Greedy Power Allocation for Multicarrier Systems with Reduced Complexity

Waleed Al-Hanafy and Stephan Weiss

University of Strathclyde, Glasgow, UK

NRSC'2010, 16-18 March 2010
Faculty of Elec. Eng., Menouf - Egypt

Overview

Motivation

- With the increased demand for high-quality wireless communication services
- And the scarcity of available radio spectrum
- Wireless Comm. with MIMO channels is emerged
- Aim — An efficient (simplified) high data rate transmission scheme

Problem Formalisation

For a MIMO or multicarrier system of N subchannels, data throughput can be optimised as:

$$\max \sum_{i=1}^{N} b_i, \tag{1}$$

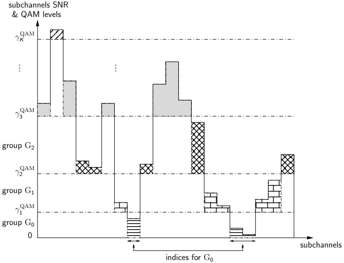
$$\text{subjected to}: \begin{cases} \sum_{i=1}^{N} P_i \leq P_{\text{budget}}, \\ \forall \, \text{subchannel} \; i \begin{cases} \mathcal{P}_{b,i} = \mathcal{P}_b^{\text{target}} \\ b_i \leq b^{\max} = \log_2 M_K \end{cases} \end{cases} \tag{2}$$

Previous Work

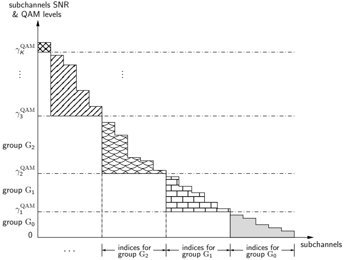
- Waterfilling-based solutions — [Baccarelli2002], [Zhang2003]
  - Limitations: SNR-gap approximation and $\begin{cases} b_i^{(r)} = \lfloor b_i \rfloor \\ b_i^{(r)} \rightarrow \infty \end{cases}$ thus lowering the overall throughput
- Optimal discrete bit loading — greedy approach [Campello1999], [Fasano2002]
- Greedy power allocation — [Zeng2009]
  - Limitations: high computational complexity
- Low-complexity greedy algorithm based on look-up tables is proposed in [Assimakopoulos2006]
  - Limitations: does not lead to pronounced reduction especially for large N

Subchannels Grouping Concept

Not ordered:



Ordered:



$$\mathcal{P}_{b,i} = \mathcal{F}\left(\gamma_i, M_k\right) = \begin{cases} Q\left(\sqrt{2\gamma_i}\right) & \text{for BPSK} \\ \dfrac{1-\left[1-2\left(1-\frac{1}{\sqrt{M_k}}\right)\cdot Q\left(\sqrt{\frac{3\gamma_i}{M_k-1}}\right)\right]^2}{\log_2 M_k} & \text{for } M_k \text{ QAM} \end{cases}$$

$$\longrightarrow \gamma_k^{\mathrm{QAM}} = \mathcal{F}^{-1}\left(\mathcal{P}_b^{\mathrm{target}}, M_k\right)$$

UPA algorithm & Initialisation Setup

1. Uniformly allocate transmit power budget among all subchannels:

$$\mathrm{CNR}_i = \frac{\sigma_i^2}{\mathcal{N}_0}, \qquad \gamma_i = \frac{P_{budget}}{N} \times \mathrm{CNR}_i \tag{3}$$

2. For each subchannel i, reside in a QAM group k of modulation order M_k such that:

$$\gamma_i \geq \gamma_k^{\mathrm{QAM}} \quad \text{and} \quad \gamma_i < \gamma_{k+1}^{\mathrm{QAM}} \tag{4}$$

3. For each QAM group cal. the group's total allocated bits and excess (unused) power

$$B_k^{\mathrm{u}} = \sum_{i \in \mathrm{G}_k} b_{i,k}^{\mathrm{u}} = \sum_{i \in \mathrm{G}_k} \log_2 M_k \tag{5}$$

$$P_k^{\mathrm{ex}} = \sum_{i \in \mathrm{G}_k} \frac{\gamma_i - \gamma_k^{\mathrm{QAM}}}{\mathrm{CNR}_i} = \sum_{i \in \mathrm{G}_k} P_i - \frac{\gamma_k^{\mathrm{QAM}}}{\mathrm{CNR}_i} \tag{6}$$

4. Now, the total throughput and used power are therefore,

$$B_u = \sum_{k=1}^{K} B_k^{\mathrm{u}} \quad \text{and} \quad P_{\mathrm{u}}^{\mathrm{used}} = P_{\mathrm{budget}} - \sum_{k=0}^{K} P_k^{\mathrm{ex}} \tag{7}$$

