Kombination adaptiver und nicht-adaptiver OFDMA-Übertragungsverfahren bei nicht perfekter Kanalkenntnis

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Verbundprojekt:
Aufwandsgünstige Realisierung von hochperformanten OFDM-Systemen mit partieller Kanalkenntnis

Motivation

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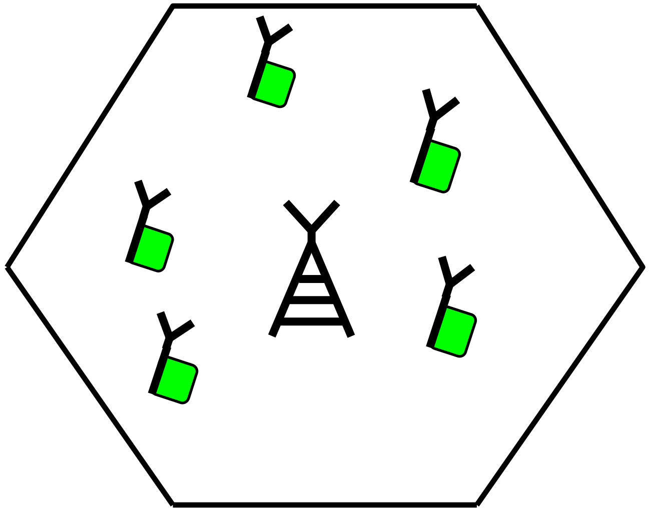
OFDMA	
Perfect CSIT	No CSIT
pure adaptive	*pure non-adaptive*



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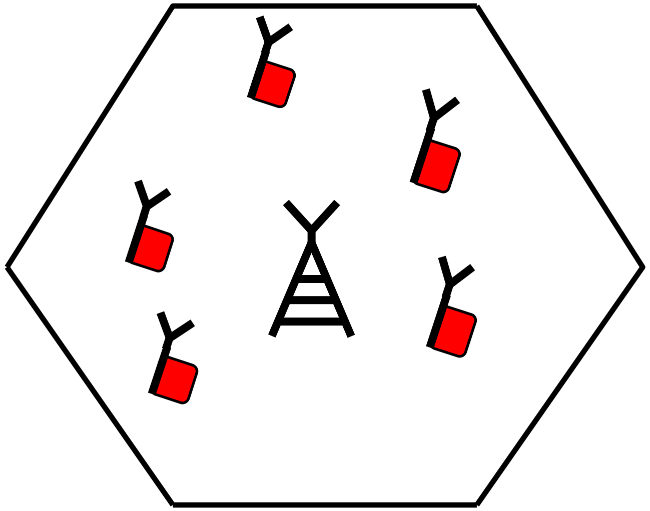

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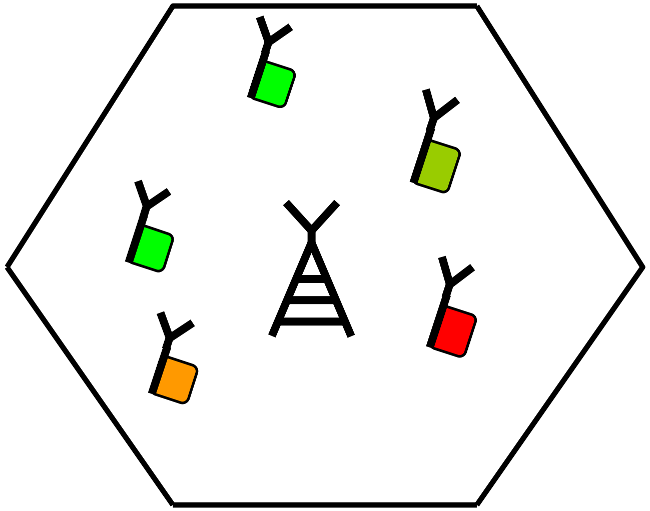
OFDMA

Perfect CSIT	No CSIT
pure adaptive	*pure non-adaptive*

Imperfect CSIT

Combination adaptive – non-adaptive



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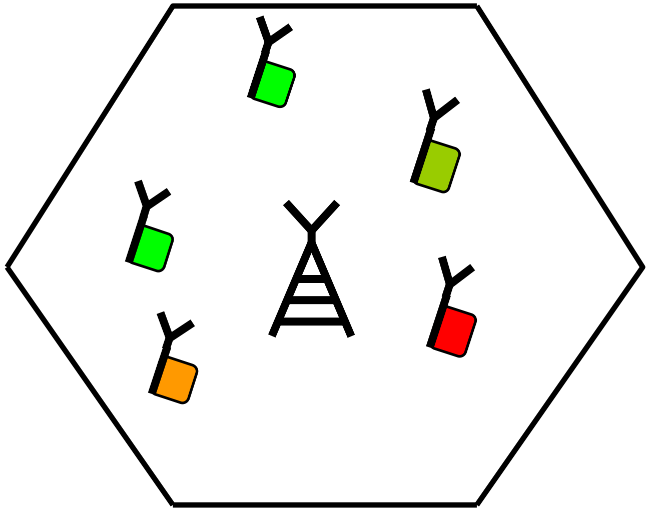
Perfect CSIT *pure adaptive*	No CSIT *pure non-adaptive*
Imperfect CSIT *Combination adaptive – non-adaptive*	



How to combine adaptive and non-adaptive transmission ?

How to decide which user is served adaptively or non-adaptively ?

System model

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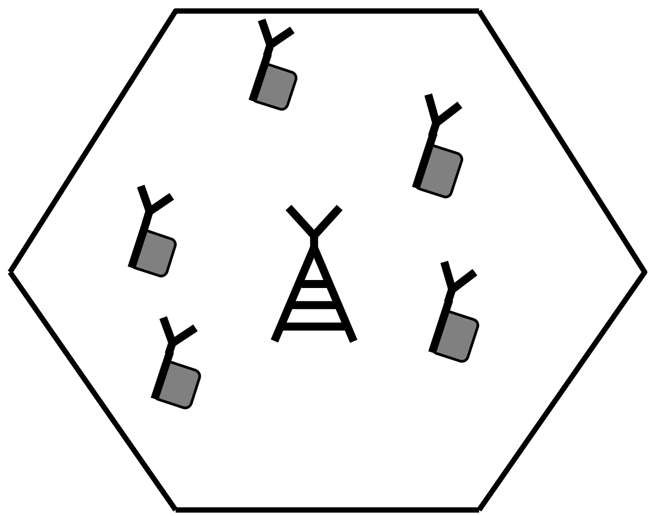
- OFDMA, *N* subcarriers
- Downlink
- One BS with one transmit antenna
- *U* MSs with one receive antenna each
- MSs uniformly distributed inside the cell
- Pathloss and i.i.d. Rayleigh fading
- Channel Quality Information (CQI): Instantaneous SNR of user *u* on subcarrier *n* in time slot *k*:

$$\gamma_u(n,k) = \bar{\gamma}_u \cdot |H_u(n,k)|^2$$



- CQI imperfect
  - Outdated $\rho_u = J_0\left(2\pi \cdot \frac{f_c}{c} \cdot v_u \cdot T\right)$
  - Noisy estimates $\sigma^2_{E,u} = (1+\bar{\gamma}_u)^{-1}$

Combining adaptive and non-adaptive transmission

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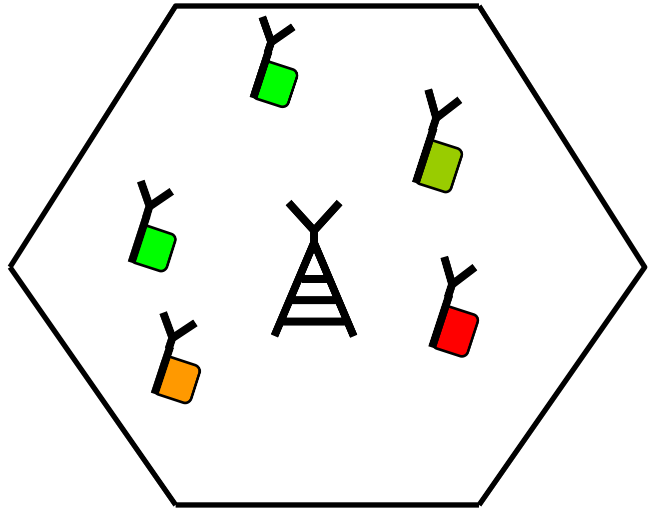
- Idea:
  - Users with reliable CQI apply adaptive transmission
  - Users with unreliable CQI apply non-adaptive transmission



Combining adaptive and non-adaptive transmission

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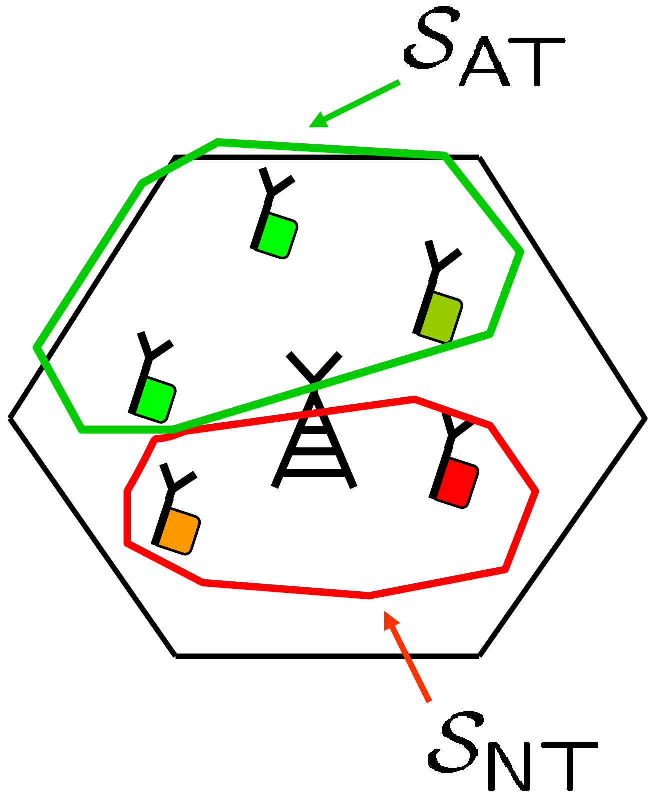
- Divide users in two sets



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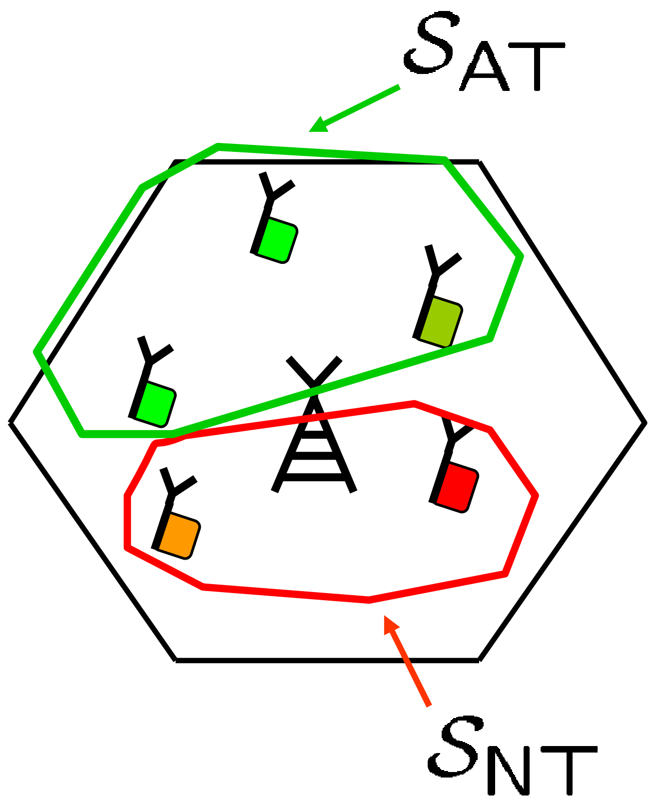
  - User data rate applying AT depends on number U_{AT} of adaptive users



