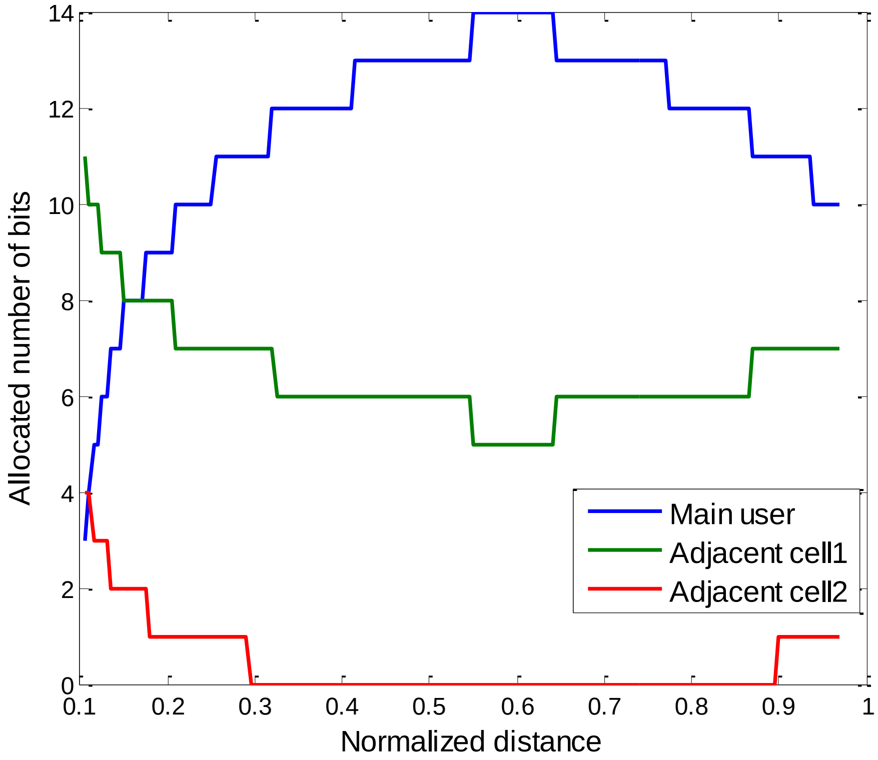


- **Ergodic capacity of the proposed algorithm obtains better performance than other average bit-partition schemes.**

- **Data rate with increasing number of total feedback bits.**
- **All algorithms' rate increases as the total bits number.**
- **When more interference cells exist, more bits located to quantize ICI channels, performance decrease.**



- **Bit partition condition when a main user moves straightforward from center to edge of cell.**
- **When user moves from center gradually close to a RRU (about 0.6 normalized distances from the center), channel condition becomes better, more bits are allocated to quantize desired channel, bits allocated to the interference cells decreases, Vice verse.**



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- Propose a power allocation scheme in cooperative distributed MIMO systems.
- The rank of the transmit correlation matrix in every RRU is also considered.
- The proposed scheme can obtain obvious capacity gain with less feedback information.

Derived SER of MPSK:

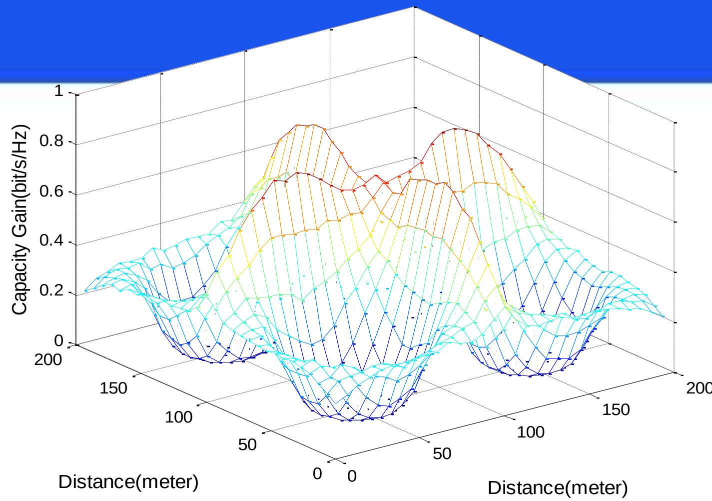
$$P_{M_g} \approx \sum_{l=1}^{L} \frac{N\pi_l \sigma_n^2}{4P_l \alpha_l^2 \sin^2 \frac{\pi}{M_g} + 3\sigma_n^2},$$