Full GPA algorithm

1. Initialise bit and power allocation by applying the UPA algorithm
2. The excess (unused) power $P_d^{\mathrm{gpa}} = \sum_{k=0}^{K} P_k^{\mathrm{ex}}$ is iteratively allocated to subchannels as:
   1. For each iteration: find subchannel i with the min req. upgrade* power

$$P_i^{\mathrm{up}} = \frac{\gamma_{k_i+1}^{\mathrm{QAM}} - \gamma_{k_i}^{\mathrm{QAM}}}{\mathrm{CNR}_i} \quad (8)$$

   2. Promote this subchannel to the next higher QAM level and update power $P_d^{\mathrm{gpa}} = P_d^{\mathrm{gpa}} - P_i^{\mathrm{up}}$
   3. Repeat substeps (1) & (2) until either $P_d^{\mathrm{gpa}} < \min(P_i^{\mathrm{up}})$ or $\min(k_i) = K$
3. Compute the total bit loading

$$B_{\mathrm{gpa}} = \sum_{i=1}^{N} b_i^{\mathrm{gpa}} \quad (9)$$

*Notice — It is possible to find subchannels in lower QAM levels that need less power to upgrade than others in higher QAM levels - hence its high complexity

Grouped-GPA (g-GPA) algorithm

1. For each QAM group k apply the GPA algorithm for local subchannels $i \in \mathrm{G}_k$
2. Compute the total allocated bits and left-over power

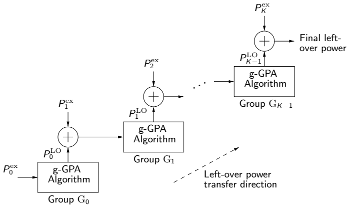
$$B_{\mathrm{g}} = \sum_{k=0}^{K-1} B_k^{\mathrm{g}} + B_K^{\mathrm{u}} \quad \text{and} \quad P_{\mathrm{g}}^{\mathrm{LO}} = \sum_{k=0}^{K-1} P_k^{\mathrm{LO}} + P_K^{\mathrm{ex}} \qquad (10)$$

Table: **Computational analysis for both GPA and g-GPA algorithms**

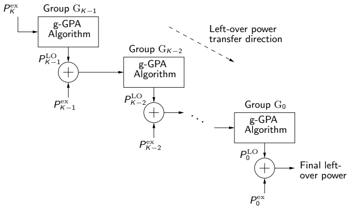
algorithm	no. of operations
GPA (order and no order)	$L_1(2N+7)+4N+1$
g-GPA (no order)	$\alpha[L_2(2\beta+4)+2\beta+2] \approx K[L_2(\frac{2N}{K}+4)+\frac{2N}{K}+2]$
g-GPA (order)	$\alpha[L_2(\beta+5)+2\beta+2] \approx K[L_2(\frac{N}{K}+5)+\frac{2N}{K}+2]$

Mu-GPA and Md-GPA algorithms

Mu-GPA:



Md-GPA:

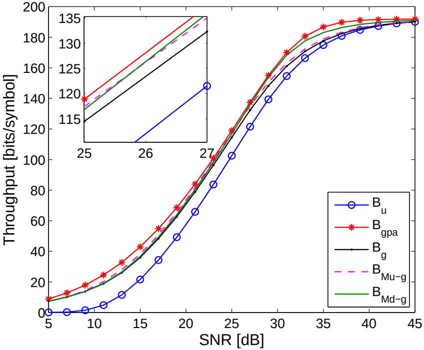


- Common procedures:
  1. Apply g-GPA for the first QAM group
  2. Add the resultant P_k^{LO} to P_{k+1}^{ex} and allocate to the next QAM group using g-GPA
  3. Repeat step steps (1) & (2) until last QAM group
- Differences: Mu-GPA starts with G_0, whereas Md-GPA starts with G_{K-1}

Performance Evaluation

system throughput results

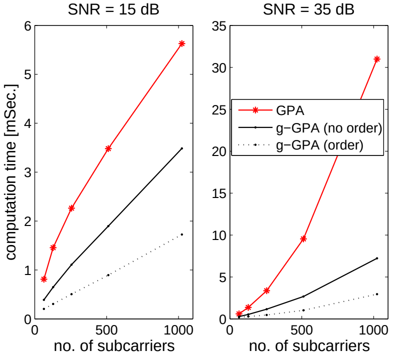
- A 32-subcarrier system with target BER $\mathcal{P}_b^{\text{target}} = 10^{-3}$ is considered
- System throughput is shown for different loading schemes with varying SNR
- Mu-GPA is better for low-to-medium SNR while Md-GPA outperforms for medium-to-high SNR



Performance Evaluation (Contd.)

complexity evaluation results

- The computational complexity is evaluated using average run-time for full-GPA and g-GPA algorithms with varying no. of subchannels and at different SNR values
- Significant complexity reduction is gained using g-GPA at high SNR and large no. of subchannels



Conclusions

- GPA is the optimal discrete power/bit allocation — very complex for large number of subchannels
- A reduced-complexity version of GPA (g-GPA) is proposed by applying GPA on subsets of subchannels using the QAM-level grouping concept
- Two refinement algorithms are proposed to further utilise the LO power with superiority SNR regions
- Simulation results show very close performance to GPA algorithm within their SNR respective regions

Questions

- Thank You — Any Questions