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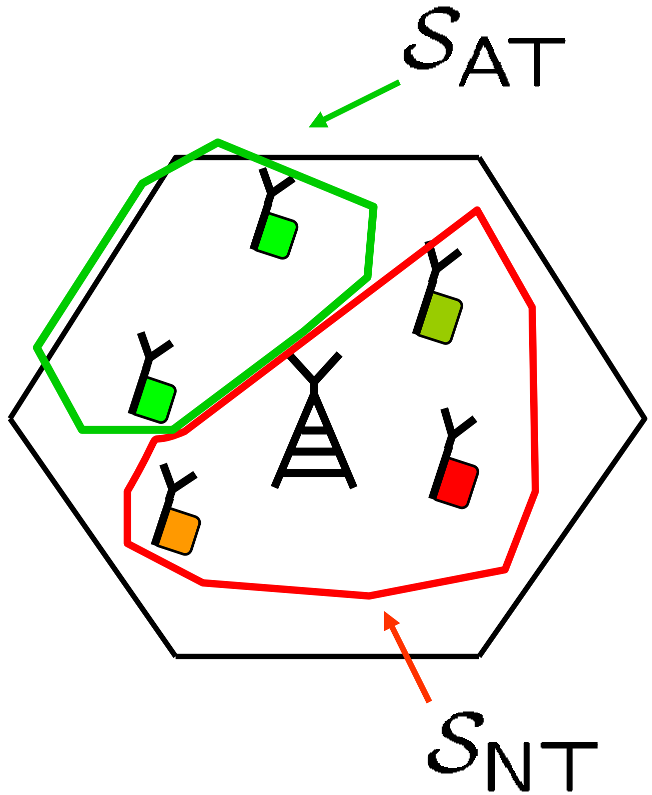

Combining adaptive and non-adaptive transmission

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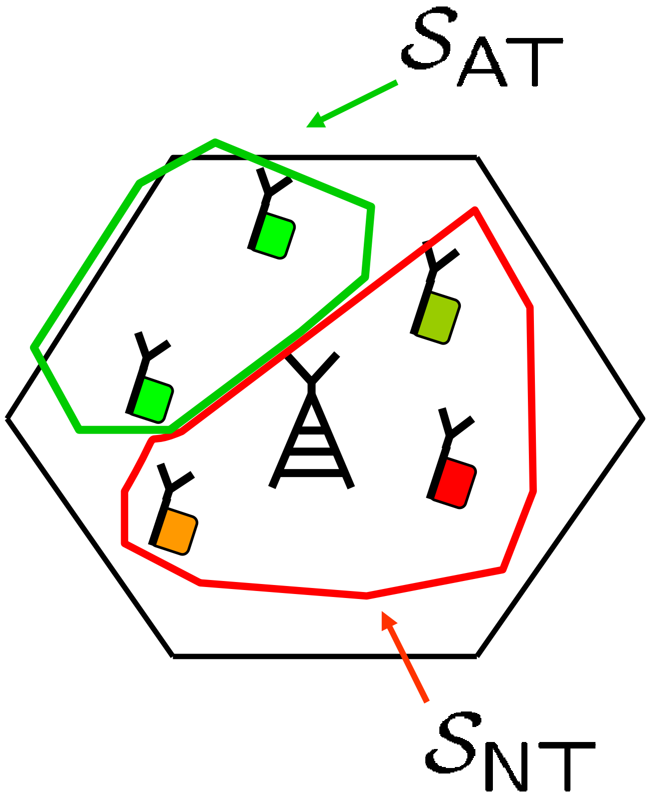
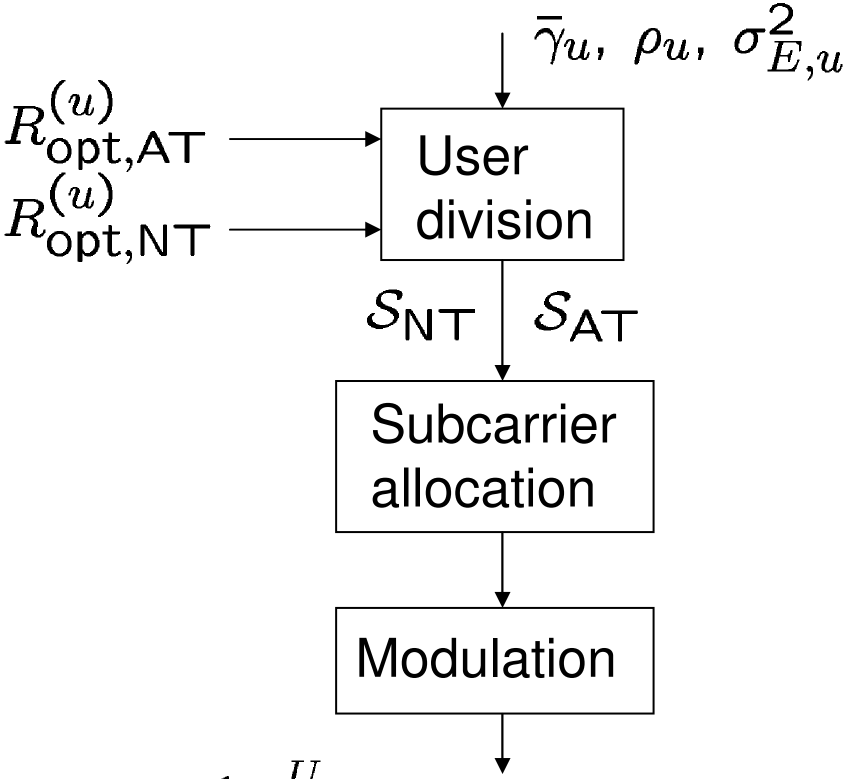
- Idea:
  - Users with reliable CQI apply adaptive transmission
  - Users with unreliable CQI apply non-adaptive transmission
- Divide users in two sets
  - User data rate applying AT depends on number U_{AT} of adaptive users
  - Decision whether user u is an adaptive user or a non-adaptive user cannot be made user wise independent from the other users
  - Joint consideration of all users



System overview



$$R_{\text{sys}} = \frac{1}{U} \sum_{u=1}^{U} \vartheta_u \cdot R^{(u)}_{\text{opt,AT}}(\vartheta^{\mathsf{T}}\vartheta) + (1 - \vartheta_u) \cdot R^{(u)}_{\text{opt,NT}}$$

$$\vartheta_u = \begin{cases} 0 & \text{user } u \text{ in set } \mathcal{S}_{\text{NT}} \\ 1 & \text{user } u \text{ in set } \mathcal{S}_{\text{AT}} \end{cases} \qquad \vartheta = [\vartheta_1, \cdots, \vartheta_U]^{\mathsf{T}}$$

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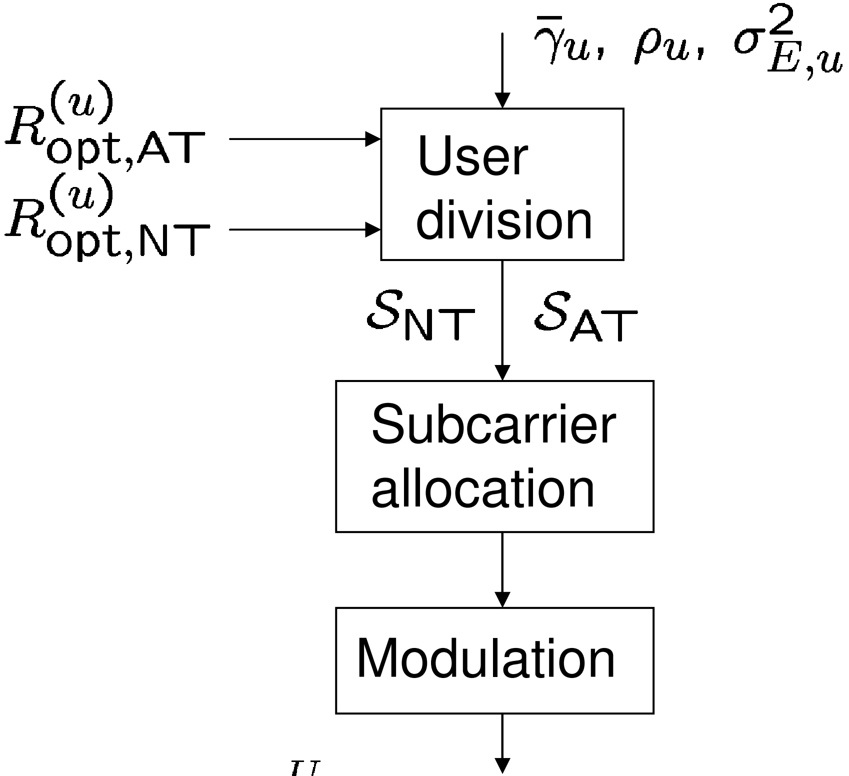

2 subcarrier allocation schemes:

	1st step	2nd step
NA→A	non-adaptive	adaptive
A→NA	adaptive	non-adaptive

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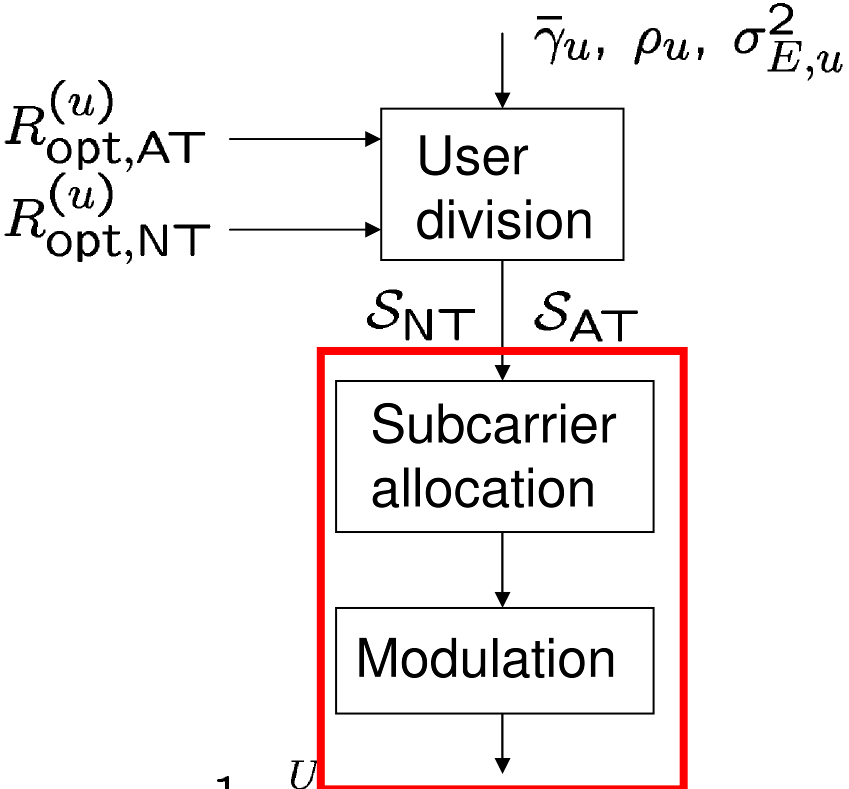