u_3 **is chosen to satisfy** $P_j = u_3 P_{j,a} P_{j,b}$

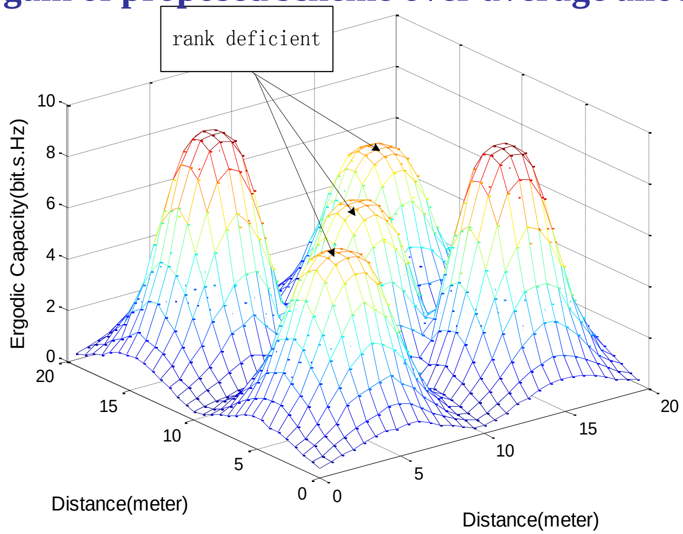
$$\sum_{j=1}^{g} P_j = P_0$$

$$P_{j,a} = \left(\frac{q_j}{u} - \frac{q_j \sigma_n^2}{M \alpha_j} \right)^+ \qquad P_{j,b} = \frac{P_0 r_j}{\sum_{i=1}^{g} r_i}, (j = 1, \cdots, g)$$

Simulation Parameters	
port number	5
Transmit antenna	(4,4,4,4,4)
Receive antenna	3
Rank of DA port	(4,3,3,3,4)
Pass loss exponent	4.0
Shadow fading	8dB



Capacity gain of proposed scheme over average allocation scheme



Capacity gain of proposed scheme over average allocation scheme

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Adaptive RRU cluster selection in MU-DAs:

- An low-complexity RRU cluster selection algorithm based on maximizing SINR criterion.
- More RRU will reduce the ICI interference but cause more quantization error. Less RRUs will increase quantization precision but reduce diversity gain.
- Bit partition between desired cluster channel and inference cluster channel.

Deriving of users' SINR:

The received signal of user :

$$y_k = \mathbf{H}_k^{\Re_k} \hat{\mathbf{w}}_k^{\Re_k} x_k + \underbrace{\sum_{i=1, i \neq k}^{K} \mathbf{H}_k^{\Re_k} \hat{\mathbf{w}}_i^{\Re_k} x_i}_{MUI\ within\ cluster\ \Re_k} + \underbrace{\mathbf{H}_k^{\overline{\Re_k}} \hat{\mathbf{w}}_j^{\overline{\Re_k}} x_j}_{interferecnce\ \ from\ cluster\ \overline{\Re_k}} + n_k ,$$

The SINR of user k with quantized feedback can be given as:

$$SINR_k = \frac{\left|\mathbf{H}_k^{\Re_k} \hat{\mathbf{w}}_k^{\Re_k}\right|^2}{\sigma^2 + \sum_{k=1, k\neq i}^{K} \left|\mathbf{H}_k^{\Re_k} \hat{\mathbf{w}}_i^{\Re_k}\right|^2 + \left|\mathbf{H}_k^{\overline{\Re_k}} \hat{\mathbf{w}}_k^{\overline{\Re_k}}\right|^2}$$

Using Jesen's inequality, and notice that:

$$E\left(\left|\tilde{\mathbf{H}}_k \hat{\mathbf{w}}_i\right|^2\right) = 2^{\frac{-B_k}{M-1}} \Big/ N_t \left|\Re_k\right|$$

$$E\left(\left|\mathbf{H}_k^{\overline{\Re_k}} \hat{\mathbf{w}}_k^{\overline{\Re_k}}\right|^2\right) = 2^{\frac{-B^{\overline{\Re_k}}}{N_t\left|\overline{\Re_k}\right|-1}} \Big/ N_t \left|\overline{\Re_k}\right|$$

$$E\left(\left|\mathbf{H}_k^{\Re_k} \hat{\mathbf{w}}_k^{\Re_k}\right|^2\right) = \beta\left(1, N_t\left|\Re_k\right|-1\right) = \frac{1}{N_t\left|\Re_k\right|}$$

