CeSIP Centre for excellence in Signal and Image Processing

University of Strathclyde Engineering

Reduced Complexity Schemes to Greedy Power Allocation for Multicarrier Systems

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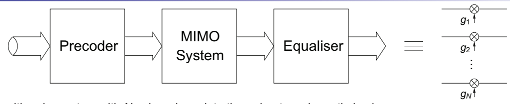
Problem Formalisation & Previous Work



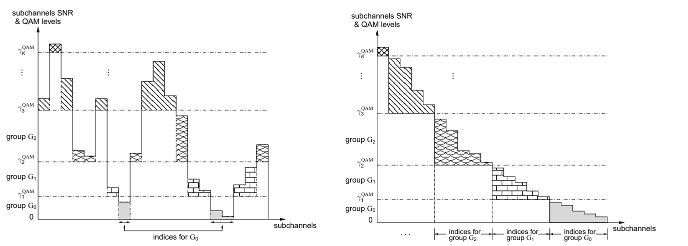
For an OFDM multicarrier system with N subcarriers, data throughput can be optimised as:

$$\text{Maximise}: \quad \sum_{i=1}^{N} b_i, \tag{1}$$

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

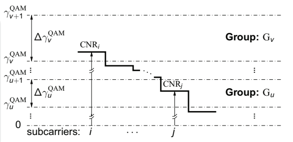
- Waterfilling-based solutions — [Baccarelli2002], [Zhang2003]
  - Limitations: SNR-gap approximation and $\begin{cases} b_i^{(r)} = \lfloor b_i \rfloor \\ b_i^{(r)} \to \infty \end{cases}$, thus lowering the overall throughput
- Optimal discrete bit loading — greedy approach [Campello1999], [Fasano2002]
- Example - 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 a pronounced reduction especially for large N

Subcarriers Grouping Concept



complexity reduction — key idea

- All subcarriers N must be addressed in every iteration in the case of the GPA algorithm as it is possible to find upgrade powers such as: $P_j^{\text{up}} < P_i^{\text{up}}$, where $P_i^{\text{up}} = \frac{\Delta\gamma_v^{\text{QAM}}}{\text{CNR}_i}$ and $P_j^{\text{up}} = \frac{\Delta\gamma_u^{\text{QAM}}}{\text{CNR}_j}$



UPA & Full GPA algorithms

- Uniformly allocate transmit power budget among all subcarriers:

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

- Reside subcarriers i in QAM groups k of modulation order M_k such that:

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

- For each QAM group calculate the group's total allocated bits and excess (unused) power given, respectively as

$$B_k^{\text{u}} = \sum_{i\in G_k} b_{i,k}^{\text{u}} = \sum_{i\in G_k} \log_2 M_k, \quad \text{and} \quad P_k^{\text{ex}} = \sum_{i\in G_k} \left(\gamma_i - \gamma_k^{\text{QAM}}\right)/\text{CNR}_i \tag{5}$$

- Evaluate total allocated bits and unused power as $B_u = \sum_{k=1}^{K} B_k^{\text{u}}$, and $P^{\text{ex}} = \sum_{k=0}^{K} P_k^{\text{ex}}$

- Initiate $b_i^{\text{gpa}} = b_i^{\text{u}}$ in (5), index $k_i = k$ in (4) and $P_d^{\text{gpa}} = P^{\text{ex}}$. Then, iteratively allocate P_d^{gpa} to subcarriers as follows:
  1. For each iteration, find the subcarrier j with the min required upgrade power as

$$j = \underset{1\le i\le N}{\operatorname{argmin}}\,(P_i^{\text{up}}), \quad \text{where} \quad P_i^{\text{up}} = \left(\gamma_{k_i+1}^{\text{QAM}} - \gamma_{k_i}^{\text{QAM}}\right)/\text{CNR}_i \tag{6}$$

  2. Promote this subcarrier to the next higher QAM level and update powers, i.e.,

$$b_j^{\text{gpa}} = b_j^{\text{gpa}} + \left\{\log_2 M_{k_j} - \log_2 M_{k_j-1}\right\}, \quad \text{and} \quad P_j^{\text{up}} = \left(\gamma_{k_j+1}^{\text{QAM}} - \gamma_{k_j}^{\text{QAM}}\right)/\text{CNR}_j, \quad P_d^{\text{gpa}} = P_d^{\text{gpa}} - P_j^{\text{up}} \tag{7}$$