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Subcarrier allocation

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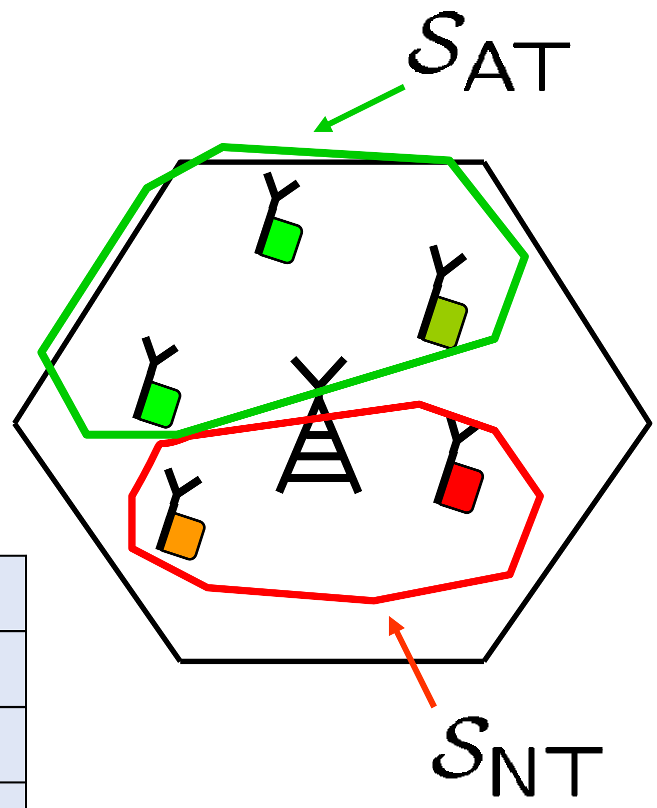
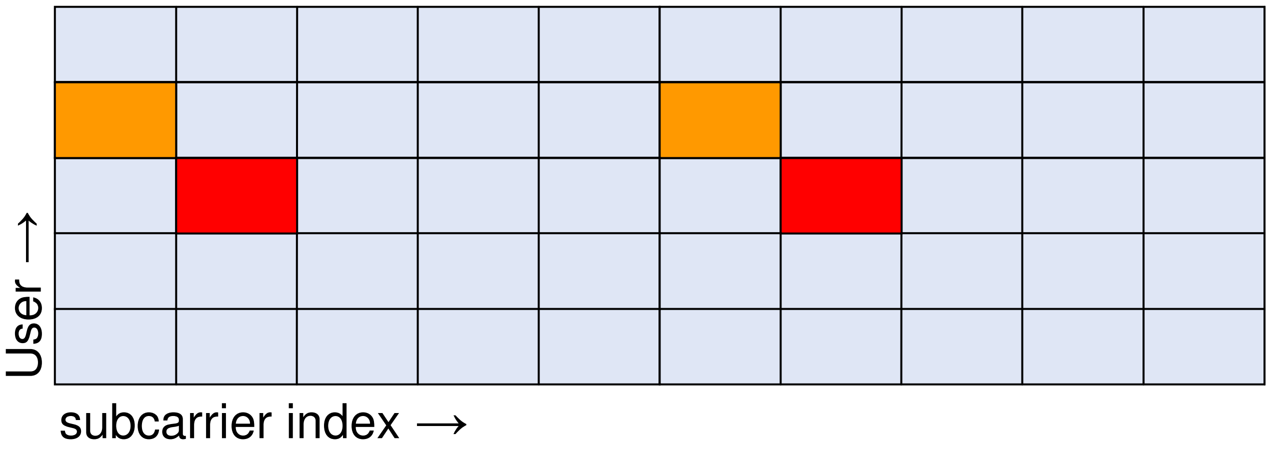
1) NA→A

- First allocate $N_U \cdot \text{card}\{\mathcal{S}_{\text{NT}}\}$ subcarriers to users of set $\mathcal{S}_{\text{NT}}$

$$N_U = \frac{N}{U}$$ Number of subcarriers per user





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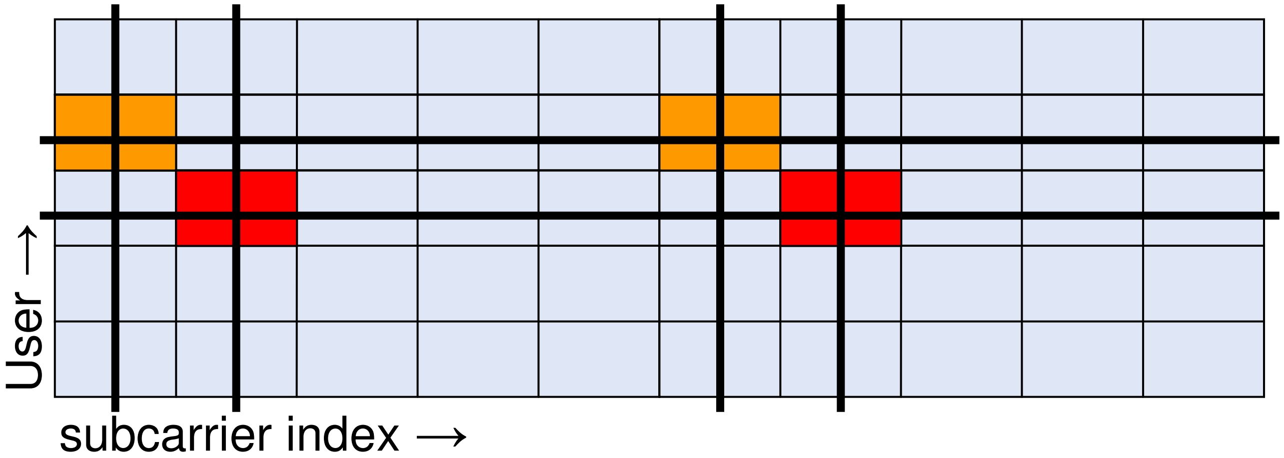
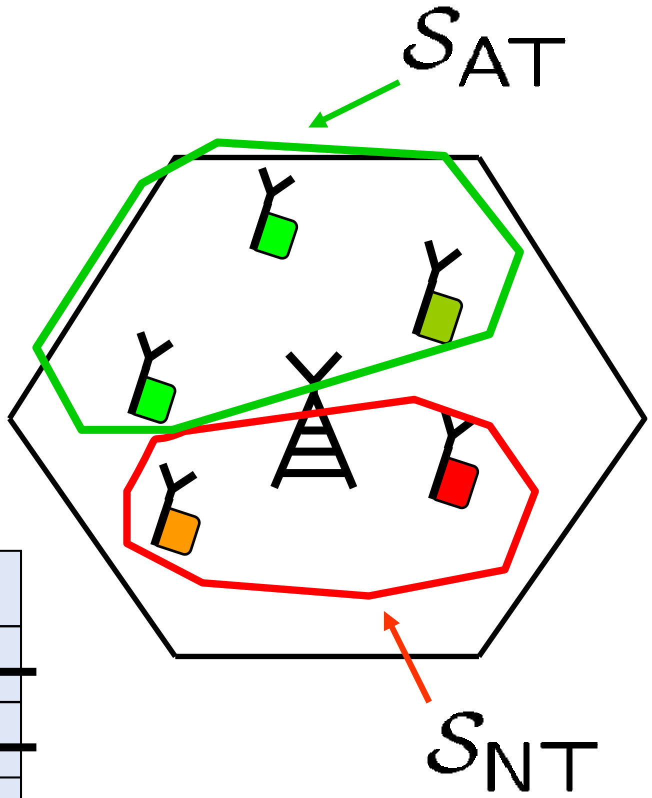


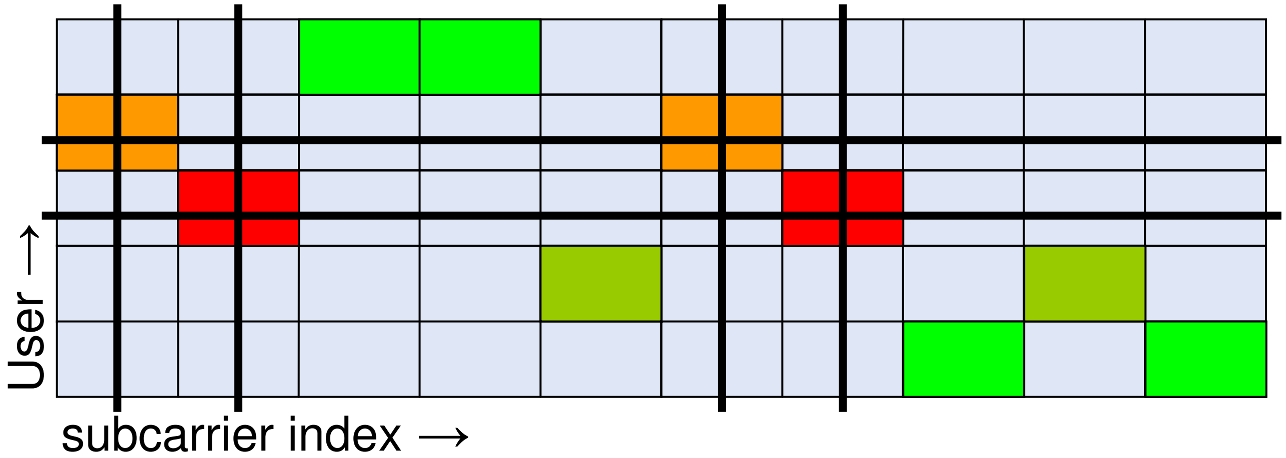


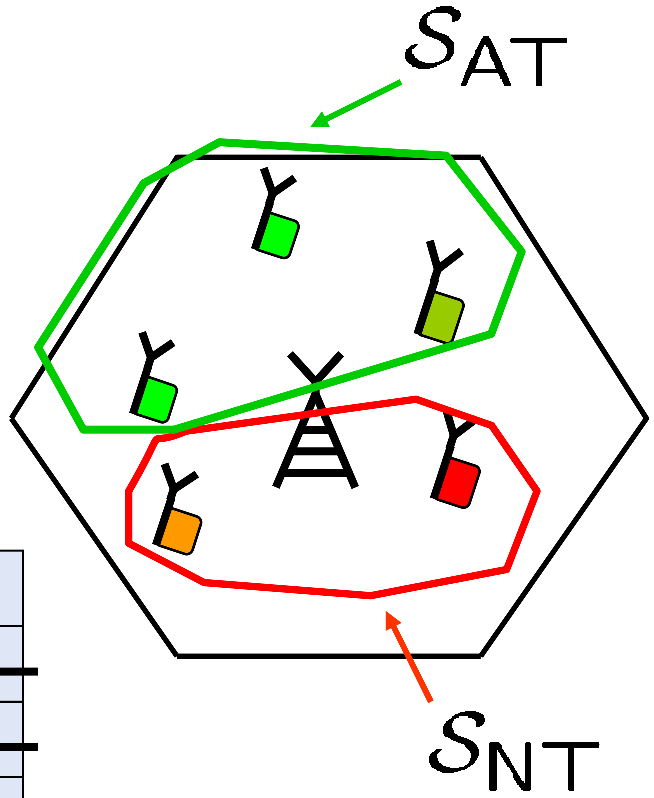
Subcarrier allocation

1) NA→A

- First allocate $N_U \cdot \text{card}\{\mathcal{S}_{\text{NT}}\}$ subcarriers to users of set $\mathcal{S}_{\text{NT}}$
- Subsequently, allocate the remaining subcarriers to users of set $\mathcal{S}_{\text{AT}}$ following Proportional Fair Scheduling approach

$$u^{\star}(n,k) = \arg\max_u \left\{ \frac{\gamma_u(n,k)}{\bar{\gamma}_u} \right\}$$