The lower-bound of SINR:

$$E\left\{SINR_k\right\} \geq \frac{E\left(\left\|\mathbf{H}_k^{\Re_k}\right\|^2\right) E\left(\left|\mathbf{H}_k^{\Re_k}\hat{\mathbf{w}}_k^{\Re_k}\right|^2\right)}{\sigma^2 + E\left(\left\|\mathbf{H}_k^{\Re_k}\right\|^2\right)\sum_{k=1,k\neq i}^{K} E\left(\left|\mathbf{H}_k^{\Re_k}\hat{\mathbf{w}}_i^{\Re_k}\right|^2\right) + E\left(\left\|\mathbf{H}_k^{\overline{\Re_k}}\right\|^2\right) E\left(\left|\mathbf{H}_k^{\overline{\Re_k}}\hat{\mathbf{w}}_k^{\overline{\Re_k}}\right|^2\right)}$$

$$= \frac{\left(\sum_{j=1}^{|\Re_k|} L_k^j\right) \square \left(\frac{1}{N_t|\Re_k|}\right)}{\sigma^2 + (K\text{-}1)\left(\sum_{j=1}^{|\Re_k|} L_k^j\right)\left(\frac{2^{\frac{-B^{\Re_k}}{N_t|\Re_k|-1}}}{N_t|\Re_k|}\right) + \left(\sum_{l=1}^{|\overline{\Re_k}|} L_k^l\right)\left(\frac{2^{\frac{-B^{\overline{\Re_k}}}{N_t|\overline{\Re_k}|-1}}}{N_t|\overline{\Re_k}|}\right)} = \gamma_k$$

Bit partition to minimum denominator term, differentiating with respect to $B^{\Re_k}$

$$M_1 2^{\frac{-B^{\Re_k}}{N_t|\Re_k|-1}} + M_2 2^{\frac{-\left(B_{tot}-B^{\Re_k}\right)}{N_t\left|\overline{\Re_k}\right|-1}}$$

The optimum bit number:

$$B_{opt}^{\Re_k} = \frac{\left(N_t\left|\Re_k\right|-1\right)\left[\left(N_t\left|\overline{\Re_k}\right|-1\right)\log_2\left(\frac{M_1}{M_2}\right)+B_{tot}\right]}{N_t M-2}$$

Where: $M_1 = \frac{-(K\text{-}1)\left(N_t\left|\Re_k\right|-1\right)\left(\sum_{j=1}^{|\Re_k|} L_k^j\right)}{N_t\left|\Re_k\right|}$ **and** $M_2 = \frac{\left(\sum_{l=1}^{\left|\overline{\Re_k}\right|} L_k^l\right)}{N_t\left|\overline{\Re_k}\right|}$

Low-complexity adaptive RRU selection algorithm:

Algorithm 1: Adaptive RRU Selection

Initialization: Set $\Re_k = \emptyset$ and $\overline{\Re_k} = B_c$

While $\overline{\Re_k} \neq \emptyset$ do

Find $j^* = \arg\max_{j \in \overline{\Re_k}} L_k^j$

If $\gamma_k^{BP}\left(\Re_k \cup \{j^*\}\right) > \gamma_k^{BP}\left(\Re_k\right)$ then

$\Re_k = \Re_k \cup \{j^*\}$ and $\overline{\Re_k} = \overline{\Re_k} \setminus \{j^*\}$