  3. Repeat steps (1) & (2) until $P_d^{\text{gpa}} < \min(P_i^{\text{up}})$ or $\min(k_i) = K$

Proposed grouped-GPA (g-GPA) Algorithm

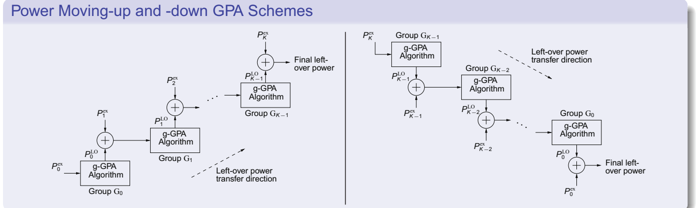
- For each QAM group k apply the GPA algorithm for local subcarriers $i \in G_k$ using:

g-GPA Algorithm for Subcarriers in the kth QAM Group G_k

1. $\forall i \in G_k$, calculate $P_i^{\text{up}} = \left(\gamma_{k+1}^{\text{QAM}} - \gamma_k^{\text{QAM}}\right)/\text{CNR}_i$
2. Initiate $b_{i,k}^{\text{g}} = b_{i,k}^{\text{u}}$ and $P_k^{\text{LO}} = P_k^{\text{ex}}$
   while $P_k^{\text{LO}} \ge \min(P_i^{\text{up}})$
3. $j = \underset{i\in G_k}{\operatorname{argmin}}(P_i^{\text{up}})$
4. $P_k^{\text{LO}} = P_k^{\text{LO}} - P_j^{\text{up}}$
   if $k = 0$
5. $b_{j,k}^{\text{g}} = \log_2 M_1$, $P_j^{\text{up}} = +\infty$
   else
6. $b_{j,k}^{\text{g}} = b_{j,k}^{\text{g}} + \log_2 \frac{M_{k+1}}{M_k}$, $P_j^{\text{up}} = +\infty$
   end
   end
7. $B_k^{\text{g}} = \sum_{i\in G_k} b_{i,k}^{\text{g}}$

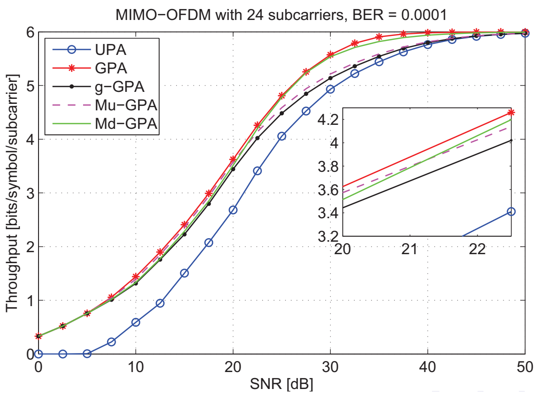
Mu-GPA and Md-GPA Algorithms

Power Moving-up and -down GPA Schemes



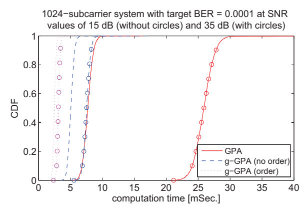
- *Common procedures*:
  1. Apply g-GPA for the first QAM group
  2. Add the resultant P_k^{LO} to P_{k+1}^{ex} and allocate to the next QAM group using g-GPA
  3. Repeat steps (1) & (2) until last QAM group
- *Differences*:
  1. Mu-GPA starts with G_0, whereas Md-GPA starts with G_{K-1}
  2. P_K^{ex} is missed by Mu-GPA, while P_0^{ex} is missed by Md-GPA (resulting in distinctive preferences in SNR regions)

Performance Evaluation



Complexity Evaluation & Conclusions

algorithm	no. of operations
GPA	$L_1(2N+7)+4N+1$
g-GPA (no order)	$\sum_{k=0}^{K-1} L_2^k(2N_k+4)+2N_k+2 \approx$ $L_2(2\frac{N}{K}+4)+2\frac{N}{K}+2$
g-GPA (order)	$\sum_{k=0}^{K-1} L_2^k(N_k+5)+2N_k+2 \approx$ $L_2(\frac{N}{K}+5)+2\frac{N}{K}+2$



Concluding Remarks

- Suboptimal discrete bit loading schemes have been proposed in this paper
- Compared to optimum greedy power allocation (GPA) algorithm, these schemes perform GPA on groups of subcarriers
- Two of these schemes have been suggested with a refined power allocation stage
- Simulations show that performance very close to the full GPA algorithm can be attained by the two algorithms at a much reduced computational complexity