Subcarrier allocation

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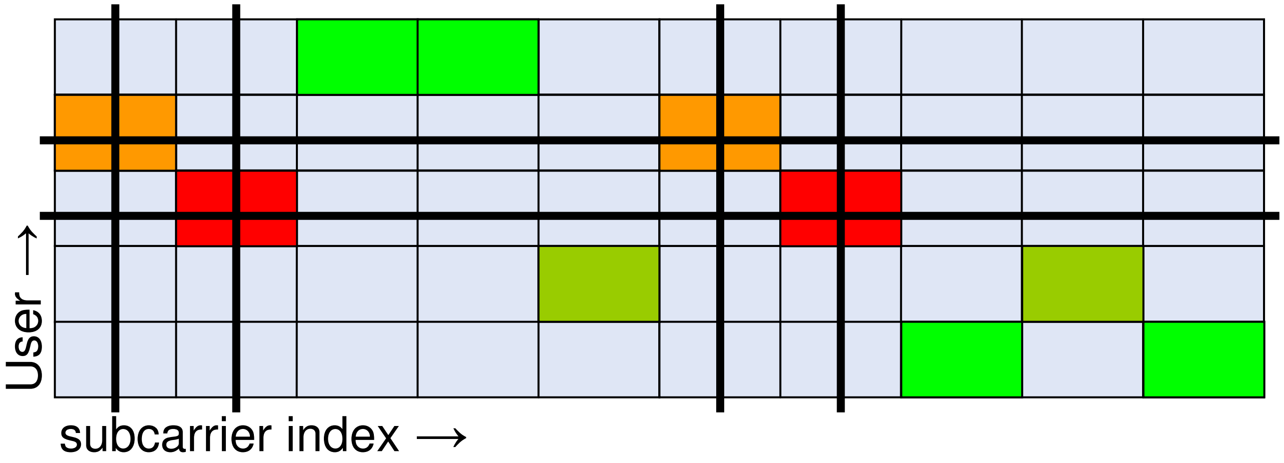
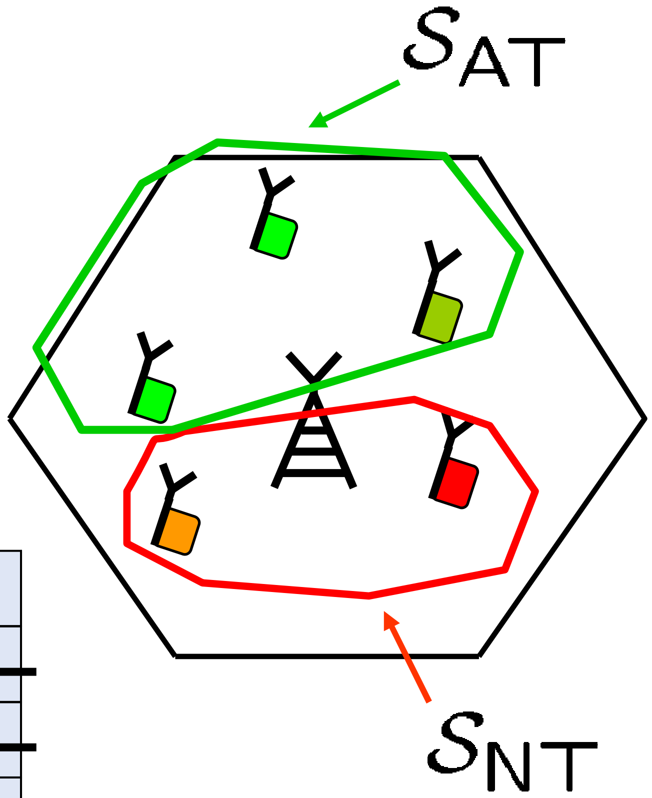
- Perform modulation (fixed and adaptive)





$$\gamma^{(\mathbf{u})} = [\gamma_0^{(u)}, \gamma_1^{(u)}, \cdots, \gamma_M^{(u)}]^T$$

$$M = card\{\mathcal{M}\}$$

Subcarrier allocation

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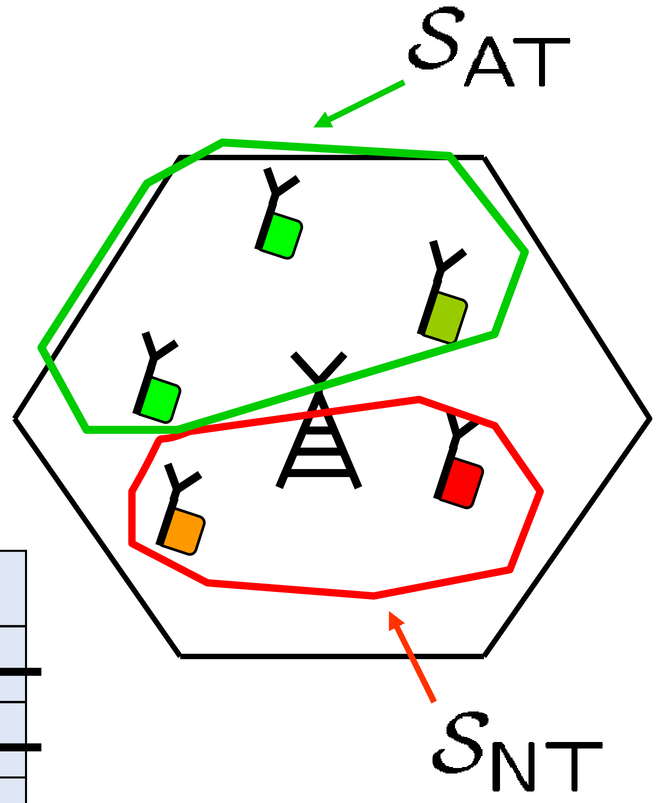
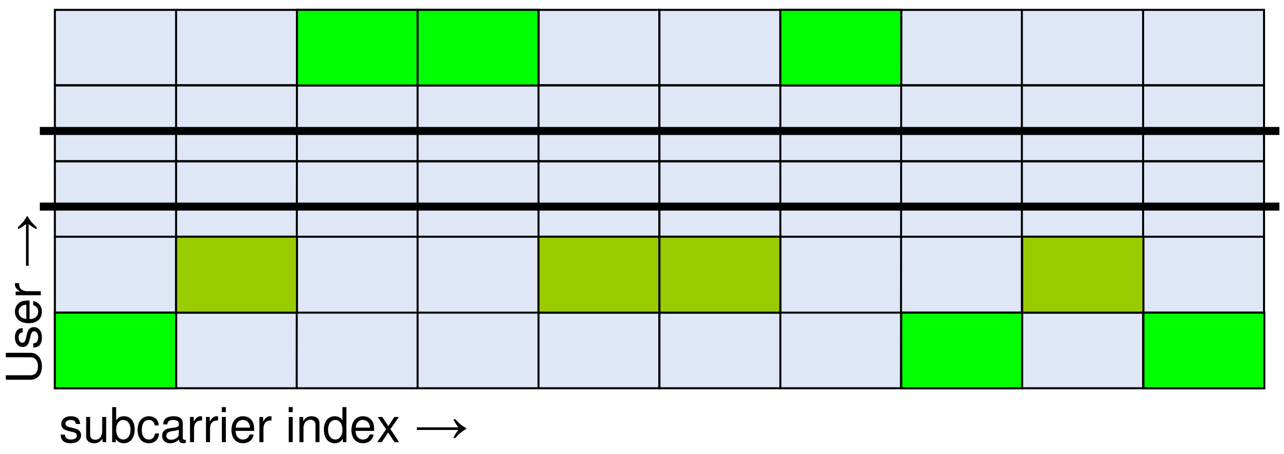
2) A→NA

- First allocate all subcarriers to users of set $\mathcal{S}_{AT}$





Subcarrier allocation

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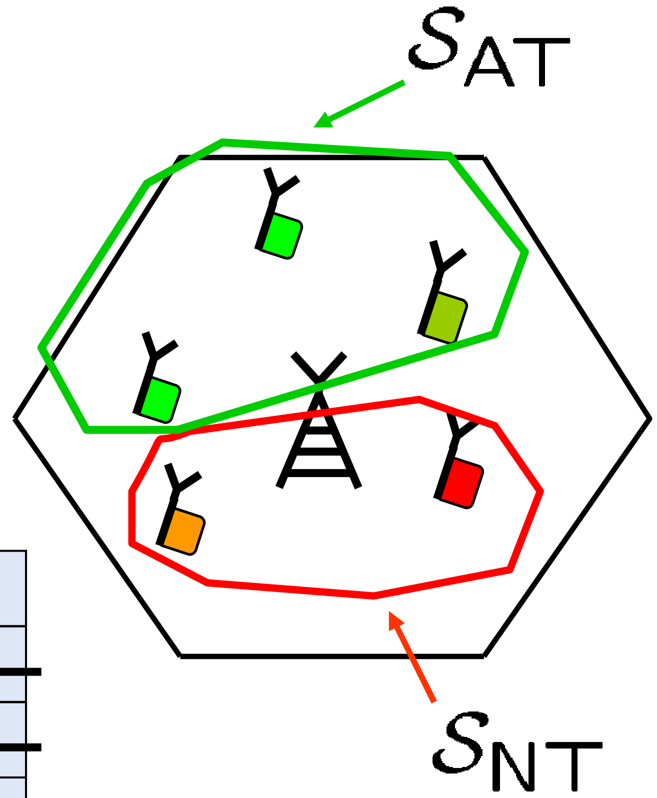
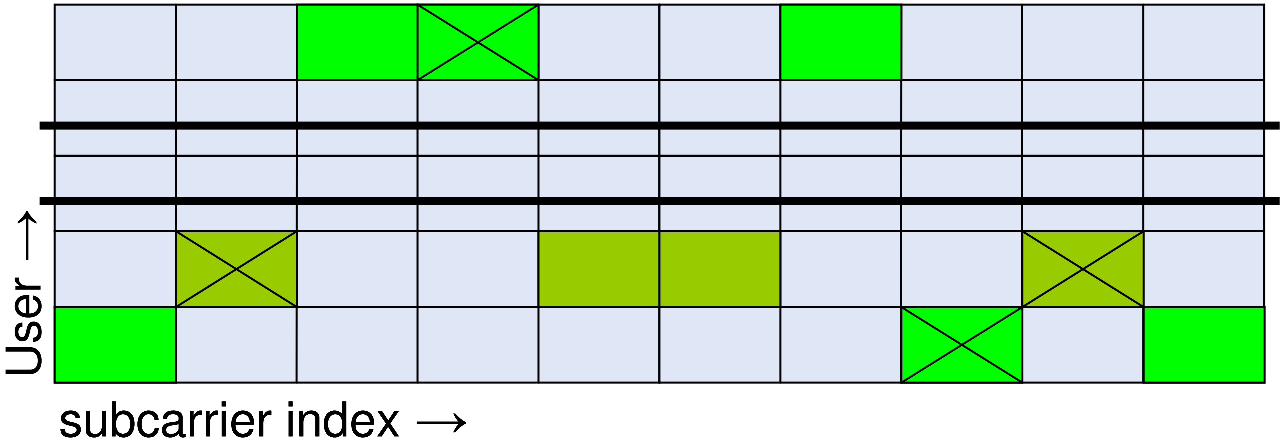
2) A→NA

- First allocate all subcarriers to users of set $\mathcal{S}_{\mathrm{AT}}$
- Select the $N_U \cdot \mathrm{card}\{\mathcal{S}_{\mathrm{NT}}\}$ worst subcarriers

