A New Low-Cost Discrete Bit Loading using Greedy Power Allocation

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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 — high data throughput transmission scheme

Problem Formalisation

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

$$\max \sum_{i=1}^{N} b_i , \qquad (1)$$

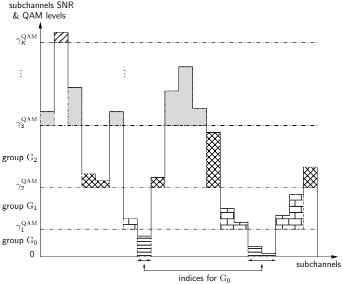
$$\text{subjected to} : \begin{cases} \sum_{i=1}^{N} P_i \leq P_{\text{budget}}, \\ \forall \, \text{subchannel } i \begin{cases} \mathcal{P}_{b,i} = \mathcal{P}_b^{\text{target}} \\ b_i \leq b^{\max} = \log_2 M_K \end{cases} \end{cases} \qquad (2)$$

Previous Work

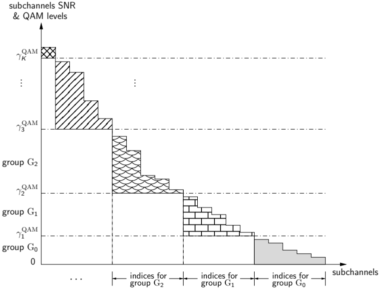
- Waterfilling-based solutions — [Krongold2000], [Baccarelli2002], [Zhang2003]
  - Limitations: SNR-gap approximation and $\begin{cases} b_i^{(r)} = \lfloor b_i \rfloor \\ b_i^{(r)} \rightarrow \infty \end{cases}$, thus lowering the overall throughput
- Optimal discrete bit loading — greedy approach [Campello1998], [Campello1999]
- 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:



$$\mathcal{P}_b \approx \mathcal{P}_s/\log_2 M_k, \text{ where } \mathcal{P}_s = 1 - \left[1 - 2\left(1 - \frac{1}{\sqrt{M_k}}\right) Q\left(\sqrt{\frac{3\gamma_i}{M_k - 1}}\right)\right]^2 \quad (3)$$

$$\gamma_k^{\text{QAM}} = \frac{M_k - 1}{3}\left[Q^{-1}\left(\frac{1 - \sqrt{1 - \mathcal{P}_b \log_2 M_k}}{2\left(1 - 1/\sqrt{M_k}\right)}\right)\right]^2 \quad (4)$$

UPA algorithm & Initialisation Setup

1. Uniformly allocate transmit power budget among all subchannels:

$$\mathrm{CNR}_i = \frac{\sigma_i^2}{\mathcal{N}_0}, \qquad \gamma_i = \frac{P_{budget}}{N} \times \mathrm{CNR}_i \tag{5}$$

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

$$\gamma_i \geq \gamma_k^{\mathrm{QAM}} \quad \text{and} \quad \gamma_i < \gamma_{k+1}^{\mathrm{QAM}} \tag{6}$$

3. For each QAM group calculate:
   - group's total allocated bits:

$$B_k^{\mathrm{u}} = \sum_{i \in \mathrm{G}_k} b_{i,k}^{\mathrm{u}} = \sum_{i \in \mathrm{G}_k} \log_2 M_k \tag{7}$$

   - total excess (unused) power

$$P_k^{\mathrm{ex}} = \frac{P_{budget}}{N} - \sum_{i \in \mathrm{G}_k} \frac{\gamma_k^{\mathrm{QAM}}}{\mathrm{CNR}_i} \tag{8}$$

4. Total throughput and used power are therefore,

$$B_u = \sum_{k=1}^{K} B_k^{\mathrm{u}} \quad \text{and} \quad P_{\mathrm{u}}^{\mathrm{used}} = P_{\mathrm{budget}} - \sum_{k=0}^{K} P_k^{\mathrm{ex}} \tag{9}$$

GPA algorithm

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

$$P_i^{\text{up}} = \frac{\gamma_{k_i+1}^{\text{QAM}} - \gamma_{k_i}^{\text{QAM}}}{\text{CNR}_i} \tag{10}$$

    2. Promote this subchannel and update power $P_d^{\text{gpa}} = P_d^{\text{gpa}} - P_i^{\text{up}}$
    3. Repeat steps (a)-(b) until either $P_d^{\text{gpa}} < \min(P_i^{\text{up}})$ or $\min(k_i) = K$

Compute the total left-over power

$$P_{\text{g}}^{\text{LO}} = \sum_{k=0}^{K-1} P_k^{\text{LO}} + P_K^{\text{ex}} \tag{11}$$