Else

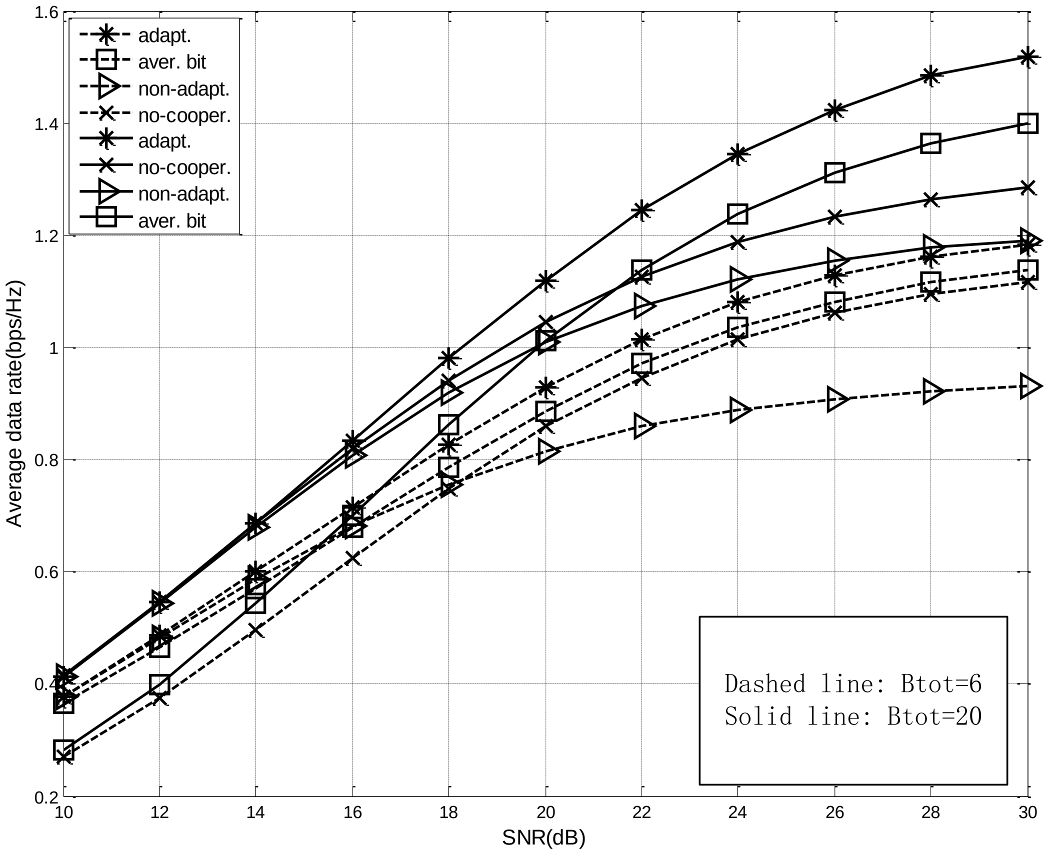
Return $\Re_k^* = \Re_k$

End if

End while

Simulation Results

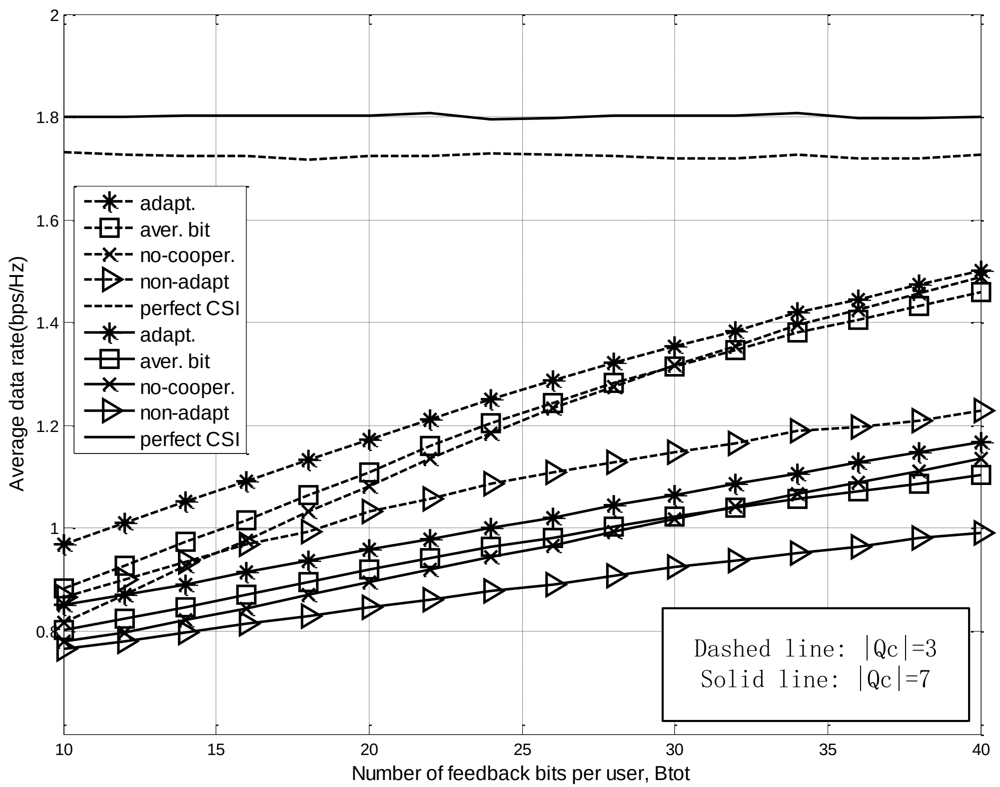
Simulation parameters:
K=3,M=4.
cell radius: 50 meters
path loss exponent: 3.5
shadowing fading: 8dB



- **Proposed algorithm has evident rate gain than other staple schemes, such as non-adaptive (The whole set chosen) and no-cooperation (only one RRU is chosen), especially in high SNR region.**
- **Using optimum bit partition can get a further gain than average bit partition.**

■Proposed algorithm achieves better performance than other schemes, and increased with more feedback bits.

■When total cluster sets become larger, the performance decreases correspondingly. That can be explained that more RRus will cause more severe ICI and reduce quantization precision.



Thank you for your attention !