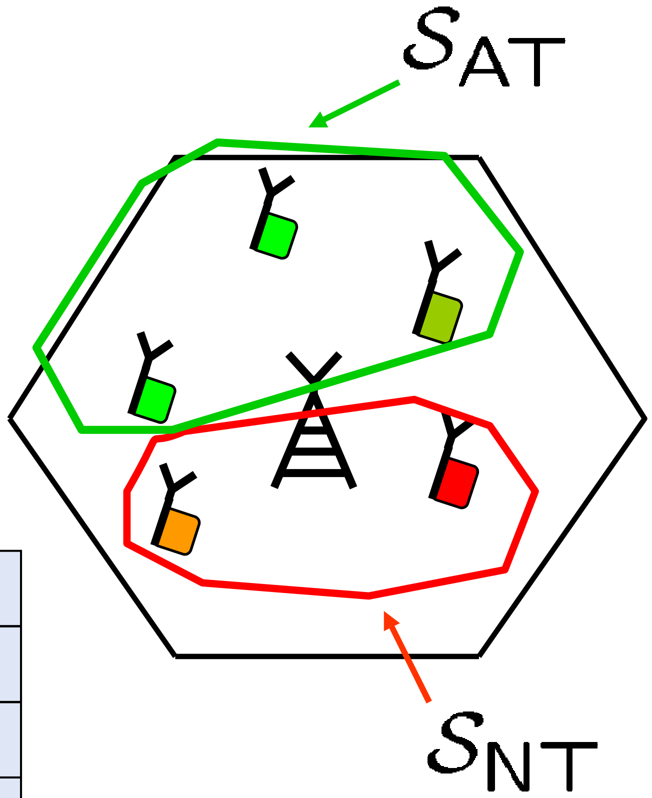


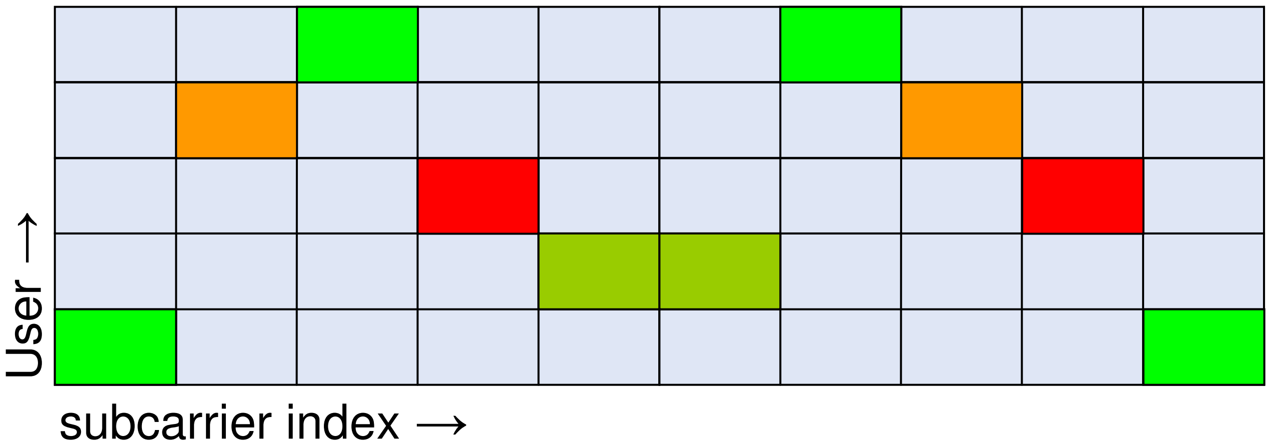


Subcarrier allocation

2) A→NA

- First allocate all subcarriers to users of set $\mathcal{S}_{\mathrm{AT}}$
- Select the $N_U \cdot \mathrm{card}\{\mathcal{S}_{\mathrm{NT}}\}$ worst subcarriers
- Re-allocate these subcarriers to users of set $\mathcal{S}_{\mathrm{NT}}$





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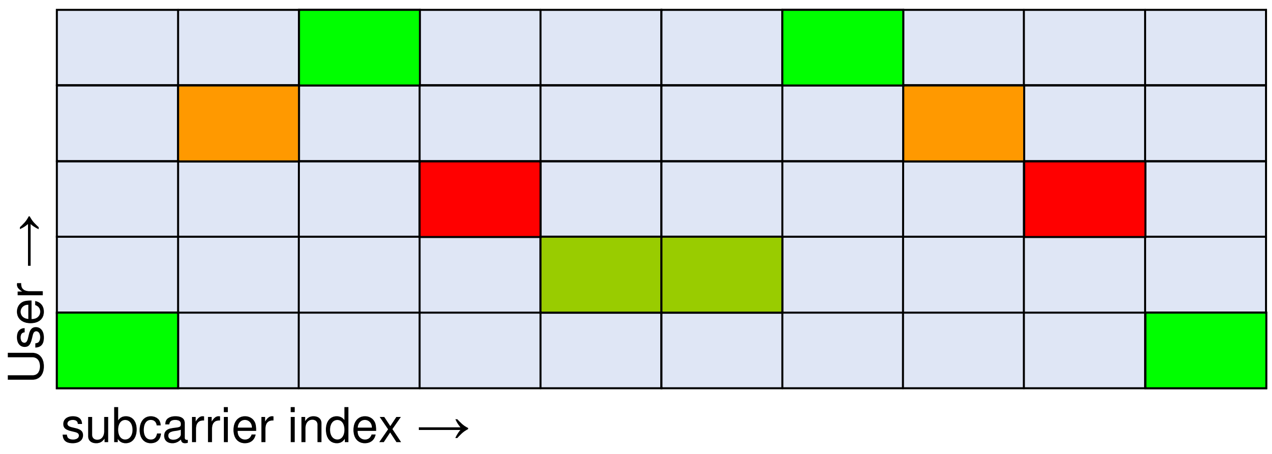

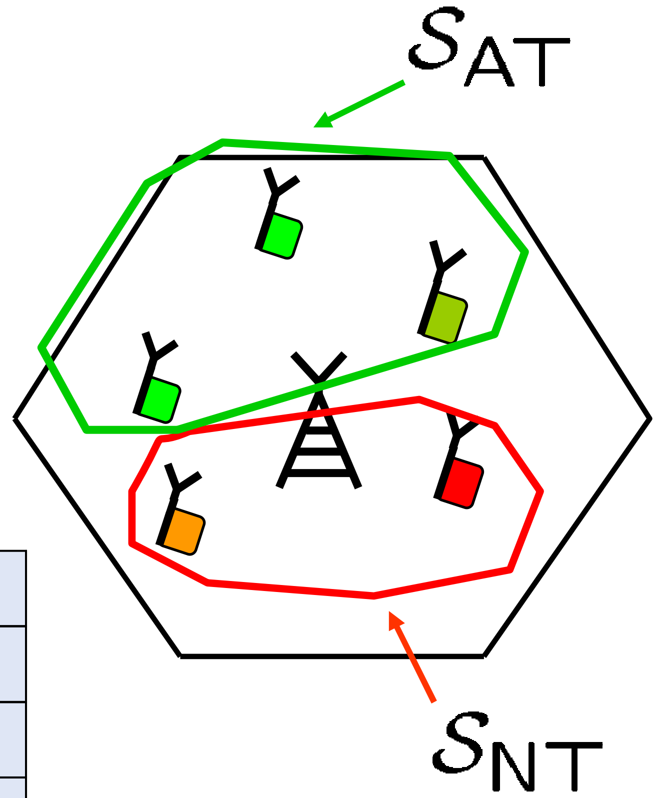

Data rate and Bit Error Rate (BER)

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Analytical expressions for the average user data rate and BER of user *u* taking into account imperfect CQI:

- User data rate for users in set $\mathcal{S}_{\mathsf{AT}}$:

$$R_{\mathsf{AT}}^{(u)} = f_i(\mathcal{M}, \bar{\gamma}_u, N_U, U_{\mathsf{AT}}, \gamma^{(\mathbf{u})}, \sigma_{E,u}^2, \rho_u)$$

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$\boldsymbol{\gamma}^{(\mathbf{u})}$ - SNR thresholds

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$\bar{\gamma}_u$ - average SNR

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U_{AT} - Number of adaptive users

$\gamma^{(\mathbf{u})}$ - SNR thresholds

$\sigma_{E,u}^2$ - Estimation error variance

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Analytical expressions for the average user data rate and BER of user *u* taking into account imperfect CQI:

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$$R_{\mathsf{AT}}^{(u)} = f_i(\mathcal{M}, \bar{\gamma}_u, N_U, U_{\mathsf{AT}}, \gamma^{(\mathbf{u})}, \sigma_{E,u}^2, \rho_u)$$

$$\overline{BER}_{\mathsf{AT}}^{(u)} = f_i(\mathcal{M}, \bar{\gamma}_u, N_U, U_{\mathsf{AT}}, \gamma^{(\mathbf{u})}, \sigma_{E,u}^2, \rho_u)$$

- User data rate for user in set $\mathcal{S}_{\mathsf{NT}}$:

$$R_{\mathsf{NT}}^{(u)} = f(\mathcal{M})$$

$$\overline{BER}_{\mathsf{NT}}^{(u)} = f(\mathcal{M}, \bar{\gamma}_u, N_U)$$

i - Subcarrier allocation

$$i = \begin{cases} 1 & \mathsf{NA}\rightarrow\mathsf{A} \\ 2 & \mathsf{A}\rightarrow\mathsf{NA} \end{cases}$$

$\mathcal{M}$ - Modulation schemes

$\bar{\gamma}_u$ - average SNR

N_U - Number of subcarriers per user

U_{AT} - Number of adaptive users

$\gamma^{(\mathbf{u})}$ - SNR thresholds

$\sigma_{E,u}^2$ - Estimation error variance

ρ_u - Correlation coefficient

Data rate and Bit Error Rate (BER)

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- Optimizing data rate:

$$R_{\mathsf{opt,AT/NT}}^{(u)} = \max\left(R_{\mathsf{AT/NT}}^{(u)}\right)$$

subject to

$$\overline{BER}_{\mathsf{AT/NT}}^{(u)} \leq BER_T$$

- User data rate for user in set $\mathcal{S}_{\mathsf{NT}}$:

$$R_{\mathsf{NT}}^{(u)} = f(\mathcal{M})$$

$$\overline{BER}_{\mathsf{NT}}^{(u)} = f(\mathcal{M}, \bar{\gamma}_u, N_U)$$

Data rate and Bit Error Rate (BER)

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subject to

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$$R_{\mathsf{opt,AT}}^{(u)} = f_i(\bar{\gamma}_u, N_U, U_{\mathsf{AT}}, \sigma_{E,u}^2, \rho_u)$$

$$R_{\mathsf{opt,NT}}^{(u)} = f(\bar{\gamma}_u, N_U)$$

System overview

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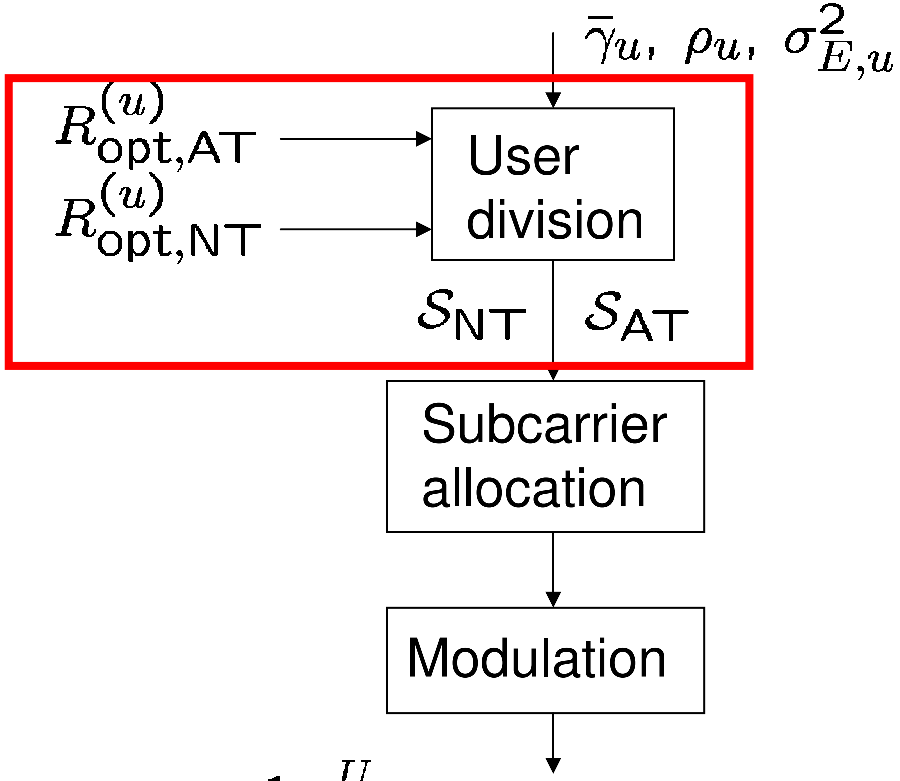

$$R_{\text{sys}} = \frac{1}{U}\sum_{u=1}^{U} \vartheta_u \cdot R^{(u)}_{\text{opt,AT}}(\vartheta^{\mathsf{T}}\vartheta) + (1-\vartheta_u)\cdot R^{(u)}_{\text{opt,NT}}$$

$$\vartheta_u = \begin{cases} 0 & \text{user } u \text{ in set } \mathcal{S}_{\text{NT}} \\ 1 & \text{user } u \text{ in set } \mathcal{S}_{\text{AT}} \end{cases} \qquad \vartheta = [\vartheta_1, \cdots, \vartheta_U]^{\mathsf{T}}$$