Note*: it is possible to find subchannels in lower QAM levels that need less power to upgrade than others in higher QAM levels

QAM-L-GPA algorithm

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

$$P_{\mathrm{g}}^{\mathrm{LO}} = \sum_{k=0}^{K-1} P_k^{\mathrm{LO}} + P_K^{\mathrm{ex}} \quad (12)$$

Table: **Computational analysis for both GPA and QAM-L-GPA algorithms**

algorithm	no. of operations
GPA (no order)	$L_1(2N+7)+4N+1$
GPA (order)	same as (no order)
QAM-L-GPA (no order)	$\alpha\left[L_2(2\beta+4)+2\beta+2\right] \approx K\left[L_2(\frac{2N}{K}+4)+\frac{2N}{K}+2\right]$
QAM-L-GPA (order)	$\alpha\left[L_2(\beta+5)+2\beta+2\right] \approx K\left[L_2(\frac{N}{K}+5)+\frac{2N}{K}+2\right]$

Mu-GPA and Md-GPA algorithms

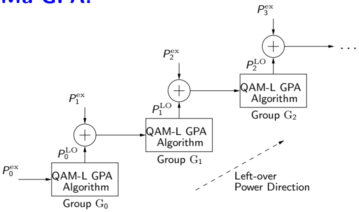
algorithms

- Common procedures:
  1. Apply g-GPA for the first QAM group
  2. The resultant P_k^{LO} added to P_{k+1}^{ex} will be allocated to the next QAM group using g-GPA
  3. Repeat step 2 until last QAM group
- Differences: Mu-GPA starts with G_0, whereas Md-GPA starts with G_{K-1}

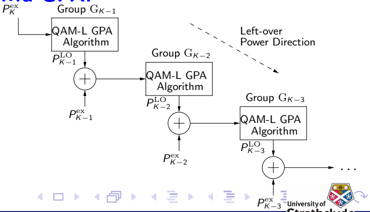
$$P_{\mathrm{Mu-g}}^{\mathrm{LO}} = P_{K-1}^{\mathrm{LO}} + P_K^{\mathrm{ex}} \qquad (13)$$

$$P_{\mathrm{Md-g}}^{\mathrm{LO}} = P_0^{\mathrm{LO}} + P_0^{\mathrm{ex}} \qquad (14)$$

Mu-GPA:



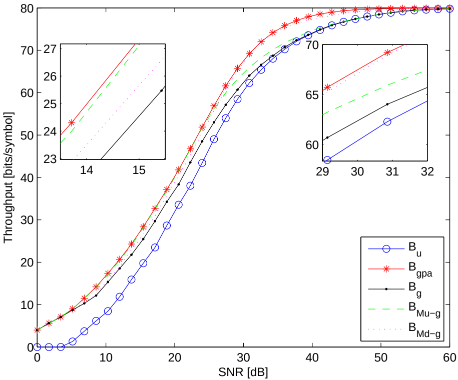
Md-GPA:



Performance Evaluation

system throughput

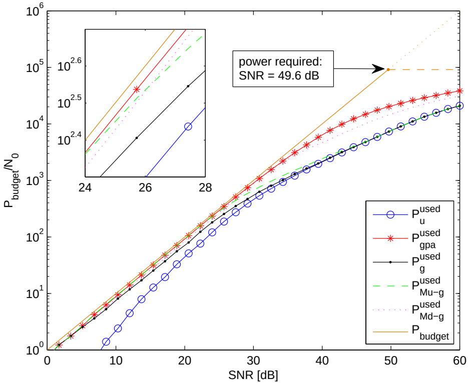
- A 10x10 frequency-flat MIMO system is considered
- System throughput is shown for different loading schemes with varying SNR
- Mu-GPA is better for low-to-medium SNR while Md-GPA outperforms for medium-to-high SNR



Performance Evaluation (Contd.)

power utilisation

- The effective power utilised by different allocation schemes is shown
- The closer the power to transmit power budget, the higher the performance of the allocation schemes
- Both Mu-GPA and Md-GPA algorithms preform very close to the full GPA in their superiority regions



Conclusions

- GPA is the optimal discrete power/bit allocation — very complex for large number of subchannels
- A low-cost GPA is proposed for subsets of subchannels using QAM grouping concept
- Two refinement algorithms are proposed to further utilise the LO power with superiority SNR regions
- Simulation results show very close performance within their SNR respective regions to GPA algorithm

Questions

- Thank You — Any Questions