User division

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- Aim: Maximize average system data rate, satisfy minimum user data rate

$$R_{\text{sys,opt}} = \max_{\vartheta} \left(\frac{1}{U} \sum_{u=1}^{U} \vartheta_u \cdot R^{(u)}_{\text{opt,AT}}(\vartheta^{\top}\vartheta) + (1-\vartheta_u) \cdot R^{(u)}_{\text{opt,NT}} \right)$$

$$\text{subject to}$$

$$R^{(u)}_{\text{opt}} \geq R^{(u)}_{\text{opt,NT}} \;\; \forall\, u = 1, \ldots, U \qquad \vartheta = [\vartheta_1, \cdots, \vartheta_U]^{\top}$$

User division

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- Aim: Maximize average system data rate, satisfy minimum user data rate

$$R_{\text{sys,opt}} = \max_{\vartheta} \left(\frac{1}{U} \sum_{u=1}^{U} \vartheta_u \cdot R^{(u)}_{\text{opt,AT}}(\vartheta^{\mathsf{T}}\vartheta) + (1-\vartheta_u) \cdot R^{(u)}_{\text{opt,NT}} \right)$$

subject to

$$R^{(u)}_{\text{opt}} \geq R^{(u)}_{\text{opt,NT}} \quad \forall\, u = 1, \ldots, U \qquad \vartheta = [\vartheta_1, \cdots, \vartheta_U]^{\mathsf{T}}$$

- Solutions and complexity:

	NA→A	A→NA
Exhaustive Search	$\mathcal{O}(2^U)$	$\mathcal{O}(2^U)$
Set composition Number U_{AT} of users in set S_{AT} is important, not which users	$\mathcal{O}(U^3)$	$\mathcal{O}(U^3)$
Maximum number U_{AT} of users in set S_{AT} Determine maximum number U_{AT} which satisfies user data rate constraint	$\mathcal{O}(U^2)$	$\mathcal{O}(U^2)$ (suboptimal)

Numerical Results

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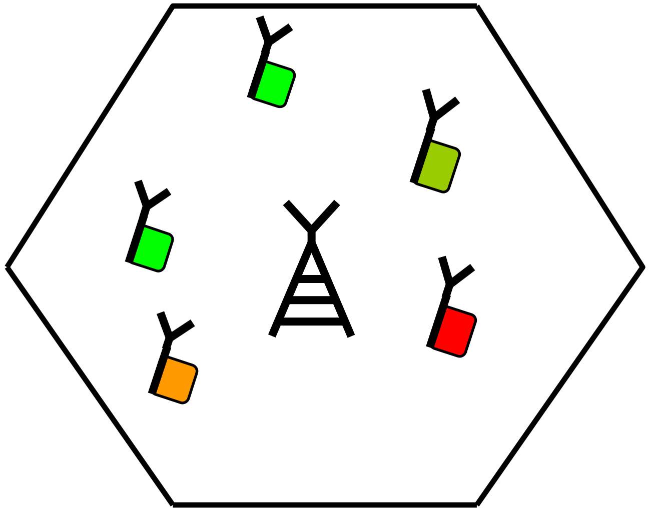
Number ***N*** of subcarriers	250
Number ***U*** of users	25
Cell radius ***R***	300 m
Minimum distance d_0	10 m
Pathloss coefficient α	2.6
Modulation	uncoded M-PSK and M-QAM
Target bit error rate BER_T	$1 \cdot 10^{-3}$
Carrier frequency f_c	2 GHz
Time delay ***T***	2 ms



Results average system data rate NA→A

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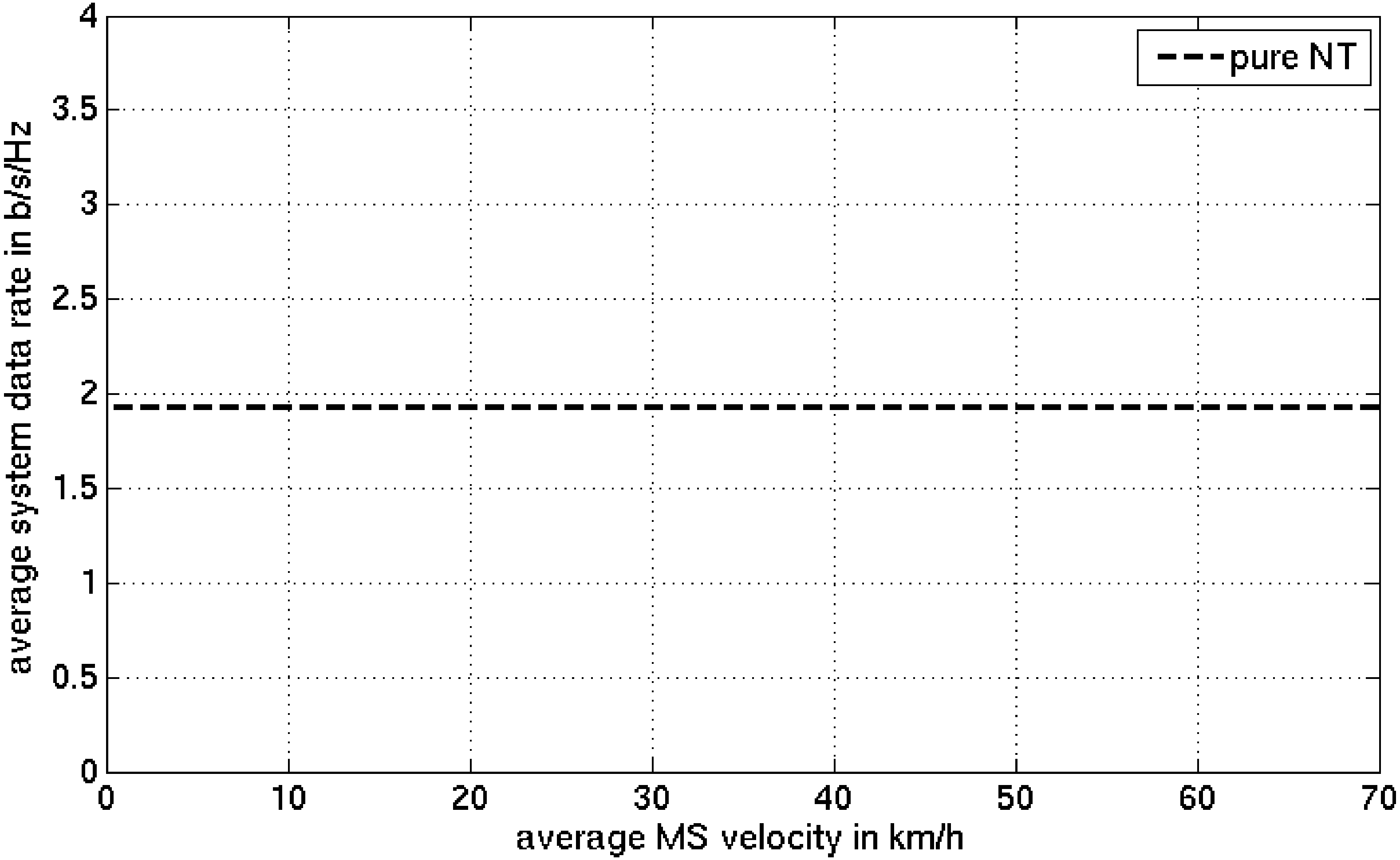

Results average system data rate NA→A

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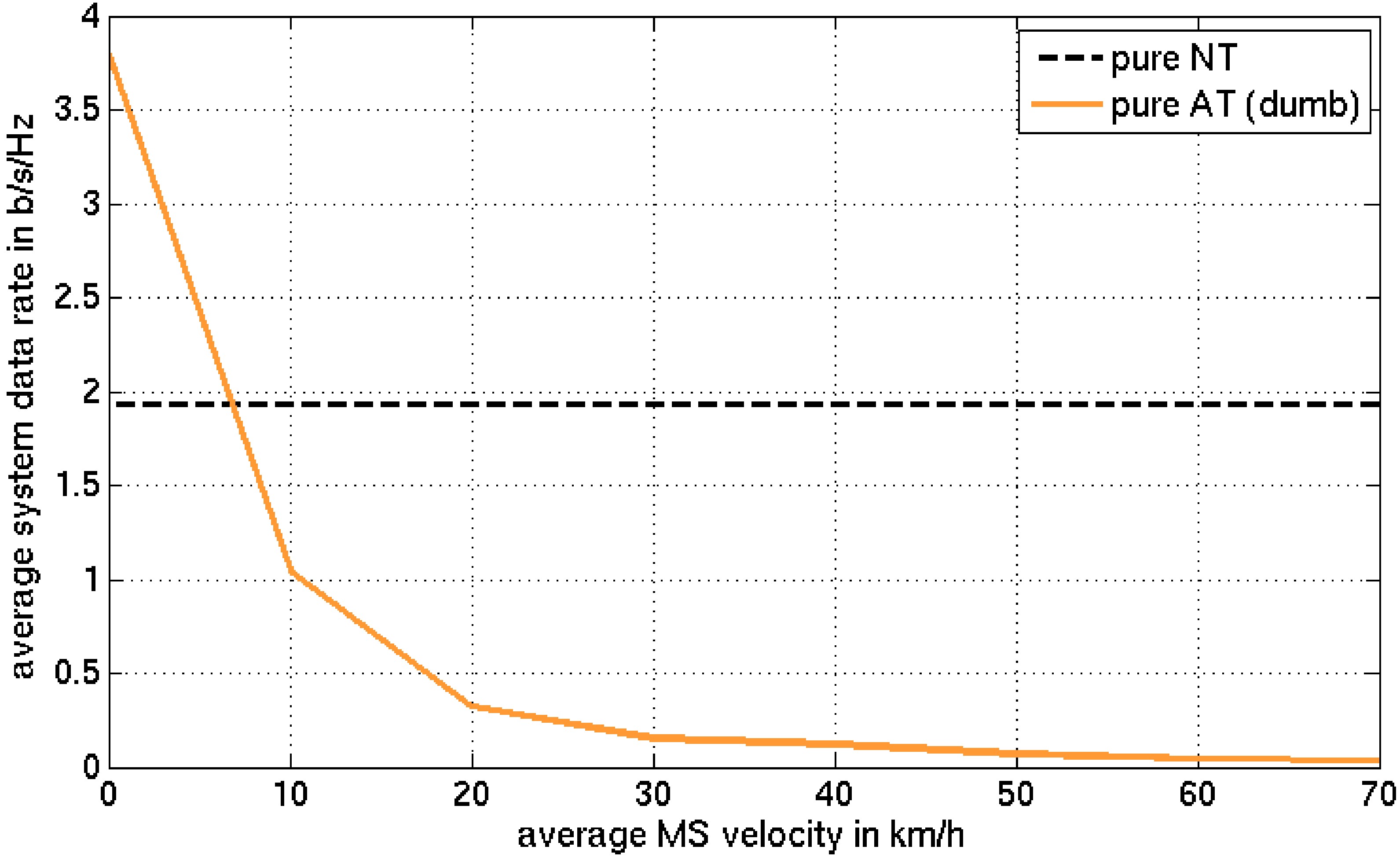

Results average system data rate NA→A

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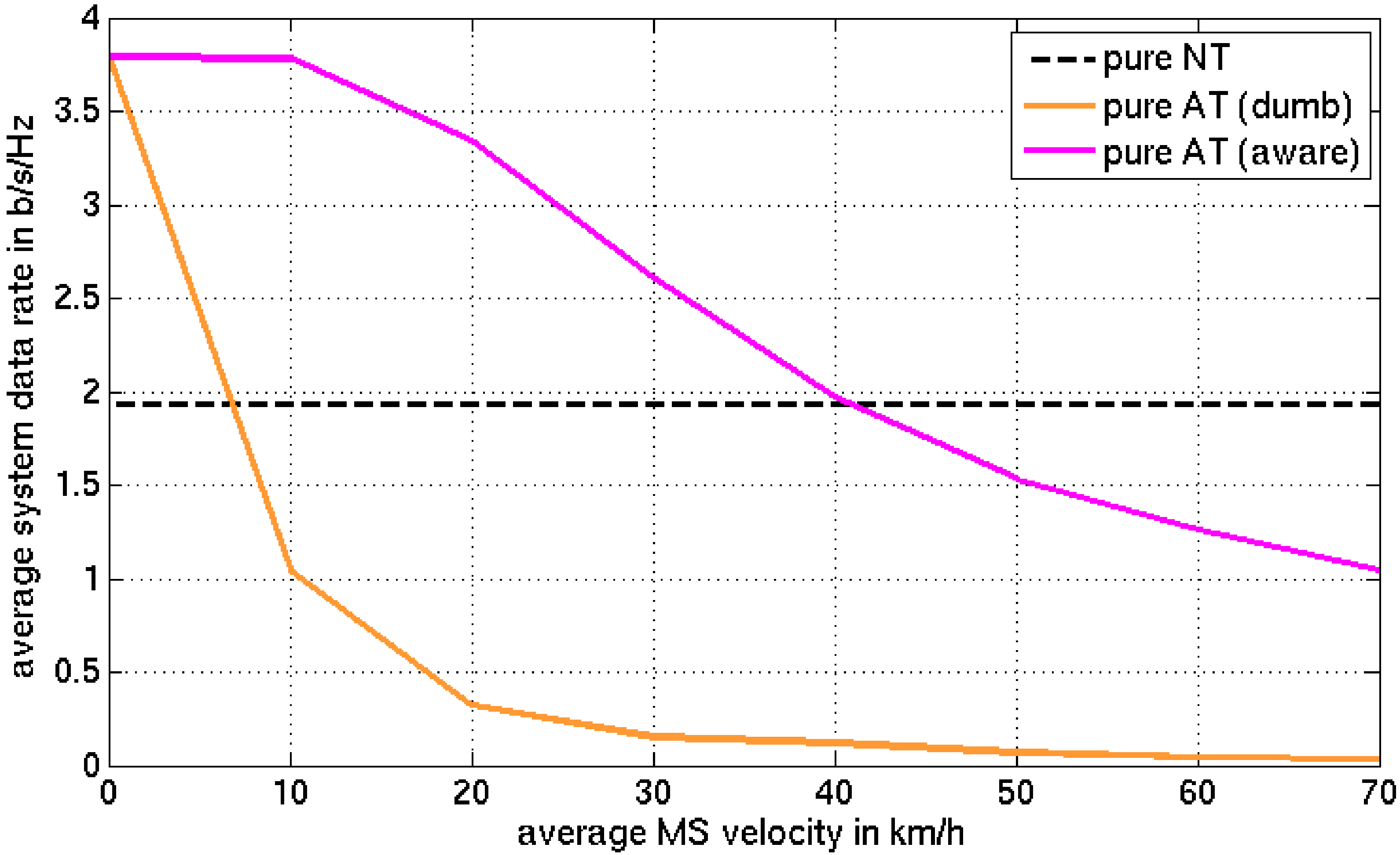

Results average system data rate NA→A

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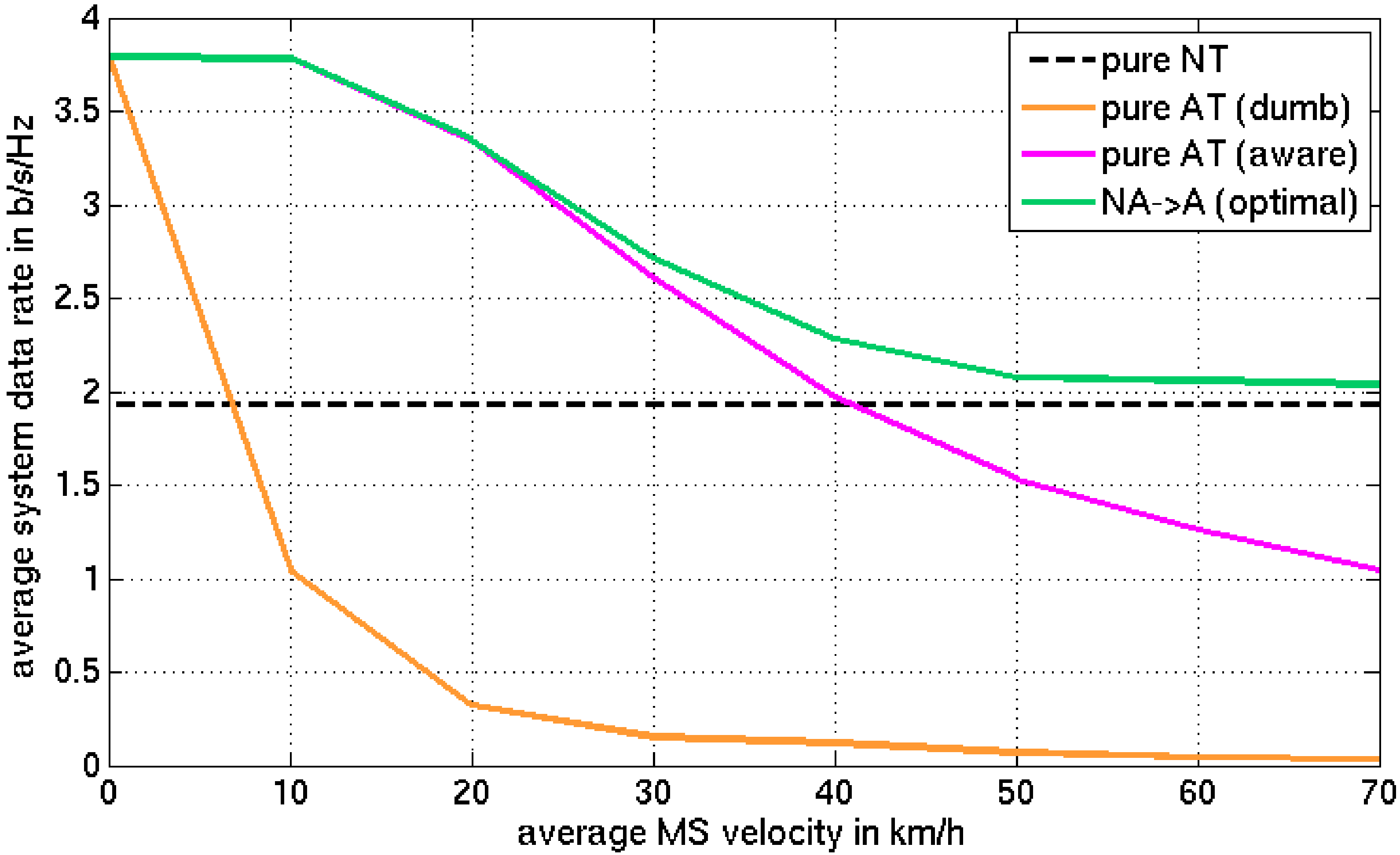
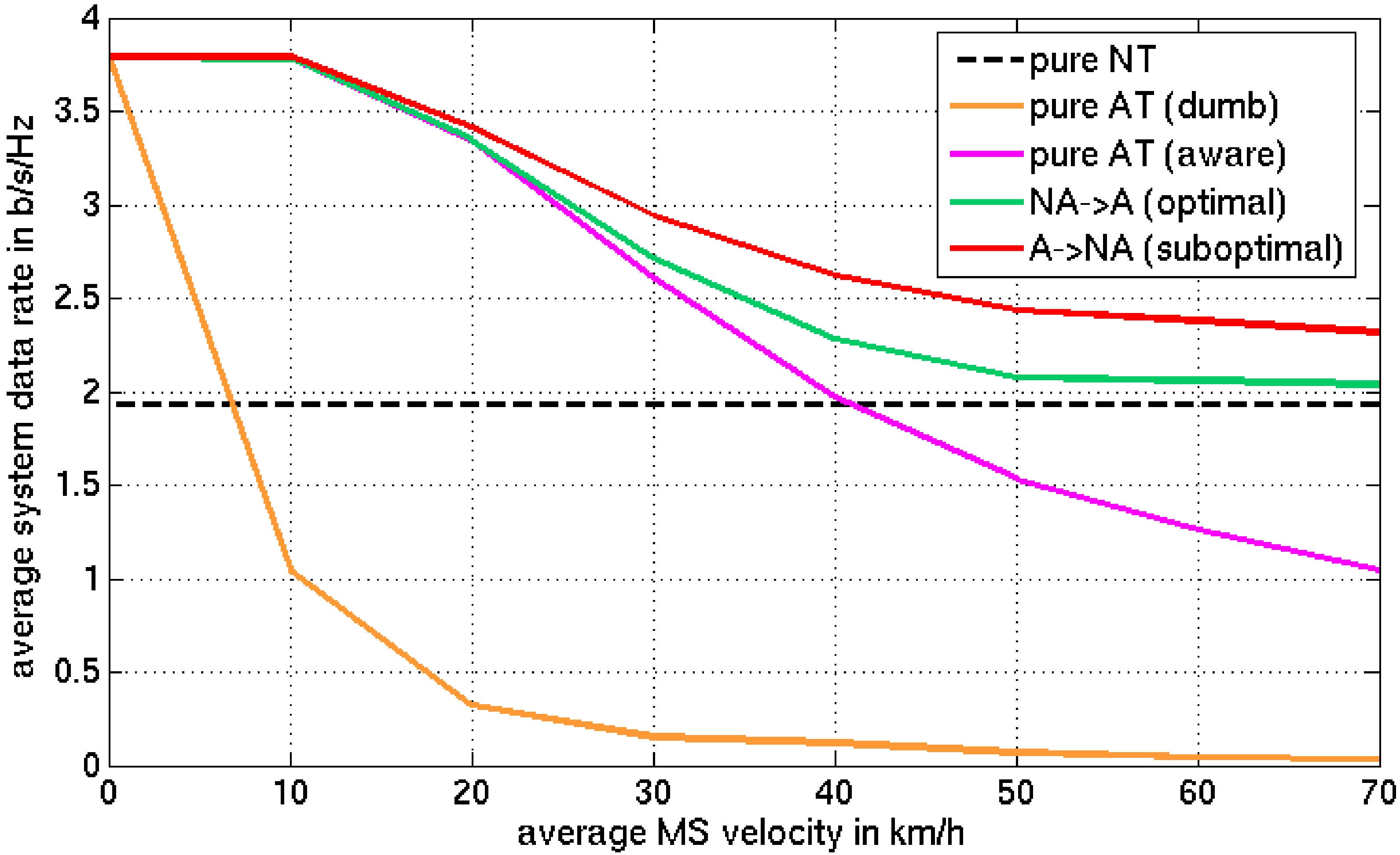


Results average system data rate A→NA



Results average system data rate A→NA

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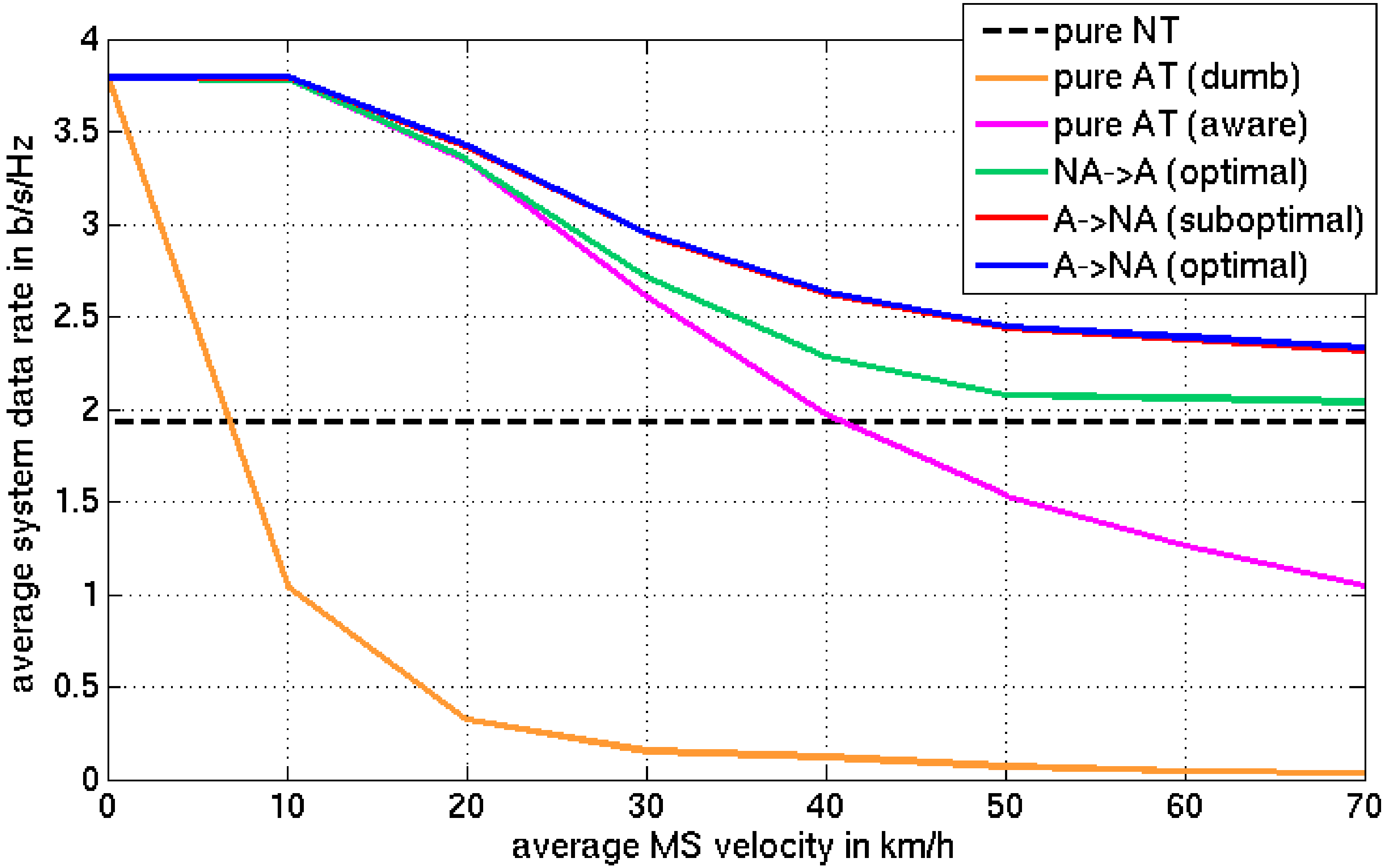

User satisfaction

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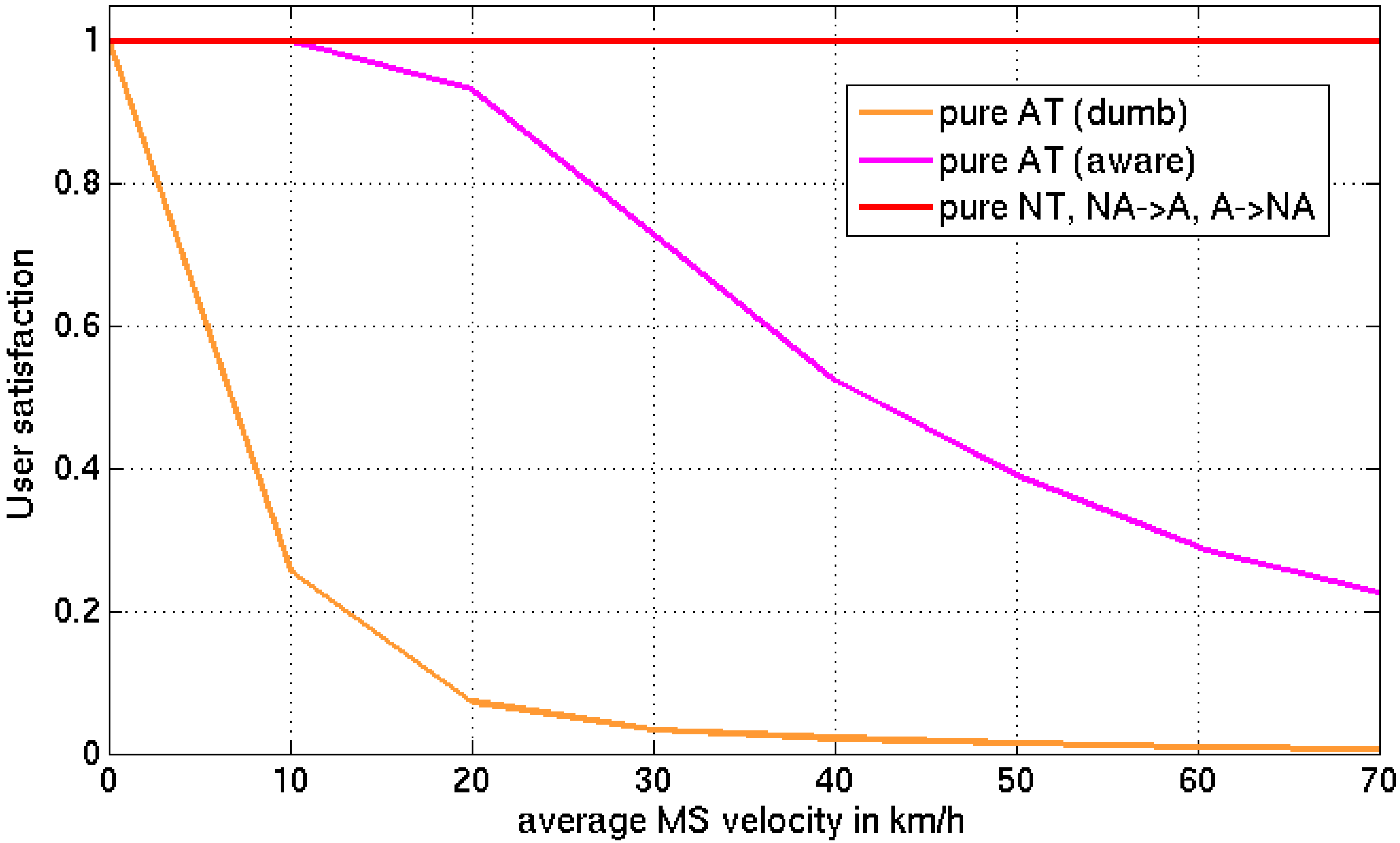

Conclusions

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- Combining of adaptive and non-adaptive multiuser OFDMA transmission schemes based on user division
- Two different subcarrier allocation schemes
- Two optimal and one suboptimal algorithm performing the user division based on analytical expressions for the user data rate and BER
- Both subcarrier allocation schemes outperform pure adaptive and pure non-adaptive subcarrier allocation schemes in the presence of imperfect CQI in terms of achievable data rate while satisfying minimum user data rate
- A→NA subcarrier allocation performs best

Publications

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Journal:

- A. Kühne and A. Klein, "Throughput analysis of Multi-user OFDMA-Systems using imperfect CQI feedback and diversity techniques," *IEEE Journal on Selected Areas in Communications*, vol. 26, no. 8, pp. 1440-1451, October 2008.

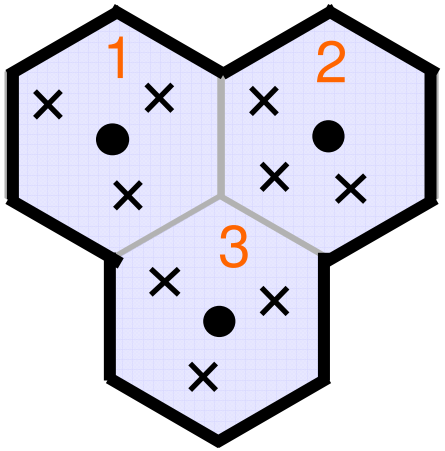
Conferences:

- A. Kühne and A. Klein, "An analytical consideration of imperfect CQI feedback on the performance of a multi-user OFDM-system," *in Proc. 12th International OFDM-Workshop*, Hamburg, Germany, August 2007.
- A. Kühne and A. Klein, "Adaptive subcarrier allocation with imperfect channel knowledge versus diversity techniques in a multi-user OFDM-system," *in Proc. International Symposium on Personal, Indoor and Mobile Radio Communications*, Athens, Greece, September 2007.
- A. Kühne and A. Klein, "Adaptive MIMO-OFDM using OSTBC with imperfect CQI feedback," *in Proc. International ITG Workshop on Smart Antennas*, Darmstadt, Germany, February 2008.
- A. Kühne and A. Klein, "Adaptive multiuser OFDMA systems with high priority users in the presence of imperfect CQI," *in Proc. 7th International Workshop on Multi-Carrier Systems & Solutions (MC-SS)*, Herrsching, Germany, May 2009 (to be published)

Joint contributions with project partner University of Rostock:

- A. Kühne, A. Klein, X. Wei and T. Weber, "Transmit Antenna Selection with imperfect CQI feedback in Multi-user OFDMA systems," *in Proc. 13th International OFDM-Workshop*, Hamburg, Germany, August 2008.
- X. Wei, T. Weber, A. Kühne and A. Klein, "Optimum MMSE Detection with Correlated Random Noise Variance in OFDM Systems," *in Proc. 13th International OFDM-Workshop*, Hamburg, Germany, August 2008.
- X. Wei, T. Weber, A. Kühne and A. Klein, "Joint Transmission with imperfect partial channel state information," *in Proc. IEEE Vehicular Technology Conference (VTC)*, Barcelona, Spain, April 2009 (to be published)

Joint transmission with imperfect partial CSI



- Multi-cell scenario
- Presentation Xinning Wei, University of Rostock, “Partial Channel-State Information in Cooperative Transmission”